# Climate Technology Centre & Network
# Solar Photovoltaic Accreditation Training Program
# Pilot Training

## Morogoro, Tanzania

**November 6th- 10th, 2017**

# Climate Technology Centre & Network
# Solar Photovoltaic Accreditation Training Program

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| | ▪ **Climate Technology Centre & Network Technical Assistance Program –Tanzania Partnership**<br>♦ The Tanzania Commission of Science & Technology (COSTECH)<br>♦ Tanzania Renewable Energy Association (TAREA)<br>♦ Climate Technology Centre and Network (CTCN)<br>♦ Tanzania Vocational Education & Training Authority (VETA)<br>♦ United Nations Industrial Development Organization (UNIDO)<br>♦ National Renewable Energy Laboratory (NREL) |

| | 08:00 – 12:00<br>Theoretical Background | 12:00 – 13:00 | 13:00 –17:00<br>Application and Hands-on Exercises |
|---|---|---|---|
| **Day 1**<br>Monday Nov 6th | ▪ **Welcome and Opening Remarks** (1 hr.)<br>♦ Presentation of COSTECH program (by Dr. Kafuku) (10 min)<br>♦ Presentation of TAREA program (by Mr. Matthew Matimbwi) (10 min)<br>♦ Presentation of VETA program (by Principal, Mr. Maro) (10 min)<br>♦ Presentation of UNIDO program (by Mr. Victor Akim) (10 min)<br>♦ Presentation of CTCN (by Adrian Guhr) (10 min)<br>♦ NREL Introduction (by Andy Walker) (10 min)<br>▪ **Introduction** (0.5 hr.)<br>♦ Purpose of the training and overview of the week<br>♦ Survey of Expertise<br>▪ ***Health Break*** *(30 mins.)*<br>▪ **Photovoltaic Technologies** (1 hr.)<br>♦ Principles of Solar Power<br>♦ Characteristics of PV Cells<br>♦ PV Module Performance<br>▪ **Photovoltaic Inspections** (1 hr.)<br>♦ Terminology & Severity Rating<br>♦ Inspection Procedures<br>♦ Accept & Reject Criteria | **LUNCH** | ▪ **PV Inspection -continued** (1.5 hrs.)<br>♦ Print out Checklist & Catalogue of Defects for New Module<br>♦ Print out Checklist & Catalogue of Defects for Used Module<br>♦ Demonstrate using defected modules<br>▪ ***Health Break*** *(30 mins.)*<br>▪ **Hands-On Inspecting Modules** (2 hrs.)<br>♦ Using voltmeter verify good and defected panels for Isc and Voc<br>♦ Isc and Voc measurements PV cells<br>♦ Isc and Voc measurements PV panels<br>▪ **Review and Adjournment** |

| | 08:00 – 12:00<br>Theoretical Background | 12:00 –<br>13:00 | 13:00 –17:00<br>Application and<br>Hands-on Exercises |
|---|---|---|---|
| **Day 2**<br>Tuesday<br>Nov 7th | ▪ **Applications of PV in Remote Areas** (1 hr.)<br>♦ PV Stand-alone Systems<br>♦ Applications for Stand-alone Systems<br>♦ PV Water pumping<br>♦ PV Solar Lighting<br>♦ Health Care and Refrigeration<br>▪ **Solar Resource** (1 hr.)<br>♦ Solar Radiation Fundamentals<br>♦ Site Data and PV tilt<br>♦ Solar Site Analysis<br>▪ ***Health Break*** *(30 mins.)*<br>▪ **Installation Safety** (0.5 hr.)<br>♦ Review electrical and PV installation safety<br>▪ **Electric Load Analysis** (1 hr.)<br>♦ Energy Efficiency<br>♦ Electric Load Requirements<br>♦ Refrigeration<br>♦ Lighting<br>♦ Calculating Load Estimates | **LUNCH** | ▪ **Use Solar Resource Tools** (1.5 hrs.)<br>♦ Use solar Pyranometer for accurate solar measurement<br>♦ PV Watts (on smart phone)<br>♦ Use solar Pathfinder to demonstrate shading<br>♦ Use Solar SunEye on phone App to demonstrate shading<br>▪ ***Health Break*** *(30 mins.)*<br>▪ **Calculating Loads** (2 hrs.)<br>♦ Inspect tags on different equipment and verify load calculations<br>♦ Review other spreadsheets and mobile apps available for load calculations<br>♦ Calculate loads for water pumping and solar street light<br>▪ **Review and Adjournment** |

| | 08:00 – 12:00<br>Theoretical Background | 12:00 –<br>13:00 | 13:00 –17:00<br>Application and<br>Hands-on Exercises |
|---|---|---|---|
| **Day 3**<br>Wednesday<br>Nov 8th | ▪ **Photovoltaic Electric Principles** (1.5 hrs.)<br>♦ Terminology (Power vs Energy)<br>♦ Electric Circuits<br>♦ Series and Parallel Circuits<br>▪ ***Health Break (30 mins.)***<br>▪ **Inverters** (30 mins.)<br>♦ Operating Principles<br>♦ Inverter types<br>♦ Sizing<br>▪ **Photovoltaic System Wiring** (1.5 hrs.)<br>♦ Wire Size calculations<br>♦ Overcurrent Protection & Sizing<br>♦ Disconnects, Grounding and Surge Suppression | **LUNCH** | ▪ **PV Panel Exercise** (1.5 hrs.)<br>♦ Types of current (DC & AC)<br>♦ Demonstrate with voltage meter<br>♦ Series & Parallel wiring exercise<br>▪ ***Health Break*** *(30 mins.)*<br>▪ **Begin to Build out Boards** (2 hrs.)<br>♦ Calculate wire size, cut and install on the board<br>♦ Discuss appliance size (light bulb, fan, cell phones) to match the power system<br>♦ Add Inverters<br>▪ **Review and Adjournment** |

| | 08:00 – 12:00<br>Theoretical Background | 12:00 –<br>13:00 | 13:00 –17:00<br>Application and<br>Hands-on Exercises |
|---|---|---|---|
| **Day 4**<br>Thursday<br>Nov 9th | ▪ **Batteries** (2 hrs.)<br>♦ Battery Types and Operation<br>♦ Battery Specifications<br>♦ Battery Safety<br>♦ Battery Wiring Configuration<br>♦ Battery Sizing<br>▪ ***Health Break** (30 mins.)*<br>▪ **PV/Battery Controllers** (30 mins.)<br>♦ Charge Controller Features<br>♦ Charge Controller Specifications<br>♦ PV + Battery Charge Controller Sizing<br>▪ **PV + Battery System Sizing** (1.5 hrs.)<br>♦ Sizing calculations for PV + Battery<br>♦ Full System Wire Sizing Exercise | LUNCH | ▪ **Battery configuration Exercise** (1.0 hr.)<br>♦ Series & Parallel wiring of batteries<br>▪ **Continue Building out Board** (1.5 hrs.)<br>♦ Add batteries and charge controllers to test board<br>▪ ***Health Break** (30 mins.)*<br>▪ **Continue Building out Board** (1.5 hrs.)<br>♦ Ensure breakers and switches are in place<br>♦ Complete the board<br>▪ **Review and Adjournment** |

| | 08:00 – 12:00<br>Theoretical Background | 12:00 –<br>13:00 | 13:00 –17:00<br>Application and<br>Hands-on Exercises |
|---|---|---|---|
| **Day 5**<br>Friday<br>Nov 10th | ▪ **Commissioning a PV System** (2 hrs.)<br>♦ Commissioning PV Systems<br>♦ Battery Commissioning<br>♦ Commissioning Report<br>♦ PV System O&M plans<br>♦ Theft prevention<br>▪ ***Health Break** (30 mins.)*<br>▪ **Accreditation Review** (1 hr.)<br>♦ Survey of Expertise<br>▪ **Closing Remarks and Evaluation** (30 min.) | LUNCH | ▪ **Demonstration by MOBISOL**<br>♦ Introduction to Mobisol's PV installation and monitoring systems<br>♦ Tour and Q & A<br>▪ ***Health Break** (30 mins.)*<br>▪ **Demonstration by ENSOL**<br>♦ Introduction to ENSOL's PV installations and monitoring systems<br>♦ Tour and Q & A<br>▪ **Review and Adjournment** |

*For more information about the Solar PV Accreditation Training Course, contact:*
*Kari Burman kari.burman@nrel.gov or Andy Walker andy.walker@nrel.gov*

## Climate Technology Centre & Network
## Solar Photovoltaic Accreditation Training Program

## Day One

NREL 40 1977 - 2017

## CLIMATE TECHNOLOGY CENTRE & NETWORK SOLAR PHOTOVOLTAIC ACCREDITATION TRAINING PROGRAM

Presented by: Andy Walker and Kari Burman
National Renewable Energy Laboratory
November 6th -10th , 2017



## PV Installer's Training

## Pilot Training Course

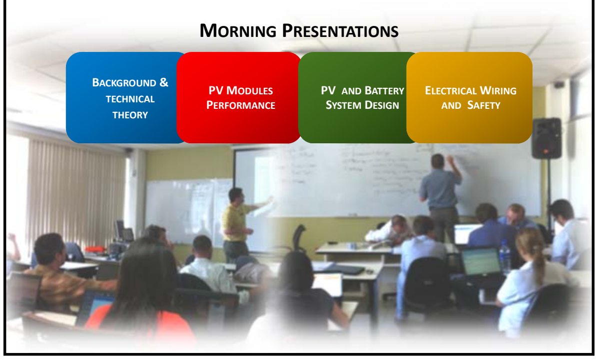
- Objective of the Pilot Training Course:
  - Provide Tanzanian's vocational institutes, TAREA and others with a training program for solar PV installers. The pilot training is being jointly delivered with Tanzanian solar PV technicians and experts for their validation along with other key stakeholders
  - Additional Participants, include developers and regional energy trainers and officers. This should enhance the awareness and capacity to assess the quality of PV technology throughout Tanzania.
  - Stakeholders in the country will have access to training material serving as guidance to identify low quality PV technology and correctly install PV + battery systems.

## PV Installer's Training Course

- Objective of the PV Installer's Training Course:
  - This training will serve the PV installers with some electrical system knowledge…a level above the most basic skills for installing out-of-the box watt-scale solar PV.
  - The training will focus on the off-grid solar photovoltaic + battery systems, up to a system size that could power a community center.
  - Through the pilot training, solar PV installers will gain the knowledge and skills to:
    - Assess the quality of PV cells and modules
    - Identify inferior goods entering the market
    - Install the technology effectively
    - Trouble shoot and maintenance of solar systems (isolated solar PV for power supplies, solar water pumps and solar street lights)



## Training Course Methodology




## How will the Pilot Training be implemented?

- NREL working with TAREA developed the agenda and draft materials for this pilot training.
- The agenda reflects the training outline developed by TAREA for PV trainers and installers in remote, off-grid areas.
- NREL will present the "classroom" portion of the training, including theoretical lectures, worksheets and inspection check lists to be presented in the morning.

## Training Course Attributes

### Afternoon Assessments and Analysis

**Hands on PV Module Inspection**

Review check list of inspection items

Inspection procedures training

**PV + Battery Prototype Designs**

Resource analysis training (PVWatts, solar shading tool )

Load calculations (spreadsheets)

Additional resources provided on DVDs

## How will the Pilot Training be implemented?

- TAREA, NREL and support technicians will lead the hands-on demonstration exercises to build a PV + battery prototype system presented in the afternoons. Different size PV panels will be used to demonstrate wiring calculations.
- It is up to Tanzanian public institutions in partnership with the private sector to determine how the curriculum will be adopted and incorporated in solar PV installers certification program.
- There will be 10 support technicians and 20 trainees during the pilot training.
- The hands –on exercises will have 5 workstations with 4 trainees and 2 support technicians



## Tools Needed for Hands-on portion

- Watt Meter – Electrical power and consumption measurement
- PV panels – small modules hands-on analysis
- Inverters – for small AC appliances
- Batteries – for a prototype system
- Charge Controller-for charging batteries
- Small appliances, light bulbs, fans - Load for prototype system
- Wire – Demonstrate series and parallel wiring
- Switches, USB ports – turning on and off and provide mobile phone charging
- Work Board
- Overcurrent protection

## Materials provided to participants

- Thumb Drive for Trainers (TAREA, VETA, etc) with Resources in English
  - Presentations
  - Calculation spreadsheets
  - Reference documents, checklists
  - Data collection sheets
- Handouts for the solar PV Installers with Resources in Swahili
  - Guidance documents, check lists, and data collection sheets
  - Troubleshooting documents published by TAREA
  - Certificate of participation



**Thank You**

**Please Provide Feedback**

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# CLIMATE TECHNOLOGY CENTRE & NETWORK SOLAR PHOTOVOLTAIC ACCREDITATION TRAINING PROGRAM


**Presented by: Andy Walker and Kari Burman**
**National Renewable Energy Laboratory**

November 6th -10th, 2017



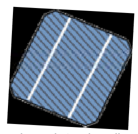
# Photovoltaic Technologies

## Module Overview

- **Principles of Solar Power**
- **Characteristics of PV Cells**
- **PV Module Performance**

## Principles of Solar Power

- Solar Power
  - Solar power is electricity generated from sunlight.
  - Key to solar power is the photovoltaic (PV) cell
  - PV cells converts sunlight into electricity.
  - Sunlight is clean, easy to harness, and a free source of energy.
- Converting Sunlight into Electrical Power
  - Photovoltaics are silicon semiconductor devices similar to diodes and transistors.
  - PV convert solar energy into direct DC current using the action of the cell.

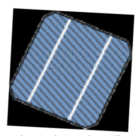


Photovoltaic Solar Cell



## Principles of Solar Power

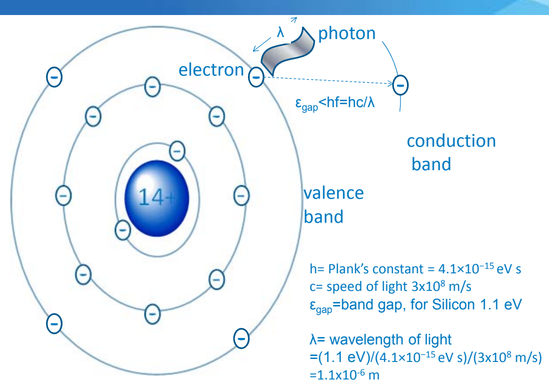
- Converting Sunlight into Electrical Power
  - PV cells are made from wafers of highly purified silicon (Si) doped with special impurities.
  - The impurities give the wafer an abundance of electrons and holes within their structure (holes are the absence of an electron).
  - When sunlight hits the silicon material, electrons are pushed out of their orbit around the atom to become free electrons.
  - Exposing silicon to light causes the electrons to become mobile.



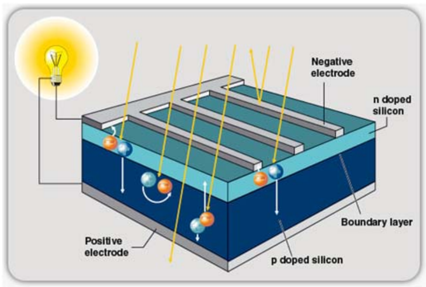
Photovoltaic Solar Cell



## Silicon: A Semiconductor

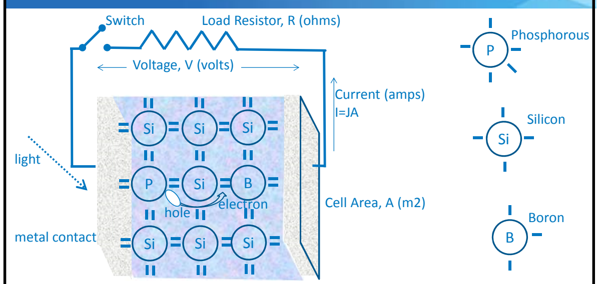


## PV Cell






## The Photovoltaic Effect




**No material is consumed and the process could continue indefinitely**



## Equivalent Circuit of a PV Cell

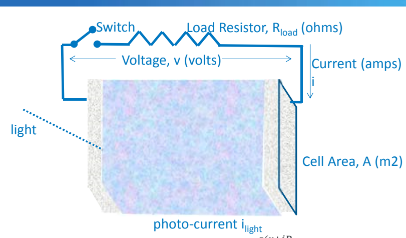



photo-current $i_{light}$

Shockley's diode equation $i_{diode} = J_o\left[e^{\frac{q(v+iR_{series})}{kT}} - 1\right]$

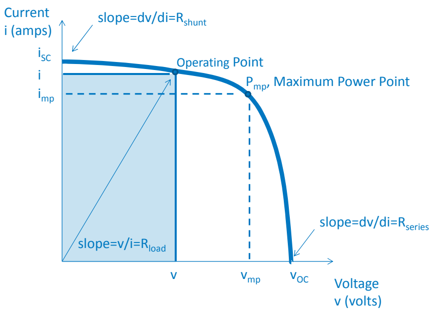
Sum of voltage around a loop = 0 $i_{shunt} = \frac{v+iR_{series}}{R_{shunt}}$

Sum of current into a connection = 0

$$i = i_{light} - i_o\left[e^{\frac{q(v+iR_{series})}{kT}} - 1\right] - \frac{v+iR_{series}}{R_{shunt}}$$

***This is the i-v curve Equation***

## I-V Curve of a PV Cell

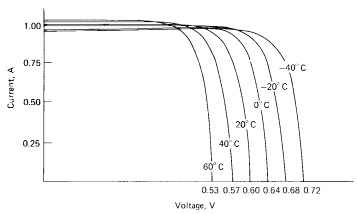



Notice that $R_{shunt} >> R_{series}$



## IV Curve: Voltage and Temperature

- Voltage (Volts) of each cell depends on
  - The material's band gap (eV)
  - Decreases slightly with increasing temperature



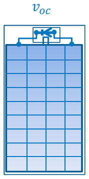

**Changing voltage with changing temperature.**



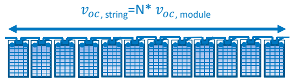
## IV Curve: Voltage and Temperature

**Dependence of Open Circuit Voltage on Temperature**

$v_{oc}$



$v_{oc,\ string}$=N* $v_{oc,\ module}$



Voltage of modules in series add

As temperature goes down, voltage goes up-
must design for the coldest possible temperature so as not to exceed maximum voltage

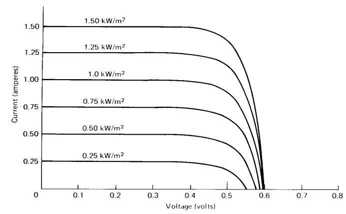
Maximum voltage :
600V in US (UL, NEC)
1000 V in EU
Relates to integrity electrical insulation on modules, wire, disconnects, etc.

β, voltage temperature coefficient measured in a test, in units of Volts/C, but is more often normalized by dividing by $v_{oc}$ and then in %/C ("percent per degree C")

$v_{oc} = v_{oc\ at\ 25C}[1 + \beta_{oc}(T - 25C)]$

## I-V Curve: Sunlight and Current

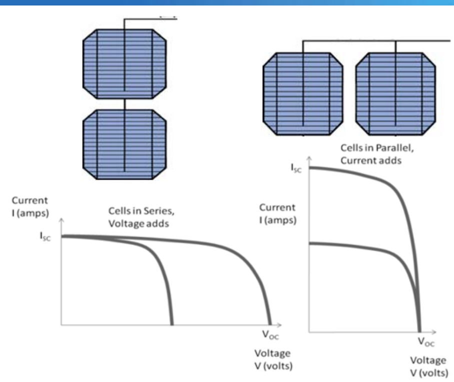
- Current (Amps) of each cell depends on:
  - Surface area
  - Intensity of incident sunlight (kW/m2)




**Changing current with changing insolation.**



## PV Cells in Series and Parallel






## Conclusions Regarding i-v Curve

- Voltage
  - Depends on band gap (constant)
  - Voltage goes down with increasing temperature
  - Voltage increases logrithmically with insolation
  - Voltage not a function of cell area, $A_c$ ($m^2$)
  - Voltage increases with cells in series
  - Voltage proportional to load resistance v=iR
- Current
  - Current increases linearly with insolation
  - Current increases linearly with cell area, $A_c$ ($m^2$)
  - Current increases with cells in parallel
  - Current inversely proportional to load resistance, i=v/R

## PV Cell Power

- Power of PV Cells
  - Most commercially available PV cells have solar power ratings.
  - $P_{mp}$ indicates the maximum deliverable solar power that the cell can provide in watts.

$$P_{mp} = V_{out} * I_{max}$$

- Example

  Calculate the maximum output current of a single 0.5V silicon PV cell with a maximum rated power output of 1.75 Watts at full sun.

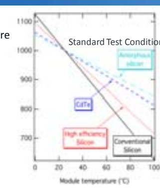
  - $I_{max} = P_{mp}/V_{out}$
  - $I_{max}$ =1.75W/0.5V = 3.5 amps



## Linear Approximation for Temperature Dependence

PV Output vs. Temperature

Normalized at 1000




Coefficients vary, so check data sheets

$\delta_{mp}$ power temperature coefficient which is the rate at which the **power** reduces with increasing temperature and is reported in units of 1/C or %/C.

$$P_{mp} = P_{mp\ at\ 25C}[1 + \delta_{mp}(\mathrm{T_{cell}} - 25C)]$$



## Efficiency of a PV Device, η

Output power/input power

$$\eta = \frac{iv}{I_c A_c}$$

Maximum efficiency

$$\eta_{max} = \frac{i_{mp} v_{mp}}{I_c A_c}$$

$$\text{Solar cell efficiency (\%)} = \frac{\text{Power out (W) x 100\%}}{\text{Area (m}^2\text{) x 1000 W/m}^2}$$

10% efficiency = 100 W/m$^2$ or 10 W/ft$^2$

## Power Output and Efficiency of a PV Module as a function of Insolation and Temperature

$P_{mp}$ as a function of temperature and insolation..

$$P_{solar} = \frac{P_{STC}\,KI_c}{(I_{STC})}[1 + \delta(T_{cell} - T_{STC})]$$

where standard test conditions are $I_{STC}$=1000 W/m$^2$; and $T_{STC}$=25C.

Using the efficiency, $\eta = P/I_c A_c$, measured under STC conditions, we can also express power output as

$$P_{solar} = A_c K I_c \eta_{STC}[1 + \delta(T_{cell} - T_{STC})]$$

where $\eta_{STC}$ is the efficiency of the PV modules under standard test conditions. For cell temperatures other than STC conditions we can calculate efficiency as

$$\eta_{solar} = \eta_{STC}[1 + \delta(T_{cell} - T_{STC})]$$

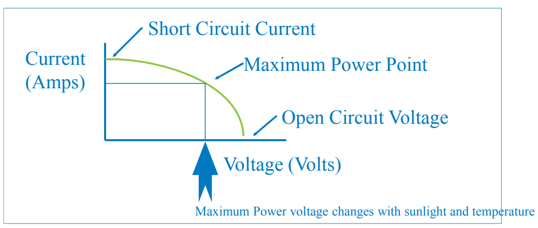


## Module Overview

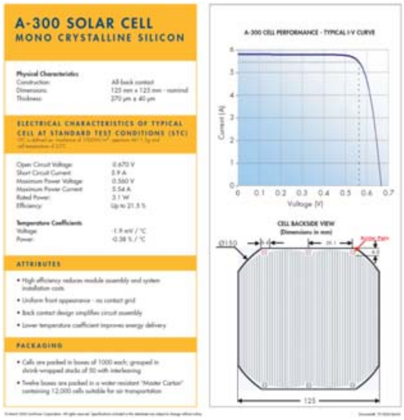
- **Principles of Solar Power**
- **Characteristics of PV Cells**
- **PV Module Performance**



## PV Cells- Characteristics




Isc= short circuit current (amps)
Voc= open circuit voltage (V)
Imp= maximum power point current (amps)
Vmp=maximum power point voltage (volts)
Pmp= maximum power (watts) and Maximum Power Point
β = voltage temperature coefficient Volts/C or in %/C
δmp = power temperature coefficient 1/C or %/C.


# A-300 SOLAR CELL
## MONO CRYSTALLINE SILICON

**Physical Characteristics**

| | |
|---|---|
| Construction: | All-back contact |
| Dimensions: | 125 mm x 125 mm - nominal |
| Thickness: | 270 µm ± 40 µm |

**ELECTRICAL CHARACTERISTICS OF TYPICAL CELL AT STANDARD TEST CONDITIONS (STC)**

| | |
|---|---|
| Open Circuit Voltage: | 0.670 V |
| Short Circuit Current: | 5.9 A |
| Maximum Power Voltage: | 0.560 V |
| Maximum Power Current: | 5.54 A |
| Rated Power: | 3.1 W |
| Efficiency: | Up to 21.5 % |

**Temperature Coefficients**

| | |
|---|---|
| Voltage: | -1.9 mV / °C |
| Power: | -0.38 % / °C |

**ATTRIBUTES**

- High efficiency reduces module assembly and system installation costs
- Uniform front appearance - no contact grid
- Back contact design simplifies circuit assembly
- Lower temperature coefficient improves energy delivery

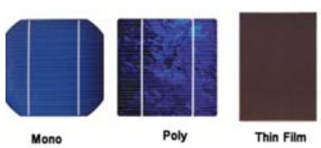
**PACKAGING**

- Cells are packed in boxes of 1000 each; grouped in shrink wrapped stacks of 50 with interleaving
- Twelve boxes are packed in a water resistant "Master Carton" containing 12,000 cells suitable for air transportation



## PV Cells

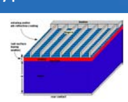
- Types of PV Cells made from Silicon:
  - Mono-crystalline Silicon (also known as single-crystal silicon)
  - Poly-crystalline Silicon (also known as multi-crystal silicon)
  - Thin Film Silicon



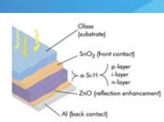

Photovoltaic Solar Cell

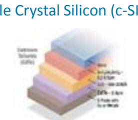


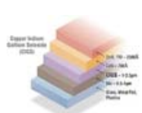
## Types of Photovoltaic Cells

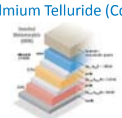

Single Crystal Silicon (c-SI)


Multi-Crystal Silicon (mc-SI)

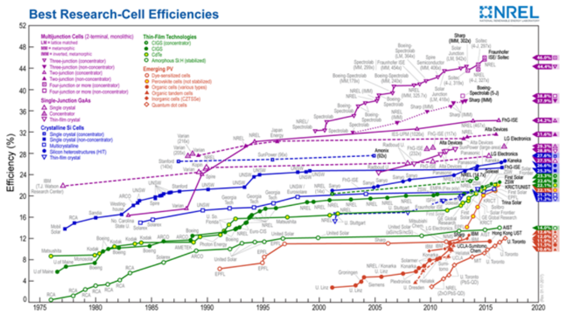

Amorphous Silicon (a-SI)


Cadmium Telluride (CdTe)


Copper Indium Gallium Di-Selenide (CIGS)


Multi-Junction (GaAs; GaInP; Ge)

## PV Cell Efficiencies






## Efficiencies of Different PV Panels 2017


http://news.energysage.com/what-are-the-most-efficient-solar-panels-on-the-market/



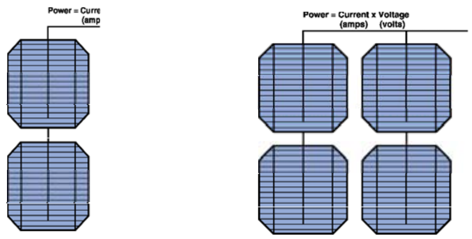
## Module Overview

- **Principles of Solar Power**
- **Characteristics of PV Cells**
- **PV Module Performance**

## PV Cells

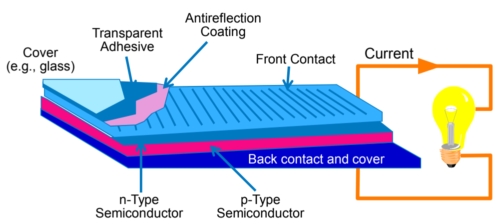
*PV cells are wired in series to increase voltage...*

*and in parallel to increase current*






## Laminate of PV Module



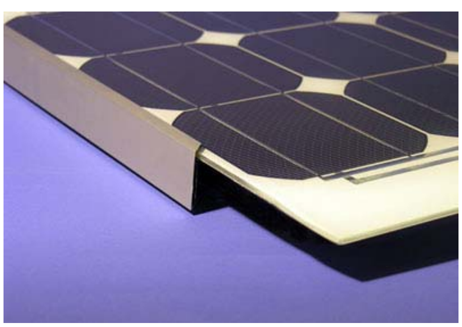

$$\text{Solar panel efficiency (\%)} = \frac{\text{Power out (W)} \times 100\%}{\text{Area (m}^2\text{)} \times 1000\ \text{W/m}^2}$$

10% efficiency = 100 $W/m^2$ or 10 $W/ft^2$

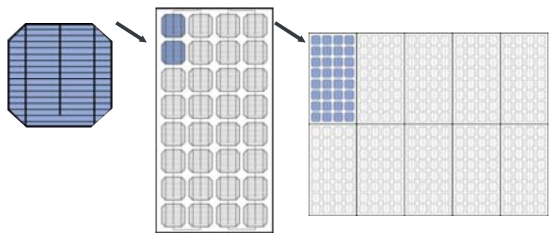


## PV is Modular

**Laminate with or without Frame**



## PV is Modular



**Cells are assembled into modules... and modules into arrays.**



## PV Module Nameplate Rating

"Rated Power" is the output of a PV module under standard reference conditions:

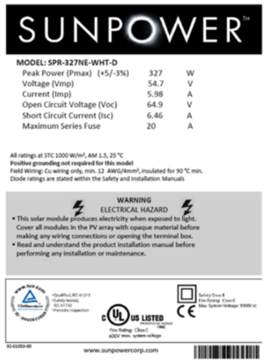
- 1 kW/m² sunlight
- 25 C cell temperature
- 1 m/s wind speed

ASTM E1036-96, Standard Test Method for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells



## Module Nameplate

## Example Nameplate



SUNPOWER™

**MODEL: SPR-327NE-WHT-D**

| | | |
|---|---|---|
| Peak Power (Pmax) (+5/-3%) | 327 | W |
| Voltage (Vmp) | 54.7 | V |
| Current (Imp) | 5.98 | A |
| Open Circuit Voltage (Voc) | 64.9 | V |
| Short Circuit Current (Isc) | 6.46 | A |
| Maximum Series Fuse | 20 | A |

All ratings at STC 1000 W/m², AM 1.5, 25 °C
**Positive grounding not required for this model**
Field Wiring: Cu wiring only, min. 12 AWG/4mm², insulated for 90 °C min.
Diode ratings are stated within the Safety and Installation Manuals

**WARNING**
**ELECTRICAL HAZARD**

- This solar module produces electricity when exposed to light. Cover all modules in the PV array with opaque material before making any wiring connections or opening the terminal box.
- Read and understand the product installation manual before performing any installation or maintenance.

c UL US LISTED
Fire Rating: Class C
600V max. system voltage

www.sunpowercorp.com



## Example Data Sheet

| ELECTRICAL DATA | E20-327 | E19-320 |
|---|---|---|
| Nominal Power[12] (Pnom) | 327 W | 320 W |
| Power Tolerance | +5/-0% | +5/-0% |
| Avg. Panel Efficiency[13] | 20.4% | 19.9% |
| Rated Voltage (Vmpp) | 54.7 V | 54.7 V |
| Rated Current (Impp) | 5.98 A | 5.86 A |
| Open-Circuit Voltage (Voc) | 64.9 V | 64.8 V |
| Short-Circuit Current (Isc) | 6.46 A | 6.24 A |
| Maximum System Voltage | 600 V UL & 1000 V IEC | |
| Maximum Series Fuse | 20 A | |
| Power Temp Coef. (Pmpp) | -0.38% / °C | |
| Voltage Temp Coef. (Voc) | -176.6 mV / °C | |
| Current Temp Coef. (Isc) | 3.5 mA / °C | |

| OPERATING CONDITION AND MECHANICAL DATA | |
|---|---|
| Temperature | - 40°F to +185°F (- 40°C to +85°C) |
| Max load | Wind: 50 psf, 2400 Pa, 245 kg/m² front & back<br>Snow: 112 psf, 5400 Pa, 550kg/m² front |
| Impact resistance | 1 inch (25 mm) diameter hail at 52 mph (23 m/s) |
| Appearance | Class A |
| Solar Cells | 96 Monocrystalline Maxeon Gen II Cells |
| Tempered Glass | High Transmission Tempered Anti-Reflective |
| Junction Box | IP-65 Rated |
| Connectors | MC4 Compatible |
| Frame | Class 1 black anodized, highest AAMA Rating |
| Weight | 41 lbs (18.6 kg) |

| TESTS AND CERTIFICATIONS | |
|---|---|
| Standard tests | UL 1703, IEC 61215, IEC 61730 |
| Quality tests | ISO 9001:2008, ISO 14001:2004 |
| EHS Compliance | RoHS, OHSAS 18001:2007, lead-free, PV Cycle |
| Ammonia test | IEC 62716 |
| Salt Spray test | IEC 61701 (passed maximum severity) |
| PID test | Potential-Induced Degradation free: 1000V |
| Available listings | CEC, JET, KEMCO, MCS, FSEC, CSA, UL, TUV |

REFERENCES:




## International Electrotechnical Commission (IEC) Standard IEC 61853-1

Requires that module performance be reported under 5 different sets of conditions. ASTM standard G173-03 spectrum and "1.5 air mass," (1.5AM) is the standard atmosphere used in all five test conditions.

**Standard Test Conditions (STC):**
For non-focusing modules for use on Earth, the specified STC insolation is $I_c$=1000 W/m² and the cell temperature is $T_{cell}$=25C (78F).

For focusing collectors, the standard for insolation of direct beam radiation of 850 W/m² (IEC, 2006).

**Nominal Operating Cell Temperature (NOCT):** Insolation $I_c$=800 W/m²; ambient temperature $T_{ambient}$=20C; wind speed = 1 m/s to specify air movement cooling the module.

**Low Irradiance Conditions (LIC):** Insolation $I_c$=200 W/m²; module temperature $T_{cell}$=25C

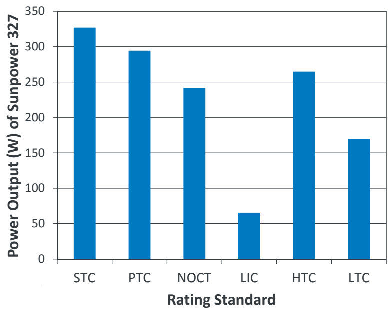
**High Temperature Conditions (HTC)** Insolation $I_c$=1000 W/m²; module temperature $T_{cell}$=75C

**Low Temperature Conditions (LTC)** Insolation $I_c$=500 W/m²; module temperature $T_{cell}$=15C

Also in the US we have:

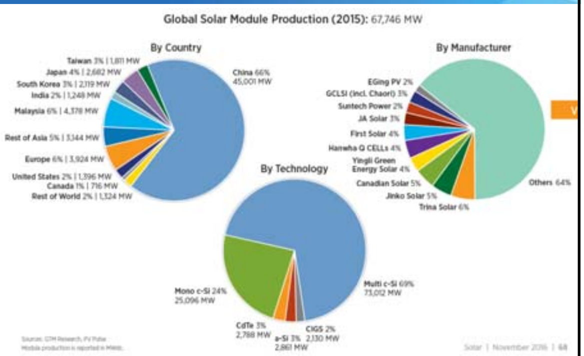
Performance Test Conditions (PTC): Insolation 1,000 W/m2 plane-of-array irradiance, 20°C ambient temperature, and 1 m/s wind speed.

## Comparison of Ratings for Sunpower 327 W PV Module





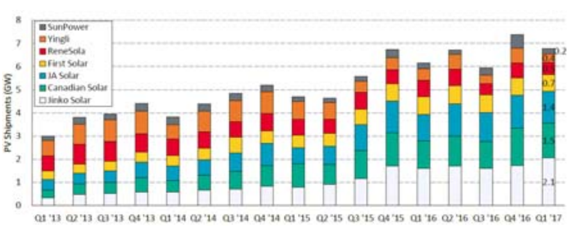

## Worldwide PV Manufacturing




http://www.nrel.gov/docs/fy17osti/66591.pdf



## PV Manufacturers' Shipments




Feldman and Margolis Q3 FY16 Update

## Cost of Photovoltaics


- From January 2017 to July 2017, module prices for larger buyers and polysilicon prices fell 8% and 10% respectively due to the leveling off of global demand and increased competition for market share.
  - Module pricing for small buyers fell 24% from January 2017 to July 2017
  - Cell and wafer pricing increased 4% over that same period.
- Despite the continued drop in global module pricing, many analysts report an increase in U.S. module pricing due to fears of tariffs being put in place on all foreign c-Si modules and cells due to the Section 201 filing by SolarWorld and Suniva (ITC determination on Section 201 case is set for September 22nd; however, the implementation may not happen until 2018, if at all)
  - U.S. module pricing reported between $0.40/W to $0.50/W.
  - Many developers and distributors are stockpiling panels in preparation for a potential tariff.
  - The $0.78/W minimum module price that is requested in the filing was approximately the average ASP in 2012.

**Sources**: "Modules (large buyers)" from PVInsights, accessed 07/26/17. Remaining data from BNEF Solar Spot Price Index (07/26/17). Other information from: BNEF (07/05/17); Cowen & Co. (07/13/17); Deutsche Bank (07/13/17); Mercom (04/04/17, 05/08/17); SPV Market Research (April 2017).

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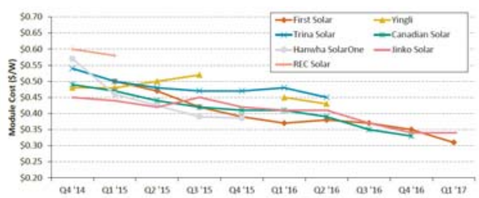
## Cost of Photovoltaics




- In Q1 '17, module costs were reported between $0.31/W and $0.34/W.
  - Q1 '17 costs for First Solar and Jinko Solar were, on average, 17% less than Q1 '16, though these two companies may not be representative of the industry as a whole.
- As prices have come down, fewer companies are publicly reporting manufacturing costs.
  - Canadian Solar did reiterate its $0.29/W cost target by year end.

**Sources**: Company figures based on Q1 '17 (and previous) SEC filings by the respective companies. Deutsche Bank (07/18/17)

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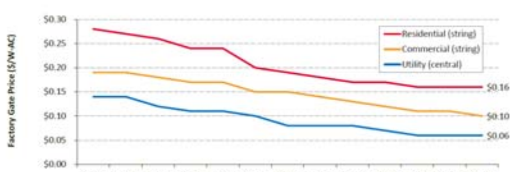
## Inverter Costs




- Central and string inverter prices were relatively flat from Q3 2016 to Q1 2017
  - Central and string inverter prices have dropped 43%–57% since Q1 2014
  - As prices have dropped, manufacturers have included new standards and features.

**ource**: GTM Research/SEIA "Solar Market Insight Q2 2017."

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Thank You
Please Provide Feedback
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1977 - 2017

# CLIMATE TECHNOLOGY CENTRE & NETWORK SOLAR PHOTOVOLTAIC ACCREDITATION TRAINING PROGRAM


**Presented by: Andy Walker and Kari Burman**
**National Renewable Energy Laboratory**

November 6th -10th , 2017



# PV Inspection

## Module Overview

- Why do we need inspection?
- Terminology
- Severity Rating
- Inspection Procedure
- Accept and Reject Criteria
- Checklist: New Module
- Checklist: Used Module
- Catalogue Of Defects: New Modules
- Catalogue Of Defects: Used Modules

## Background

- This presentation talks about how to visually inspect front-contact poly-crystalline and mono-crystalline silicon solar photovoltaic (PV) modules for major defects.
- The modules under consideration may be of any size or rated power, however some specific use-cases for solar modules may have different requirements.
- Therefore adaption of the inspection guide is application and institution dependent (ex. labelling may not be present for a solar module sold as part of a small off-grid lighting kit).



## Background

- This guide is meant to supplement and support rather than replace international testing standards (for example IEC 61215 or UL 1703). [1],[2]
- A lack of visually observable defects is necessary but not sufficient to determine if a module would pass IEC 61215 testing.

[1] "IEC 61215: Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualifications and type approval 2nd Edition," International Electrotechnical Commission, Geneva, 2005. (https://webstore.iec.ch/publication/24312)

[2] "UL Standard for Safety for Flat-Plate Photovoltaic Modules and Panels, UL 1703. Third Edition.," Underwriters Laboratories Inc, Northbrook, Mar. 2002. (http://www.linpin.com.cn/upload/20111202082155835583.pdf)



## Module Overview

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## Why is inspection required?

- Inspection guide was developed as a response to observations of sub-standard quality and counterfeit solar products present in developing world markets.
- Many consumers and retailers are not aware of the presence of significant visually observable defects that may limit performance and/or lead to premature product failure.
- Nor are they aware that good quality PV modules should last 25 years or more.

Note that no amount of visual inspection or electrical product testing can guarantee that a module will perform reliably for 25 years.



## Why is inspection required?

- Although visual inspection cannot catch all possible defects, it can be used as a screening method to identify poor performing products and potential early failure modes.
- Inspection guide was developed with the intention of being a quick tool that is inexpensive to implement, as it does not require any test equipment.
- Although helpful, no prior knowledge of solar photovoltaics is required to benefit from this guide, and an inspector should be able to be trained in its use in two days or less.



## Who can use the Inspection Guide document?

- Border agents to inspect product shipments at ports of entry to a country. Standardized rejection criteria could be used as grounds for barring defective products for import in conjunction with an adopted IEC standard such as IEC 61215.
- Standards agencies or regulatory authorities in search and seizure efforts. A tool that can be used onsite to determine if defective or fraudulent products are found for sale in markets.
- Retailers/distributors to ensure they are receiving acceptable quality products from manufacturers.

## Who can use the Inspection Guide document?

- Installers/Technicians when selecting product from retailers or distributors for customers.
- Educators as a teaching tool for students of solar energy, for example when training technicians.
- Inspectors of already installed solar products to catalogue defects and attempt to trouble-shoot failures. However, as this guide deals primarily with new modules, alternative tools are recommended for this task.[3]

[3] Example - C. E. Packard, J. H. Wohlgemuth, and S. R. Kurtz, "Development of a Visual Inspection Data Collection Tool for Evaluation of Fielded Pv Module Condition," National Renewable Energy Laboratory (NREL), Golden, CO., NREL/TP-5200-56154, Aug. 2012.(https://www.nrel.gov/docs/fy12osti/56154.pdf)



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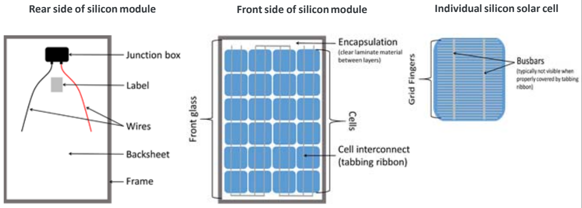
## Terminology

The schematics in the this section describe where each component is found on a common solar PV module which you might be aware or have seen in earlier presentations.



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## Severity Rating

- A Severity Rating is defined to give users guidelines on how concerning a particular defect may be.
- The range of the scale indicates influence to performance and/or reliability, and given is from 1 (low severity) to 5 (high severity).
- A range is provided when the severity of a defect can vary, for example with the size of the affected area.
- An additional icon is given if the defect poses a potential safety risk to the installer or the end user.

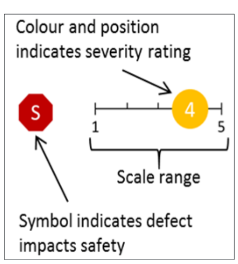




## Severity Rating

S: Symbol indicating a safety risk, separate from quantitative scale

1. **[Green]** The defect is an indicator of poor quality with no direct effect on performance or reliability.
2. **[Light Yellow]** The defect has a minor impact on performance and/or reliability
3. **[Yellow]** The defect has a moderate impact on performance and/or reliability
4. **[Dark Yellow]** The defect has a high impact on performance and/or reliability
5. **[Red]** The defect is indicative of a major quality issue, a critical failure, or a counterfeit panel



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## Inspection Procedure

- Institutions/Organizations may choose to adapt the checklist into a format unique to the needs of the given application.
- For example, different institutions/applications might require specific administrative details to be recorded beyond the fields of Module ID, Inspector and Date that are currently included (ex. location, reason for inspection, shipment, company, actions taken, comments, etc. )



## Inspection Procedure

The following procedure should be followed for each product lot to be inspected (ex. shipment, retail location, installation, etc.).

1. Identify and differentiate the different product types/sizes to be inspected within the lot
2. Select a minimum of 8 samples of each size/type randomly for inspection (see IEC 61215 for sampling recommendations). Care should be taken to select samples from different locations (boxes, containers, etc.) within a lot (for example do not simply select the first 8 samples that are seen). Depending on the application this may not be sufficient: for example if inspecting existing modules at a solar installation, it would likely be desirable to inspect 100% of samples

## Inspection Procedure

3. The inspector should complete one checklist per sample, proceeding through the list of defects in the order in which they are presented in order to ensure completeness.
   a. For each defect in sequence complete the checklist with an indication of defect presence, severity and whether or not the defect represents a potential safety risk.
   b. Depending on the requirements and the resources of the institution, it may be of interest to take photos of defects for inclusion in an inspection report, along with overview photos of the front, back, and label of a module.
   c. If further information or clarification is needed, refer to the detailed Catalogue of Defects (Slide 30 onwards) which includes a description of the affected component, defect photos, a description of the defect, why it's important and guidelines on assessing defect severity.
   d. For used samples, both "new" and "used" checklists should be completed in this order. Inspectors should be sufficiently familiar with defects unique to used modules such that they can be identified during the inspection of ostensibly new products.



## Inspection Procedure

4. Once the inspection checklist is complete the inspector can review the results to determine whether the inspected module is acceptable for the intended application. The accept/reject criteria for a single module and an entire lot may be based on the criteria discussed in next slides or as per a standardized procedure determined by a given institution.



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## Accept/Reject Criteria

- Acceptance and Rejection criteria may be application and end user dependent
  - For example: small modules for off-grid applications may have slightly different quality requirements than full sized modules for utility scale applications.
  - The market for small off-grid modules may tolerate minor defects whereas the utility-scale market may not allow any visual defects which might pose even a small risk to the reliability and therefore the long term economic viability of the project
- Users of the guide should make final accept/reject decisions based on a consistent, standardized and documented process which is justified by the needs of the market being served.

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## Accept/Reject Criteria

- A solar PV module sample will be considered to be rejected due to its observable quality defects if any one of the following conditions are met:
  1. If any single observed defect has been evaluated as a severity of 5.
     - A severity of 5 indicates a major quality issue: a critical failure or a fraudulent module. This evaluation alone is sufficient justification for the rejection of a sample.
  2. If any single observed defect has been evaluated to pose a safety risk. Under no conditions should a module that risks the safety of an installer or end user be considered acceptable.

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## Accept/Reject Criteria

3. If any combination of observed defects that have a summed severity score greater than or equal to 5 (acceptable summed value could be raised or lowered at the discretion of a given institution).
   - This condition allows for the possibility to accept modules with minor defects that do not critically affect the performance or reliability.
   - This is done with the intent of not putting prohibitively stringent demands on developing markets that can tolerate minor deficiencies.
4. If any module that is expected to be new shows any of the used module defects. The defects listed under the used module checklist (slide 29) should be exclusively visible on used modules.
   - At the discretion of the institution/organization, the inspector might be directed to also always complete the used module checklist in order to rule out these defects, or alternatively simply complete the last row of the new module checklist to indicate the module does not appear to be used previously.

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## Accept/Reject Criteria

- If one or more samples are rejected for any of the previous conditions then further action is required.
- Dependent on the application to which this process is applied and the goals of the inspection, several options are possible at the discretion of the responsible institution/organization:
  1. Reject the entire lot under inspection.
  2. If only one of initial 8 samples is defective, reselect at minimum 8 random samples from the lot and repeat the above inspection procedure. If rejects are again found then reject the entire lot.
  3. Require 100% inspection on all samples within the lot and reject all non-conforming samples.
  4. Instigate a more in-depth secondary inspection to further investigate the quality of the lot under question, likely including electrical testing



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## Checklist: New Module

Module ID:__________ Inspector: __________ Date: ________

**CHECKLIST: New Module**

| COMPONENT | DEFECT | | Defect Present? No | Yes | If Yes, Score | Safety Issue? |
|---|---|---|---|---|---|---|
| 1. Label | 1.1 | Missing | | | | |
| | 1.2 | Poorly attached | | | | |
| | 1.3 | Information is missing | | | | |
| | 1.4 | Incorrect spelling | | | | |
| 2. Backsheet | 2.1 | Delamination | | | | |
| 3. Junction Box | 3.1 | Faulty electrical connection | | | | |
| | 3.2 | Cracks/breaks/gaps in housing | | | | |
| | 3.3 | Sealant failure | | | | |
| | 3.4 | Electrical polarity not indicated | | | | |
| 4. Wiring | 4.1 | Wire(s) missing or poorly attached | | | | |
| | 4.2 | Too short and/or too thin | | | | |
| 5. Frame | 5.1 | Damaged | | | | |
| | 5.2 | Adhesive/sealant failure | | | | |
| 6. Front Glass | 6.1 | Cracking | | | | |
| | 6.2 | Scratches | | | | |
| 7. Encapsulation | 7.1 | Delamination | | | | |
| 8. Cells | 8.1 | Fake | | | | |
| | 8.2 | Dummy pieces disguising missing material | | | | |
| | 8.3 | Cracks | | | | |
| | 8.4 | Partially covered | | | | |
| | 8.5 | Scratches | | | | |
| | 8.6 | Differently sized | | | | |
| | 8.7 | Edge chips | | | | |
| | 8.8 | All cells very shiny | | | | |
| 9. Cell Metallization | 9.1 | Fingers not connected to busbar | | | | |
| | 9.2 | Not the same pattern on all cells | | | | |
| | 9.3 | Fingers off of edge of corner of cells | | | | |
| 10. Cell Interconnection | 10.1 | Interconnection is discontinuous | | | | |
| | 10.2 | Cells connected in parallel (counterfeit) | | | | |
| | 10.3 | Poorly aligned and/or soldered | | | | |
| | 10.4 | Cells connected in parallel (real cells) | | | | |
| Defects are present suggesting module is used rather than new | | | | | | |
| SUMMARY Indicate if any defects and safety issues are present and sum score | | | | | | |

ACCEPT: ☐ REJECT: ☐

## Module Overview

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## Checklist: Used Module

Module ID: ______________ Inspector: ______________ Date: ______

**CHECKLIST: Used Module**

| COMPONENT | DEFECT | | Defect Present? No | Yes | If Yes, Score | Safety issue? |
|---|---|---|---|---|---|---|
| 1. Label | See New Module Checklist | | | | | |
| 2. Backsheet | 2.2 | Burn marks | | | | |
| | 2.3 | Discolouration | | | | |
| 3. Junction Box | See New Module Checklist | | | | | |
| 4. Wiring | 4.3 | Cracks or exposed metal | | | | |
| 5. Frame | See New Module Checklist | | | | | |
| 6. Front Glass | See New Module Checklist | | | | | |
| 7. Encapsulation | 7.2 | Discolouration | | | | |
| 8. Cells | 8.9 | "Snail trails" | | | | |
| | 8.10 | Shiny locally/inconsistent colour | | | | |
| 9. Cell Metallization | See New Module Checklist | | | | | |
| 10. Cell Interconnection | See New Module Checklist | | | | | |
| SUMMARY Indicate if any defects and safety issues are present and sum score | | | | | | |



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## Catalogue of Defects: New Modules

1. Label

Provides important product information. Adhered to the rear of a module by the module manufacturer.

### 1.1 Missing

**Description:** A label must be present. This may be unlikely if the panel is small (<5W)

**Why it's important:** Lack of label implies sub-standard manufacture. Lack of this information is a potential safety issue. Label information is needed to properly install and operate the panel.

**Severity:**

S 1 5



## Catalogue of Defects: New Modules

### 1.2 Poorly attached



**Description:** Label should be made of material that resists water or light damage. Label should not be peeling or bubbling. Label should be permanently adhered (example at right uses clear tape overtop of a poorly affixed label).

**Why it's important:** Label needs to provide panel information for the duration of the panel lifetime. Lack of this information is a potential safety issue as described above.

**Severity:**

S 1 5



## Catalogue of Defects: New Modules

### 1.3 Information is missing



Label on left gives no Current data. Label on right gives no Manufacturer data. Neither gives Model or Serial #.

**Description:** Label should give the following: Maximum Power, Current and Voltage at Maximum Power, Short-Circuit Current, Open-Circuit Voltage, Maximum system voltage, Manufacturer name, Model #, Serial # (sometimes on a small label on the front of the module, can be a barcode). High quality products will have marking symbols from UL, IEC or TUV.

**Why it's important:** Data is needed to properly install, operate and maintain equipment. Lack of this information is a potential safety issue.

**Severity:**

S 1 5

## Catalogue of Defects: New Modules

### 1.4 Incorrect spelling


**Description:** Words should be spelt correctly in whatever language is used

**Why it's important:** Does not affect performance, reliability or safety, but is an indicator of the lack of professionalism of the manufacturer.

**Severity:** 1 (scale 1–5)



## Catalogue of Defects: New Modules

2. Backsheet

Back substrate of module. Protects module interior from the elements

### 2.1 Delamination


[3]

**Description:** Backsheet not well laminated to module. Surface is bubbled or peeling.

**Why it's important:** Bubbles are space for moisture to accumulate. Moisture in the module will decrease performance and affect long term reliability.

**Severity:** 3 (scale 1–5)

[3] C. E. Packard, J. H. Wohlgemuth, and S. R. Kurtz, "Development of a Visual Inspection Data Collection Tool for Evaluation of Fielded Pv Module Condition," National Renewable Energy Laboratory (NREL), Golden, CO., NREL/TP-5200-56154, Aug. 2012.

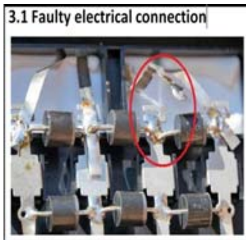


## Catalogue of Defects: New Modules

3. Junction Box

Electrical enclosure on the rear of the module where external wires connect to the internal tabbing ribbon. The junction box also contains the diode(s).

### 3.1 Faulty electrical connection



**Description:** Broken solder joints, broken wire or tabbing ribbon.

**Why it's important:** Broken electrical contacts can cause module failure.

**Severity:** 5 (scale 1–5)

## Catalogue of Defects: New Modules

### 3.2 Cracks/breaks/gaps in housing

**Description:** Cracks in the housing, missing a continuous seal for the lid or around the wires. Possibility of water ingress.

**Why it's important:** Accumulated moisture can cause short circuits or corrosion of the metal contacts, increasing the risk of melting or fire. The junction boxes on high quality modules will be permanently sealed to mitigate this risk.

**Severity:**

S 1 4 5



## Catalogue of Defects: New Modules

### 3.3 Sealant failure

**Description:** Holes in the seal, brittle material (should feel rubbery with fingernail) or adhesion failure. Possibility of water ingress.

**Why it's important:** Accumulated moisture in the junction box can cause short circuits or corrosion of the metal contacts. Corrosion can increase the risk of melting or fire.

**Severity:** If the sealant is brittle but not yet failed then the severity should be 3. If means of water ingress is visible, the severity should be 4.

S 1 3 4 5



## Catalogue of Defects: New Modules

### 3.4 Electrical polarity not indicated

**Description:** Does not include a clear indication of the positive (+ or red) and negative (- or black) terminal of the module. Can be done with colour-coded wires instead of marked on junction box.

**Why it's important:** Improper wiring of the module could cause a safety risk or lead to equipment failure.

**Severity:**

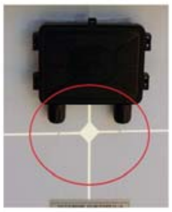
S 1 5

## Catalogue of Defects: New Modules

### 4. Wiring

The wires carry electricity from the module to the charge controller or inverter.

**4.1 Wire(s) missing or insecurely attached**



**Description:** One or both wires are missing or loosely connected to the module.

**Why it's important:** Two wires are necessary to make a circuit. All new modules come with wires securely soldered to the tabbing ribbon and diodes inside the junction box.

**Severity:** If the product is intended to be sold directly to the consumer, then wires are required for module function and severity is a 5. If further assembly is intended, no defect is present.

1 — 5



## Catalogue of Defects: New Modules

**4.2 Too short and/or too thin**

**Description:** Wires aren't long enough to make a robust (waterproof, electrically sound) connection to the rest of the system. Wires too short to reach past the frame of the module are likely a concern. Thickness requirements depend on module current. Examples of max ratings include: 2.9A for 17AWG (1.04mm$^2$), 7.4A for 13AWG (2.63mm$^2$), 15A for 10AWG (5.26mm$^2$), 30A for 7AWG (10.55mm$^2$)[4]

**Why it's important:** If wires are too thin they could melt or burn. For safety, all electrical connections must take place inside a sealed enclosure, ex. junction box.

**Severity:**

S 1 — 3 — 5

[4] "Wire Gauge and Current Limits Including Skin Depth and Strength," Jun-2006. (http://www.powerstream.com/Wire_Size.htm)



## Catalogue of Defects: New Modules

### 5. Frame

The frame provides structure, rigidity, and mounting features. Sometimes non-metal for small modules (for example <10W). Metal is needed for rigidity for large modules. If metal is used, electrical grounding is required.

**5.1 Damaged**

**Description:** Bent or cracked frame or the corners are not well aligned.

**Why it's important:** Loss of mechanical integrity, to the extent that the installation and/or operation of the module would be impaired. For example, may not be rigid enough to withstand handling during installation and/or high winds.

**Severity:** Low severity and no safety risk if dents/cracks in the frame are unlikely to affect mechanical integrity. High severity and safety risk if damage could lead to safety issues from cracked glass, poor electrical grounding, or if installation and/or operation are likely to be impaired.

S 1 2 3 4 5

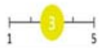
## Catalogue of Defects: New Modules

### 5.2 Adhesive/Sealant failure

**Description:** Discontinuous perimeter seal or loose attachment to module.

**Why it's important:** The adhesive is also a sealant that prevents water ingress into the module. Water in the module layers will decrease performance and affects long term reliability. Severity depends on atmospheric humidity.

**Severity:**






## Catalogue of Defects: New Modules

6. Front Glass

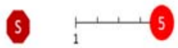
Provides structure to the module and protects the cells. Allows transmission of light to the cells.

### 6.1 Cracking

**Description:** Front glass is cracked locally or over the full area.

**Why it's important:** Module mechanical integrity is compromised. Possible path for water ingress. Mechanical and electrical safety issue.

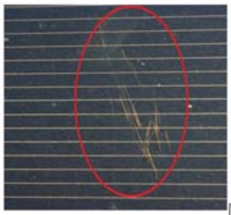
**Severity:**






## Catalogue of Defects: New Modules

### 6.2 Scratches



[3]

**Description:** Permanent scratches in the surface of the front glass. Cannot be removed with cleaning.

**Why it's important:** Transmission of light to the underlying cells, and therefore module power, is reduced.

**Severity:** Severity increases with affected area. A score of 5 should be given If 10% or greater area is affected above any individual cell.


[3] C. E. Packard, J. H. Wohlgemuth, and S. R. Kurtz, "Development of a Visual Inspection Data Collection Tool for Evaluation of Fielded Pv Module Condition," National Renewable Energy Laboratory (NREL), Golden, CO., NREL/TP-5200-56154, Aug. 2012.

## Catalogue of Defects: New Modules

### 7. Encapsulation

Used to laminate module layers together. Transparent to allow light to reach cells.

**7.1 Delamination**

**Description:** Any local separation of the layers between the front glass and the cells or the front glass and the backsheet. May appear continuous (top left) or spotted (right and bottom, due to texture of glass). Also could be bubbles. Most commonly appears around busbars or at the edge of the panel.

**Why it's important:** Can reduce structural integrity of the module. Transmission of light to the underlying cells, and therefore module current, is reduced.

**Severity:** Bubbles of delamination forming a continuous path between any part of the electrical circuit and the edge of the module is a safety risk due to possible water ingress. If delamination does not form such a path no safety risk exists. Influence on performance increases with affected area. A score of 5 is given if 10% or greater of any individual cell's area is affected. A barely visible bubble would correspond to a score of 2.

S 1 2 3 4 5

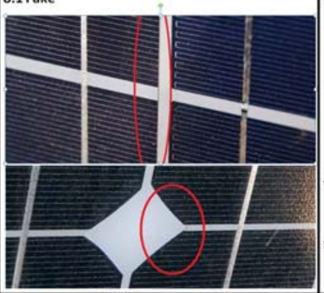


## Catalogue of Defects: New Modules

### 8. Cell

Active component of the solar module. Electricity producing material converts sunlight to electricity.

**8.1 Fake**



**Description:** Cells not made of active material, are instead printed paper images. Likely only a portion of the cells in a given module may be fake. May be evident in the white space between fake cells, where the edge of the paper can be seen. Examples of fake poly and mono-crystalline cells in top and bottom images respectively. If counterfeiters instead cut around each paper cell individually it will be harder to spot, and instead might be caught when inspecting the cell interconnection.

**Why it's important:** Purposely deceitful behaviour of manufacturer. The customer pays for fraudulent material that will not produce power.

**Severity:**

1 5



## Catalogue of Defects: New Modules

**8.2 Dummy pieces disguising missing material**

**Description:** Inactive material (dummy cell fragment or dark paper) has been placed behind an active cell in order to hide the fact that the cell has broken and has a piece missing.

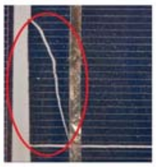
**Why it's important:** Power output of the module limited by the missing material area. Purposely deceitful behaviour by the manufacturer. Indication of sub-standard cells and practices.

**Severity:** Power loss depends on size; a score of 5 should be given if 10% or greater of any individual cell's area is missing. If the piece that is missing extends up to the edge of the metallization, a score of 3 is given. If the piece does not contain any metallization, this defect is instead an Edge Chip (section 8.7).

1 3 4 5

## Catalogue of Defects: New Modules

**8.3 Cracks**

Left: large crack across the cell, but both halves are still connected to busbars. Right: smaller crack is actually more severe: a portion of the cell is no longer electrically connected.

**Description:** Cell is cracked. Crack may be partially or all the way across a cell. Partial cracks are likely to propagate over time. Depending on size cracks may be hard or impossible to spot. The white backsheet may be visible through large cracks.

**Why it's important:** Power output of the module limited if portions are removed from the electrical circuit. Visible cracks indicate poor mechanical handling by manufacturer; likely more cracks exist that are not currently visible.

**Severity:** Severity depends on affected area. A crack is considered a major defect (score of 5) when its propagation could remove more than 10% of that cell's area from the electrical circuit [1]. The presence of a crack of any size that does not, or likely will not through its propagation, isolate any portion of the cell from the electrical circuit is a score of 2.




## Catalogue of Defects: New Modules

**8.4 Partially covered**



**Description:** A cell is partially and permanently covered, for example by the frame, a label, or by another cell.

**Why it's important:** Reduces active cell area. Current will be limited by the smallest cell area. An indicator of sub-standard manufacturer design and fabrication.

**Severity:** Influence on performance increases with affected area. A score of 5 is given if 10% or greater of any individual cell's area is covered.




## Catalogue of Defects: New Modules

**8.5 Scratches**

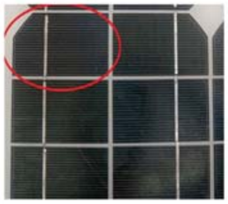

**Description:** Scratches in the surface of the cell from poor handling during module assembly. Often next to tabbing ribbon and caused by operator scraping the cell during soldering.

**Why it's important:** Deep scratches risk shorting the cell, but shallow scratches may have minimal impact.

**Severity:** Severity hard to evaluate visually.

## Catalogue of Defects: New Modules

**8.6 Differently sized**



The circled cell is a different shape and size than the other cells having full corners.

**Description:** Cell fragments of different sizes connected in series within a module.

**Why it's important:** Current will be limited by the smallest cell area. Larger cells will operate at a higher temperature as they burn off excess current, potentially decreasing product lifetime. Indication of a poor module design. Can be compensated for by increasing height, which can be roughly checked by comparing the number of metal fingers on differently sized cells.

**Severity:** 2 (scale 1–5)

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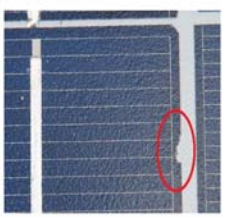
## Catalogue of Defects: New Modules

**8.7 Edge chips**



**Description:** A small region is missing from the edge of the cell. Does not enter metallized region.

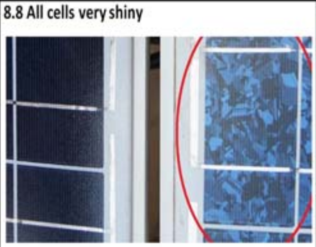
**Why it's important:** Edge region is generally low power producing, so defect has minimal impact. Is a concern if many cells in a module have this defect; it indicates poor mechanical handling.

**Severity:** 1 (scale to 5)

NATIONAL RENEWABLE ENERGY LABORATORY 53

## Catalogue of Defects: New Modules

**8.8 All cells very shiny**



**Description:** Cells are very shiny, reflecting instead of absorbing light.

**Why it's important:** May be less efficient than darker cells, which is not inherently a problem if a module is sold based on rated power. Retailers selling such modules at a higher price to uninformed consumers who associate "shiny" with "new" or better is deceitful practice.

**Severity:** 1 (scale to 5)

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## Catalogue of Defects: New Modules

### 9. Cell Metallization

Metal fingers collect and conduct current from the cell to the busbars (covered by tabbing ribbon)

**9.1 Fingers not connected to busbar**

**Description:** Metal fingers are not connected to the busbars of a cell.

**Why it's important:** Current of unconnected region cannot be used. Severity depends on effected region. In the example here 1/3 of the cell area is effectively unused. Indicates a poor design and a sub-standard manufacturer.

**Severity:** Severity depends on affected area. Considered a major defect when 10% or greater of a cell's area is excluded from the electrical circuit [1].

1 4 5



## Catalogue of Defects: New Modules

**9.2 Not the same pattern on all cells**

**Description:** Different metallization patterns apparent on different cells in the same module.

**Why it's important:** Not inherently an issue if cells have the same performance characteristics. However if mis-matched cells are combined in a module, higher performing cells will be limited by lower performers. Potential indicator of poor manufacturing practices.

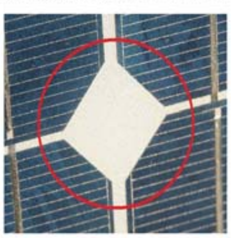
**Severity:**

1 5



## Catalogue of Defects: New Modules

**9.3 Fingers off of edge of corner of cells**



**Description:** Metal fingers go right to cell edge in corner of cell.

**Why it's important:** Indicates deceitful behaviour of manufacturer; lower cost/performance poly-crystalline cells cut to look like high cost/performance mono-crystaline cells.

**Severity:**

1 5

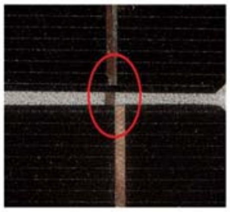
Deceitful behavior – Manufacturer might use cheaper (and lower efficiency) poly crystalline cells and cut the edges off to give the customer the impression that these are more expensive and efficient mono crystalline cells.
Recommendation: Pay attention to the pattern of the cell which will give this away.

## Catalogue of Defects: New Modules

10. Cell Interconnection

Tabbing ribbon that is soldered to bus bars. Connects cells together and conducts current to external circuit.

**10.1 Interconnection is discontinuous**



**Description:** There is no cell interconnection, or tabbing ribbon is present but does not connect cells together (is discontinuous). Note that some small consumer products cover the tabbing ribbon with black material for aesthetic purposes.

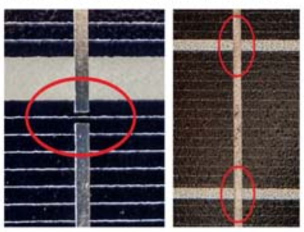
**Why it's important:** Power of unconnected cells does not contribute to module power. Indicator of a partially or completely counterfeit/fake product.

**Severity:** 5 (scale 1–5)



## Catalogue of Defects: New Modules

**10.2 Cells connected in parallel (counterfeit)**



**Description:** Tabbing ribbon appears two dimensional in the area between cells. Rather than connecting the bottom of one cell to the top of the next (standard series connection), the top of one cell is connected to the top of the next (parallel connection).

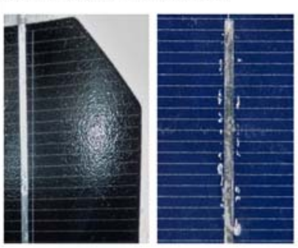
**Why it's important:** Often indicates a counterfeit product with fake printed paper instead of soldered tabbing ribbon.

**Severity:** 5 (scale 1–5)



## Catalogue of Defects: New Modules

**10.3 Poorly aligned and/or soldered**



**Description:** Poorly soldered tabbing ribbon. For example misaligned to busbars or excess solder dripped on cell.

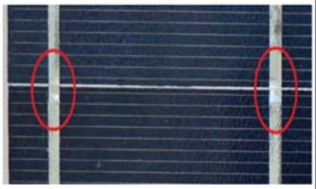
**Why it's important:** Tabbing ribbon mis-aligned to busbars increases resistances and decreases module power. Excess solder shades cells locally, decreasing current. Overall indicators of low quality control standards of the manufacturer.

**Severity:** 2 (scale 1–5)

The reason behind this defect is poor processing and quality control.

## Catalogue of Defects: New Modules

**10.4 Cells connected in parallel (real cells)**



**Description:** Real cells tabbed together in a parallel connection to combine small cut cell fragments with full-sized cells in one module

**Why it's important:** Poor manufacturing practice. Typically correlates with a manual process and broken cells.

**Severity:** 2 (scale 1–5)



## Module Overview

- **Why do we need inspection?**
- **Terminology**
- **Severity Rating**
- **Inspection Procedure**
- **Accept and Reject Criteria**
- **Checklist: New Module**
- **Checklist: Used Module**
- **Catalogue Of Defects: New Modules**
- **Catalogue Of Defects: Used Modules**



## Catalogue of Defects: Used Modules

- The defects discussed in this section appear over time as gradually worsening or catastrophic events.
- This section is included so that if these defects are found at border inspections or at retail locations, it can be immediately identified that the modules are not new and should be rejected.
- If the intended use is specifically to inspect used modules, for example to evaluate PV arrays after a given time of operation, other resources would likely be more suited and complete.
- Note that all used modules can also have all defects that new modules have, but the converse is not true. Therefore when evaluating used modules, both "new" and "used" module checklists should be employed.

## Catalogue of Defects: Used Modules

2. Backsheet

Back substrate of module. Protects module interior from the elements.

### 2.1 Burn marks

**Description:** Burnt, blackened area. Damage cannot be cleaned off. There may be a hole in the backsheet.

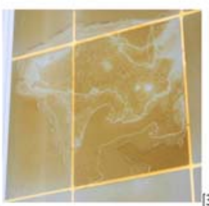
**Why it's important:** Indicates a catastrophic failure event occurred. Performance, reliability and safety are likely to be severely compromised.

**Severity:** S; 5 (scale 1–5)



## Catalogue of Defects: Used Modules

### 2.2 Discolouration



[3]

**Description:** Colour varies across the backsheet, and cannot be cleaned off

**Why it's important:** Backsheet material is likely degraded. This indicates that the module is suffering from a reliability problem.

**Severity:** 4 (scale 1–5)

[3] C. E. Packard, J. H. Wohlgemuth, and S. R. Kurtz, "Development of a Visual Inspection Data Collection Tool for Evaluation of Fielded Pv Module Condition," National Renewable Energy Laboratory (NREL), Golden, CO., NREL/TP-5200-56154, Aug. 2012.



## Catalogue of Defects: Used Modules

4. Wiring

The wires carry electricity from the module to the charge controller or inverter.

### 4.1 Cracks or exposed metal

[3]

**Description:** The wire insulation is cracked or revealing the metal conductor

**Why it's important:** Exposed metal in the electrical circuit is a safety risk.

**Severity:** S; 4 (scale 1–5)

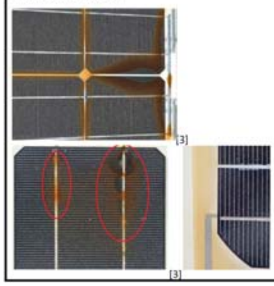
[3] C. E. Packard, J. H. Wohlgemuth, and S. R. Kurtz, "Development of a Visual Inspection Data Collection Tool for Evaluation of Fielded Pv Module Condition," National Renewable Energy Laboratory (NREL), Golden, CO., NREL/TP-5200-56154, Aug. 2012.

## Catalogue of Defects: Used Modules

7. Encapsulation

Used to laminate module layers together. Transparent to allow light to reach cells.

**7.2 Discolouration**



**Description:** Colour variation anywhere inside the module. Can be next to or above the cells, along the busbars or cell interconnects. Could be from a catastrophic event or degradation over time.

**Why it's important:** Indicates encapsulation material is degraded. Transmission of light to the underlying cells, and therefore module current, is reduced. Likely to degrade further over time.

**Severity:** Severity depends on affected area. Considered a major defect when 10% or greater of a cell's area is affected [1].

1 3 4 5

[3] C. E. Packard, J. H. Wohlgemuth, and S. R. Kurtz, "Development of a Visual Inspection Data Collection Tool for Evaluation of Fielded Pv Module Condition," National Renewable Energy Laboratory (NREL), Golden, CO., NREL/TP-5200-56154, Aug. 2012.

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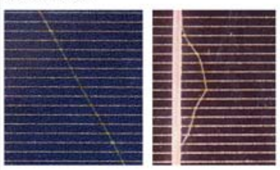
## Catalogue of Defects: Used Modules

8. Cell

Active component of the solar module. Electricity producing material converts sunlight to electricity.

**8.9 "Snail trails"**



**Description:** Lines on cell surfaces; might appear silvered as well as yellow or brownish around metal fingers. Appears after several months of sun exposure. Correlates to presence of under-lying micro-crack that may have previously been invisible. May be difficult to distinguish from cracks or scratches.

**Why it's important:** Same as for cracks (Section 8.3).

**Severity:** Severity depends on affected area. A crack is considered a major defect when its propagation could remove more than 10% of that cell's area from the electrical circuit [1]. The presence of a crack of any size that does not, or likely will not through its propagation, isolate any portion of the cell from the electrical circuit is a score of 2.

1 2 3 4 5

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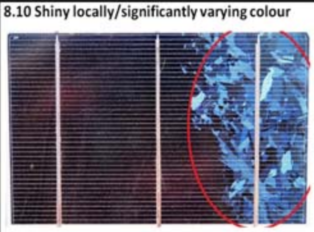
## Catalogue of Defects: Used Modules

**8.10 Shiny locally/significantly varying colour**



**Description:** Shiny silicon crystals are visible on a cell locally. Some colour variation from cell to cell can be expected (ex. slightly different shades of blue), but largely varying colour across one cell can be a concern.

**Why it's important:** A shiny cell is reflecting significant light instead of absorbing it and generating power. Where cells have become shiny or changed colour locally, cells have a poor or degrading anti-reflective coating which is an indicator of poor module performance.

**Severity:**

1 5

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## Acknowledgement

SILICON SOLAR MODULE VISUAL INSPECTION GUIDE
*Catalogue of Defects to be used as a Screening Tool*
Version 1.8, 2016-12-01
K. Sinclair, M. Sinclair



**Thank You**

**Please Provide Feedback**

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## CLIMATE TECHNOLOGY CENTRE & NETWORK SOLAR PHOTOVOLTAIC ACCREDITATION TRAINING PROGRAM

**Presented by: Andy Walker and Kari Burman**
**National Renewable Energy Laboratory**
November 6th -10th, 2017



## Applications for PV Stand-Alone Systems

## Module Overview

- **PV Stand-alone Systems**
- **Applications of PV Stand-alone Systems**
- **PV Water Pumping**
- **PV Solar Lighting**
- **Health Care and Refrigeration**

## PV Stand-Alone Systems

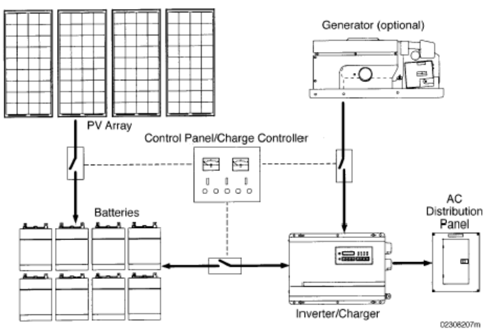
- PV Stand-Alone System Components:
  - **PV Array** to convert sunlight to electricity
  - Array **Support Structure** and Enclosure to protect equipment
  - **Batteries** to store charge for when it is needed
  - **Charge Controller** to protect battery from over-charging
  - **Low Voltage Disconnect** to protect battery from over-discharging
  - **Inverter** to convert direct current (DC) to alternating current (AC)*
  - Wiring, combiner boxes, fuses and disconnects

* Inverters can be on and off-grid. It is important to ensure that one has the right appliances for the right purpose.



## PV Stand-Alone Systems

### Typical Off-grid Configuration






## Module Overview

- **PV Stand-alone Systems**
- **Applications of PV Stand-alone Systems**
- **PV Water Pumping**
- **PV Solar Lighting**
- **Health Care and Refrigeration**

## Applications of PV Stand-alone Systems

- Applications of PV Stand-alone Systems:
  - Ideal for remote rural areas and applications where other power sources are unavailable
  - May be more cost effective to install a single stand-alone PV system than pay the costs of having the grid extended to the area
  - Provides power for Lighting, cell phones, radios, water pumping and refrigeration and other appliances
  - Used in agriculture, remote homes, schools, medical clinics, etc.



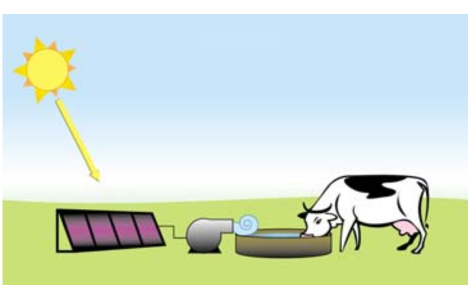
## Module Overview

- **PV Stand-alone Systems**
- **Applications of PV Stand-alone Systems**
- **PV Water Pumping**
- **PV Solar Lighting**
- **Solar Water Heating**
- **Health Care and Refrigeration**



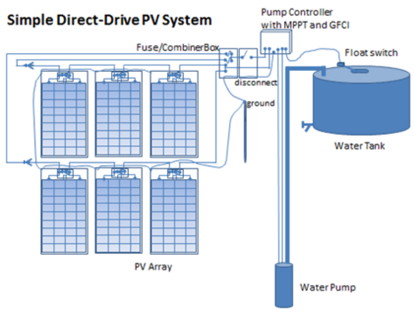
## PV Water Pumping

**Simple Direct Drive PV System**



## PV Water Pumping

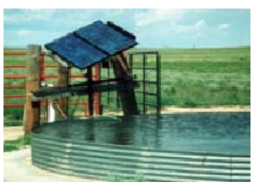
### Simple Direct Drive PV System






## PV Water Pumping

### Direct Drive PV System Example



- Array, Controller, Pump
  - No batteries
- Centrifugal Pump
  - High flow, low head
- Positive Displacement Pump
  - Low flow, high head

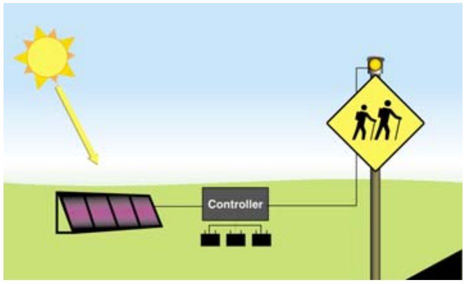


## Module Overview

- PV Stand-alone Systems
- Applications of PV Stand-alone Systems
- PV Water Pumping
- PV Solar Lighting
- Health Care and Refrigeration

## PV Solar Lighting

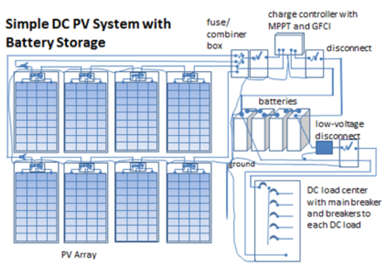
**Simple DC PV System with Battery Storage**






## PV Solar Lighting

**Simple DC PV System with Battery Storage**





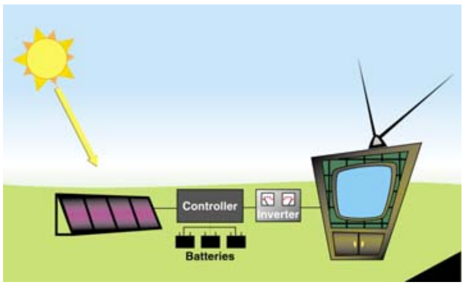

## PV Solar Lighting

**DC PV System Example: PJKK Federal Building, HI**

- 2 solar panels per lamp with peak output of 96 watts
- 39 Watt fluorescent lamps, 2500 lumens
- 90 amp-hour battery powers 12 hours per night

## AC PV System Appliances

**AC PV System with Inverter**





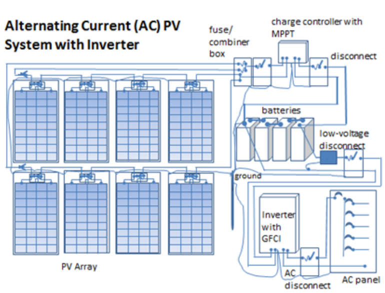

## PV Solar Lighting

**Inverters: Convert Direct Current (DC) to Alternating Current (AC)**



## PV Solar Lighting

**Alternating Current (AC) PV System with Inverter**



## Module Overview

- PV Stand-alone Systems
- Applications of PV Stand-alone Systems
- PV Water Pumping
- PV Solar Lighting
- **Health Care and Refrigeration**



## Health Care and Refrigeration

- Applications of electricity in Health clinics and laboratories:
  - Refrigeration
    - Vaccine
    - Blood storage
  - Medical devices for testing blood
    - centrifuges, microscopes
    - blood chemical analyzer, hematology mixer
  - Computer data logging
    - Laptops, printers,
    - internet connections
  - Lighting
  - Communication equipment



## Health Care and Refrigeration

**Healthcare Clinic in Rwanda**

# Thank You

**Please Provide Feedback**

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www.nrel.gov

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1977 - 2017

## CLIMATE TECHNOLOGY CENTRE & NETWORK SOLAR PHOTOVOLTAIC ACCREDITATION TRAINING PROGRAM

**Presented by: Andy Walker and Kari Burman**
**National Renewable Energy Laboratory**
November 6th -10th , 2017



# Solar Resource

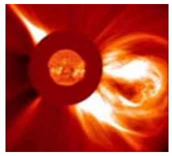
## Module Overview

- **Solar Radiation Fundamentals**
- **Solar Resource Measurements**
- **Solar Resource Maps**
- **Solar Resource and PV Orientation**

## Solar Radiation

- What is Solar Radiation?

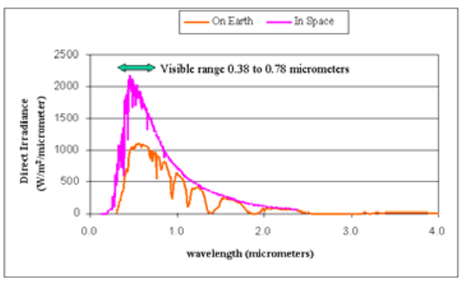
  Radiant energy emitted by the sun, mainly electromagnetic energy
- Three types of Solar Radiation:
  - Ultraviolet (UV) radiation
  - Visible
  - Infrared



A coronal mass ejection
Credits: ESA & NASA/SOHO



## Solar Spectrum




- 6% ultraviolet, 48% visible, and 46% infrared light
- Annual average radiation 1,366 $W/m^2$ in space, typically less than 1000 W/m2 on Earth.

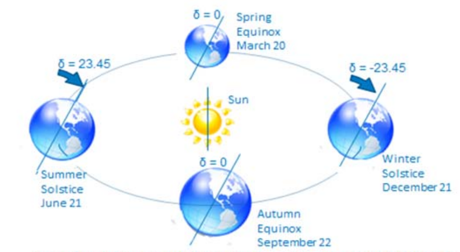


## Solar Radiation

- Latitude, ϕ
  - Tropic of Cancer: sun straight up at least one day per year (summer solstice)
  - Arctic Circle: no sun for on least one day per year - winter solstice (December 22 ,winter solstice)
  - Morogoro Tanzania: Latitude: -6.797221; Longitude: 37.653

## Day of Year: Declination and the Seasons

**Day of Year: Declination and the Seasons**




The declination is the angle of tilt between the Earth's axis about which it rotates every 24 hours and the axis about which the Earth revolves around the sun every 365 days. Varies like a sine wave throughout the year

δ=23.45*(SIN(360/365*(284+day of year)))



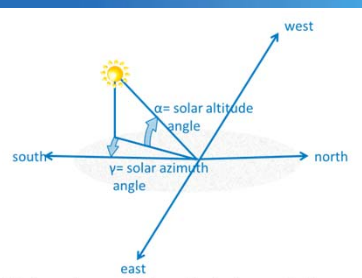
## Hour Angle, ω

- Hour Angle, ω
  - Earth rotates 360 deg in 24 hours, or 15 degrees per hour
  - Hour angle, ω=(15degrees/hour) * (Solar Time - 12)


| Solar Time | 6 am | 12 noon | 6 pm |
|---|---|---|---|
| Hour angle, ω | -90 deg | 0 deg | 90 deg |



## Position of the Sun




- Altitude angle, α, angle from the horizon up to the sun
  sin α=cos ϕ cos δ cos ω + sin ϕ sin δ
- Azimuth angle, γ, horizontal from due south to the sun, sin γ = sin ω cos δ/ cos α
- ϕ =latitude (deg), ω =hour angle (deg), δ =declination (deg)

## Example: Position of the Sun

Place: Morogoro, Tanzania
Latitude: -6.797221;
Longitude: 37.653
Time: 11 am
Date: November 7, 2017

Day of year= 31+28+31+30+31+30+31+31+30+31+ 7 =311
Declination, δ =23.45*SIN(360/365*(284+*270*))=-17.1
Hour Angle, ω =(15 degrees/hour)*(11:00-12:00) = -15 deg

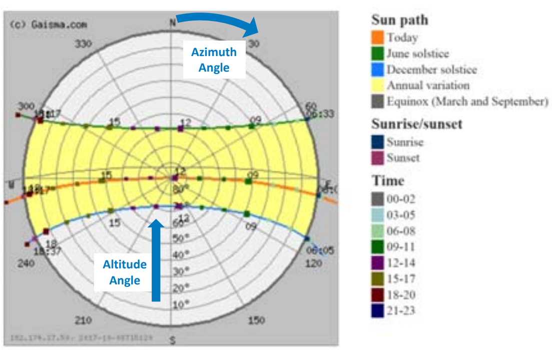
Altitude, α=asin(cos(-6.79)*cos(-17.1)*cos(-15)+sin(-6.79)*sin(-17.1)
=72 degrees above horizon

Azimuth, γ = asin(sin (-17) cos (-17.1)/ cos (72)) = -9.7 degrees
Negative means east of south.

In MS Excel: =DEGREES(ASIN(SIN(RADIANS(-43))*COS(RADIANS(-2))/COS(RADIANS(32))))



## Sun Path Diagram; Dar Es Salaam, Tanzania






## Solar Resource Definitions

- I:

Irradiance or Insolation (W/m2). Incoming solar power

- DNI

Direct Normal Irradiance is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. Typically, you can maximize the amount of irradiance annually received by a surface by keeping it normal to incoming radiation. This quantity is of particular interest to concentrating solar thermal installations and installations that track the position of the sun.

- DIF

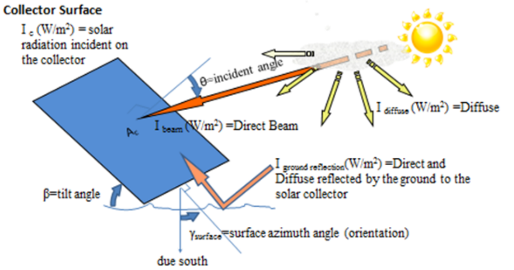
Diffuse Horizontal Irradiance is the amount of radiation received per unit area by a surface (not subject to any shade or shadow) that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions.

- GHI

Global Horizontal Irradiance is the total amount of shortwave radiation received from above by a horizontal surface. This value is of particular interest to photovoltaic installations and includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DIF).

## Solar Radiation

**Direct Beam, Diffuse and Global Solar Insolation in the Plane of a Solar Collector Surface**




**Direct beam radiation is scattered by dust and water droplets in the atmosphere, resulting in direct beam, diffuse, and ground-reflected solar radiation incident on the solar collector.**

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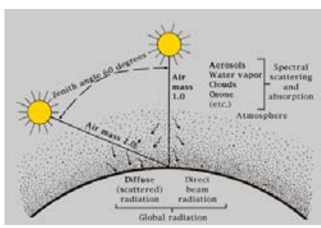
## Solar Radiation on Earth's Surface

- Solar Energy at the Earth's Surface
  - Changes with time of day (minutes, hours)
  - Changes with time of year (seasons, years, decades)
  - Changes with location on the earths surface

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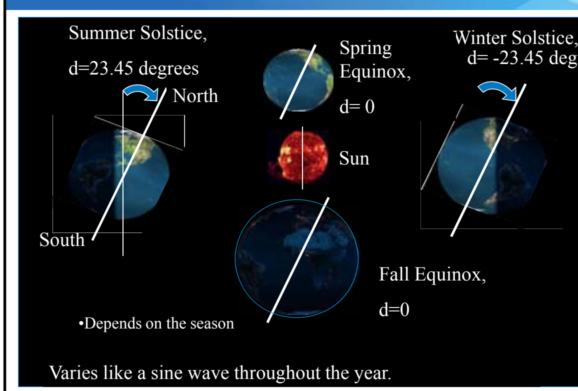
## Solar Radiation on Earth's Surface

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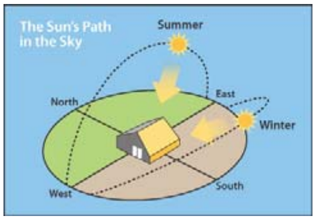
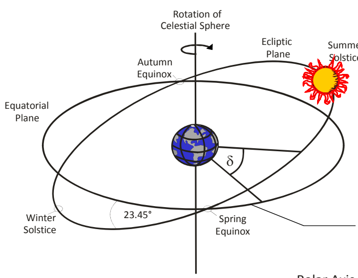
## Solar Radiation on Earth's Surface

- The Sun's Seasonal Path
  - Sun is higher in the sky in the Summer
  - Sun is lower in the sky in the Winter






## Solar Radiation on Earth's Surface



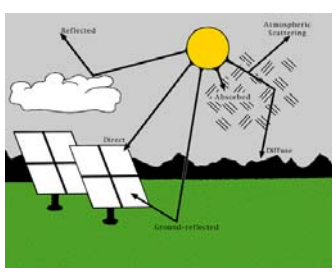

$$\delta(°) = 23.45 \sin\left(\frac{360}{365}(DoY + 284)\right)$$

Polar Axis

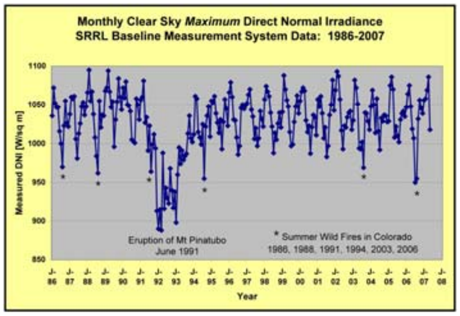


## Solar Radiation on Earth's Surface

- Barriers for Solar Radiation to Earth's Surface
  - 26% is reflected or scattered
  - 18% is absorbed in atmosphere



## Changes with Time: Inter-annual Variability

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## Module Overview

- Solar Radiation Fundamentals
- **Solar Resource Measurements**
- Solar Resource Maps
- Solar Resource and PV Orientation

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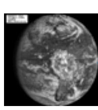
## Approaches to Solar Resource Assessment

- Empirical or theoretical models from weather satellite images



- Ground Measurements

- Empirical Performance of Installed Facilities

Feedback, Calibration NREL

Interpretation

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## Solar Resource Measurements

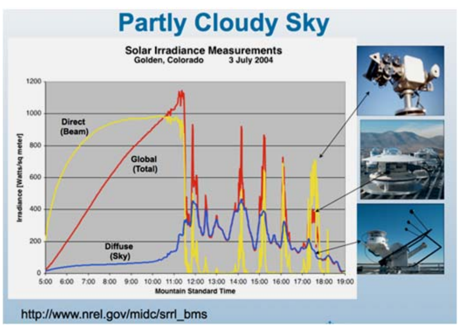
Pyrheliometer:
Direct Beam Insolation

Shaded Pyranometer:
Diffuse Insolation

Pyranometer:
Global Horizontal Insolation



## Solar Resource Maps- Creation






## Module Overview

- **Solar Radiation Fundamentals**
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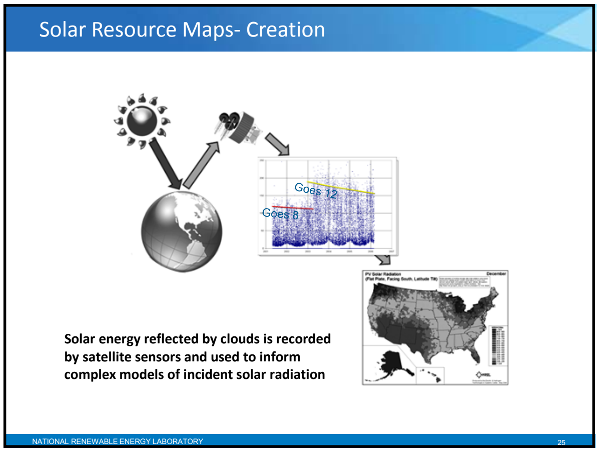
- **Solar Resource Maps**
- **Solar Resource and PV Orientation**


Solar Resource Maps- Creation
Goes 12
Goes 8
Solar energy reflected by clouds is recorded by satellite sensors and used to inform complex models of incident solar radiation
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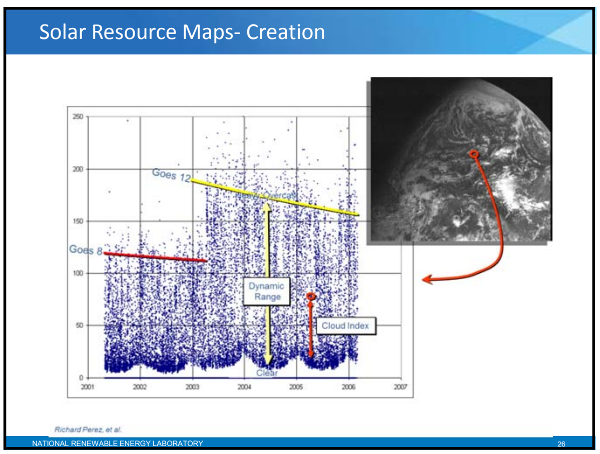
Solar Resource Maps- Creation
250
200
150
100
50
0
2001
2002
2003
2004
2005
2006
2007
Goes 12
Goes 8
Dynamic Range
Cloud Index
Clear
Richard Perez, et al.
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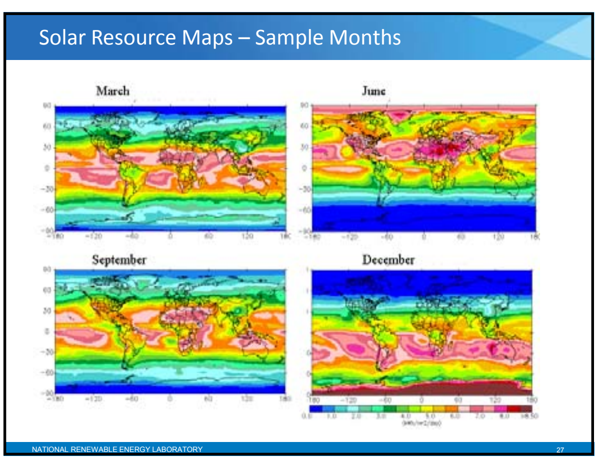
Solar Resource Maps – Sample Months
March
June
September
December
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27

## Solar Resource Maps and Data

### Direct Normal Irradiation


Go to http://globalsolaratlas.info



## Solar Resource Maps and Data

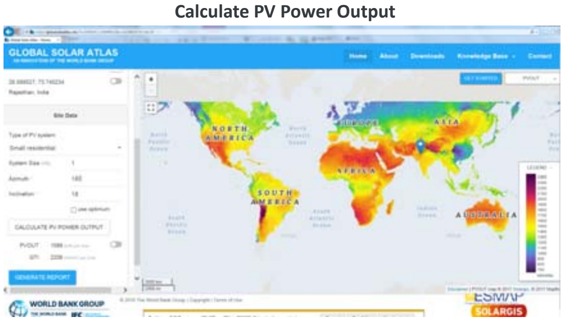
### Global Horizontal Irradiation


Go to http://globalsolaratlas.info



## Solar Resource Maps and Data

### Calculate PV Power Output




Go to http://globalsolaratlas.info

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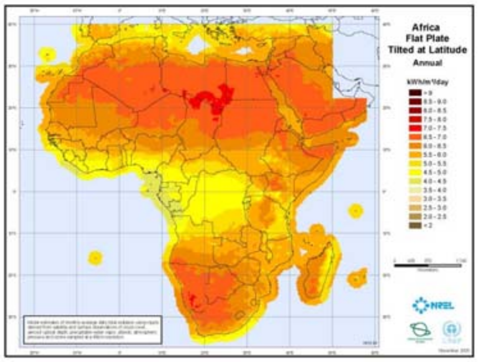




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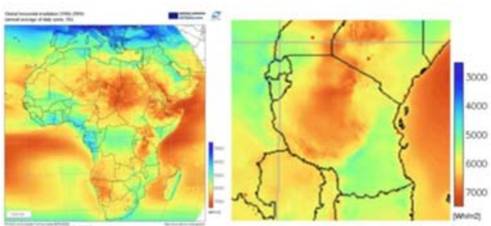



Left, annual average of daily GHI values provided by PVGIS (1984-2005); right, detailed map of Tanzania region provided by PVGIS



## Direct Normal Insolation (kWh/m2/day)

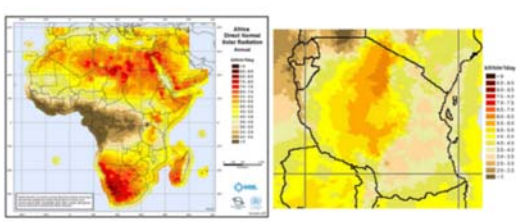
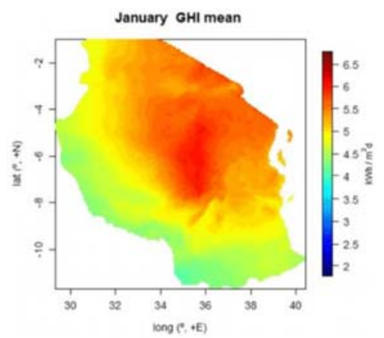


Fig 5 Left, annual average of daily DNI values provided by NREL; right, detailed map of Tanzania region provided by NREL (within the frame of SWERA Project)

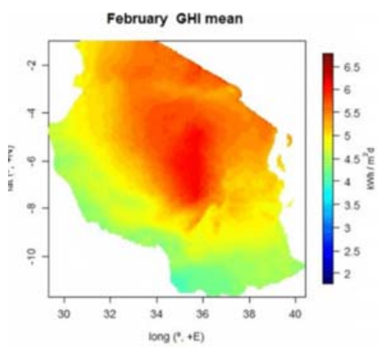
## Solar Resource Maps and Data




https://www.researchgate.net/publication/290183256_Solar_Resource_Mapping_in_Tanzania



## Solar Resource Maps and Data

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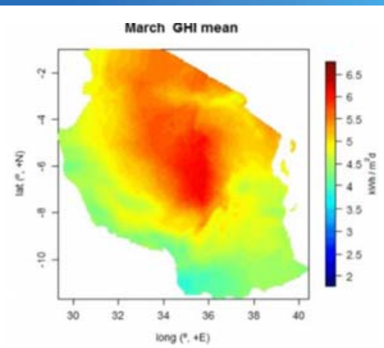


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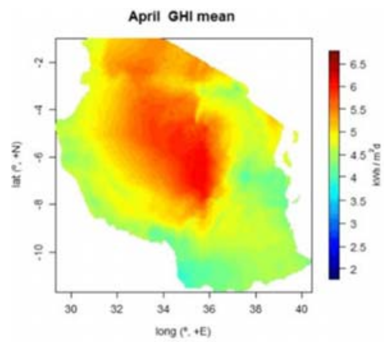


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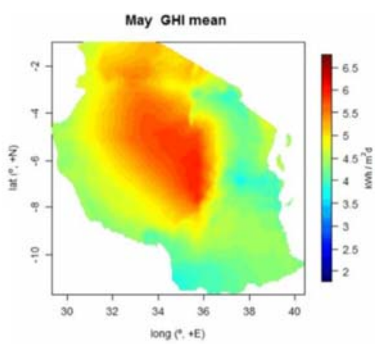


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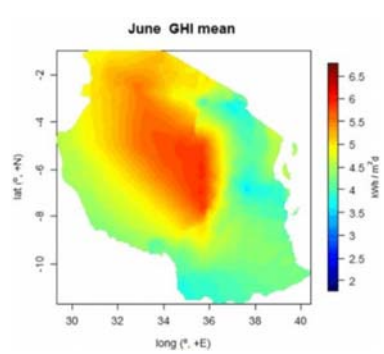


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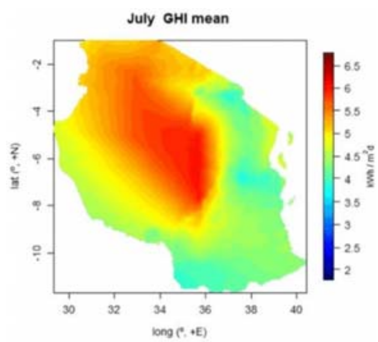


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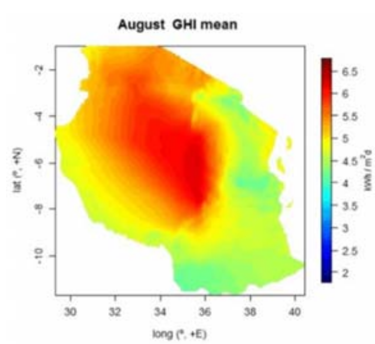


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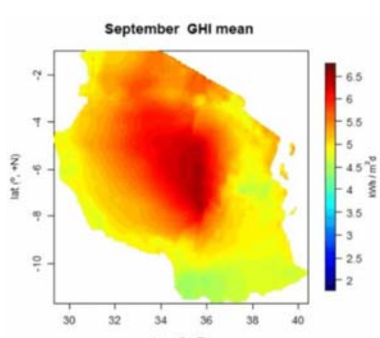


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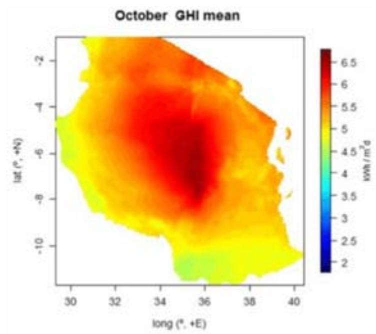


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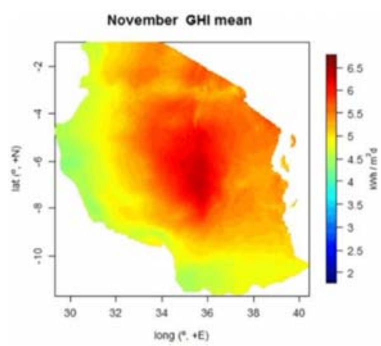


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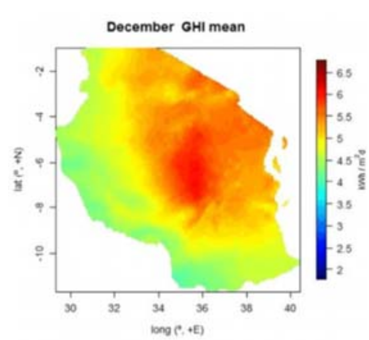
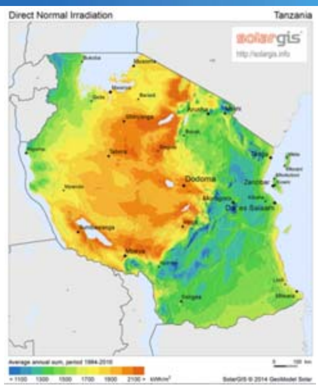



https://www.researchgate.net/publication/290183256_Solar_Resource_Mapping_in_Tanzania

## Direct Normal Irradiation






## Global Horizontal Irradiation




## Surface Measurements

**Tanzania Meteorological Agency (TMA) http://www.meteo.go.tz/.**

**Fig 6 . TMA network stations (Osima, 2014).**

**Table 4 Clustering of the ground stations.**

| STATION | Lat (S) | Lon (E) | GHI (kWh/m2) | ID | CLUSTER |
|---|---|---|---|---|---|
| Mwanza | 2.47 | 32.92 | 5.51 | 3 | 3 |
| Kilimanjaro | 3.42 | 37.07 | 4.76 | 5 | 1 |
| Same | 4.08 | 37.72 | 4.72 | 6 | 1 |
| Kigoma | 4.88 | 29.63 | 4.60 | 7 | 2 |
| Kondoa | 5.00 | 35.75 | 5.89 | 8 | 3 |
| Tabora Arpt | 5.08 | 32.83 | 5.65 | 9 | 3 |
| Dodoma | 6.17 | 35.77 | 5.88 | 10 | 3 |
| Zanzibar | 6.22 | 39.22 | 4.91 | 11 | 2 |
| Morogoro | 6.83 | 37.65 | 4.40 | 12 | 1 |
| Dar Es Salaam | 6.88 | 39.20 | 4.88 | 13 | 1 |
| Iringa | 7.67 | 35.75 | 6.24 | 14 | 3 |
| Mtwara | 10.27 | 40.18 | 4.62 | 15 | 2 |
| Songea | 10.68 | 35.58 | 4.18 | 16 | 2 |

**https://www.researchgate.net/publication/290183256_Solar_Resource_Mapping_in_Tanzania**

## Module Overview

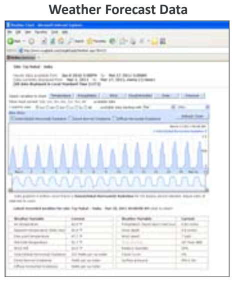
- **Solar Radiation Fundamentals**
- **Solar Resource Measurements**
- **Solar Resource Maps**
- **Solar Resource and PV Orientation**



## Uses of Solar Radiation Data

- Why Do We Need Solar Radiation Data?
  - Agriculture
  - Astronomy
  - Atmospheric Science
  - Climate Change
  - Health
  - Numerical Weather Prediction
  - Oceanography
  - Renewable Energy

**Weather Forecast Data**



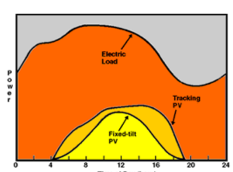
172 hour forecast example

http://weatheranalytics.com/renewableforecast.html



## Solar Radiation Data for Photovoltaic Power

- Computer Simulation
  - Power from two PV Systems on grid
  - Fixed-tilt PV generates less power than the tracking PV system in one day




## Solar Radiation

**Solar Radiation kWh/m2/day**
**South Facing, tilt=latitude**
**(hours of full sun/day)**

| Month | Solar Radiation (kWh/m^2/day) |
|---|---|
| Jan | 4.785 |
| Feb | 5.350 |
| Mar | 5.470 |
| April | 5.366 |
| May | 5.129 |
| June | 5.234 |
| July | 5.137 |
| Aug | 5.262 |
| Sept | 5.345 |
| Oct | 5.177 |
| Nov | 4.568 |
| Dec | 4.250 |
| | 5.09 |
| Total | |

**PV Watts Request Tanzania; location VOI, Kenya**



## Climate Data for Dar Es Salaam, Tanzania

| Variable | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Insolation, kWh/m²/day | 5.79 | 5.93 | 5.40 | 4.52 | 4.50 | 4.57 | 4.52 | 4.76 | 5.59 | 5.67 | 5.76 | 5.78 |
| Clearness, 0 - 1 | 0.54 | 0.55 | 0.52 | 0.46 | 0.50 | 0.54 | 0.52 | 0.51 | 0.55 | 0.54 | 0.54 | 0.55 |
| Temperature, °C | 26.76 | 26.89 | 26.88 | 26.66 | 26.33 | 25.69 | 25.04 | 24.83 | 25.03 | 25.52 | 26.00 | 26.46 |
| Wind speed, m/s | 4.33 | 3.98 | 4.46 | 5.84 | 7.21 | 7.63 | 7.47 | 6.64 | 5.89 | 5.90 | 5.26 | 4.32 |
| Precipitation, mm | 70 | 49 | 120 | 229 | 153 | 40 | 26 | 23 | 25 | 49 | 106 | 114 |
| Wet days, d | 9.7 | 4.3 | 11.6 | 16.5 | 14.0 | 5.8 | 5.9 | 5.7 | 5.0 | 6.9 | 8.9 | 12.3 |

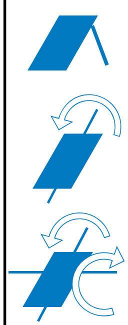
**These data were obtained from the NASA Langley Research Center Atmospheric Science Data Center; New et al. 2002**



## Influence of Collector Orientation

- The Tilt of the PV Panel
  - Winter the sun is lower in the sky and so the tilt needs to be higher
  - Summer the sun is higher in the sky so the tilt needs to be lower
  - The rule of thumb: Tilt = latitude


## Fixed Tilt and Tracking



Fixed Tilt Facing Equator
- tilt=latitude
- tilt<latitude for summer gain
- tilt>latitude for winter gain

One Axis Tracking around axis
- tilted or flat

Two Axis Tracking both azimuth and altitude of sun around two axes

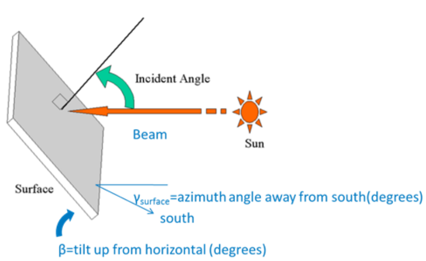


## Direct beam radiation on collector

- $I_{c,\ beam} = I_{\ beam} * \cos\theta$
- $I_{\ beam}$ =direct beam radiation measured perpendicular to the rays of light
- θ = incident angle between surface normal and director towards the Sun



## Incident Angle, i




**Angle of incidence of direct beam insolation on a surface may be calculated given tilt angle, azimuth orientation, latitude, time of day and day of year.**

## Diffuse radiation on collector

- $I_{c,\ diffuse} = I_{diffuse} * (1+\cos\beta)/2$
- $I_{diffuse}$ =isotropic diffuse solar radiation assumed to be uniform across the hemisphere of the sky
- β = tilt angle of the surface up from the horizontal
  (1+cosβ)/2 radiation heat transfer view factor between a flat surface and the hemisphere of the sky

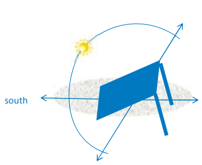


## Ground Reflected radiation on collector

- $I_{horizontal} = I_{beam} * \sin\alpha + I_{diffuse}$ (also called global horizontal)
- $I_{c,\ ground\ reflected} = (I_{beam} * \sin\alpha + I_{diffuse}) * \rho_{ground} * (1-\cos\beta)/2$
- $I_{diffuse}$ =isotropic diffuse solar radiation assumed to be uniform across the hemisphere of the sky
  - α= solar altitude angle
  - β = tilt angle of the surface up from the horizontal
  - (1-cosβ)/2 radiation heat transfer view factor between a flat surface and the ground



## Fixed Tilt

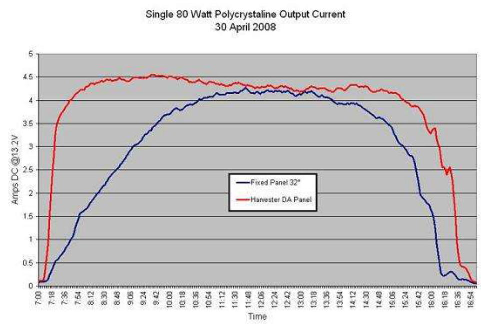



$\cos\theta = \cos(\gamma_{solar} - \gamma_{surface}) \cos\alpha \sin\beta + \sin\alpha \cos\beta$

or the simpler

$\cos\theta = \cos(\phi - \beta) \cos\delta \cos\omega + \sin(\phi - \beta) \sin\delta$

## Tracking versus Fixed Tilt

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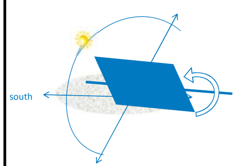
## Horizontal North-South Axis tracking azimuth of Sun




$$\cos\theta = \sqrt{(\sin\varphi \sin\delta + \cos\varphi \cos\delta \cos\omega)^2 + \cos^2\delta \sin^2\omega}$$

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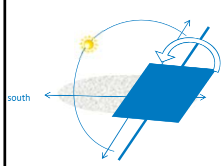
## Horizontal East-West Axis tracking altitude of Sun




$$\cos\theta = \sqrt{1 - \cos^2\delta \sin^2\omega}$$

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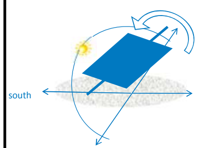
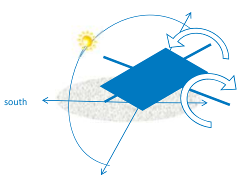
## Axis tilted at latitude tracking azimuth of Sun




$$\cos\theta = \cos\delta$$



## Two Axis tracking both azimuth and altitude of Sun




$$\text{Cos}\theta = 1$$

Alternative mounting systems for fixed collector position or for tracking the sun across the sky to increase energy production.



## References


NREL GIS Maps
http://www.nrel.gov/renewable_resources/

NREL Solar Radiation Data Manual
http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/

NASA Solar Data
http://eosweb.larc.nasa.gov/sse/

ESMAP solar data.
http://globalsolaratlas.info


Thank You
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Presented by: Andy Walker and Kari Burman
National Renewable Energy Laboratory
November 6$^{th}$ -10$^{th}$ , 2017



## Installation Safety

## Installation Safety

- Safety is an important aspect for everyone working with PV equipment, whether in the design, installation, maintenance, or use of the systems.
- The following items would constitute good, safe practice for any type of job and reduce potential for accidents and injuries:
  - A clean and orderly work area
  - Proper equipment and training in its use
  - Awareness of potential hazards and how to avoid them
  - Periodic reviews of safety procedures
  - Instructions in basic first aid

## Personal Safety

- When working with PV modules and systems, you need to be familiar with the basics of safety.

  Personal Safety Resources
  - You are your own best safety system – be alert, check everything, and work carefully.
  - Never work on PV system alone.
  - Study and understand the system before you start to work on it.
  - Review safety, testing, and installation steps with everyone involved before starting the work.
  - Make sure that your tools and test equipment are in proper working order.



## Job Site Safety

Personal Safety Resources

- Wear appropriate clothing, including hard hat, closed shoes, face shield, eye protection, and voltage rated gloves. Remove jewelry that might come in contact with the electrical components.

Job- Site Safety Resources

- Safety plan
- Eye wash solution and/or station
- First-aid kit
- Fire extinguisher
- Appropriate ladders
- Appropriate lifting equipment
- Ropes/Harness

Working with any size PV system involves a number of potential hazards, both non-electrical and electrical. Safety must be foremost in the mind of anyone working on a PV system.



## Electrical Safety Codes

- Regardless of whether or not the location of the PV system is covered by a local or national electrical safety code, it is important to follow guidelines that ensure safe electrical systems.
- Example of codes and standards to provide recommendations and guidelines for electrical safety include:
  - National Electrical Code® (*NEC*®) [1]
  - Underwriters Laboratories (UL) equipment safety testing and certification [2]
  - NFPA 70E [3]
  - Tanzania Bureau of Standards (TBS) [4]

[1] http://www.nfpa.org/nec/electrical-codes-and-standards/nfpa-70?code=70
[2] http://www.ul.com/
[3] http://www.nfpa.org/nec/electrical-codes-and-standards/nfpa-70e?code=70E
[4] http://www.tbs.go.tz/index.php/standards/category/technical_commitees

## Hardware Standards

- Hardware standards can be found from following organizations:
  - Global Approval Program for PV (PV Gap)[5]
  - Institute of Electrical and Electronics Engineers (IEEE) [6]
  - International Electrotechnical Commission (IEC) [7]
  - International Standard Organization (ISO) [8]
  - American Society for Testing and Materials (ASTM)-International [9]

[5] http://www.pvgap.org/
[6] https://www.ieee.org/index.html
[7] http://www.iec.ch/
[8] https://www.iso.org/home.html
[9] https://www.astm.org/

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## Roof Safety

**What is wrong with this picture?**

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## Roof Safety

**If you don't look like this, don't go on sloped roofs.**

Source: Memphite

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## Roof Safety

- Don't go near edges or take items where they could slide off the edge.
- Stay off steep or high roofs
- Stay off in wet or windy conditions.
- Wear shoes with a soft rubber sole for extra traction.
- Keep shoes free of mud and dirt.
- Stay off slate and tile roofs.
- Use sunscreen, sunglasses, hat, etc.

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## Electrical Safety

**What is wrong with this picture?**


Source: Practical Machinist

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## Electrical Safety

**What is wrong with this picture?**

Source: Practical Machinist

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## Electrical Safety

**What is wrong with this picture?**



## Electrical Safety

- Do not remove internal covers in any electrical panels (no exposed conductors).
- Ensure floor and equipment is dry.
- Stay back from circuits and don't touch, including items you are carrying.
- Lock-out-tag-out: Locking out circuits so that someone unaware does not energize a circuit that someone else is working on.
- Arc-flash protection: Face shield, helmet, long shirts and pants, and gloves suited for the amount of arc flash energy that is calculated based on details of the circuit being worked on.



## Physical Hazards

- When installing or working with a PV system, one should be aware of the many potential physical, electrical, and chemical hazards.

Physical Hazards (non-electrical, non-chemical)

- Exposure to sun
- Insects, snakes, and other creatures
- Cuts and bumps
- Falls, sprains, and strains
- Thermal burns

## Chemical Hazards

Electrical Hazards

- Shocks and burns

Chemical Hazards

Batteries are potentially the most dangerous PV system component if improperly handled, installed, or maintained.

- Acid burns
- Explosions
- Fires

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**Thank You**

**Please Provide Feedback**

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# CLIMATE TECHNOLOGY CENTRE & NETWORK SOLAR PHOTOVOLTAIC ACCREDITATION TRAINING PROGRAM

**Presented by: Andy Walker and Kari Burman**
**National Renewable Energy Laboratory**
November 6th -10th, 2017



# Electric Load Analysis

## Module Overview

- **Using Energy Efficiently**
- **Electrical Load Requirements**
- **Lighting**
- **Refrigeration**
- **Calculating Load Estimates**

## Energy Efficiency

- Devices that operate using electrical power are often referred to as loads.
- Loads influence the size and cost of photovoltaic system.
- A PV system designer can minimize the cost of photovoltaic system by efficiently using the energy available.
- A designer should thoroughly analyze the energy requirements to identify energy conserving opportunities.
- For example, many common household appliances like ovens, water heater, clothes dryer use electric resistance to perform their function.
  - To power these loads can be cost prohibitive for residential photovoltaics and one should find an alternate way.



## Energy Efficiency

- Water heating and space heating can be accomplished through other means like solar thermal heating, gas or propane.
- This method of supplying thermal loads from thermal sources is a more efficient use of energy, and is example of load shifting.
- Small convenience items such as toasters or dryers can be powered by photovoltaics easily as they are not used for prolonged periods, although it may use significant instantaneous power.



## Energy Efficiency

- In addition to load shifting and increased equipment efficiency, designer can lessen the need for additional power by changing their behavior and maximizing the use of daylight.
- For example, if a load can be scheduled in the mid afternoon when the batteries are full then the energy use is “free”, compared to at night when the load depletes the batteries and is subject to battery round trip efficiency of ~85% and cost of the wear on the batteries.
- Designers should involve owners and operators in design and installation process as to increase awareness on the use of batteries.

## Module Overview

- **Using Energy Efficiently**
- **Electrical Load Requirements**
- **Lighting**
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## Electrical Load Requirements

- Manufactures' literature and their equipments' nameplates often list the watts used/required for a load.
- If not mentioned, voltage (volts) and current (ampere) would be given and one can calculate power (watts) by multiplying voltage and current.
- There are three types of loads:
  - Cycling Loads
  - Phantom Loads
  - Surge Loads



## Cycling Loads

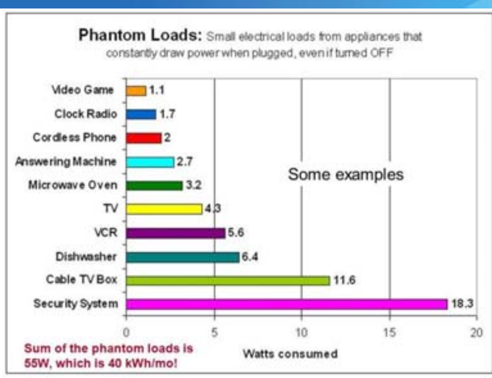
- There are some loads which will automatically turn on when they are connected to power source.
- A duty cycle is the percentage of time an appliance that is "on" is actually drawing power.
- Examples: Refrigerators or Freezers
- In addition, appliances that create or use heat usually cycle on and off.
- Examples: Electric blankets, irons, and cooking appliances.
- Thermostats controls these types of appliances.

## Phantom Loads

- A phantom load is a load which draws power even when they are turned "off" but still plugged into an outlet.
- These electronic devices provide the modern-day conveniences we rely on, but they also waste energy and cost money which needs to be considered when calculating energy use of a home.
- Phantom loads may be negligible, but they are consuming power 24 hours/day.
- It is recommended to keep phantom loads to a minimum by unplugging them.



## Phantom Loads




Source: Slideplayer.com



## Surge Loads

- When estimating electrical load, surge loads should be accounted.
- These are appliances with motors that draw more current when they start than when they operate.
- For example, an appliance uses 200 W continuously might use up to 600 W during the start.
- For specific surge requirements, see manufactures' equipment specification.
- As a rough rule of thumb,

  Surge requirements ≈ Operating watts x 3

## Module Overview

- **Using Energy Efficiently**
- **Electrical Load Requirements**
- **Lighting**
- **Refrigeration**
- **Calculating Load Estimates**



## Lighting

- Lamp Efficiency
  - Measured in lumens per watt
  - Lumen is a measure of light output from the lamp
  - When selecting lamp, efficiency is an important consideration, but it should not be the only criteria to be used.
  - In most cases, a more efficient light source can be substituted for a less efficient source with little or no loss in visibility or color rendition.
  - If a lamp produces more lumens for each watt of electrical energy input or uses less electrical input to produce same amount of lumens, it is more efficient.



## Lighting


Source :http://arcadianhome.com

## Types of Lamps Available




## Lighting

- Lighting Controls
  - Lighting control and operation is an important factor when sizing a photovoltaic system
  - Lowering the load will reduce the size and cost of a photovoltaic system and would reduce the cost
- Lighting controls include:
  - Manual switches
  - Timers
  - Photocells
  - Sensors



## Lighting

**Manual Switch**

1. Least expensive
2. Most commonly used controls
3. If DC lighting is used, DC switches are needed

**Timers**

1. Automatically turns light on and off
2. It may require small amount of power for their own operation

**Photocells**

1. Device that sense light levels
2. Security or safety lighting can be controlled by photocells.
3. More dependable than manual switch
4. More accurate than timers
5. Many options available in market

**Sensors**

1. Sensors activate lights when they detect motion or infrared light

## Lighting - Exercise

Q. A 12 Volt direct current, 13- watt fluorescent light is controlled by a photocell. The average daily on-time is 12 hours per day.

How many watt-hours are consumed by the light on an average day?



## Lighting - Exercise

A. Multiply 13 watts by 12 hours which would result in 156 watt-hours.



## Module Overview

- **Using Energy Efficiently**
- **Electrical Load Requirements**
- **Lighting**
- **Refrigeration**
- **Calculating Load Estimates**

## Refrigeration

- Commonly, the refrigerator is one of the single largest energy loads in a residential home
- In a stand alone PV systems, buying an energy efficient refrigerator is extremely important.
- There are three basic options that are commercially available:
  - Propane powered
  - AC powered
  - DC powered (12V, 24V or 48 V)

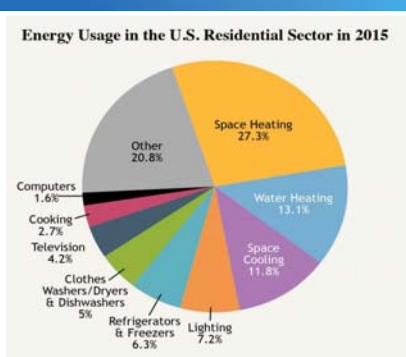


## Refrigeration

| Propane Powered Refrigerators | AC Powered Refrigerators | DC Powered Refrigerators |
|---|---|---|
| • Used in remote locations in US over 70 years<br>• They are widely available and used throughout the recreational vehicle and marine industry<br>• Low maintenance<br>• Safe and cost-effective solution for remote refrigeration purposes<br>• Limitations of these refrigerators include periodic refueling and make them less able to be powered by photovoltaic systems | • Normally used in homes and run by utility supplied electricity<br>• They require inverter if they are to be in a stand-alone system.<br>• The availability of high efficient AC refrigerators combined with the high efficiency of today's inverters, makes them a common choice | • Higher cost than AC powered refrigerators<br>• Does not require inverter and can be operated directly from battery<br>• It was common back when inverters were less efficient |

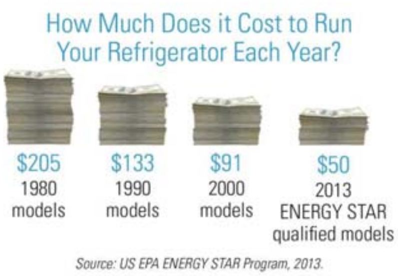


## Refrigeration




Source:EIA

## Refrigeration






## Design Criteria for Refrigerator

- When deciding to buy a refrigerator, one should choose a unit with following specifications:
  - Superior insulation with a high R value
  - Small current draw when operating
  - Compartmentalized storage/separate freezer
  - Efficient compressor waste heat removal
  - Energy star rated- pick the lowest annual energy use that meets needs
- There are many ways to design a refrigerator into a kitchen to allow more efficient operation:
  - Avoid direct sunlight
  - Avoid placing adjacent to heating appliances
  - Place on an interior wall
  - Insure adequate air flow around unit



## Refrigeration

- Refrigeration loads can be accurately estimated from the manufacture's specifications and a thorough knowledge of use patterns.
- Refrigerator on-time is seasonal because the load is affected by ambient temperature.
- Routine maintenance, such as cleaning or defrosting, can reduce unnecessary on-time, and improve performance.

## Module Overview

- **Using Energy Efficiently**
- **Electrical Load Requirements**
- **Refrigeration**
- **Lighting**
- **Calculating Load Estimates**



## Considerations for Calculating Load Estimates

- Load estimations can be difficult to calculate due to the number of variables.
- One should consider the following things while estimating electrical loads:
  - Use correct load estimates
  - Account for duty cycle when sizing equipment
  - Use manufacturer's literature wherever possible
  - Consider all energy conservation, equipment efficiency, and load shifting opportunities
  - Future loads may vary because
    - Number of people may change
    - Seasonal variation
    - Loads may be added or removed
    - Efficiency of loads may decrease with age



## Load Calculation Steps

- Imagine if a customer calls you and tells you that she wants to power her house with PV solar. What would be your initial steps?
- You visit her house:
  - What is the first thing you do?
    - Make a list of all the appliances in the house.
    - Check the nameplate of the appliances ( for voltage, current and other parameters).
  - After you have the list of appliances and the nameplate data for appliances, what do you do next?
    - Ask the owner which appliances should be PV powered and which not.
    - Ask for the usage (number of hours) for appliances that the house owner wants to be solar powered
      - ✓ Compare the usage numbers with national average numbers

## Load Calculation Steps

- After collecting all the data, fill in the load calculation worksheet.
- This is the first step in order to size the PV system. The next steps would be covered in further modules [Also, see the guidance document]



## Exercise

**Load Calculation Worksheet**



**Thank You**

**Please Provide Feedback**

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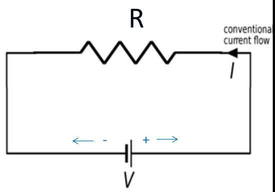
# Photovoltaic Electric Principles

## Module Overview

- **Terminology**
- **Matching Appliances to the System**
- **Electrical Circuits**
- **Series and Parallel Circuits in Power Sources**
- **Series and Parallel Circuits in Electrical Loads**
- **Exercises**

## Terminology

- Electric Current is the flow of electrons through a circuit. (Amps)
- Voltage is the force or pressure of moving electrons in a circuit. (Volts)
- Resistance is the measure of the opposition to the current flow.
- The power of the system is measured in watts (W) or kilowatt (kW).
- The energy of a system is measured in watt-hours (Wh) or kilowatt-hours (kWh).






## Electrical Voltage

- A volt is the unit of force (electrical pressure) that causes electrons to flow through wire.
- Voltage (V or E) is electric potential energy per unit charge, measured in joules per coulomb ( = volts).
- Electrical pressure sometimes is referred as the electromotive force (EMF).
- Some common voltages used in direct current light-duty electrical system include 12 V, 24 V, 48 V.
- In Tanzania, Europe, Australia and Asia the standard voltage for alternating current is in the range of 220-240 V, typical 230 V.



## Terminology

- An ampere or amps is the SI unit for measuring an electric current , which is the flow of electric charge across a surface at the rate of one coulomb per second (Amps=Coulombs/second).
- Coulomb is charge of roughly $6.2\times10^{18}$ electrons.
- One amp of current flowing for one hour is referred as amp-hour (Ah). This term is mostly used when describing battery capacity.

$$\text{Current} = \frac{\text{Charge}}{\text{Time}}$$

Or

$$I = \frac{Q}{t}$$

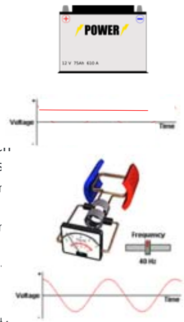
Where:
I = Current in Amperes (A)
Q = Charge in Coulombs (C)
t = time

The System International unit for current is the Ampere (A), where

$$1\,A = 1\frac{C}{s}$$

## Alternating Current (AC) & Direct Current (DC)

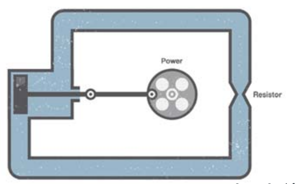
- There are two types of electric current.
  - Alternating current (AC)
  - Direct current (DC)
- Direct Current (DC) is a constant voltage, with current flowing in one direction
  - Produced by batteries and PV panels;
  - Voltages such as 12V; 24V; 48V; or higher
- Alternating current (AC) is electric current in which direction of the flow reverses at periodic intervals
  - The voltage of an AC power source changes from in time.
  - This type of current is produced by an alternator. In an alternator, a magnetic field causes electrons to flow in one direction, then in the reverse direction.
  - AC is used to deliver power to houses, office buildings, etc.
  - Root-Mean Square voltage 230 V frequency is 50 Hz






## Alternating Current (AC) & Direct Current (DC)

Alternating Current: The Water Analogy




Source: Spark fun

- To generate AC in a set of water pipes, we connect a mechanical crank to a piston that moves water in the pipes back and forth (our “alternating” current). Notice that the pinched section of pipe still provides resistance to the flow of water regardless of the direction of flow.

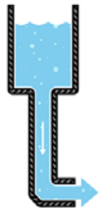


## Alternating Current (AC) & Direct Current (DC)

- Direct current (DC) is electric current that flows in one direction (unidirectional).
- DC sources provide a constant voltage over time.
- Examples of DC electronics include:
  - Cell phones
  - Current produced by PV modules and stored in batteries
  - Flat-screen TVs (AC goes into the TV, which is converted to DC)
  - Flashlights
  - Hybrid and electric vehicles

## Alternating Current (AC) & Direct Current (DC)

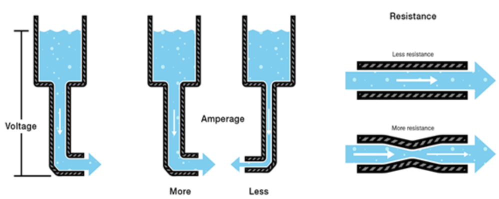
- Using the water analogy again, DC is similar to a tank of water with a hose at the end.
- The tank can only push water one way: out the hose (unidirectional).
- Similar to the DC-producing battery, once the tank is empty, water no longer flows through the pipes.





## Electrical Resistance

- Ohm (Ω) is the unit of electrical resistance.
- When an electric current of one ampere passes through a component across which a potential difference (voltage) of one volt exists, then the resistance of that component is one ohm.
- Using the water analogy, the current is analogous to the flow rate of water, voltage is the pressure pushing that water through a pipe, and resistance is the width of the pipe.






## Electrical Power and Energy

- A watt is unit of electric power which is equivalent to a current of one ampere under a pressure of one volt.

  **Watt=amp * volt**
- Watts indicate the rate at which an appliance/system uses or produces electrical energy.
- Since consumers need to gauge how much electricity they use, the watt-hour, an electrical unit of energy, is an important measurement.
- An appliance that consumes electrical energy at a rate of one watt for one hour will have consumed a quantity of electricity equal to one watt-hour.

## Electrical Power and Energy

- To calculate watt-hours, there are two things one needs to consider
  - Appliance/system's rate watts
  - The duration of time appliance/system would be operated
- The term watt-hours should sound familiar, since utility companies bill their customers for the number of kilowatt-hours consumed**.** Kilowatt-hours of electricity is equal to 1,000 watt-hours and is abbreviated in kWh.



## Equations

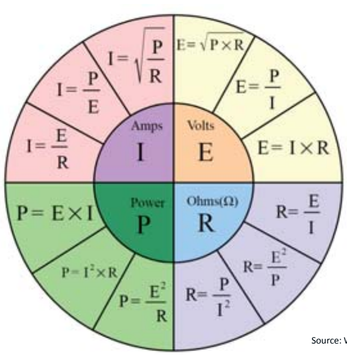
Power = Watts (W) = Volts (V) x Current (A)
1,000 W = 1kW

Energy = Watt-hours (Wh) = Watts (W) x Time (Hours)
1,000Wh = 1kWh

Amp-hours (Ah) = Amps x Time (Hours)



## Equation Wheel




Source: Wikimedia

## Module Overview

- Terminology
- **Matching Appliances to the System**
- Electrical Circuits
- Series and Parallel Circuits in Power Sources
- Series and Parallel Circuits in Electrical Loads
- Exercises



## Matching Appliances to the System

- When choosing an appliance for a PV system, there are two important rules that must be observed:
  - The voltage of an appliance must match the voltage supplied to it by the power source, such as a battery, generator, or photovoltaic modules.
  - An appliance must be compatible with the type of current (AC or DC) that is supplied to it.
  - The appliance must be very efficient



## Module Overview

- Terminology
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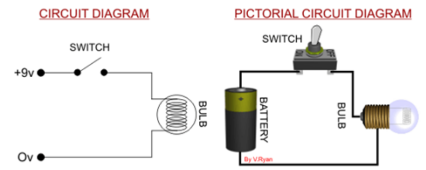
## Electrical Circuits

- An electrical circuit is the continuous path of the electron flow from a voltage source, such as battery or photovoltaic module, through a conductor (wire) to a load and back to the source.
- The switch controls the continuity of current flow. If the switch is turned off (an open circuit), the wire between source and the load is disconnected, and the bulb will be off.
- If the switch is turned on (a closed circuit),the wire between source and the load is connected, and the bulb be on.



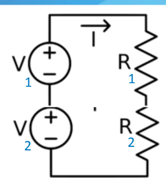


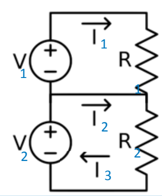

## Electricity Laws

- $V = I * R$
- Sum of voltage around any loop is zero

  $V_1 + V_2 - I*R_1 - I*R_2=0$
- Sum of current into any connection is zero

  $I_1 + I_2 - I_3 = 0$






## Module Overview

- **Terminology**
- **Matching Appliances to the System**
- **Electrical Circuits**
- **Series and Parallel Circuits in Power Sources**
- **Series and Parallel Circuits in Electrical Loads**
- **Exercises**

## Series and Parallel Circuits in Power Sources

- Photovoltaic modules and batteries are a system's building blocks.
- While each module or battery has a rated voltage or current, they can be wired together to obtain a desired system voltage and current.
- There are two types of wiring connections
  - Series
  - Parallel

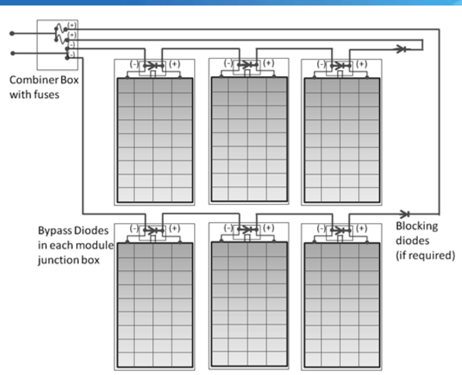


## Series and Parallel Wiring

- Current through series string limited by minimum module current.
- Voltage of combined strings limited by minimum string voltage.
- Advantages of Series Wiring:
  - High voltage;
  - Need smaller wire;
  - Less line losses.
- Advantages of Parallel Wiring:
  - More resistance to shading;
  - Module breakage or theft (redundancy).



## Series and Parallel Wiring



## Series Circuits

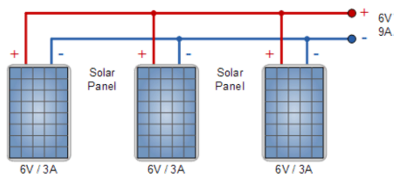
- Series wiring connections are made at the positive (+) end of one module to the negative (-) end of another module.
- When loads or power are connected in series, the voltage increases and the current will remain constant.


Source: HES PV



## Parallel Circuits

- Parallel wiring connections are made from the positive (+) to positive (+) terminals between modules.
- When loads or power are connected in parallel, the current increases and the voltage will remain constant.




Source: Alternate energy tutorials



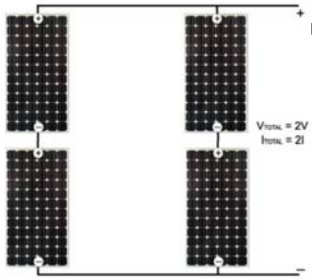
## Series and Parallel Circuits in Power Sources

Remember….

- In series connection, current remains same and voltage increases.
- In parallel connection, voltage remains same and current increases.

## Series and Parallel Circuits in Power Sources

- Combination of series and parallel wiring connection is done to get the desired output voltage and current.

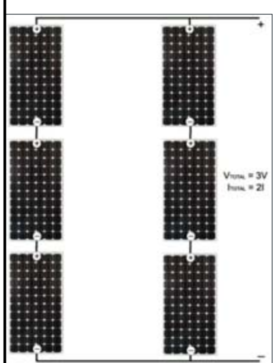



**Each module is of voltage V and current as I**

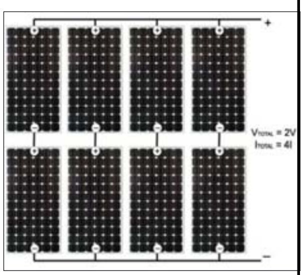
Source: Clean Energy Zone



## Series and Parallel Circuits in Power Sources




**Each module is of voltage V and current as I**

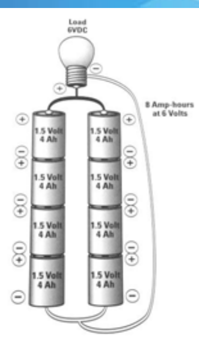



Source: Clean Energy Zone



## Series and Parallel Circuits in Power Sources

- In this figure, a series string of four batteries have been added in parallel to another string of four batteries to increase storage (amp-hours).
- The new string is wired in parallel, which increases the available amp-hours, thereby adding additional storage capacity and increasing usage time.
- The second string could not be added in series because the total voltage would be 12 volts, which is not compatible with 6 volt of lamp.




Source: Solar Energy International

## Module Overview

- **Terminology**
- **Matching Appliances to the System**
- **Electrical Circuits**
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- **Series and Parallel Circuits in Electrical Loads**
- **Exercises**



## Series and Parallel Circuits in Electrical Loads

- Like photovoltaic modules described earlier, loads can be wired in series, parallel, or series/parallel configuration to get the desired output.

Loads in series:

- Loads wired in series result in a voltage drop that is additive.
- The total voltage drop is equal to the sum of all the loads in the circuit.
- Current is equal through all loads in the circuit



## Series and Parallel Circuits in Electrical Loads

- The figure shows two 6V light bulbs wired in series and supplied by 12 V battery.
- The voltage drop caused by each bulb is 6 V; thus the total voltage drop is 12 V, which is equal to the 12 V of battery.
- The two light bulbs are connected in series and are jointly controlled.
- If one bulb burns out, the circuit will be open, and no current will pass through the second bulb.
- For this reason it is not recommended to wire loads in series.

Source: Solar Energy International

## Series and Parallel Circuits in Electrical Loads

Loads in parallel

- For loads wired in parallel, the voltage drop for each remains equal to the source voltage.
- Current drawn from source is increased with each load added in parallel.
- Electrical circuits are commonly wired with all the loads in parallel because:
  - Each load can be controlled individually
  - Adding more loads does not affect the operating voltage of any other load

Source: Solar Energy International



## Module Overview

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## Series and Parallel Wiring Exercises

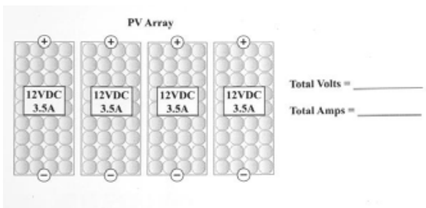
- Use the following worksheets to practice series and parallel wiring for 12- and 24- volt systems.
- Enter the your answers in the blanks on each page.
- Draw lines to make connections

Instructions:

1. Connect the photovoltaic modules (array) either in series or parallel or series/parallel to get the desired system voltage
2. Calculate total module output; volts and amps

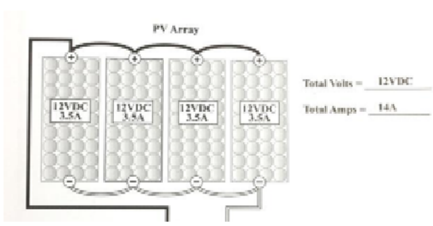
## Problem 1

**Design a 12 V system with four 12 V PV modules**





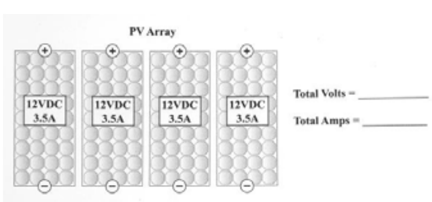

## Solution 1

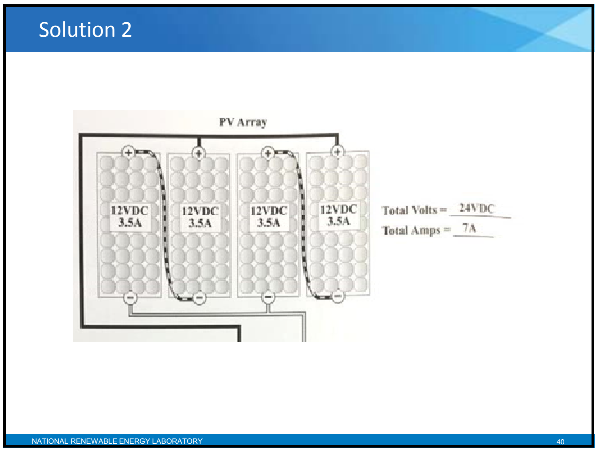





## Problem 2

**Design a 24 V system with four 12 V PV modules**




Solution 2
PV Array
12VDC
3.5A
12VDC
3.5A
12VDC
3.5A
12VDC
3.5A
Total Volts = 24VDC
Total Amps = 7A
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40


Thank You
Please Provide Feedback
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kari.burman@nrel.gov
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## CLIMATE TECHNOLOGY CENTRE & NETWORK SOLAR PHOTOVOLTAIC ACCREDITATION TRAINING PROGRAM

Presented by: Andy Walker and Kari Burman
National Renewable Energy Laboratory
November 6th -10th , 2017



# Inverters

## Module Overview

- **Operating Principles**
- **Inverter Types**
- **Inverter Issues**
- **Advancements in Inverter Arrangements**
- **Advancements in Inverter Features**
- **Inverter Sizing**

## Operating Principles

- Solar panels output Direct Current (DC). As DC electricity cannot be used directly by common household appliances nor fed into the mains grid; it first needs to be converted to Alternating Current (AC).
- Inverter is a device that converts DC to AC.
- The advent of sophisticated integrated circuits, field effect transistors and high frequency transformers has allowed creation of lighter and more efficient inverters.


Source: Clean Energy Reviews



## Operating Principles

- Other inverter applications include:
  - Fuel cells
  - Wind turbines and micro turbines
  - Variable frequency drive (VFD)
  - Uninterruptible power supply (UPS)
  - Electronic ballasts and induction heaters
  - HVDC power transmission



## Module Overview

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## Inverter Types

- Solar inverters are classified into three broad categories
  - Grid-tied inverters
  - Grid-tied with battery backup inverters
  - Stand-alone inverters

1. Grid-tied inverters

- The number of grid-tied PV systems continues to dramatically increase every year.
- Because of this, the number of available grid-tied inverter options/model continues to increase as well.
- Grid-tied inverters need to meet requirements of IEEE Standard 1547.
- Grid-tied inverters use maximum power point tracking (MPPT) to get the maximum possible power from the PV array.



## Inverter Types

2. Grid-tied with battery backup inverters

- They are complex than grid-tied inverters.
- They are designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid.
- These inverters are capable of supplying AC energy to selected loads during a utility outage, and are required to have anti-islanding protection.

3. Stand-alone inverters

- It is used in isolated system where the inverter draws its DC energy from batteries charged by photovoltaic arrays
- They do not interface with the utility grid and are not required to have anti-islanding protection.



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- **Inverter Sizing**

## Inverter Issues

- **Safety and performance standards:**
  - IEC
  - IEEE
  - UL
- **Preventative Maintenance Low (solid-state electronics)**
- **Corrective Maintenance High**
  - Circuit boards
  - Capacitors
- **Efficiency Losses**

Source: Caprica Solar



## Inverters Preventive Maintenance

- Regular preventive maintenance of solar inverters throughout their lifetime can
  - Ensure maximum availability
  - Minimum unplanned repair costs.
  - Reliability of solar inverters can be ensured
  - Lifetime extended.
- Solar inverter preventive maintenance consists of annual inverter inspections and component replacements according to product-specific maintenance schedules.



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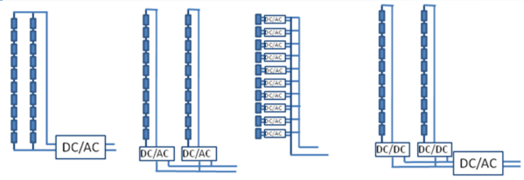
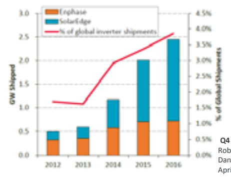
## Advances in Different Inverter Arrangements




Central Inverter | String Inverters | Micro-inverter | DC Optimizer




**Micro- and String Inverters**

- More expensive than Central Inverter
- Reduces production losses
- Provides rapid shutdown near array
- Provides detailed data
- More conventional AC wiring

**Q4 2016/Q1 2017 Solar Industry Update**
Robert Margolis, NREL David Feldman, DOE
Daniel Boff, DOE
April 25, 2017



## Module Overview

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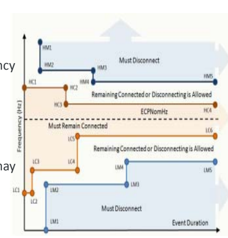
## Advances in Inverter Features

- **Grid Reliability Functions**
  - Low Voltage Ride Through
  - Low Frequency Ride Through
- **Real Power Control Functions**
  - Frequency/Watt
    - Reduces real power output with rising frequency
  - Volt/Watt
    - Reduces real power output with rising voltage
- **Supply Reactive Power and Voltage Support**
  - Volt/VAR
    - Provides reactive power (kVAR) support and may reduce real power (kW)
- **Communications**
  - On/Off; Curtailment
  - Change Autonomous Settings
  - Cyber Security
- **Standard: IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems**




Frequency, EPRI

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## Sizing of Inverters

**Problem 1**

A family living in mountains near Dodoma, wants to power the following 220 volt alternating current loads with his 12- volt direct current photovoltaic system:

- 300-watt blender
- 1000-watt saw
- 640-watt vacuum cleaner
- 30-watt VCR

The family wants to run the saw and the VCR simultaneously. All other loads will be operated individually.

**Use the inverter worksheet in the next slide to size the inverter.**

*As a rough "rule of thumb" minimum surge requirements for stand-alone inverters of a load can be calculated by multiplying the required watts by 3



## Sizing of Inverters

| Inverter Sizing Worksheet | | | |
|---|---|---|---|
| | | | |
| **AC Total Connected Watts** | **DC System Voltage** | **Estimated Surge Wattage** | **Listed Desired Features** |
| | | | |
| **Inverter Specifications:** | **Make:** | **Model:** | |
| | | | |

## Sizing of Inverters

**Solution 1**

**a) AC output watts**

Family wants to operate saw and VCR simultaneously, the **AC Total Connected Watts** is 1000 watts of saw plus 30 watts of VCR i.e. 1030 watts in total.

Thus, an inverter with at least 1030 watts output is required.

| Inverter Sizing Worksheet | | | |
|---|---|---|---|
| | | | |
| AC Total Connected Watts | DC System Voltage | Estimated Surge Wattage | Listed Desired Features |
| 1030 | | | |
| Inverter Specifications: | Make: | Model: | |
| | | | |



## Sizing of Inverters

**b) DC input voltage from battery**

A 12 V battery is a given value in this problem, thus a 12 V inverter rated for at least 1030 watts is appropriate, and this size is readily available.

AC Total Connected Watts divided by DC System Voltage equals the Maximum DC amps Continuous. This value will be used later to design the size of the wire.

| Inverter Sizing Worksheet | | | |
|---|---|---|---|
| | | | |
| AC Total Connected Watts | DC System Voltage | Estimated Surge Wattage | Listed Desired Features |
| 1030 | 12 | | |
| Inverter Specifications: | Make: | Model: | |
| | | | |



## Sizing of Inverters

**c) Output Voltage**

Choose an inverter with 220 V output to match the AC load voltage.

**d) Frequency**

A unit capable of producing 50 cycles per second AC should be specified to match the requirements of the loads.

**e) Surge capacity**

Accounting for load surge requirements, the peak wattage of 1030 is multiplied by 3 to get an estimated surge watts of 3090. This is a rough estimate using rule of thumb.

## Sizing of Inverters

| Inverter Sizing Worksheet | | | |
|---|---|---|---|
| | | | |
| AC Total Connected Watts | DC System Voltage | Estimated Surge Wattage | Listed Desired Features |
| 1030 | 12 | 3090 | |
| Inverter Specifications: | Make: | Model: | |
| | | | |



## Thank You

**Please Provide Feedback**

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

# Photovoltaic System Wiring

## Module Overview

- **Introduction**
- **Wire Sizing**
- **Overcurrent Protection**
- **Overcurrent Protection Sizing**
- **Disconnects**
- **Grounding**
- **Surge Suppression**

## Introduction

- PV System installations must be in compliance with the National Electrical Code in effect (NEC® in the US) to ensure that they will be safe and functional.
- Direct current (DC) wiring systems are substantially different from conventional household Alternating current (AC) wiring systems.
- PV systems often consist of DC and AC circuits.
- AC and DC wiring systems are not compatible and must be separated.

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## Introduction

Wire Types

- Wires types differ in conductor material and insulation.
  - Conductor : Any material that allows electric current to pass through. Examples- metals
  - Insulator: Any material that does not allows electric current to pass through. Example- plastic, rubber
- The two common conductor material used in residential and commercial wiring are copper and aluminum.

| | Copper | Aluminum |
|---|---|---|
| Conductivity (for the same size of wire) | More | Less |
| Durability | More | Less |
| Cost | More | Less |
| Weight | Heavy | Light |

NATIONAL RENEWABLE ENERGY LABORATORY 5

## Introduction

- Conductors itself can be solid or stranded.
- Stranded conductors consist of many small wires that increases its flexibility and is recommended choice when a large wire size is required.
- Insulation covering can provide protection from heat, abrasions, moisture, ultraviolet light and/or chemicals.
- The NEC® designates what types of wire may be used for various applications as shown in the table on next slide.

NATIONAL RENEWABLE ENERGY LABORATORY 6

## Introduction

**Wire Types**

| Type | Covering Temp | Max. Provisions | Location Covering | Insulation | Outer |
|---|---|---|---|---|---|
| THHN | Heat Resistant Thermoplastic | 90°C 194°F | Dry or Damp | Flame Retardant & Heat Resistant Thermoplastic | Nylon Jacket |
| THW | Moisture & Heat Resistant Thermoplastic | 75–90° C 167–194°F | Dry or Wet | Flame Retardant & Moisture & Heat Resistant Thermoplastic | None |
| THWN | Moisture & Heat Resistant Thermoplastic | 75°C 167°F | Dry or Wet | Flame Retardant & Moisture & Heat Resistant Thermoplastic | Nylon Jacket |
| TW | Moisture Resistant Thermoplastic | 60°C 140°F | Dry or Wet | Flame Retardant & Moisture Resistant Thermoplastic | None |
| UF | Underground Feeder & Branch Circuit Cable-Single Conductor | 60–75°C 140–167°F | Service Entrance | Moisture and Heat Resistant | Integral with insulation |
| USE | Underground Service Entrance Cable-Single Conductor | 75°C 167°F | Service Entrance | Moisture and Heat Resistant<br>Non-metallic Covering | Moisture Resistant |

*A more complete table can be found in NEC®

Source: Solar Energy International and NEC®



## Introduction

- Electrical wire insulation is color coded to designate its function and use.
- Technicians should understand the color-coding of conventional electrical wire to ensure safe and efficient operation, troubleshooting, and repair.

**Color Coding of Wires**

| Alternating Current (AC) Wiring: COLOR | APPLICATION | Direct Current (DC) Wiring: COLOR | APPLICATION |
|---|---|---|---|
| Any color other than green or white/gray | Ungrounded conductor (Hot, L1, L2) | Any color other than green or white/gray allowed (convention is red) | Ungrounded conductor (typically positive) |
| White/gray | Grounded conductor (neutral) | White/gray | Grounded conductor (typically negative) |
| Green or bare | Equipment ground | Green or bare | Equipment ground |

*A more complete table can be found in NEC®

Source: Solar Energy International and NEC®



## Introduction

- When using the color coding of wire table shown on slide 8, designers should know whether the wiring is being used in alternating current and direct current.
- Large conductors (21.1 mm2 and larger) usually have only black colored insulation. Therefore, it is allowable to use colored electrical tape or paint to color code the wire ends where electrical connections are made.

## Introduction

- Cable: Two or more insulated conductors having an overall covering.
  - As with wire, the protective covering on cables is rated for specific uses, such as resistance to moisture, ultraviolet light, heat, chemicals or abrasions.
- Conduit: It is a metal or plastic that contains wires and offers a protective enclosure for the wires.
  - Conduit is often used in PV systems where wires need to be concealed or protected.
- Tables in the NEC® list the maximum number and size of wire which can be run through a given conduit size (conductor should fill no more than 40% of conduit cross-sectional area).
- Using too small of wire or too many wires within conduit will result in overheating and damage to the wire's protective insulation



## Module Overview

- **Introduction**
- **Wire Sizing**
- **Overcurrent Protection**
- **Overcurrent Protection Sizing**
- **Disconnects**
- **Grounding**
- **Surge Suppression**



## Wire Sizing

- There are three important criteria for selecting wire size
  - Ampacity
  - Voltage drop
  - Minimum size required by codes and standards

Ampacity

- It refers to the current carrying (amps) ability of a wire.
- Larger the wire, more the capacity.
- Using wire with low ampacity than wire that carries a larger current will overheat the wire.
- Overheating means wasted energy and inefficiency, and can result in melted insulation, a short circuit or fire.

## Conversion from American Wire Gauge to Cross Sectional Area

| American Wire Gauge (#AWG) | Diameter (inches) | Diameter (mm) | Cross Sectional Area ($mm^2$) |
|---|---|---|---|
| 0000 (4/0) | 0.460 | 11.7 | 107 |
| 000 (3/0) | 0.410 | 10.4 | 85.0 |
| 00 (2/0) | 0.365 | 9.27 | 67.4 |
| 0 (1/0) | 0.325 | 8.25 | 53.5 |
| 1 | 0.289 | 7.35 | 42.4 |
| 2 | 0.258 | 6.54 | 33.6 |
| 3 | 0.229 | 5.83 | 26.7 |
| 4 | 0.204 | 5.19 | 21.1 |
| 5 | 0.182 | 4.62 | 16.8 |
| 6 | 0.162 | 4.11 | 13.3 |
| 7 | 0.144 | 3.67 | 10.6 |
| 8 | 0.129 | 3.26 | 8.36 |
| 9 | 0.114 | 2.91 | 6.63 |
| 10 | 0.102 | 2.59 | 5.26 |
| 11 | 0.0907 | 2.30 | 4.17 |
| 12 | 0.0808 | 2.05 | 3.31 |
| 13 | 0.0720 | 1.83 | 2.63 |
| 14 | 0.0641 | 1.63 | 2.08 |
| 15 | 0.0571 | 1.45 | 1.65 |
| 16 | 0.0508 | 1.29 | 1.31 |
| 17 | 0.0453 | 1.15 | 1.04 |
| 18 | 0.0403 | 1.02 | 0.82 |
| 19 | 0.0359 | 0.91 | 0.65 |
| 20 | 0.0320 | 0.81 | 0.52 |
| 21 | 0.0285 | 0.72 | 0.41 |
| 22 | 0.0254 | 0.65 | 0.33 |
| 23 | 0.0226 | 0.57 | 0.26 |
| 24 | 0.0201 | 0.51 | 0.20 |
| 25 | 0.0179 | 0.45 | 0.16 |
| 26 | 0.0159 | 0.40 | 0.13 |

Source: Engineering Toolbox



## Wire Sizing

Ampacity of Copper Wire

| AWG | In Conduit or Cable UF, THW | In Conduit or Cable USE, THWN | Single Conductors in Free Air UF, THW | Single Conductors in Free Air USE, THWN |
|---|---|---|---|---|
| 14 | 15 | 15 | 20 | 20 |
| 12 | 20 | 20 | 25 | 25 |
| 10 | 30 | 30 | 40 | 40 |
| 8 | 40 | 50 | 60 | 70 |
| 6 | 55 | 65 | 80 | 95 |
| 4 | 70 | 85 | 105 | 125 |
| 2 | 95 | 115 | 140 | 170 |
| 1/0 | 125 | 150 | 195 | 230 |
| 2/0 | 145 | 175 | 225 | 265 |
| 3/0 | 165 | 200 | 260 | 310 |
| 4/0 | 195 | 230 | 300 | 360 |

* It is a simplified chart. It does not contain temperature derating. The detailed version of the report could be found in NEC®

Source: Solar Energy International and NEC®



## Wire Sizing

- When sizing wire in a PV system, one should start by finding out the maximum current load.
- Maximum current load: It is the greatest current going through the circuits of PV system at one time.
- For the wire run from the PV panels to the controller or battery
  - Use the module short circuit current (Isc) multiplied with number of modules in parallel
- For the wire from battery to the DC service panel
  - Use the total load amperes.
- Once the total current is calculated, multiply it by 125%, so that the conductor never carries more than 80% of its rated capacity.
- This safety precautions must be done on all wires in a PV system.

## Wire Sizing

- NEC® requires an additional safety factor to be included in the wire that connects the PV array to the batteries, or the PV array to inverter in batteryless system.
- This is to handle any extra current produced by the panels caused by reflection or exceptionally sunny days.
- To account for this power, the array short circuit must be multiplied by an additional 125% to ensure the proper conductor size and meets the code requirements.
- Once the NEC® required amps is calculated, look at the ampacity of copper table to see which wire and type of conduit is needed.



## Wire Sizing

An additional factor of 1.25 is applied to acknowledge that sunlight may be reflected onto PV modules by clouds or surrounding buildings or shiny objects resulting in acurrent higher than the rated current For the wire run from the PV panels to the controller or battery

Isc x Number of modules in parallel =Total Amps x 1.25 x 1.25 (NEC® required amps)

For the wire from battery to the DC service panel

Total load current (in amperes) x 1.25



## Wire Sizing Exercise

Problem 1

A photovoltaic array has a short circuit (Isc) of 40 amperes and the system has a DC load of 20 amperes. Determine the type of and gauge (AWG) of wire is required. Use ampacity of copper wire table given below .

Ampacity of Copper Wire

| AWG | In Conduit or Cable UF, THW | In Conduit or Cable USE, THWN | Single Conductors in Free Air UF, THW | Single Conductors in Free Air USE, THWN |
|---|---|---|---|---|
| 14 | 15 | 15 | 20 | 20 |
| 12 | 20 | 20 | 25 | 25 |
| 10 | 30 | 30 | 40 | 40 |
| 8 | 40 | 50 | 60 | 70 |
| 6 | 55 | 65 | 80 | 95 |
| 4 | 70 | 85 | 105 | 125 |
| 2 | 95 | 115 | 140 | 170 |
| 1/0 | 125 | 150 | 195 | 230 |
| 2/0 | 145 | 175 | 225 | 265 |
| 3/0 | 165 | 200 | 260 | 310 |
| 4/0 | 195 | 230 | 300 | 360 |

Source: Solar Energy International and NEC®

## Solution 1

Find the total amps for each section of wire

Wire run from the PV array to battery
Using equation
Isc x Number of modules in parallel =Total Amps x 1.25 x 1.25 (NEC® required amps)
= 40 x 1.25 x 1.25
NEC® required amps = 62.5 amperes
The wire must have an ampacity that can handle 62.5 amperes.

Based on ampacity wire copper table , using THWN in conduit ,the wire need would # 6 AWG

Wire run from the battery to load
Using equation
Total load current (in amperes) x 1.25
=20 x 1.25
=25 amperes
The wire must have an ampacity that can handle 25 amperes.
Based on ampacity wire copper table , using THWN in conduit ,the wire need would # 10 AWG or 5.26 mm2



## Wire Sizing

Voltage drop

- It is the loss of voltage due to wire's resistance and length.
- It is important to consider efficient design practices to minimize energy loss.
- Voltage drop in a wire is a function of the following three parameters:
  - Wire gauge
  - Length of wire
  - Current flow in the wire
- Greater the wire length, the greater resistance to the current flow.
- Excessively long wire runs would result in low voltage, loss of power to the load, and lower system efficiency.
- Inductive loads, such as motors ,have a large in-rush current to start and are particularly sensitive to voltage drop.



## Wire Sizing

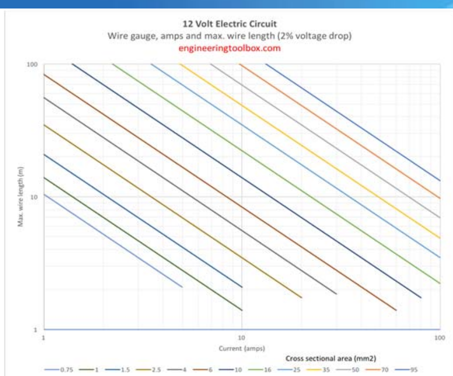
- Using a larger wire size, decreasing the current flow, or decreasing the length of wire are all solutions to reduce voltage drop.
- A good design practice is to keep the system wiring voltage loss between 2% to 5%.
- Tables on slide 23,24,and 25 list the recommended maximum on way length for 2% voltage drop in various sizes depending upon the required current and the system voltage. These table values include an allowance for the fact that the wire must travel the distance twice, once to the load and then back.
- How to use these tables?
  - Find out the appropriate table to use.
  - Find the load current in the left hand column.
  - Read across the right until you find the first number that is greater than or equal to one way distance to the load .
  - Read straight up from that value to find the minimum wire size.

## Wire Sizing

- Note: When using the voltage drop tables to size the wire one does not need to include NEC® safety factors when calculating the current for each wire run.
- Note: When designing a system, always consider that the system owner may want to add more loads to the system without running a new wire, particularly if the wire is buried or inaccessible.



## Wire Sizing






## There are many on-line calculators to calculate wire voltage drop

http://photovoltaic-software.com/DC_AC_drop_voltage_energy_losses_calculator.php

This free online calculator gives the AC and DC Power, Voltage Drop, wire energy losses, resistive heating, for three phase and single phase wiring.




## Module Overview

- **Introduction**
- **Wire Sizing**
- **Overcurrent Protection**
- **Overcurrent Protection Sizing**
- **Disconnects**
- **Grounding**
- **Surge Suppression**



## Overcurrent Protection

- Overcurrent or excess current is a situation where a larger than intended electric current passes through a conductor, leading to excessive generation of heat, and the risk of fire or damage to equipment.
- The NEC® specifies the maximum overcurrent protection for each conductor size.
- Two types of overcurrent protection are:
  - Circuit breakers
  - Fuses
- When the current exceeds the rated capacity of circuit breakers or fuses, the circuit will become open and stop all the current flow.

## Overcurrent Protection

Circuit Breakers

- A device capable of making and breaking an electric circuit under normal and abnormal condition.
- It must be Underwriters Laboratory (UL) listed and be DC rated if used in direct current applications.
- When the current exceeds circuit breaker's rated amperage, the circuit will become open and one needs to just reset the circuit breaker to get back to normal condition
- There are different types of circuit breakers available in the market.

Source: ABB

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## Overcurrent Protection

Fuses

- It consists of a wire or metal strip that will burn through when current exceeds fuse's rate amperage and will open the circuit.
- It needs to be replaced to get back to the normal condition.
- Common causes of fuse failure from excess current are
  - Overload :Operation of too many loads on the same circuit
  - Short circuit or ground fault :Caused by faulty wiring or equipment.

Source: Wikipedia

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## Module Overview

- **Introduction**
- **Wire Sizing**
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## Sizing of Overcurrent Protection

- A common misconception is that the breakers and fuses are designed to protect equipment from damage.
- Remember, their primary task is to protect the wire from overheating and potentially causing a fire.
- To achieve this, the rating of an overcurrent device must be less than or equal to the ampacity of the wire used, while still passing the full amperage of the power source or power draw, including the safety factors.

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## Sizing of Overcurrent Protection

- Overcurrent protection devices have standard ratings as follows: 1 amp increment from 1-15 amps; 5 amp increment from 15-50 amps; 10 amps increment from 50-110 amps;25 amps increment from 125-250 amps and higher (NEC®).
- If the rated ampacity of the chosen wire gauge falls between one of the above mentioned standard rating values, the next larger rating of overcurrent device should be used.

NATIONAL RENEWABLE ENERGY LABORATORY 32

## Sizing of Overcurrent Protection

Note:

- Ultimately, designer must verify that the overcurrent device will protect the conductor under conditions of use.
- One must perform over protection check that takes into account deration factors for the operating temperature of the wire and the number of wires in a single conduit.

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## Sizing of Overcurrent Protection

Problem 3

A photovoltaic array has a short circuit (Isc) of 36 amperes.

What is the minimum size breaker or fuse one could use on 42.2 mm2 (# 1/0 AWG) wire running from PV to battery?

Hint

Use the equations in slide 18



## Sizing of Overcurrent Protection Exercise

Solution

60 amps breaker is required.

The minimum overcurrent device is sized to the amperage of the power sources or power draw, including the safety factors.

For the wire run from the PV panels to the controller or battery

Isc x Number of modules in parallel =Total Amps x 1.25 x 1.25 (NEC® required amps)

= 36 amps x 1.25 x 1.25

=56.25 amps

Viewing the standards (slide 36), the next larger size breaker would be 60 amps.

If you put 50 amps breaker on this wire, one may encounter nuisance tripping when 56.25 amps current is flowing.

Therefore, 60 amps breaker needs to be used to avoid this issue.



## Module Overview

- **Introduction**
- **Wire Sizing**
- **Overcurrent Protection**
- **Overcurrent Protection Sizing Exercise**
- **Disconnects**
- **Grounding**
- **Surge Suppression**

## Disconnects

- Each piece of equipment in a PV system, such as inverter, batteries, and charge controllers, must be able to disconnect from all sources of power (NEC®).
- To comply with NEC® code, disconnects must satisfy the following:
  - They can be switches or circuit breakers
  - They need be to accessible
  - They must not have any exposed live parts
  - They must indicate whether they are on or off (closed or open)
  - They must be rated for the nominal system voltage and available current (NEC®)



## Disconnects

- Circuit breakers designed in the system for overcurrent protection can be used as disconnects.
- Fuses are not considered disconnects unless they are switch fuses.




## Module Overview

- **Introduction**
- **Wire Sizing**
- **Overcurrent Protection**
- **Overcurrent Protection Sizing Exercise**
- **Disconnects**
- **Grounding**
- **Surge Suppression**

## Grounding

- The following list contains NEC® definitions for grounding terms that one should be familiar with.
  - Grounded: Connected to the earth or to some conducting body that serves as earth.
  - Grounded conductor: Current carrying conductor that is grounded at one point.
  - Grounding conductor: A conductor not normally carrying current used to connect the exposed metal portions of equipment or grounded circuit to the electrode system.
  - Grounding electrode conductor: Bare copper wire connecting grounded conductor and/or equipment grounding conductor to the grounding electrode.
  - Grounding electrode: Usually a ground rod or a bare metal well casing.
  - Ungrounded conductor: Current carrying conductor not connected/bonded with ground.



## Grounding

- Why Ground?
  - To limit voltages due to lightning, line surges or unintentional contact with higher voltage lines.
  - To stabilize voltages and provide common reference point being the earth.
  - To provide a path in order to facilitate the operation of overcurrent devices.
- There are two specific ways to ground
  - System grounding
  - Equipment grounding



## Grounding

Equipment grounding

- In this case, earth is connected to non current carrying part or the chassis (the external body of the equipment).
- It is used to protect the personnel from shocks caused by a ground fault and is required in all PV systems by NEC®.

System grounding

- In this case, earth is connected to the current carrying parts by taking one conductor from two-wire system and connecting it to ground.
- It is used to protect the equipment.
- The NEC® code in the US requires this type of grounding for all systems over 50 volts.
- If one chooses not to system- ground a PV system under 50 volts then both conductors need to have overcurrent protection, which is cumbersome and costly.

## Module Overview

- **Introduction**
- **Wire Sizing**
- **Overcurrent Protection**
- **Overcurrent Protection Sizing Exercise**
- **Disconnects**
- **Grounding**
- **Surge Suppression**

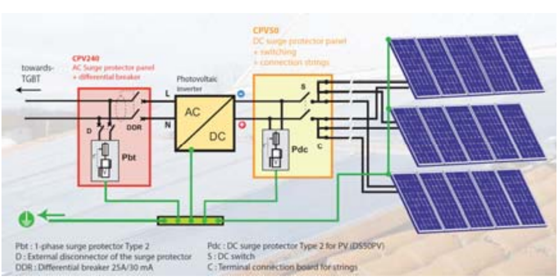


## Surge Suppression

- Surge suppression is the diverting and/or diminishing of excessive current and voltage from the AC power line, which can damage sensitive electronic equipment. Power surges generally last less than 50 microseconds, but can reach as much as 6,000 volts and draw 3,000 amps when they arrive at the equipment.
- PV arrays mounted in the open, on tops of buildings, can act like a lightning rods.
- The PV designer and installer should provide appropriate means to deal with lightning induced surges coming into the system.



## Wiring of Surge Suppressor

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**Climate Technology Centre & Network**
**Solar Photovoltaic Accreditation Training Program**

# Day Four

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## CLIMATE TECHNOLOGY CENTRE & NETWORK SOLAR PHOTOVOLTAIC ACCREDITATION TRAINING PROGRAM

**Presented by: Andy Walker and Kari Burman**
**National Renewable Energy Laboratory**
November 6th -10th, 2017



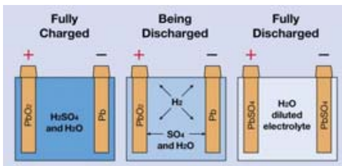
## Batteries

## Module Overview

- **Battery Types and Operations**
- **Battery Specifications**
- **Battery Safety**
- **Battery Wiring Configuration**
- **Battery Sizing**

## Battery Types and Operations

- Batteries store energy in direct current form (DC).
- Since PV systems produce power only when the sun is shinning batteries are used to provide back-up power.
- Battery cells allow the electrical energy to be stored as chemical energy within the cell and then converted back to electricity as needed.
- Figure below shows the chemical reaction of a typical lead acid battery.




Source: Homepower



## Battery Types and Operations

- Battery life span is dependent on battery type
  - The percent of discharge
  - The number of charge and discharge cycles it performs
- There are many different types of batteries and chemical compositions.
- Two main commercialized types of batteries used with PV systems are:
  - Lead-acid
  - Lithium-ion

Lead -acid Battery
Source: Electronic Tutorials


Lithium-ion Battery
Source: Electronic Tutorials



## Battery Types and Operations

- Lead-acid Batteries
  - Lead-acid closely resemble an automotive battery, however automotive batteries are not recommended for PV applications because they are not deep-cycle.
  - PV system require a battery to discharge small amounts of current over long durations and to recharge under variable conditions.
  - Deep-cycled lead-acid batteries can be discharged down to 45%-80% of its rated capacity.
  - Deep-cycled lead-acid batteries are best suited for PV systems because they are rechargeable, widely available in many sizes, easy to maintain, and relatively inexpensive.

## Battery Types and Operations

- Lead-acid
  - Commercially available since the 1800's.
  - Two main types of lead-acid batteries:
    - Vented lead-acid (VLA)
    - Valve regulated (VRLA)
  - VLA, are also known as liquid or flooded batteries which require water to be routinely added to the batteries to maintain the system.
  - VRLA are also known as sealed batteries. It requires less maintenance than the VLA and eliminate the threat of an acid spill due to their sealed design.


Source: Gravita Technomech



## Battery Types and Operations

- Lithium Ion (Li-ion) Batteries
  - A newer technology than the lead-acid batteries.
  - They are popular because they are lightweight, have highly reactive elements and they hold their charge, can handle hundreds of charge/discharge cycles.
  - There are different types of Li-ion batteries and below are listed the most common:
    - Lithium iron phosphate (LFP)
    - Lithium nickel manganese cobalt oxide (NMC)
    - Lithium nickel cobalt aluminum oxide (NCA)
    - Lithium manganese oxide (LMO)
    - Lithium titanate (LTO)
  - The characteristics of these batteries will be compared with lead-acid batteries in the following table in the next slide.



## Battery Types and Operations

| | BATTERY CHEMISTRIES | | | | | |
|---|---|---|---|---|---|---|
| | Lead Acid | Lithium- Ion | | | | |
| | VRLA (Deep-Cycle) | LFP | NMC | NCA | LTO | LMO |
| **Usage** | Resiliency, Grid Support, Peak load shifting, Intermittent energy smoothing, UPS | Resiliency, Grid Support, Peak load shifting, Intermittent energy smoothing, UPS | | | | |
| **Energy density (Wh/kg)** | 30-50 | 90-120 | 150-220 | 200-260 | 70-80 | 100-150 |
| **Lifetime cycles (80% depth of discharge)** | 500-800 | 1000-2000 | 1000-2000 | 500 | 3000-7000 | 300-700 |
| **Efficiency (%)** | 85-90 | 93-98 | 93-98 | 93-98 | 93-98 | 90-95 |
| **Charge Time** | 8-16 hrs | 2-4 hrs | 2-4 hrs | 2-4 hrs | 1-2 hrs | 1-2 hrs |
| **Advantages** | Well-known and reliable technology, able to withstand deep discharges, relatively low cost, and ease of manufacturing. Have vents to release hydrogen/oxygen during charge. | High energy density, able to withstand deep discharges, and long cycle lives. | | | | |
| **Disadvantages** | Relatively low number of life cycles (must be replaced more often) and lower energy density (larger size for less energy storage). | More expensive than lead acid systems and may become thermally unstable. Overheating or short circuits in Li-ion cells may cause thermal run-away--a phenomenon where the internal heat generation in a battery increases faster than it can dissipate. This heat can damage or destroy the cells and is a potential source for fires. Electronic protection circuits are added to the battery pack to prevent thermal run-away. | | | | |
| **Safety (Thermal Run-away)** | Considered thermally safe. | High thermal stability | Increased thermal stability | Thermal instability | Highest thermal stability | Increased thermal stability |

Anderson, Kate; Burman, Kari; Simpkins, Travis; Helson, Erica; Lisell, Lars; Case, Tria. 2016. New York Solar Smart DG Hub-Resilient Solar Project: Economic and Resiliency Impact of PV and Storage on New York Critical Infrastructure. NREL/TP-7A40-66617. Accessed at: http://www.nrel.gov/docs/fy16osti/66617.pdf.

## Battery Types and Operations

Lead-acid Battery Bank

Lead-acid Battery Bank

Tesla's new Li-Ion Powerwall for home battery systems



## Module Overview

- **Battery Types and Operations**
- **Battery Specifications**
- **Battery Safety**
- **Battery Wiring Configuration**
- **Battery Sizing**



## Battery Specifications

- Battery Capacity
  - Rated in (Ah) capacity – 100 Ah battery will deliver 1 amp for 100 hours
- Energy Density
  - Units are Wh/kg – power per kilogram of weight
- Rate of Discharge
  - Battery's capacity in relation to the number of hours that it is discharged. The rate in which a battery is discharged affects its capacity. A battery discharged over 24 hours may have 100 Ah capacity but if it is discharged over 8 hours it will only have 85 Ah capacity.

## Battery Specifications

- Depth of Discharge (DOD)
  - It refers to how much capacity will be withdrawn. Battery life is directly related to how deep the battery is cycled. If a battery is discharged to 50% of full capacity every day is will last twice as long as if it is discharged to 80% (100% to 20% state of charge).
- Life Time Cycles
  - Batteries express their life expectancy in terms of number of cycles (not years).
  - Life expectancy is a function of DOD. The battery that is discharged to a deeper percent of its capacity will not last as many years as a battery that is discharged at a shallower rate.



## Battery Specifications

- Days of Autonomy
  - Autonomy refers to the number of days a batter system will provide a given load without being recharged by the PV array or another source.
- Environmental Conditions
  - Batteries are sensitive to temperature. The battery capacity will decrease at colder temperature and capacity will increase at higher temperatures.
  - Manufacturers generally rate batteries at 25°C.
  - Battery life expectancy increases with colder temperature and decreases in environments with higher temperatures.



## Battery Specifications

- Measuring Battery State of Charge (SOC)
  - A voltmeter can be used to measure a battery's state of charge.
  - Battery should sit at rest for a few hours (disconnected from load).
  - Table shows the expected voltage reading for a given SOC of a 12 Volt deep cycle lead acid battery.
  - At some point the battery process stops as the battery can no longer deliver power to a load. The current drops to zero and the potential difference no longer exists.

**12 Volt Battery Charge Condition**

| Open Circuit Voltage | State of Charge |
|---|---|
| 12.65V | 100% |
| 12.58V | 90% |
| 12.55V | 80% |
| 12.48V | 70% |
| 12.40V | 60% |
| 12.32V | 50% |
| 12.24V | 40% |
| 12.10V | 30% |
| 11.90V | 20% |
| 11.70V | 10% |
| 11.30V | 0% |

## Module Overview

- **Battery Types and Operations**
- **Battery Specifications**
- **Battery Safety**
- **Battery Wiring Configuration**
- **Battery Sizing**



## Battery Safety

- General Battery Safety Rules
  - Remove any jewelry before handling batteries.
  - Wear protective clothing especially safety glasses.
  - Use proper insolated tools.
  - Disconnect batteries from power source while working around batteries.
  - Wash hands after handling batteries.
  - Follow manufacturers safety instructions.


Source: US Batteries


Source: Vaping 360



## Battery Safety

- General Battery Safety Rules
  - Label areas where batteries are charging.
  - Vent battery box to the outside.
  - Keep battery cable lengths the same size.
  - Keep number of parallel connections to a minimum.
  - Keep open flames and sparks away from batteries. No smoking near batteries.

## Battery Safety

- General Battery Safety Rules
  - Have baking soda accessible to neutralize acid spills.
  - Don't mix different battery types.
  - Don't mix old batteries with new.
  - Don't water batteries before equalizing.
  - Don't check amps across terminals.

Source: Terrey Penney



## Module Overview

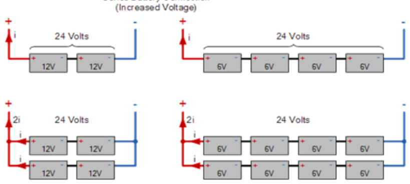
- **Battery Types and Operations**
- **Battery Specifications**
- **Battery Safety**
- **Battery Wiring Configuration**
- **Battery Sizing**



## Battery Wiring Configuration

- Wiring Batteries in Series and Parallel
  - Similar to wiring PV modules
  - Series Battery Connections – increases voltage
  - Parallel Battery Connections – increases current

Series Battery Connection
(Increased Voltage)




Parallel Battery Connection
(Increased Current)

## Series and Parallel Wiring Exercises

- Use the following worksheets to practice series and parallel wiring for 12-,24-48- volt systems.
- Enter the your answers in the blanks on each page.
- Draw lines to make connections

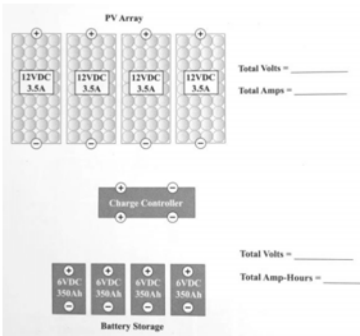
Instructions

1. Connect the photovoltaic modules(array) either in series or parallel or series/parallel to get the desired system voltage
2. Calculate total module output ; volts and amps
3. Connect the array to charge controller
4. Connect batteries either in series or parallel or series/parallel to get desired system voltage
5. Calculate total battery bank voltage and amp-hour capacity
6. Connect the battery bank to the charge controller



## Problem 1

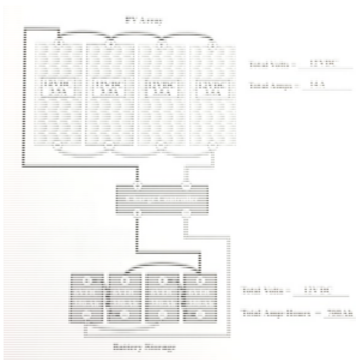
**Design a 12 V system with four 12 V PV modules**




Source: Solar Energy International



## Solution 1



## Module Overview

- **Battery Types and Operations**
- **Battery Specifications**
- **Battery Safety**
- **Battery Wiring Configuration**
- **Battery Sizing**



## Battery Sizing Exercise

- Use Battery Sizing Table
  - Home in Morogoro are designing a PV system to meet their 1080 Wh/day AC electrical load.
  - They will use a 12 V DC system with 2 days of autonomy.
  - Maximum depth of discharge (DOD) is 0.50.
  - The deep-cycle battery that they chose is 6V at 200Ah.
  - Batteries will be kept in conditioned space at 77degree F.
  - Assume inverter efficiency to be 95%.
  - Assume wiring efficiency to be 98%



## Battery Sizing Exercise

**Battery Sizing Worksheet**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| AC Average Daily Load (Watt-hours/day) | ÷ | Efficiency (Inverter efficiency x Wiring efficiency) | + | DC Average Daily Load (Watt-hours/day) | ÷ | DC System Voltage (V) | = | Average Amp-hour/day (Ah) |
| [( | ÷ | ) | + | ] | ÷ | | = | |
| | | | | | | | | |
| Average Amp-hour/day (Ah) | x | Days of Autonomy | ÷ | Discharge Limit | ÷ | Battery Capacity (Ah) | = | Batteries in Parallel |
| | x | | ÷ | | ÷ | | = | |
| | | | | | | | | |
| DC System Voltage (V) | ÷ | Battery Voltage (V) | = | Batteries in Series | x | Batteries in Parallel | = | Total Number Batteries |
| | / | | = | | x | | = | |

## Battery Sizing Exercise

**Solution 1**

**Battery Sizing Worksheet**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| AC Average Daily Load (Watt-hours/day) | ÷ | Efficiency (Inverter efficiency x Wiring efficiency) | + | DC Average Daily Load (Watt-hours/day) | ÷ | DC System Voltage (V) | = | Average Amp-hour/day (Ah) |
| [(1080 | ÷ | 0.931) | + | N/A] | ÷ | 12 | = | 96.70 |
| | | | | | | | | |
| Average Amp-hour/day (Ah) | x | Days of Autonomy | ÷ | Discharge Limit | ÷ | Battery Capacity (Ah) | = | Batteries in Parallel |
| 96.70 | x | 2 | / | 0.5 | / | 200 | = | 1.93 ≈ 2 |
| | | | | | | | | |
| DC System Voltage (V) | ÷ | Battery Voltage (V) | = | Batteries in Series | x | Batteries in Parallel | = | Total Number Batteries |
| 12 | / | 6 | = | 2 | x | 2 | = | 4 |



**Thank You**

**Please Provide Feedback**

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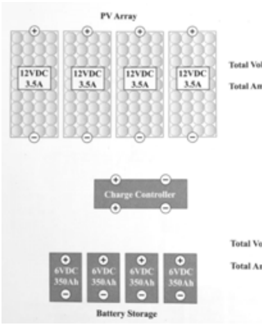
## Extra Configuration Slides

## Problem 2

**Design a 24 V system with four 12 V PV modules**

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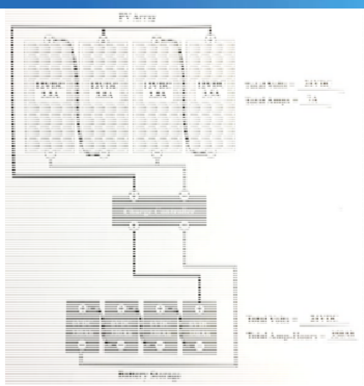
## Solution 2



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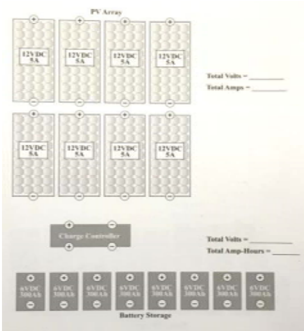
## Problem 3

**Design a 48 V system with eight 12 V PV modules**

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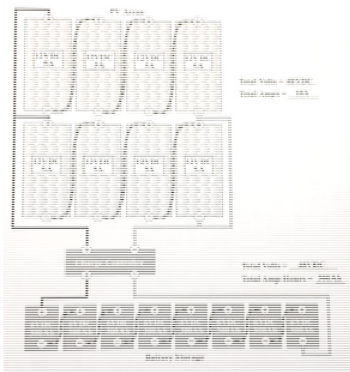
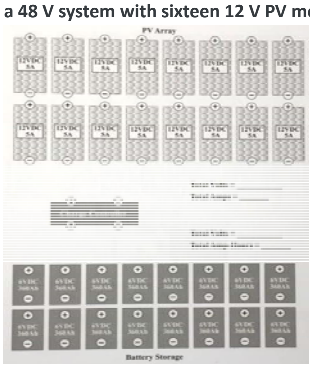
## Solution 3





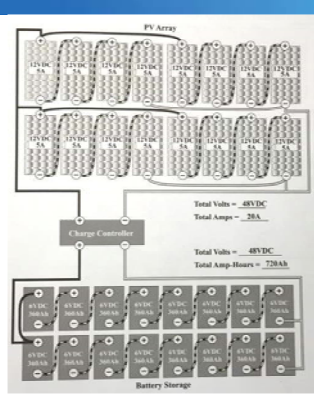
## Problem 4

**Design a 48 V system with sixteen 12 V PV modules**






## Solution 4



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CLIMATE TECHNOLOGY CENTRE & NETWORK SOLAR PHOTOVOLTAIC ACCREDITATION TRAINING PROGRAM

Presented by: Andy Walker and Kari Burman
National Renewable Energy Laboratory
November 6th -10th, 2017



# PV Controllers

## Module Overview

- **Features of Battery Charge Controller**
- **Charge Controller Specifications**
- **PV and Battery Charge Controller Sizing**

## Features of PV Controllers

- Charge Controllers
  - Charge controllers are essential for all power systems that charge batteries, weather it is PV, wind, hydro or utility
  - Basic function of a controller is to prevent reverse current, overcharging or over discharging the batteries
  - PV charge controllers consistently monitor the battery voltage
- Block Reverse Current
  - When batteries are not being charged, they may have some loss of current through small discharge or reverse current.
  - Most controllers charge a battery through a semiconductor or diode which acts as a valve to pass current only one direction.
  - These are known as Shunt Controllers
- PV charge controllers prevent over charging
  - When the batteries are charged 100%, the controller will stop the current from the PV panels into the batteries.
  - If energy continues to be applied, the battery voltage gets too high, and water may leak out of some batteries
  - The battery will degrade rapidly and may overheat if overcharged.
  - May divert power to non-critical loads to prevent overcharging




## Features of PV Controllers

- Low Voltage Disconnect (LVD)
  - The deep-cycle batteries used with PV systems are designed to discharge to about 80% of their capacity.
  - If batteries discharge to 100%, they are damaged.
  - When a battery is discharging, the voltage drops.
  - The only way to prevent over discharge is to disconnect loads and to reconnect when the voltage has recovered.
  - The low voltage disconnect circuit will disconnect loads at a given set point ( typical set point might be 20% or 11.9 V on 12 V battery).
  - A typical LVD reset point is 13 volts to have the batteries recover substantially.
- Lights , Meters and Alarms
  - Charge controllers activate lights or buzzers to indicate low battery voltage.
  - Load timer may use clocks to time out loads, say for security lights.
  - May have an amp-hour meter to monitor the energy available
- Generator Start control
  - This option automatically turns on an auxiliary power source, such as a generator.

**12 Volt Battery Charge Condition**

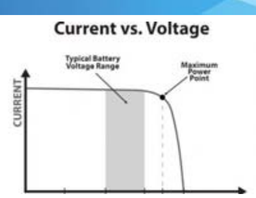
| Open Circuit Voltage | State of Charge |
|---|---|
| 12.65V | 100% |
| 12.58V | 90% |
| 12.55V | 80% |
| 12.48V | 70% |
| 12.40V | 60% |
| 12.32V | 50% |
| 12.24V | 40% |
| 12.10V | 30% |
| 11.90V | 20% |
| 11.70V | 10% |
| 11.30V | 0% |

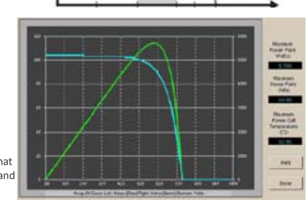


## Features of PV Controllers

- Maximum Power Point Tracking
  - Maximum Power Point Tracking (MPPT) is an algorithm that is included in some charge controllers to extract the maximum amount of power from PV modules.
  - The voltage at which a PV module can produce maximum power is called 'maximum power point' or 'peak power voltage.
  - The maximum power from a PV module varies with:
    - solar radiation
    - ambient temperature
    - solar cell temperature

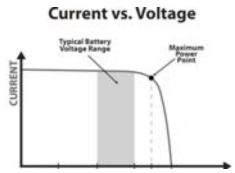
  Note: An array has higher voltage at colder temperatures.
  - MPPT allows the controller to track the maximum power point of the PV array throughout the day in order to deliver the maximum available solar energy to the batteries.
  - A MPPT is an electronic DC to DC converter that optimizes the match between the PV panels and the battery bank.

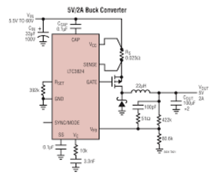


## Features of PV Controllers

- Voltage Step Down Controllers
  - The voltage step down feature in some MPPT controllers is new and allows a higher voltage array to be connected to a lower voltage battery bank.
  - Before Step Down DC-DC controllers were available a 12V battery would require a 12V array and a 12V standard charge controller.
  - Advantage of Step Down controllers:
    - Allows the design of a PV system at a higher voltage which uses smaller diameter wire (less current) from the array to controller.
    - Allows for PV array expansion without having to increase the size of the wire and conduit






## Features of PV Controllers

- Recommended Basic Features in Controllers
  - Indicator lights: To indicate when the batteries are fully charged or low or when Low voltage disconnects have shut down the loads.
  - Meters: Meters are used to monitor the system and display the status of the system on site or remotely.
  - Temperature Compensation: some controllers have a temperature sensor to automatically adjust charging voltage when batteries are above or below 25degrees C.
  - Low Voltage Disconnect (LVD): Automatically cuts off DC loads when battery discharges to a given set level.
  - Low Voltage alarm: Audible alarm when the state of charge (SOC) drops below a given set level.
  - Array Power diverter: Option to bypass excess array charging power to a non-critical loads.



## Module Overview

- **Features of Battery Charge Controller**
- **Charge Controller Specifications**
- **PV and Battery Charge Controller Sizing**

## PV Controller Specifications

- Specifying a Standard Controller:
  - Array Amps Isc: A Controller must be able to handle a PV array's short circuit current. Additionally the designer must multiply the module's Isc by 125% safety factor to estimate the minimum charge controller array amps.
  - DC System Voltage: All components must be wired to the same DC voltage.
  - Maximum DC Load Amps: For systems with DC loads, the charge controller must be sized to handle the max DC load current that will pass through the controller
- Specifying a Controller with MPPT or Step Down Features:
  - Battery Voltage: Controller output voltage rating = nominal battery voltage
  - Maximum Array Voltage: A controller will have a voltage range for the allowable voltage from the PV array. The maximum voltage rating for the controller should not be exceeded by the PV array.
  - Maximum Output Amps: A controller must be capable of handling the maximum output amps going to the battery. For MPPT features the input amps to the controller must be lower than the rated output amps to the battery. Note: if the designed input amps to the controller = the controller's rated output current there is no room to convert the excess voltage to current.



## Module Overview

- **Features of Battery Charge Controller**
- **Charge Controller Specifications**
- **PV and Battery Charge Controller Sizing**



## PV Controller Sizing Exercise

- Use Controller Sizing Table
  - A client wishes to simultaneously power the following items with three PV modules wired in parallel:
  - Three 12V DC lights (30 watts) and
  - 12V DC television (14 Watts)
  - PV modules have peak current of 2.95 A and Isc = 3.28A
  - Calculate the maximum array output Amps used to size a controller

## Controller Sizing Exercise

**Controller Sizing Worksheet**

| Module Short Circuit Current (Isc) | x | Modules in Parallel | x | 1.25 | = | Array Short Circuit Amps (Isc) | Controller Array Amps | Listed Desired Features |
|---|---|---|---|---|---|---|---|---|
| | x | | x | 1.25 | = | | | |

| DC Total Connected Watts (W) | / | DC System Voltage | = | Maximum DC Load Amps | Controller Load Amps |
|---|---|---|---|---|---|
| | / | | = | | |

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## Controller Sizing Exercise

**Answer:**

**Controller Sizing Worksheet**

| Module Short Circuit Current (Isc) | x | Modules in Parallel | x | 1.25 | = | Array Short Circuit Amps (Isc) | Controller Array Amps | Listed Desired Features |
|---|---|---|---|---|---|---|---|---|
| 3.28 | x | 3 | x | 1.25 | = | 12.3 | 12.3 | |

| DC Total Connected Watts (W) | / | DC System Voltage | = | Maximum DC Load Amps | Controller Load Amps |
|---|---|---|---|---|---|
| 104 | / | 12 | = | 8.67 | 9 |

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**Thank You**

**Please Provide Feedback**

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# CLIMATE TECHNOLOGY CENTRE & NETWORK SOLAR PHOTOVOLTAIC ACCREDITATION TRAINING PROGRAM

**Andy Walker and Kari Burman**
**National Renewable Energy Laboratory**
November 6th -10th , 2017



## PV System Sizing

## Module Overview

- **Introduction**
- **PV System Sizing**

## Introduction

- Stand-alone photovoltaic systems are low maintenance, versatile solutions to the electric power needs of any off-grid application.
- They provide electric power for telecommunication stations, water pumping systems, street lights, remote homes and much more throughout the entire world.
- These stand-alone photovoltaic system have proven to be reliable and cost-effective alternative to conventional power.
- Sizing a photovoltaic system is not particularly complex.
- This module illustrates six step process to size a system based on the user's project needs, goals, and budget.



## Introduction

- Sizing a photovoltaic system include the following steps:
  1. Estimating electric loads
  2. Sizing and specifying batteries
  3. Sizing and specifying an array
  4. Specifying a controller
  5. Sizing and specifying an inverter
  6. Sizing system wiring



## Module Overview

- **Introduction**
- **PV System Sizing**

## PV System Sizing

**Follow PV System Sizing Worksheet**



## Step 1: Estimate Electric Load

**Electrical Appliance Typical Energy Consumption Table**

| Appliance | Consumption (Watts) | Appliance | Consumption (Watts) |
|---|---|---|---|
| Toaster | 800-1500 | Television - 25" color | 150 |
| Popcorn Popper | 250 | Television - 19" color | 70 |
| Blender | 300 | Television - 12" black and white | 20 |
| Electric cooker with oven | 1000-2500 | VCR | 40 |
| Microwave | 600-1500 | CD player | 35 |
| Waffle Iron | 1200 | Stereo | 20 |
| Hot Plate | 1200 | Clock radio | 1 |
| Frying Pan | 1200 | AM/FM auto cassette player | 8 |
| Dishwasher | 1200-1500 | Satellite dish | 30 |
| Sink waste disposal | 450 | CB radio | 5 |
| Washing machine - Automatic | 500 | Electric clock | 3 |
| Washing machine - Manual | 300 | Radiotelephone - Receiving mode | 5 |
| Vacuum cleaner - High Power | 1600-2000 | Radiotelephone - Transmitting mode | 40-150 |
| Vacuum cleaner - Upright | 200-700 | Lights:100 watt incandescent | 100 |
| Vacuum cleaner - Hand | 100 | Lights:25 watt compact fluorescent | 28 |
| Sewing machine | 100 | Lights:50 watt DC incandescent | 50 |
| Iron | 1000 | Lights:40 watt DC halogen | 40 |
| Clothes dryer - Electric | 4000 | Lights:20 watt DC compact flourescent | 22 |
| Clothes dryer - Gas heated | 300-400 | Lights: Compact fluorescent 40 watt Incandescent equivalent | 11 |
| Heater - Electric water heater | 4000 | Lights: Compact fluorescent 60 watt Incandescent equivalent | 16 |
| Heater - Engine block | 150-1000 | Lights: Compact fluorescent 75 watt Incandescent equivalent | 20 |
| Heater - Portable | 1500 | Lights: Compact fluorescent 100 watt Incandescent equivalent | 30 |
| Heater - Waterbed | 400 | Electric mower | 1500 |
| Heater - Stock tank | 100 | Hedge trimmer | 450 |
| Furnace blower | 300-1000 | Weed eater | 500 |



## Step 1: Estimate Electric Load

**Load Estimation Worksheet**

| Sr.No | Individual Loads | Quantity | X | Volts | X | Current | equals to (=) | Watts | | X | Use | X | Use | ÷ | 7 | equals to (=) | Watt hours | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | AC | DC | | hrs/day | | days/wk | | days | | AC | DC |
| 1 | | | | | | | | | | | | | | | 7 | | | |
| 2 | | | | | | | | | | | | | | | 7 | | | |
| 3 | | | | | | | | | | | | | | | 7 | | | |
| 4 | | | | | | | | | | | | | | | 7 | | | |
| 5 | | | | | | | | | | | | | | | 7 | | | |
| 6 | | | | | | | | | | | | | | | 7 | | | |
| 7 | | | | | | | | | | | | | | | 7 | | | |
| 8 | | | | | | | | | | | | | | | 7 | | | |
| 9 | | | | | | | | | | | | | | | 7 | | | |
| 10 | | | | | | | | | | | | | | | 7 | | | |
| 11 | | | | | | | | | | | | | | | 7 | | | |
| 12 | | | | | | | | | | | | | | | 7 | | | |
| 13 | | | | | | | | | | | | | | | 7 | | | |
| 14 | | | | | | | | | | | | | | | 7 | | | |
| 15 | | | | | | | | | | | | | | | 7 | | | |
| 16 | | | | | | | | | | | | | | | 7 | | | |
| 17 | | | | | | | | | | | | | | | 7 | | | |
| 18 | | | | | | | | | | | | | | | 7 | | | |
| 19 | | | | | | | | | | | | | | | 7 | | | |
| 20 | | | | | | | | | | | | | | | 7 | | | |
| 21 | | | | | | | | | | | | | | | 7 | | | |
| 22 | | | | | | | | | | | | | | | 7 | | | |
| 23 | | | | | | | | | | | | | | | 7 | | | |

**AC Total Connected Watts = ___** **AC Average Daily load = ___**

**DC Total Connected Watts = ___** **DC Average Daily load = ___**

## Step 2: Sizing and specifying batteries

- Use Battery Sizing Worksheet

  Inputs:

  - Inverter efficiency, typically between 85-95%.
  - Assume wiring efficiency to be 98%

  Calculate the Average A-H/day from Load calculations

  $$\frac{\text{AC Loads (Wh/day)}}{\text{(Inverter Eff)x(wire Eff)}} + \text{DC Load (Wh/day)} = \text{Total Wh/d}$$

  $$\frac{\text{Total Wh/d}}{\text{DC System Voltage}} = \text{A-H/day}$$



## Step 2: Sizing and specifying batteries

- Battery sizing (continued)

  Choose a particular battery and get the A-H capacity off the label from the manufacturer.

  $$\frac{\text{(A-H/day) x Days of Autonomy}}{\text{(Discharge limit) x (Bat. A-H capacity)}} = \text{Batteries in Parallel}$$

  $$\frac{\text{DC System Voltage (V)}}{\text{Battery Voltage (V)}} = \text{Batteries in Series}$$

  **Batteries in Series x Batteries in Parallel = Total number of Batteries**



## Step 2: Sizing and specifying batteries

**Battery Sizing Worksheet**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| AC Average Daily Load (Watt-hours/day) | ÷ | Efficiency (Inverter efficiency x Wiring efficiency) | + | DC Average Daily Load (Watt-hours/day) | ÷ | DC System Voltage (V) | = | Average Amp-hour/day (Ah) |
| [( | ÷ | ) | + | ] | ÷ | | = | |
| | | | | | | | | |
| Average Amp-hour/day (Ah) | x | Days of Autonomy | ÷ | Discharge Limit | ÷ | Battery Capacity (Ah) | = | Batteries in Parallel |
| | x | | ÷ | | ÷ | | = | |
| | | | | | | | | |
| DC System Voltage (V) | ÷ | Battery Voltage (V) | = | Batteries in Series | x | Batteries in Parallel | = | Total Number Batteries |
| | / | | = | | x | | = | |

## Step 3: Sizing an Array

- Use PV Array Sizing Worksheet

  Inputs:
  - Battery efficiency from selected batteries in step 2, typically 85%
  - Assume wiring efficiency to be 98% (typical for voltage drop of 2%)
  - Peak Sun-Hr a day

  Calculate the Peak Amps for the PV Array

$$\frac{\text{Avg A-H per day}}{(\text{Battery Eff x wiring Eff}) \times (\text{Peak Sun-Hr a day})} = \text{Peak Amps for Array}$$



## Step 3: Sizing an Array

- Use PV Array Sizing Worksheet (continued)

$$\frac{\text{Array Peak Amps (I peak)}}{\text{Peak Amps of Module (Imax)}} = \text{Number of module in Parallel}$$

$$\frac{\text{DC System Voltage}}{\text{Nominal Module Voltage}} = \text{Number of module in Series}$$

Number of Modules in Series x Modules in Parallel = Total number of Modules



## Step 3: Sizing an Array

**Array Sizing Worksheet**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Average Amp-hour/day (Ah) | ÷ | Efficiency (Battery efficiency x Wiring efficiency) | ÷ | Peak Sun Hrs/day | = | Array Peak Amps | | |
| ( | ÷ | ) | ÷ | | = | | | |
| | | | | | | | | |
| Array Peak Amps | ÷ | Peak Amps per module | = | Modules in Parallel | | Module short circuit current (Isc) | | |
| | | | | | | | | |
| | | | | | | | | |
| DC System Voltage (V) | ÷ | Nominal Module Voltage (V) | = | Moudles in Series | x | Modules in Parallel | = | Total Modules |
| | ÷ | | = | | x | | = | |

## Step 4: Sizing Charge Controller

- Use Controller Sizing Worksheet

  Inputs:
  - Isc of PV modules
  - Modules in parallel

  Calculate the total array short circuit current (Isc total)

  (Isc module) x (modules in parallel) x 1.25 = **Array Isc**

  Controller amps (I ) > Array Isc



## Step 4: Sizing Charge Controller

- Use Controller Sizing Worksheet

  $\frac{\text{DC Load ( W)}}{\text{DC System Voltage (V)}}$ = Max DC Load Current (I)

  Controller DC current rating (I) > Max DC Load Current (I)



## Step 4: Sizing Charge Controller

**Controller Sizing Worksheet**

| Module Short Circuit Current (Isc) | x | Modules in Parallel | x | 1.25 | = | Array Short Circuit Amps (Isc) | Controller Array Amps | Listed Desired Features |
|---|---|---|---|---|---|---|---|---|
| | x | | x | 1.25 | = | | | |
| | | | | | | | | |
| DC Total Connected Watts (W) | ÷ | DC System Voltage (V) | = | Maximum DC Load Amps | | Controller Load Amps | | |
| | ÷ | | = | | | | | |

## Step 5: Sizing Inverter

- Use Inverter Sizing Worksheet

  Inputs:
  - AC Total Connected Power (W)
  - DC System Voltage

  Calculate the AC total connected load (W) from the load worksheet

  Inverter must be rated for at least the AC total connected load and at the DC system Voltage.

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## Step 5: Sizing Inverter

- Use Inverter Sizing Worksheet

  Choose an inverter that can handle the required AC Voltage and frequency being used. For Tanzania the is 230 V at 50 Hz.

  Surge Capacity
  Multiply the peak wattage by 3 to get an estimated surge (watts)

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## Step 5: Sizing Inverter

**Inverter Sizing Worksheet**

| AC Total Connected Watts (Watts) | DC System Voltage | Estimated Surge Wattage | Listed Desired Features |
|---|---|---|---|
| | | | |

*As a rough "rule of thumb" minimum surge requirements for stand-alone inverters of a load can be calculated by multiplying the required watts by 3.

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## CLIMATE TECHNOLOGY CENTRE & NETWORK SOLAR PHOTOVOLTAIC ACCREDITATION TRAINING PROGRAM


**Presented by: Andy Walker and Kari Burman**
**National Renewable Energy Laboratory**


November 6th -10th, 2017



# Commissioning PV Stand-Alone Systems

## Module Overview

- **Introduction to Commissioning**
- **Commissioning PV Systems**
- **Battery Commissioning**
- **Commissioning Report**
- **PV Operation & Maintenance Plans**
- **Theft Prevention**

## Introduction to Commissioning

- Commissioning Requirements
  - Verify that the plant is structurally and electrically safe.
  - Verify that all the components (panels, inverters, etc.) comply with standards and specifications.
  - Update documents to "as built" conditions.
  - Perform testing of all the components and as a complete system.
  - Prepare Commissioning Report.



## Introduction to Commissioning

- Benefits of Commissioning
  - Safely put the plant into operation.
  - Ensure plant performs as expected.
  - Increase efficiency and energy delivery (kWh/kW/year).
  - Decrease down-time (hours/year).
  - Extend system lifetime.
  - Reduce cost of O&M ($/kW/year).
  - Correct commissioning is required for warranty.



## Introduction to Commissioning

- Electrical Safety
  - Arc-flash protection (PV panels are energized whenever sun is shining).
  - Lock-out-tag-out.
- General Safety
  - Hardhat, safety vest, glasses, boots, no ties or scarves.
  - Sunscreen, sunglasses, hat.
  - Hand sanitizer (rodent and bird waste carries disease).
- Roof Safety
  - Fall Protection (harness, fall arrest system, guardrails).
  - Check for environmental conditions (windy, rain, snow, etc.).
  - Watch out for rusted stairs/ladders.
  - Don't let door or hatch to roof lock behind you.

## PV Performance: Standards Organizations

- UL - Underwriters Laboratories.
  *(Safety Certification, Insurance industry)*
- NFPA - National Fire Protection Association.
  *National Electric Code;*
  *(Fire Safety Testing)*
- ASTM - American Society for Testing and Materials.
  *(Performance Testing)*
- IEC - International Electrotechnical Commission.
  (*Compliance and Performance Testing)*

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## PV Performance: Standards Organizations

- IEEE - Institute of Electrical and Electronic Engineers.
  (*Performance Testing)*
- TUV Rheinland - European.
  (*Safety Certification)*
- CE - European Conformity.
  *(Performance Certification)*
- CSPC – Consumer Product Safety Commission.
  *(Safety certification)*

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## Standards Related to PV System Commissioning

| | |
|---|---|
| AS 4509 | Stand-alone power systems -Safety and installation , Design, and maintenance |
| IEEE 937 | IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems |
| IEEE 1262 | Recommended Practice for PV Module Qualification PV Module Performance and Reliability |
| IEEE 1361 | IEEE Guide for Selecting, Charging, Testing, and Evaluating Lead-Acid Batteries Used in Stand-Alone Photovoltaic (PV) Systems |
| IEEE 1547.4 | Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems |
| IEEE 1526 | Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems |
| IEEE 1561 | Guide for Optimizing the Performance and Life of Lead-Acid Batteries in Remote Hybrid Power Systems |
| IEEE 1562 | Guide for Array and Battery Sizing in Stand-Alone Photovoltaic (PV) Systems |
| IEEE 1661 | Guide for Test and Evaluation of Lead-Acid Batteries Used in Photovoltaic (PV) Hybrid Power Systems |

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## PV System Commissioning

- IEC 62446-Grid connected photovoltaic systems
  - Minimum requirements for system documentation, commissioning tests and inspection include:
    - Physical inspection, document as-built condition.
    - PV array testing.
    - Complete System testing.
    - Functional tests (inverter start/stop sequence, open AC isolator shutdown, start again on re-close).

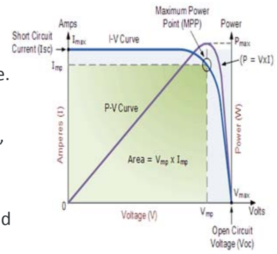


## Tools for PV Commissioning

- Tools suggested for Commissioning
  - Briefing literature package for building owner.
  - Data collection sheets and note pad.
  - Plans/Image of PV or solar thermal array to mark up.
  - Pyrometer.
  - Temperature sensors (air and PV module).
  - Voltage/Current meter.
  - Flashlight, Digital Camera, Backpack.
  - Optional: PV circuit I-V curve tracer.

## PV System Commissioning

- Different Tests of PV Circuits
  - Check fuses in Combiner Boxes and Inverter
    - Ohm-meter, seek zero ohms across removed fuse.
  - Open Circuit Voltage
    - Voltage meter, at inverter, combiner boxes, module strings.
    - Compare to each other and to expected value calculated from temperature.






## PV System Commissioning

- Different Tests of PV Circuits
  - Short Circuit Current
    - Clamp-on Current meter, at inverter, combiner boxes, module strings.
    - Compare to each other, and to expected value calculated from solar radiation.
  - Operating Voltage
  - Operating Current
  - I-V Curve Trace (optional)
    - Trace entire current-voltage curve by charging a capacitor.



## PV System Commissioning

- Continuity Check
  - Checking for continuity looks for:
    - Broken wires, short circuits, switch operation.
    - Ohm-meter is used to check circuit for resistance when power is off.
    - Short circuits have very low resistance.
    - Open circuits have very high resistance (infinite).
  - Procedure:
    - Turn power off.
    - Disconnect one conductor in the circuit and set ohm meter to high resistance setting.
    - Conventional color: **Black** lead connected to common (-) and **Red** lead to positive (+).
    - Measure the resistance with the leads connected together. Meter should read zero or buzz.
    - Now test the circuit with one lead at the disconnected point and other lead at opposite end of the circuit.
    - A closed circuit will read very low resistance for continuity.

## PV System Commissioning

Measure Voltage and Check for Polarity

- Procedure
  - Select the type of voltage to measure (AC or DC):
    - Set range on Voltmeter to correct scale.
    - For DC circuit connect black test lead to negative (-) side and red lead to positive (+).
    - For AC circuit connect black lead to common ground or neutral and red lead to hot side.
  - Turn the power ON
    - Read the voltage on the proper scale of the meter.
  - Check for polarity
    - If the meter reads a positive value then the polarity is correct.
    - If the meter needle moves backwards then the Polarity of the circuit is reversed.



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## Battery Commissioning

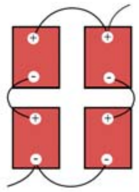
- Things to watch for in a storage system designs
  - System design will specify the amount of storage.
  - Typically only 1-2 strings of batteries is best, more than 3 leads to imbalances between the strings and reduced storage capacity and lifecycle throughput.
  - Storage type and technology driven by upfront cost, maintenance cost, environmental considerations, and expected life.
  - Never mix batteries of different manufacture, age, or health.

## Battery Commissioning

Typically only 1-2 strings of batteries is best, more than 3 leads to imbalances between the strings and reduced storage capacity and lifecycle throughput.

**EXAMPLE:**

Battery Voltage = 6V each
Battery Capacity = 400 AH each
System Voltage = 12V
System Capacity = 800 AH



**EXAMPLE:**



## Battery Commissioning

Typically only 1-2 strings of batteries is best, more than 3 leads to imbalances between the strings and reduced storage capacity and lifecycle throughput.

Twenty-four (24) 2 Volt models at 2430 AH each = 2430 AH at 48 Volts

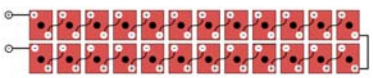


FIGURE 3:
Single Series String
+ "Best Option"

Two (2) strings of eight (8) 6 Volt 428 AH each = 2 x 428 AH at 48 Volts = 856 AH at 48 Volts

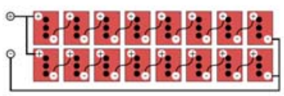


FIGURE 4:
Two Parallel Strings.
Series/Parallel

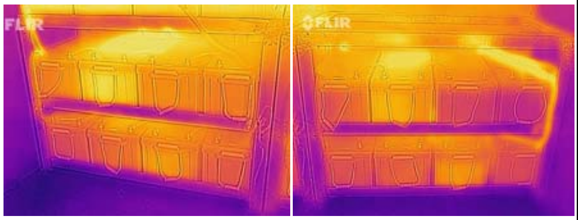


## Battery Commissioning

- Adding storage to an existing bank of batteries will quickly deplete the new batteries to the level of the existing batteries.
- Mix of different manufacture and health batteries
  - Causes weakest string to drive charge/discharge cycles, reducing total battery bank capacity and life.

## Battery Commissioning

**Battery Internal Resistance Illustration**






## Battery Commissioning

- Procedure for Battery Commissioning
  - Ensure all batteries are fully charged and filled with electrolyte (if flooded cells).
  - Ensure charge controller is configured appropriately
    - Bulk and absorption
    - Float
    - Equalization
    - Low voltage disconnect



## Battery Commissioning

**FLOODED BATTERY CHARGING PARAMETERS**

| Regular Cycling / PSOC Recovery | | 0°C (32°F) | 10°C (50°F) | 20°C (68°F) | 25°C (77°F) | 30°C (86°F) | 40°C (104°F) |
|---|---|---|---|---|---|---|---|
| 2V | BULK & ABSORPTION CHARGE VOLTAGE | 2.63 V | 2.55 V | 2.53 V | 2.50 V | 2.48 V | 2.41 V |
| | FLOAT VOLTAGE | 2.38 V | 2.30 V | 2.28 V | 2.25 V | 2.23 V | 2.16 V |
| | EQUALIZATION VOLTAGE | | | | 2.60 - 2.65 V | | |
| 12V | BULK & ABSORPTION CHARGE VOLTAGE | 15.75 V | 15.30 V | 15.15 V | 15.00 V | 14.85 V | 14.45 V |
| | FLOAT VOLTAGE | 14.25 V | 13.80 V | 13.65 V | 13.50 V | 13.35 V | 12.95 V |
| | EQUALIZATION VOLTAGE | | | | 15.6 - 15.9 V | | |
| 24V | BULK & ABSORPTION CHARGE VOLTAGE | 31.50 V | 30.60 V | 30.30 V | 30.00 V | 29.70 V | 28.90 V |
| | FLOAT VOLTAGE | 28.50 V | 27.60 V | 27.30 V | 27.00 V | 26.70 V | 27.50 V |
| | EQUALIZATION VOLTAGE | | | | 31.2 - 31.8 V | | |
| 48V | BULK & ABSORPTION CHARGE VOLTAGE | 63.00 V | 61.20 V | 60.60 V | 60.00 V | 59.40 V | 57.80 V |
| | FLOAT VOLTAGE | 57.00 V | 55.50 V | 54.60 V | 54.00 V | 53.40 V | 55.00 V |
| | EQUALIZATION VOLTAGE | | | | 62.4 - 63.6 V | | |

TABLE 2 (a): Flooded Charging Parameters - Regular Cycling/PSOC Recovery

## Battery Commissioning

- Checking electrolyte levels in flooded cells.
- Checking string current and voltage.
- Inspecting and cleaning terminals.
- Check current imbalance of parallel strings
  - DC current clamp
- IR cameras can be very useful.
- If possible, conduct load tests.



## Battery Commissioning

- How to Avoid Short Circuits in Battery Wiring
  - Never touch positive and negative terminals at one time or let a metal object touch both at once.
  - In series-parallel battery layout, never connect more than 2 cables to any single battery terminal.
  - Do not reverse connect the charge controller wires to the solar panel or battery.
  - Avoid battery banks with excessive parallel connections. If a battery fails, large currents can discharge from one parallel string to another causing battery cables to melt.



## Battery Commissioning

**Check current imbalance of parallel strings.**

## Battery Commissioning

**Corrosion due to lack of maintenance and outgassing.**



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## Commissioning Report

- Documentation of System
  - As-built drawings
  - O&M Manuals, equipment datasheets, etc.
- Verification Certificate
  - Certifies that commissioning was conducted according to standard
  - Needed for financing and warranty
- PV System Inspection Report
  - Compliance with codes and standards
- PV Array and Battery Test Report
  - Details of PV Array and Batteries
  - Results of polarity, insulation, grounding, voltage and current tests
- Complete System Performance Test
  - Comparison of actual performance with estimate based on environmental conditions

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## Operation and Maintenance (O&M)

- Perform testing of components and complete system
  - Many of the tests used in commissioning can be done periodically to check the operation of the system.
- Benefits of O&M Plans
  - Extend system lifetime; extend time period that the system delivers revenue.
  - Improve system availability; Reduce downtime; re-capture lost revenue.
  - Reduce cost of providing O&M; directly affect project cost
  - Efficiency and degradation in performance; maintain energy delivery and associated revenue.
  - Predictability of performance and O&M costs; reduce insurance and financing costs by reducing uncertainty related to lifetime, performance, and O&M costs.



## Operation and Maintenance

**Corrosion of connection of dis-similar metals.**

Photo by Andy Walker

## Operation and Maintenance

**Replace PV modules with failed ribbon contacts to module junction box.**

Photo by Andy Walker



## Operation and Maintenance

- PV Array Cleaning
  - Adapt cleaning schedule to:
    - Seasonal dirt, pollen, birds, etc.
    - Rain
  - Do not clean when hot (breakage).
  - High Volume, low pressure spray.
  - Special soap or vinegar solution (2 tbs/gallon).
  - Spray or brush.
  - Generally around 5% improvement over rain-only.
  - Sources requiring cleaning: diesel soot; construction or environmental dust; pollen; bird droppings, etc.



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## Theft Prevention

- PV Array
  - Place PV panels up high and/or in a fenced area.
  - If panels are in reach, one may want to strip screws so that they can't be removed easily.
- Storage Room
  - If possible have batteries and controls in a locked, **vented** area as shown in the picture.

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## Thank You

**Please Provide Feedback**

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# Checklists

Module ID:________________ Inspector: ________________ Date: __________

## CHECKLIST: New Module

| COMPONENT | DEFECT | | Defect Present? No | Yes | If Yes, Score | Safety issue? |
|---|---|---|---|---|---|---|
| **1. Label** | 1.1 | Missing | | | | |
| | 1.2 | Poorly attached | | | | |
| | 1.3 | Information is missing | | | | |
| | 1.4 | Incorrect spelling | | | | |
| **2. Backsheet** | 2.1 | Delamination | | | | |
| **3. Junction Box** | 3.1 | Faulty electrical connection | | | | |
| | 3.2 | Cracks/breaks/gaps in housing | | | | |
| | 3.3 | Sealant failure | | | | |
| | 3.4 | Electrical polarity not indicated | | | | |
| **4. Wiring** | 4.1 | Wire(s) missing or poorly attached | | | | |
| | 4.2 | Too short and/or too thin | | | | |
| **5. Frame** | 5.1 | Damaged | | | | |
| | 5.2 | Adhesive/sealant failure | | | | |
| **6. Front Glass** | 6.1 | Cracking | | | | |
| | 6.2 | Scratches | | | | |
| **7. Encapsulation** | 7.1 | Delamination | | | | |
| **8. Cells** | 8.1 | Fake | | | | |
| | 8.2 | Dummy pieces disguising missing material | | | | |
| | 8.3 | Cracks | | | | |
| | 8.4 | Partially covered | | | | |
| | 8.5 | Scratches | | | | |
| | 8.6 | Differently sized | | | | |
| | 8.7 | Edge chips | | | | |
| | 8.8 | All cells very shiny | | | | |
| **9. Cell Metallization** | 9.1 | Fingers not connected to busbar | | | | |
| | 9.2 | Not the same pattern on all cells | | | | |
| | 9.3 | Fingers off of edge of corner of cells | | | | |
| **10. Cell Interconnection** | 10.1 | Interconnection is discontinuous | | | | |
| | 10.2 | Cells connected in parallel (counterfeit) | | | | |
| | 10.3 | Poorly aligned and/or soldered | | | | |
| | 10.4 | Cells connected in parallel (real cells) | | | | |
| Defects are present suggesting module is used rather than new | | | | | | |
| **SUMMARY** Indicate if any defects and safety issues are present and sum score | | | | | | |

**ACCEPT:** ☐ **REJECT:** ☐

Module ID:________________ Inspector: ________________ Date: _________

## CHECKLIST: Used Module

| COMPONENT | DEFECT | | Defect Present? No | Yes | If Yes, Score | Safety issue? |
|---|---|---|---|---|---|---|
| 1. Label | See New Module Checklist | | | | | |
| 2. Backsheet | 2.2 | Burn marks | | | | |
| | 2.3 | Discolouration | | | | |
| 3. Junction Box | See New Module Checklist | | | | | |
| 4. Wiring | 4.3 | Cracks or exposed metal | | | | |
| 5. Frame | See New Module Checklist | | | | | |
| 6. Front Glass | See New Module Checklist | | | | | |
| 7. Encapsulation | 7.2 | Discolouration | | | | |
| 8. Cells | 8.9 | "Snail trails" | | | | |
| | 8.10 | Shiny locally/inconsistent colour | | | | |
| 9. Cell Metallization | See New Module Checklist | | | | | |
| 10. Cell Interconnection | See New Module Checklist | | | | | |
| SUMMARY<br>Indicate if any defects and safety issues are present and sum score | | | | | | |

# Annex B
(normative)

## Catalogue of defects: new modules

### B.1 LABEL

Provides important product information. Adhered to the rear of a module by the module manufacturer.

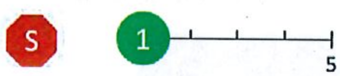
#### B.1.1 Missing

IEC

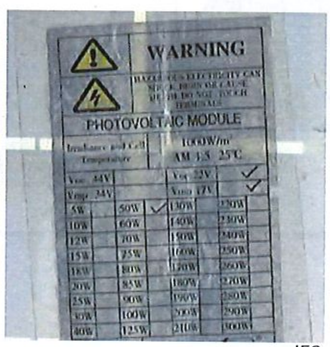
**Description:** A label shall be present. This may be unlikely if the panel is small (<5 W).

**Why it is important:** Lack of label implies sub-standard manufacture. Lack of this information is a potential safety issue. Label information is needed to properly install and operate the panel.

**Severity:**




#### B.1.2 Poorly attached

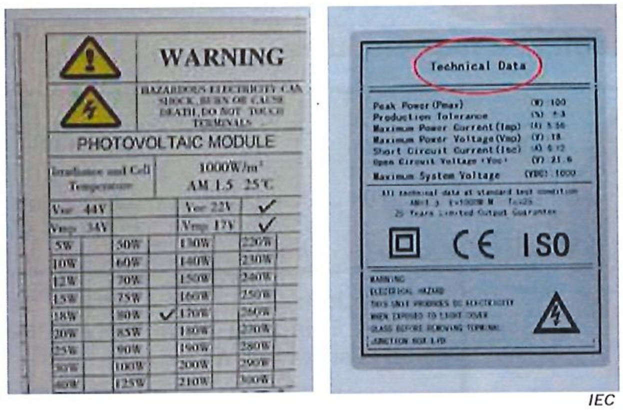

IEC

**Description:** Label should be made of material that resists water or light damage. Label should not be peeling or bubbling. Label should be permanently adhered (example at right uses clear tape overtop of a poorly affixed label).

**Why it is important:** Label needs to provide panel information for the duration of the panel lifetime. Lack of this information is a potential safety issue as described above.

**Severity:**

## B.1.3 Information is missing



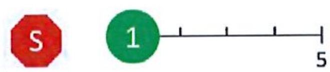

*IEC*

Label on left gives no current data. Label on right gives no manufacturer data. Neither gives model or serial #.

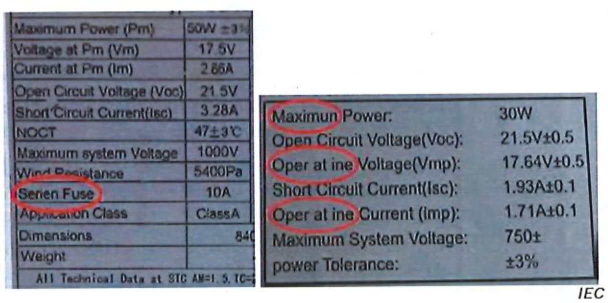
**Description:** Label should give the following: maximum power, current and voltage at maximum power, short-circuit current, open-circuit voltage, maximum system voltage, manufacturer name, model #, serial # (sometimes on a small label on the front of the module, can be a barcode). High quality products will have marking symbols from UL, IEC or TUV.

**Why it is important:** Data is needed to properly install, operate and maintain equipment. Lack of this information is a potential safety issue.

**Severity:**




## B.1.4 Incorrect spelling




*IEC*

**Description:** Words should be spelt correctly in whatever language is used.

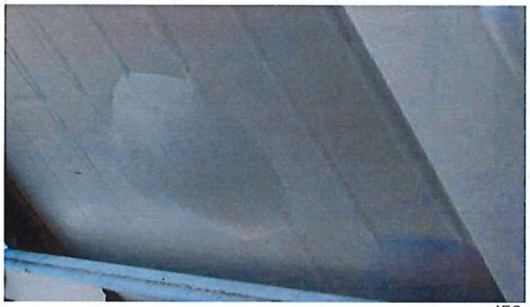
**Why it is important:** Does not affect performance, reliability or safety, but is an indicator of the lack of professionalism of the manufacturer.

**Severity:**

## B.2 BACKSHEET

Back substrate of module. Protects module interior from the elements

### B.2.1 Delamination



*IEC* [3]

**Description:** Backsheet not well laminated to module. Surface is bubbled or peeling.

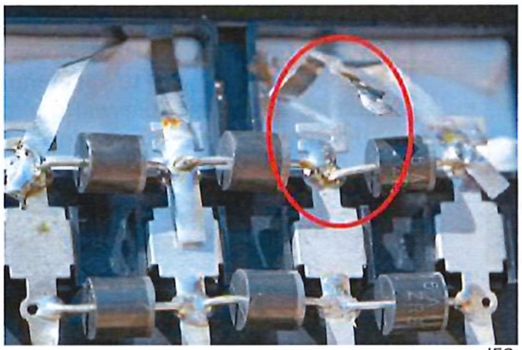
**Why it is important:** Bubbles are space for moisture to accumulate. Moisture in the module will decrease performance and affect long term reliability.

**Severity:**

## B.3 JUNCTION BOX

Electrical enclosure on the rear of the module where external wires connect to the internal tabbing ribbon. The junction box also contains the diode(s).

### B.3.1 Faulty electrical connection



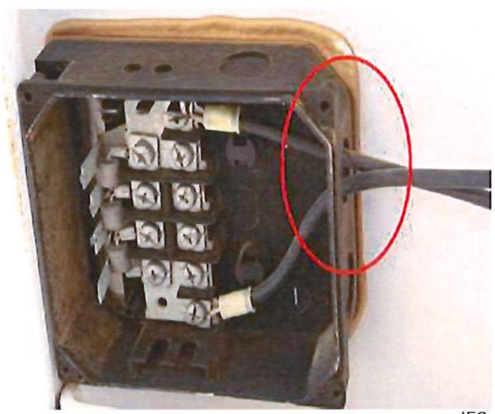
IEC

**Description:** Broken solder joints, broken wire or tabbing ribbon.

**Why it is important:** Broken electrical contacts can cause module failure.

**Severity:**


### B.3.2 Cracks/breaks/gaps in housing

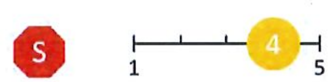


IEC

**Description:** Cracks in the housing, missing a continuous seal for the lid or around the wires. Possibility of water ingress.

**Why it is important:** Accumulated moisture can cause short circuits or corrosion of the metal contacts, increasing the risk of melting or fire. The junction boxes on high quality modules will be permanently sealed to mitigate this risk.

**Severity:**



### B.3.3 Sealant failure

IEC

**Description:** Holes in the seal, brittle material (should feel rubbery with fingernail) or adhesion failure. Possibility of water ingress.

**Why it is important:** Accumulated moisture in the junction box can cause short circuits or corrosion of the metal contacts. Corrosion can increase the risk of melting or fire.

**Severity:** If the sealant is brittle but not yet failed then the severity should be 3. If means of water ingress is visible, the severity should be 4.

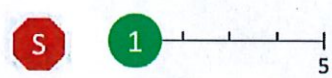

### B.3.4 Electrical polarity not indicated

Photo not available.

**Description:** Does not include a clear indication of the positive (+ or red) and negative (- or black) terminal of the module. Can be done with colour-coded wires instead of marked on junction box.

**Why it is important:** Improper wiring of the module could cause a safety risk or lead to equipment failure.

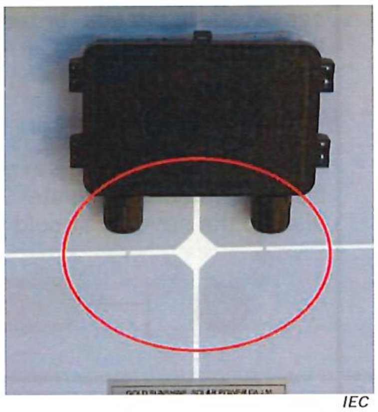
**Severity:**



## B.4 WIRING

The wires carry electricity from the module to the charge controller or inverter.

### B.4.1 Wire(s) missing or insecurely attached



IEC

**Description:** One or both wires are missing or loosely connected to the module.

**Why it is important:** Two wires are necessary to make a circuit. All new modules come with wires securely soldered to the tabbing ribbon and diodes inside the junction box.

**Severity:** If the product is intended to be sold directly to the consumer, then wires are required for module function and severity is a 5. If further assembly is intended, no defect is present.

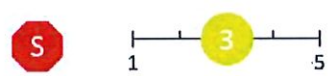

### B.4.2 Too short and/or too thin

IEC

**Description:** Wires are not long enough to make a robust (waterproof, electrically sound) connection to the rest of the system. Wires too short to reach past the frame of the module are likely a concern. Thickness requirements depend on module current. Examples of max ratings include: 2,9 A for 17 AWG (1,04 $mm^2$), 7,4 A for 13 AWG (2,63 $mm^2$), 15 A for 10 AWG (5,26 $mm^2$), 30 A for 7 AWG (10,55 $mm^2$)[4]

**Why it is important:** If wires are too thin they could melt or burn. For safety, all electrical connections shall take place inside a sealed enclosure, ex. junction box.

**Severity:**



## B.5 FRAME

The frame provides structure, rigidity, and mounting features. Sometimes non-metal for small modules (for example <10 W). Metal is needed for rigidity for large modules. If metal is used, electrical grounding is required.

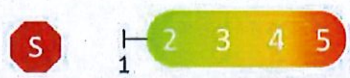
### B.5.1 Damaged

Photo not available

**Description:** Bent or cracked frame or the corners are not well aligned.

**Why it is important:** Loss of mechanical integrity, to the extent that the installation and/or operation of the module would be impaired. For example, may not be rigid enough to withstand handling during installation and/or high winds.

**Severity:** Low severity and no safety risk if dents/cracks in the frame are unlikely to affect mechanical integrity. High severity and safety risk if damage could lead to safety issues from cracked glass, poor electrical grounding, or if installation and/or operation are likely to be impaired.




### B.5.2 Adhesive/Sealant failure

IEC

**Description:** Discontinuous perimeter seal or loose attachment to module.

**Why it is important:** The adhesive is also a sealant that prevents water ingress into the module. Water in the module layers will decrease performance and affects long term reliability. Severity depends on atmospheric humidity.

**Severity:**

## B.6 FRONT GLASS

Provides structure to the module and protects the cells. Allows transmission of light to the cells.

### B.6.1 Cracking

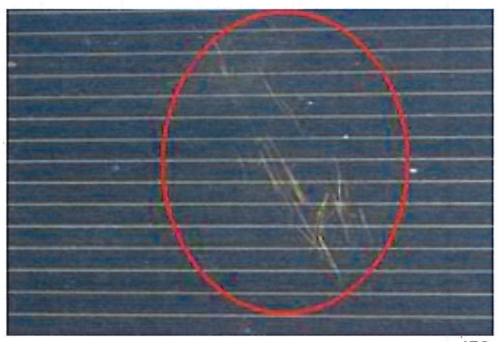
*IEC*

**Description:** Front glass is cracked locally or over the full area.

**Why it is important:** Module mechanical integrity is compromised. Possible path for water ingress. Mechanical and electrical safety issue.

**Severity:**


### B.6.2 Scratches



*IEC* [3]

**Description:** Permanent scratches on the surface of the front glass. Cannot be removed with cleaning.

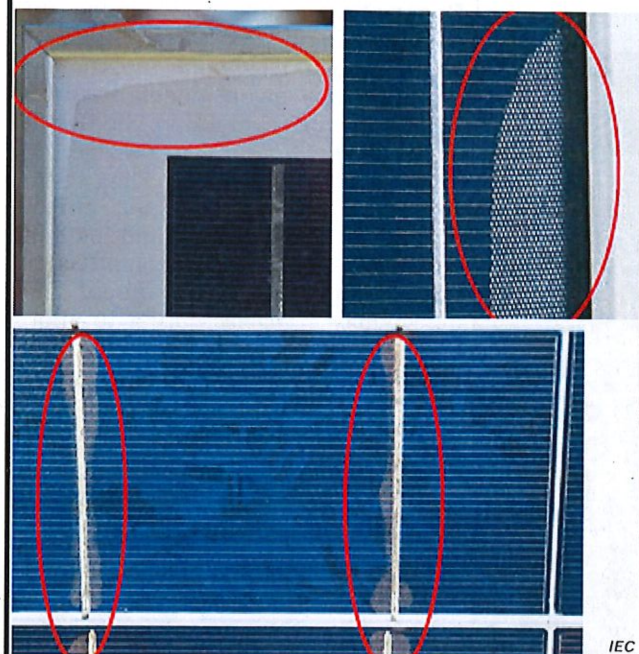
**Why it is important:** Transmission of light to the underlying cells, and therefore module power, is reduced.

**Severity:** Severity increases with affected area. A score of 5 should be given if 10 % or greater area is affected above any individual cell.

## B.7 ENCAPSULATION

Used to laminate module layers together. Transparent to allow light to reach cells.

### B.7.1 Delamination




**Description:** Any local separation of the layers between the front glass and the cells or the front glass and the backsheet. May appear continuous (top left) or spotted (right and bottom, due to texture of glass). Also could be bubbles. Most commonly appears around busbars or at the edge of the panel.

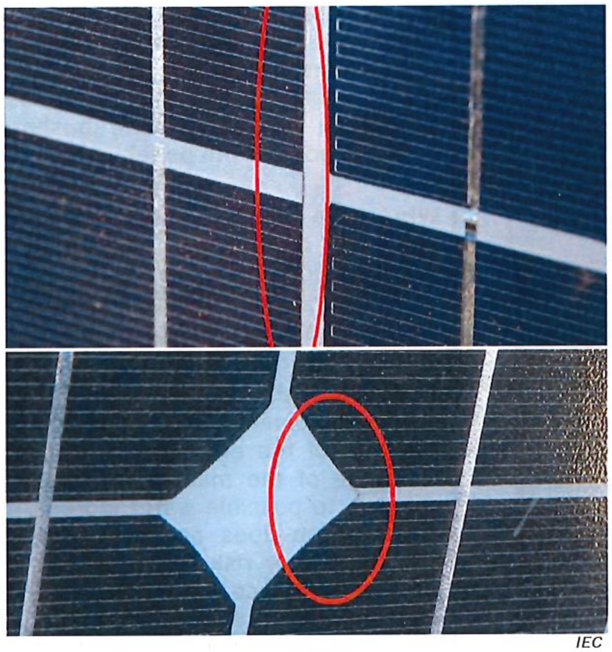
**Why it is important:** Can reduce structural integrity of the module. Transmission of light to the underlying cells, and therefore module current, is reduced.

**Severity:** Bubbles of delamination forming a continuous path between any part of the electrical circuit and the edge of the module is a safety risk due to possible water ingress. If delamination does not form such a path no safety risk exists. Influence on performance increases with affected area. A score of 5 is given if 10 % or greater of any individual cell's area is affected. A barely visible bubble would correspond to a score of 2.

## B.8 CELLS

Active component of the solar module. Electricity producing material converts sunlight to electricity.

### B.8.1 Fake



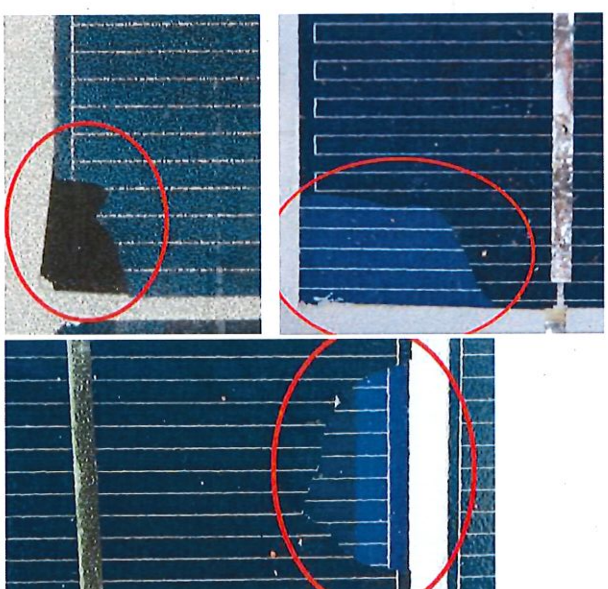
IEC

**Description:** Cells not made of active material, are instead printed paper images. Likely only a portion of the cells in a given module may be fake. May be evident in the white space between fake cells, where the edge of the paper can be seen. Examples of fake poly and mono-crystalline cells in top and bottom images respectively. If counterfeiters instead cut around each paper cell individually it will be harder to spot, and instead might be caught when inspecting the cell interconnection.

**Why it is important:** Purposely deceitful behaviour of manufacturer. The customer pays for fraudulent material that will not produce power.

**Severity:**


### B.8.2 Dummy pieces disguising missing material



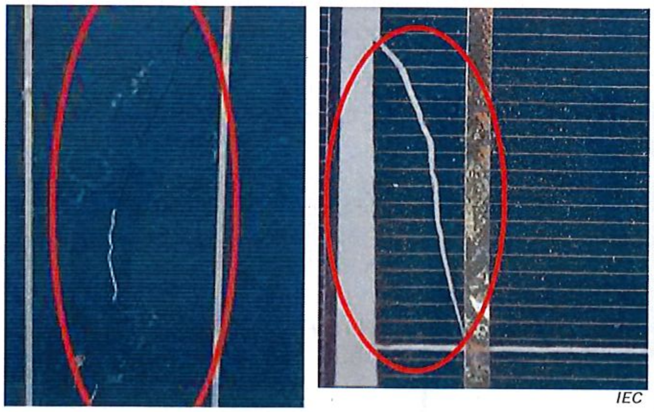
IEC

**Description:** Inactive material (dummy cell fragment or dark paper) has been placed behind an active cell in order to hide the fact that the cell has broken and has a piece missing.

**Why it is important:** Power output of the module limited by the missing material area. Purposely deceitful behaviour by the manufacturer. Indication of sub-standard cells and practices.

**Severity:** Power loss depends on size; a score of 5 should be given if 10 % or greater of any individual cell's area is missing. If the piece that is missing extends up to the edge of the metallization, a score of 3 is given. If the piece does not contain any metallization, this defect is instead an edge chip (see B.8.7).

### B.8.3 Cracks



IEC

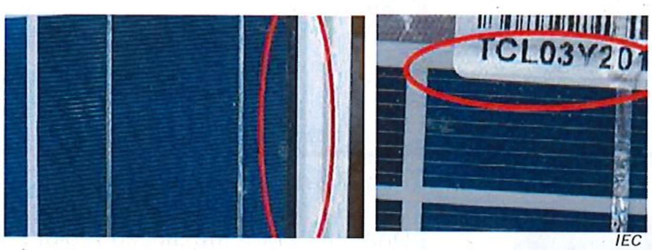
Left: large crack across the cell, but both halves are still connected to busbars. Right: smaller crack is actually more severe: a portion of the cell is no longer electrically connected.

**Description:** Cell is cracked. Crack may be partially or all the way across a cell. Partial cracks are likely to propagate over time. Depending on size cracks may be hard or impossible to spot. The white backsheet may be visible through large cracks.

**Why it is important:** Power output of the module limited if portions are removed from the electrical circuit. Visible cracks indicate poor mechanical handling by manufacturer; likely more cracks exist that are not currently visible.

**Severity:** Severity depends on affected area. A crack is considered a major defect (score of 5) when its propagation could remove more than 10 % of that cell's area from the electrical circuit [1]. The presence of a crack of any size that does not, or likely will not through its propagation, isolate any portion of the cell from the electrical circuit is a score of 2.


### B.8.4 Partially covered



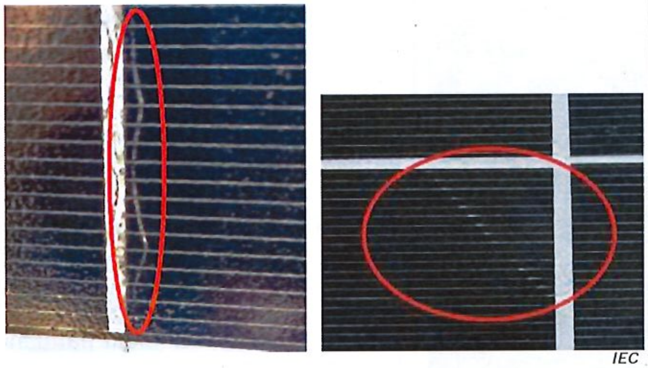

IEC

**Description:** A cell is partially and permanently covered, for example by the frame, a label, or by another cell.

**Why it is important:** Reduces active cell area. Current will be limited by the smallest cell area. An indicator of sub-standard manufacturer design and fabrication.

**Severity:** Influence on performance increases with affected area. A score of 5 is given if 10 % or greater of any individual cell's area is covered.

### B.8.5 Scratches

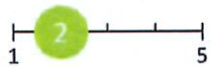


IEC

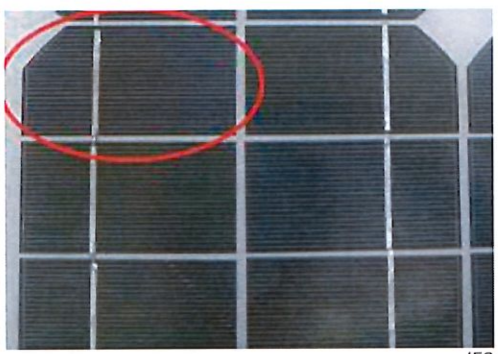
**Description:** Scratches in the surface of the cell from poor handling during module assembly. Often next to tabbing ribbon and caused by operator scraping the cell during soldering.

**Why it is important:** Deep scratches risk shorting the cell, but shallow scratches may have minimal impact.

**Severity:** Severity hard to evaluate visually.




### B.8.6 Differently sized



IEC

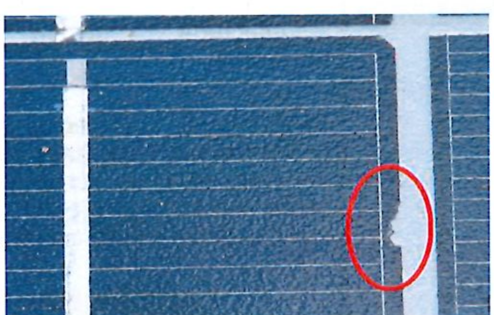
The circled cell is a different shape and size than the other cells having full corners.

**Description:** Cell fragments of different sizes connected in series within a module.

**Why it is important:** Current will be limited by the smallest cell area. Larger cells will operate at a higher temperature as they burn off excess current, potentially decreasing product lifetime. Indication of a poor module design. Can be compensated for by increasing height, which can be roughly checked by comparing the number of metal fingers on differently sized cells.

**Severity:**


### B.8.7 Edge chips

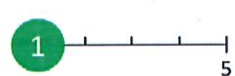


IEC

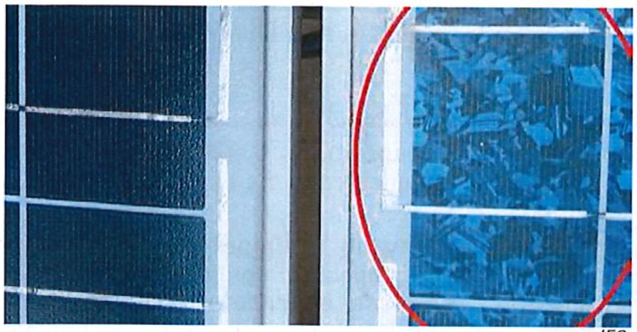
**Description:** A small region is missing from the edge of the cell. Does not enter metallized region.

**Why it is important:** Edge region is generally low power producing, so defect has minimal impact. It is a concern if many cells in a module have this defect; it indicates poor mechanical handling.

**Severity:**



**B.8.8 All cells very shiny**

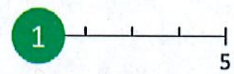


*IEC*

**Description:** Cells are very shiny, reflecting instead of absorbing light.

**Why it is important:** May be less efficient than darker cells, which is not inherently a problem if a module is sold based on rated power. Retailers selling such modules at a higher price to uninformed consumers who associate "shiny" with "new" or better is deceitful practice.

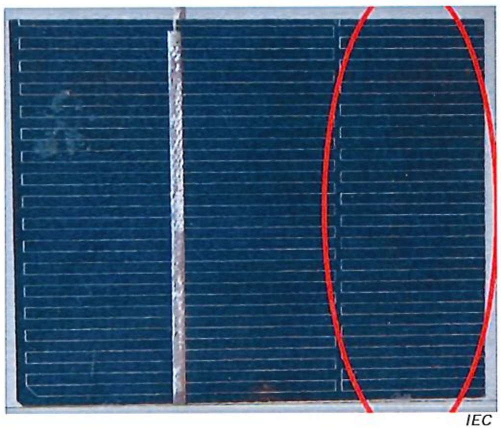
**Severity:**



## B.9 CELL METALLIZATION

Metal fingers collect and conduct current from the cell to the busbars (covered by tabbing ribbon)

### B.9.1 Fingers not connected to busbar



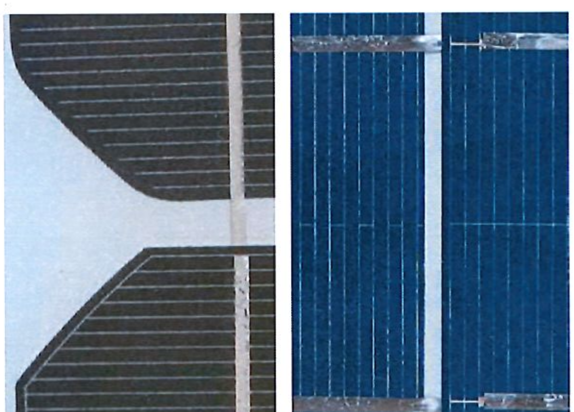
IEC

**Description:** Metal fingers are not connected to the busbars of a cell.

**Why it is important:** Current of unconnected region cannot be used. Severity depends on effected region. In the example here 1/3 of the cell area is effectively unused. Indicates a poor design and a sub-standard manufacturer.

**Severity:** Severity depends on affected area. Considered a major defect when 10 % or greater of a cell's area is excluded from the electrical circuit [1].


### B.9.2 Not the same pattern on all cells



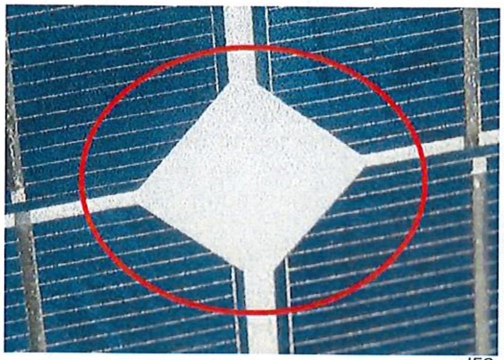
IEC

**Description:** Different metallization patterns apparent on different cells in the same module.

**Why it is important:** Not inherently an issue if cells have the same performance characteristics. However if mis-matched cells are combined in a module, higher performing cells will be limited by lower performers. Potential indicator of poor manufacturing practices.

**Severity:**

### B.9.3 Fingers off of edge of corner of cells

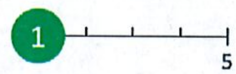


IEC

**Description:** Metal fingers go right to cell edge in corner of cell.

**Why it is important:** Indicates deceitful behaviour of manufacturer; lower cost/performance poly-crystalline cells cut to look like high cost/performance mono- crystaline cells.

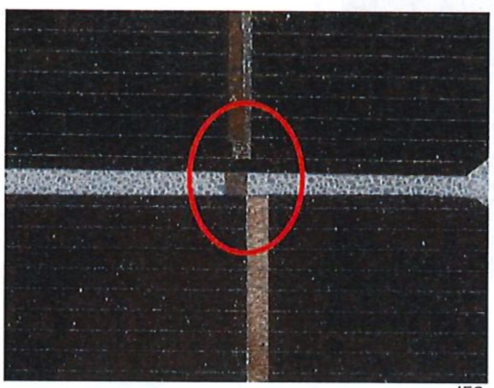
**Severity:**




## B.10 CELL INTERCONNECTION

Tabbing ribbon that is soldered to busbars. Connects cells together and conducts current to external circuit.

### B.10.1 Interconnection is discontinuous



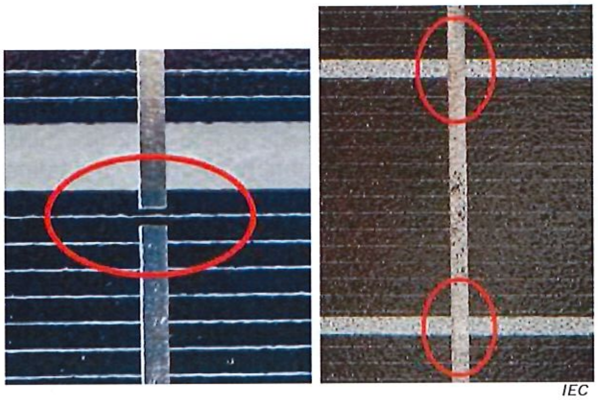
IEC

**Description:** There is no cell interconnection, or tabbing ribbon is present but does not connect cells together (is discontinuous). Note that some small consumer products cover the tabbing ribbon with black material for aesthetic purposes.

**Why it is important:** Power of unconnected cells does not contribute to module power. Indicator of a partially or completely counterfeit/fake product.

**Severity:**

**B.10.2 Cells connected in parallel (counterfeit)**



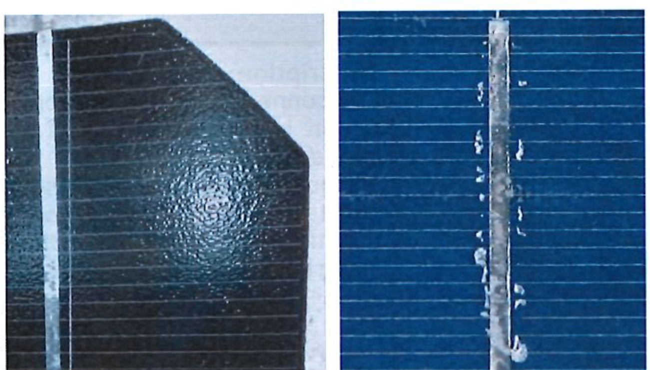
IEC

**Description:** Tabbing ribbon appears two dimensional in the area between cells. Rather than connecting the bottom of one cell to the top of the next (standard series connection), the top of one cell is connected to the top of the next (parallel connection).

**Why it is important:** Often indicates a counterfeit product with fake printed paper instead of soldered tabbing ribbon.

**Severity:**


**B.10.3 Poorly aligned and/or soldered**



IEC

**Description:** Poorly soldered tabbing ribbon. For example misaligned to busbars or excess solder dripped on cell.

**Why it is important:** Tabbing ribbon mis-aligned to busbars increases resistances and decreases module power. Excess solder shades cells locally, decreasing current. Overall indicators of low quality control standards of the manufacturer.

**Severity:**


**B.10.4 Cells connected in parallel (real cells)**

IEC

**Description:** Real cells tabbed together in a parallel connection to combine small cut cell fragments with full-sized cells in one module

**Why it is important:** Poor manufacturing practice. Typically correlates with a manual process and broken cells.

**Severity:**

# Annex C
(normative)

## Catalogue of defects: used modules

The defects included in this annex would not appear on a new module, only on a module that has already been used in operation. These defects therefore appear over time as gradually worsening or catastrophic events. This annex is included so that if these defects are found at border inspections or at retail locations, it can be immediately identified that the modules are not new and should be rejected.

If the intended use is specifically to inspect used modules, for example to evaluate PV arrays after a given time of operation, other resources would likely be more suited and complete. See for example "Development of a Visual Inspection Data Collection Tool for Evaluation of Fielded PV Module Condition" [3], which is specifically intended for this purpose and is available online. Note that all used modules can also have all defects that new modules have, but the converse is not true. Therefore when evaluating used modules, both "new" and "used" module checklists should be employed.

### C.2 BACKSHEET

Back substrate of module. Protects module interior from the elements.

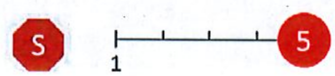
#### C.2.1. Burn marks

IEC

**Description:** Burnt, blackened area. Damage cannot be cleaned off. There may be a hole in the backsheet.

**Why it is important:** Indicates a catastrophic failure event occurred. Performance, reliability and safety are likely to be severely compromised.

**Severity:**




#### C.2.2. Discolouration

IEC [3]

**Description:** Colour varies across the backsheet, and cannot be cleaned off

**Why it is important:** Backsheet material is likely degraded. This indicates that the module is suffering from a reliability problem.

**Severity:**

## C.4 WIRING

Back substrate of module. Protects module interior from the elements.

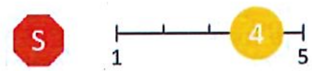
### C.4.1 Cracks or exposed metal


IEC

**Description:** The wire insulation is cracked or revealing the metal conductor.

**Why it is important:** Exposed metal in the electrical circuit is a safety risk.

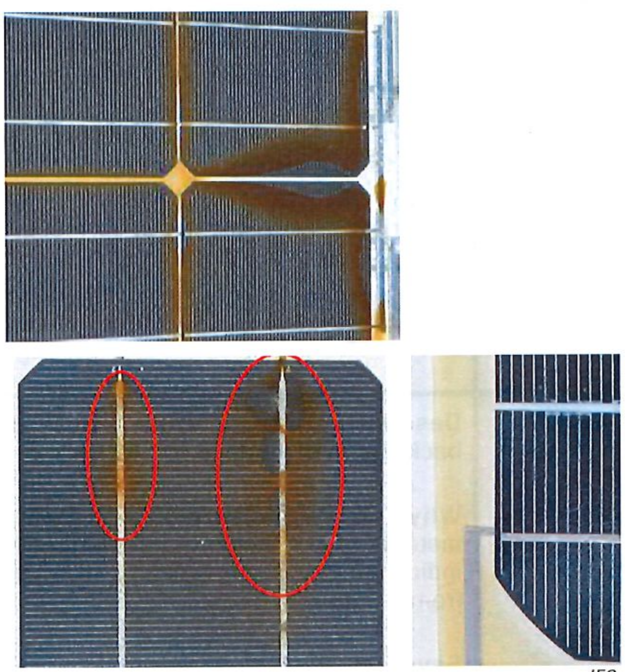
**Severity:**




## C.7 ENCAPSULATION

Used to laminate module layers together. Transparent to allow light to reach cells.

### C.7.2 Discolouration


IEC

**Description:** Colour variation anywhere inside the module. Can be next to or above the cells, along the busbars or cell interconnects. Could be from a catastrophic event or degradation over time.

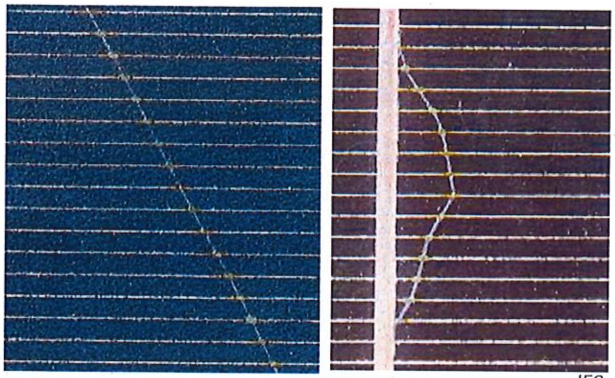
**Why it is important:** Indicates encapsulation material is degraded. Transmission of light to the underlying cells, and therefore module current, is reduced. Likely to degrade further over time.

**Severity:** Severity depends on affected area. Considered a major defect when 10 % or greater of a cell's area is affected [1].

## C.8. CELLS

Active component of the solar module. Electricity producing material converts sunlight to electricity.

### C.8.9 "Snail trails"



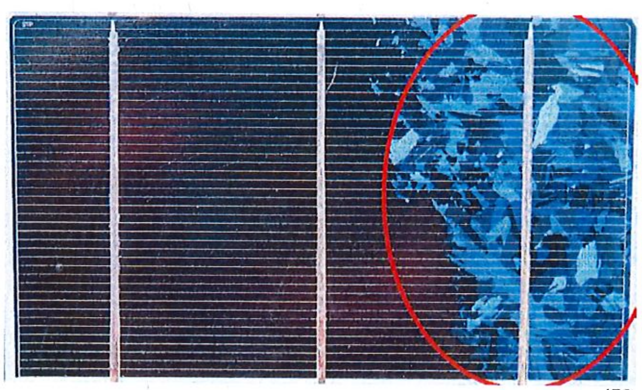
IEC

**Description:** Lines on cell surfaces; might appear silvered as well as yellow or brownish around metal fingers. Appears after several months of sun exposure. Correlates to presence of underlying micro-crack that may have previously been invisible. May be difficult to distinguish from cracks or scratches.

**Why it is important:** Same as for cracks (See B.8.3).

**Severity:** Severity depends on affected area. A crack is considered a major defect when its propagation could remove more than 10 % of that cell's area from the electrical circuit [1]. The presence of a crack of any size that does not, or likely will not through its propagation, isolate any portion of the cell from the electrical circuit is a score of 2.


### C.8.10 Shiny locally/significantly varying colour

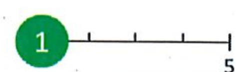


IEC

**Description:** Shiny silicon crystals are visible on a cell locally. Some colour variation from cell to cell can be expected (ex. slightly different shades of blue), but largely varying colour across one cell can be a concern.

**Why it's important:** A shiny cell is reflecting significant light instead of absorbing it and generating power. Where cells have become shiny or changed colour locally, cells have a poor or degrading anti-reflective coating which is an indicator of poor module performance.

**Severity:**



## System Commissioning Checklist

1. **Review or Develop Commissioning Protocol**
    a. Applicable standards
    b. Contract requirements
    c. Project specific requirements
2. **Complete Visual And Mechanical Inspection**
    a. Installation per system design
    b. Installation per manufacturer's requirements
    c. Installation per NEC and local AHJ requirements
    d. Installation per Utility requirements
3. **Conduct Mechanical Tests**
    a. Installation per torque specifications
    b. Field testing (e.g. pull on driven piles, soil test, concrete slump test)
4. **Conduct Electrical Tests**
    a. Proper use of diagnostic tools (e.g.: multi-meter, insulation resistance tester)
    b. Electrical resistance testing
    c. Polarity testing
    d. DC string open circuit voltage (Voc) testing
    e. DC string short circuit current (Isc) testing
    f. Continuity testing
    g. Wire termination torque verification
    h. AC voltage testing
5. **Verify System Operation**
    a. Manufacturer's start-up procedure
    b. Programming system electronics (e.g. charge controller set points, firmware updates, monitoring system connection)
    c. Calculate expected electrical parameters and compare to expected values
6. **Complete System Documentation**
    a. Punch-list Items
    b. Testing results
    c. Photographs
    d. As-Built Drawing reconciliation
7. **Orient End User to System**
    a. Safe start-up and shut-down procedure
    b. Explanation of system operation and limitations

## Operations and Maintenance (O&M)

**8. Develop Operations and Maintenance (O&M) Plan**

a. As-Built drawings
b. O&M practices and causes of failure
c. Project specific contract requirements
d. Level of detail required
e. Frequency of maintenance required
f. Appropriate level of documentation required
g. Training requirements for on-site staff
h. Consumables used and replacement part inventory
i. Start up/shutdown procedures
j. O&M response plan (e.g. response time, performance guarantee)
k. Manufacturer warranty requirements and instructions
l. Intent of design
m. Troubleshooting procedures
n. Budgeting and contracting considerations for O&M services

**9. Remotely verify System Operation and Performance**

a. Access data monitoring platform(s)
b. Data Monitoring platform alert mechanisms
c. Indicators of failure, underperformance or false alarms
d. Interpretation of performance data
e. Seasonal impacts on system performance
f. Site weather data source
g. Climate data and impact on performance
h. Data monitoring system capabilities and instrumentation quality
i. Performance analytics
j. Remote diagnostics solutions (if available)

**10. Conduct Preventative Maintenance**

a. Site access protocol
b. Site specific safety requirements
c. Site specific O+M procedure
d. Periodic visual and mechanical inspection
e. Instrumentation calibration
f. Mounting system wear, failure points and causes (e.g. loose connections, corrosion, displacement)
g. Module failure points and causes (e.g. signs of overheating, damage to J-Box, discoloration)
h. Inverter failure points and causes (e.g. critters, debris, ventilation, internal moisture)
i. Wiring system wear, failure points and causes (e.g. unsupported conductors, connector failure, loose terminations, physical damage to raceway)
j. Battery system wear, failure points and causes (e.g. cable terminations, corrosion, capacity testing, deformation of battery)
k. Site factors affecting performance (e.g. module soiling, vegetation impacts, shading
l. Array testing (e.g. Voc, Isc, fuse continuity testing)
m. Comparison of whole system performance to predicted values)

**11. Perform Corrective Maintenance**

a. Site access protocol
b. Site specific safety requirements (e.g. lock-out tag-out, Personal Protective Equipment (PPE))
c. Methods for diagnosing the failure or low performance (e.g. mutimeter, monitoring system, thermal imager)
d. Methods of repair or replacement

**12. Verification of corrective measures**

## Climate Technology Centre & Network
## Solar Photovoltaic Accreditation Training Program

## Worksheets

## Instructions: PV Laboratory Exercise Series/Parallel Wiring

**Instruments:** Voltage, Current, Insolation, Temperature (voltage and temperature according to PV Module ratings)

**Supplies:** Two PV Modules; 100 ohm potentiometer; wire-nuts or other hardware necessary to make connections.

**Instructions:** Connect the (+) terminal of one PV module junction box to the (-) terminal of the other. Measure the current and voltage with open circuit and short circuit. Install the potentiometer in the circuit and trace the I-V curve by varying the resistance.

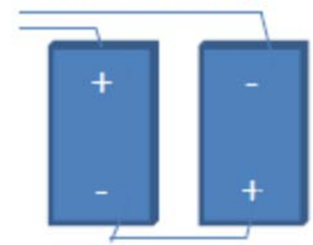
# Photovoltaics Lab: Series and Parallel Wiring

Date:
Names:

| Environmental Conditions | |
|---|---|
| Insolation ($W/m^2$) | |
| Ambient Temperature (C ) | |
| PV Cell Temperature (C) | |

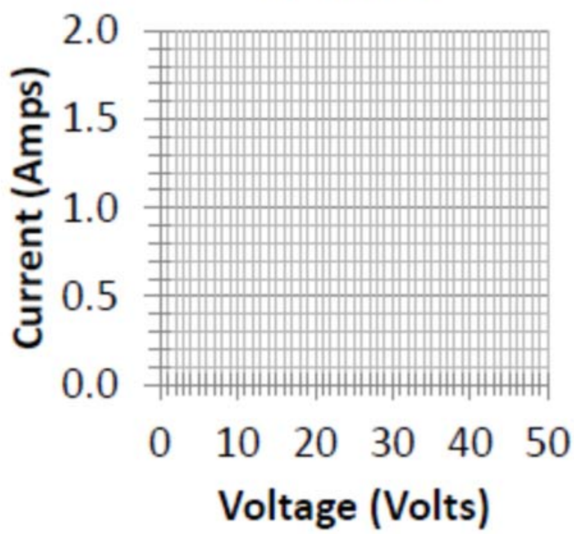
| PV Module Specifications | Voltage (Volts) | Current (Amps) | Power (W) |
|---|---|---|---|
| Open Circuit | | 0 | 0 |
| Maximum Power | | | |
| Short Circuit | 0 | | 0 |

## Series Wiring

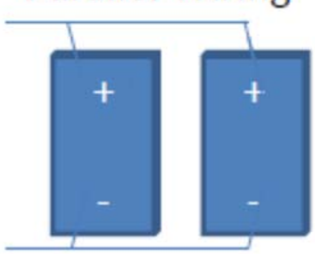



| | Voltage (Volts) | Current (Amps) |
|---|---|---|
| Open Circuit | | 0 |
| Short Circuit | 0 | |
| Short Circuit with one shaded | 0 | |

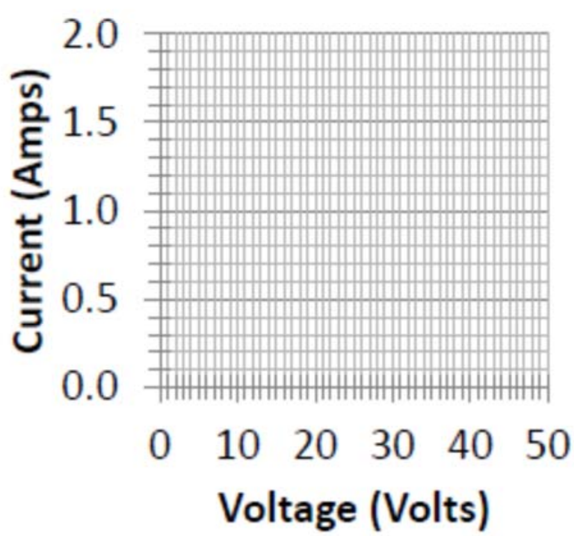
## I-V Curves




## Parallel Wiring




| | Voltage (Volts) | Current (Amps) |
|---|---|---|
| Open Circuit | | 0 |
| Short Circuit | 0 | |
| Short Circuit with one shaded | 0 | |



## These are Estimates

**Electrical Appliance Typical Energy Consumption Table**

| Appliance | Consumption (Watts) | Appliance | Consumption (Watts) |
|---|---|---|---|
| Toaster | 800-1500 | Television - 25" color | 150 |
| Popcorn Popper | 250 | Television - 19" color | 70 |
| Blender | 300 | Television - 12" black and white | 20 |
| Electric cooker with oven | 1000-2500 | VCR | 40 |
| Microwave | 600-1500 | CD player | 35 |
| Waffle Iron | 1200 | Stereo | 20 |
| Hot Plate | 1200 | Clock radio | 1 |
| Frying Pan | 1200 | AM/FM auto cassette player | 8 |
| Dishwasher | 1200-1500 | Satellite dish | 30 |
| Sink waste disposal | 450 | CB radio | 5 |
| Washing machine - Automatic | 500 | Electric clock | 3 |
| Washing machine - Manual | 300 | Radiotelephone - Receiving mode | 5 |
| Vacuum cleaner - High Power | 1600-2000 | Radiotelephone - Transmitting mode | 40-150 |
| Vacuum cleaner - Upright | 200-700 | Lights:100 watt incandescent | 100 |
| Vacuum cleaner - Hand | 100 | Lights:25 watt compact fluorescent | 28 |
| Sewing machine | 100 | Lights:50 watt DC incandescent | 50 |
| Iron | 1000 | Lights:40 watt DC halogen | 40 |
| Clothes dryer - Electric | 4000 | Lights:20 watt DC compact flourescent | 22 |
| Clothes dryer - Gas heated | 300-400 | Lights: Compact fluorescent 40 watt Incandescent equivalent | 11 |
| Heater - Electric water heater | 4000 | Lights: Compact fluorescent 60 watt Incandescent equivalent | 16 |
| Heater - Engine block | 150-1000 | Lights: Compact fluorescent 75 watt Incandescent equivalent | 20 |
| Heater - Portable | 1500 | Lights: Compact fluorescent 100 watt Incandescent equivalent | 30 |
| Heater - Waterbed | 400 | Electric mower | 1500 |
| Heater - Stock tank | 100 | Hedge trimmer | 450 |
| Furnace blower | 300-1000 | Weed eater | 500 |

| | | | |
|---|---|---|---|
| Air conditioner - Room | 1000 | 1/4" drill | 250 |
| Air conditioner - Central | 2000-5000 | 1/2" drill | 750 |
| Garage door opener | 350 | 1" drill | 1000 |
| Ceiling fan | 40 | 9" disc sander | 1200 |
| Table fan | 20 | 3" belt sander | 1000 |
| Electric blanket | 200 | 12" chain saw | 1100 |
| Blow dryer | 1000 | 14" band saw | 1100 |
| Shaver | 15 | 7-1/4" circular saw | 900 |
| Waterpik | 100 | 8-1/4" circular saw | 1400 |
| Well Pump (1/3-1 HP) | 480-1200 | Refrigerator/Freezer - 20 cu. ft. (AC) | 1412 watt-hours/day |
| Laptop | 20-60 | Refrigerator/Freezer - 16 cu. ft. (AC) | 1205 watt-hours/day |
| PC | 80-150 | Freezer - 15 cu. ft. (Upright) | 1239 watt-hours/day |
| Charger: mobile phone charger | 1 | Freezer - 15 cu. ft. (Chest) | |

## Load Estimation Worksheet

| Sr.No | Individual Loads | Quantity | X | Volts | X | Current | equals to (=) | Watts | | X | Use | X | Use | ÷ | 7 | equals to (=) | Watt hours | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | AC | DC | | hrs/day | | days/wk | | days | | AC | DC |
| 1 | | | | | | | | | | | | | | | 7 | | | |
| 2 | | | | | | | | | | | | | | | 7 | | | |
| 3 | | | | | | | | | | | | | | | 7 | | | |
| 4 | | | | | | | | | | | | | | | 7 | | | |
| 5 | | | | | | | | | | | | | | | 7 | | | |
| 6 | | | | | | | | | | | | | | | 7 | | | |
| 7 | | | | | | | | | | | | | | | 7 | | | |
| 8 | | | | | | | | | | | | | | | 7 | | | |
| 9 | | | | | | | | | | | | | | | 7 | | | |
| 10 | | | | | | | | | | | | | | | 7 | | | |
| 11 | | | | | | | | | | | | | | | 7 | | | |
| 12 | | | | | | | | | | | | | | | 7 | | | |
| 13 | | | | | | | | | | | | | | | 7 | | | |
| 14 | | | | | | | | | | | | | | | 7 | | | |
| 15 | | | | | | | | | | | | | | | 7 | | | |
| 16 | | | | | | | | | | | | | | | 7 | | | |
| 17 | | | | | | | | | | | | | | | 7 | | | |
| 18 | | | | | | | | | | | | | | | 7 | | | |
| 19 | | | | | | | | | | | | | | | 7 | | | |
| 20 | | | | | | | | | | | | | | | 7 | | | |
| | | **AC Total Connected Watts = ____** | | | | | | | | | | **AC Average Daily load = ____** | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | **DC Total Connected Watts = ____** | | | | | | | | | | | **DC Average Daily load = ____** | | | |
| | | | | | | | | | | | | | | | | | | |

| Battery Sizing Worksheet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| AC Average Daily Load (Watt-hours/day) | ÷ | Efficiency (Inverter efficiency x Wiring efficiency) | + | DC Average Daily Load (Watt-hours/day) | ÷ | DC System Voltage (V) | = | Average Amp-hour/day (Ah) |
| [( | ÷ | ) | + | ] | ÷ | | = | |
| | | | | | | | | |
| Average Amp-hour/day (Ah) | x | Days of Autonomy | ÷ | Discharge Limit (in %) | ÷ | Battery Capacity (Ah) | = | Batteries in Parallel |
| | x | | ÷ | | ÷ | | = | |
| | | | | | | | | |
| DC System Voltage (V) | ÷ | Battery Voltage (V) | = | Batteries in Series | x | Batteries in Parallel | = | Total Number Batteries |
| | ÷ | | = | | x | | = | |

# Array Sizing Worksheet

| Average Amp-hour/day (Ah) | ÷ | Efficiency (Battery efficiency x Wiring efficiency) | ÷ | Peak Sun Hrs/day | = | Array Peak Amps | | |
|---|---|---|---|---|---|---|---|---|
| ( | ÷ | ) | ÷ | | = | | | |
| | | | | | | | | |
| Array Peak Amps | ÷ | Peak Amps per module | = | Modules in Parallel | | Module short circuit current (Isc) | | |
| | | | | | | | | |
| | | | | | | | | |
| DC System Voltage (V) | ÷ | Nominal Module Voltage (V) | = | Moudles in Series | x | Modules in Parallel | = | Total Modules |
| | ÷ | | = | | x | | = | |

## Controller Sizing Worksheet

| Module Short Circuit Current (Isc) | x | Modules in Parallel | x | 1.25 | = | Array Short Circuit Amps (Isc) | Controller Array Amps | Listed Desired Features |
|---|---|---|---|---|---|---|---|---|
| | x | | x | 1.25 | = | | | |
| | | | | | | | | |
| DC Total Connected Watts (W) | ÷ | DC System Voltage (V) | = | Maximum DC Load Amps | | Controller Load Amps | | |
| | ÷ | | = | | | | | |

| Inverter Sizing Worksheet | | | |
|---|---|---|---|
| | | | |
| AC Total Connected Watts (Watts) | DC System Voltage | Estimated Surge Wattage | Listed Desired Features |
| | | | |

*As a rough "rule of thumb" minimum surge requirements for stand-alone inverters of a load can be calculated by multiplying the required watts by 3.
`

## Size a stand-alone system for a house in Tanzania with a consistent year-round use.

**Electric Load Information**:
(All loads are 220 Volts AC)

1. Ten Incandescent lights (100 Watts each) : Each used on an average of 6 hours/day.
2. One Television 25" color (150 Watts) : Used for an average of 3 hours/day.
3. Three Ceiling fans (40 Watts each) : Each used on average of 6 hours/day.
4. One Iron (1000 Watts): Used for an average of 30 minutes /day.
5. Two laptops (40 Watts each) :Used for an average 4 hours/day.

**System Specifications**:

1. DC System Voltage: 48 Volts
2. Days of autonomy : 2
3. Battery Depth of Discharge: 0.50
4. Battery Choice : Company ABC (350 Ah, 6V and efficiency 80%)
5. PV Module:
    a. Power: 80 Watts
    b. Nominal Voltage: 12
    c. Peak Amps: 5.02 A
    d. Short Circuit current (Isc): 5.34 A
6. Controller:
    a. Nominal Voltage : 48 V
    b. Maximum pass -through current : 40 A
7. Inverter:
    a. Efficiency: 95 %
    b. Continious Power Output: 4000 W
    c. Nominal Voltage: 12 V
    d. Surge Capacity: 95 Amps AC

PV array is a fixed tilt and the tilt will be adjusted to the latitude of the place in Tanzania.
There is no back-up generator.
Assume Wiring Efficiency to be 98%
Assume Peak Sun hours/day: 5.16 (http://www.dar-es-salaam.climatemps.com/sunlight.php)

**Load Estimation Worksheet**

| Sr.No | Individual Loads | Quantity | X | Volts | X | Current | equals to (=) | Watts | | X | Use | X | Use | ÷ | 7 | equals to (=) | Watt hours | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | AC | DC | | hrs/day | | days/wk | | days | | AC | DC |
| 1 | Incadescent lights | 10 | x | 220 | x | 4.55 | (=) | 1000 | | x | 6 | x | 7 | ÷ | 7 | (=) | 6000 | |
| 2 | TV | 1 | x | 220 | x | 0.68 | (=) | 150 | | x | 3 | x | 7 | ÷ | 7 | (=) | 450 | |
| 3 | Ceiling fan | 3 | x | 220 | x | 0.55 | (=) | 120 | | x | 6 | x | 7 | ÷ | 7 | (=) | 720 | |
| 4 | Iron | 1 | x | 220 | x | 4.55 | (=) | 1000 | | x | 0.5 | x | 7 | ÷ | 7 | (=) | 500 | |
| 5 | Laptops | 2 | x | 220 | x | 0.36 | (=) | 80 | | x | 4 | x | 7 | ÷ | 7 | (=) | 320 | |
| | | | | | | | | | | | | | | | | | | |
| | | **AC Total Connected Watts = 2350 Watts** | | | | | | | | | | **AC Average Daily load = 7990 Watt-hours** | | | | | | |
| | | | | **DC Total Connected Watts = ____** | | | | | | | | | | | **DC Average Daily load = ____** | | | |

| Battery Sizing Worksheet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| AC Average Daily Load (Watt-hours/day) | ÷ | Efficiency (Inverter efficiency x Wiring efficiency) | + | DC Average Daily Load (Watt-hours/day) | ÷ | DC System Voltage (V) | = | Average Amp-hour/day (Ah) |
| **[( 7990** | **÷** | **0.931 )** | **+** | **0 ]** | **÷** | **48** | **=** | **178.8** |
| | | | | | | | | |
| Average Amp-hour/day (Ah) | x | Days of Autonomy | ÷ | Discharge Limit | ÷ | Battery Capacity (Ah) | = | Batteries in Parallel |
| **(178.8** | **x** | **2** | **÷** | **0.5 )** | **÷** | **350** | **=** | **2** |
| | | | | | | | | |
| DC System Voltage (V) | ÷ | Battery Voltage (V) | = | Batteries in Series | x | Batteries in Parallel | = | Total Number Batteries |
| **48** | **÷** | **6** | **=** | **8** | **x** | **2** | **=** | **16** |

| Array Sizing Worksheet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Average Amp-hour/day (Ah) | ÷ | Efficiency (Battery efficiency x Wiring efficiency) | ÷ | Peak Sun Hrs/day | = | Array Peak Amps | | |
| **(178.8** | **÷** | **0.784)** | **÷** | **5.16** | **=** | **44.2** | | |
| | | | | | | | | |
| Array Peak Amps | ÷ | Peak Amps per module | = | Modules in Parallel | | Module short circuit current (Isc) | | |
| **44.2** | **÷** | **5.02** | **=** | **9** | | **5.34** | | |
| | | | | | | | | |
| DC System Voltage (V) | ÷ | Nominal Module Voltage (V) | = | Moudles in Series | x | Modules in Parallel | = | Total Modules |
| **48** | **÷** | **12** | **=** | **4** | **x** | **9** | **=** | **36** |

| Controller Sizing Worksheet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Module Short Circuit Current (Isc) | x | Modules in Parallel | x | 1.25 | = | Array Short Circuit Amps (Isc) | Controller Array Amps | Listed Desired Features |
| **5.34** | **x** | **9** | **x** | **1.25** | **=** | **60** | **60** | |
| | | | | | | | | |
| DC Total Connected Watts (W) | ÷ | DC System Voltage (V) | = | Maximum DC Load Amps | | Controller Load Amps | | |
| **0** | **÷** | **48** | **=** | **0** | | | | |

| Inverter Sizing Worksheet | | | |
|---|---|---|---|
| | | | |
| AC Total Connected Watts (Watts) | DC System Voltage | Estimated Surge Wattage | Listed Desired Features |
| **2350** | **48 V** | **7050** | **Battery charging capability** |

As a rough "rule of thumb" minimum surge requirements for stand-alone inverters of a load can be calculated by multiplying the required watts by 3.

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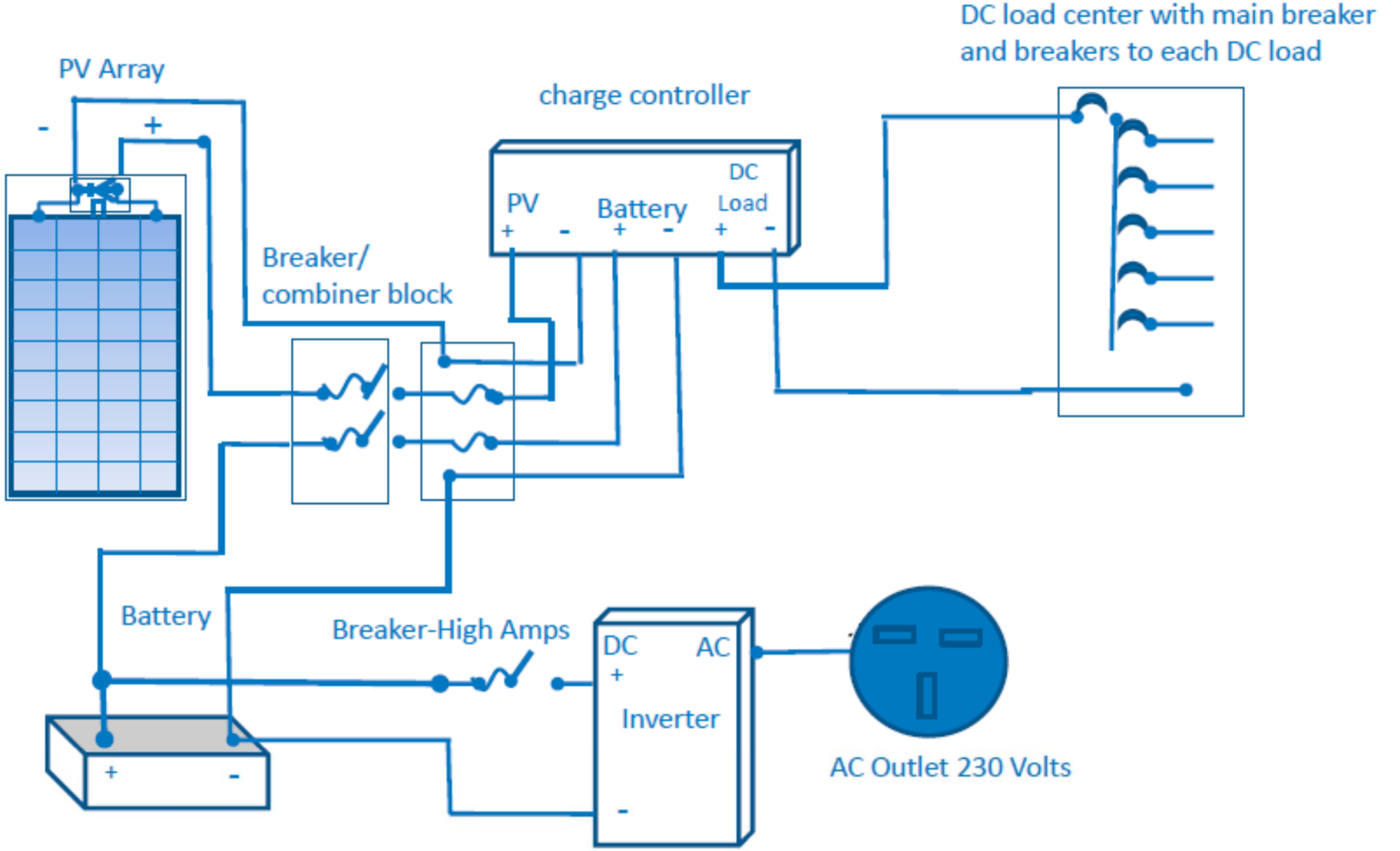
**Hands on Exercise**

# PV System with Battery Storage



## Charge controller with breaker/combiner block

**Installation of PV + Battery System**
**(Hands-on Exercise)**

1. While installing components on the board be sure to keep the PV panel away from the sun

2. Layout the components on the board to ensure the charge controller is close to the battery. The batteries should be within 5-10 ft. of the charge controller to minimize voltage drop or other losses. Note that the closer the charge controller is to the batteries and PV panels the fewer losses occur providing higher performance of the system.

3. Use wire size that is recommended in a chart for the total current (amperage) in the circuit. To calculate the amperage of a circuit, determine the number of electrical devices connected to the circuit and add up the wattage. Divide the total wattage by the voltage of the system (230V for Tanzania) to determine the expected current (amps) in the circuit.

4. First connect the batteries to the charge controller with a breaker installed on the positive (red) side.

    a. To calculate the size of the breaker, use the following formula:
       (# of PV panels in parallel) x (Isc of the PV panel) x 125% for safety.

5. Bolt the ring terminals to the battery and be careful not to short the leads.

6. Connect the PV panel to the charge controller with positive cable going through the breaker. The size breaker is calculated in step 4a.

7. Attach the inverter to the battery using ring terminals. Use a high amperage breaker in line on the positive side. (Note: if the size of the breaker is not recommended by the inverter manufacturer then calculate the size by taking the surge power of the inverter/3 * 1.25)

8. Check that the wires are all tightly connected before placing the PV panel in the sun.

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**BOM**

| Item Number | Items | Quantity | Unit Cost (TZS) | Total Cost (TZS) | Total Cost (Euro) | Total Needed for 5 workstations |
|---|---|---|---|---|---|---|
| 1 | Tool box | 1 | 150,000 | 150,000 | 67.5 | 5 |
| 2 | Spanners 6-22 | 1 | 50,000 | 50,000 | 22.5 | 5 |
| 3 | Combination plier | 1 | 20,000 | 20,000 | 9 | 5 |
| 4 | Long nose plier | 1 | 20,000 | 20,000 | 9 | 5 |
| 5 | Screw driver | 1 | 40,000 | 40,000 | 18 | 5 |
| 6 | Tester? | 1 | 5,000 | 5,000 | 2.25 | 5 |
| 7 | Slide knife | 1 | 5,000 | 5,000 | 2.25 | 5 |
| 8 | Digital multimeter | 1 | 120,000 | 120,000 | 54 | 5 |
| 9 | Claw hammer | 1 | 15,000 | 15,000 | 6.75 | 5 |
| 10 | Angular Level | 1 | 40,000 | 40,000 | 18 | 5 |
| 11 | Compass | 1 | 60,000 | 60,000 | 27 | 5 |
| 12 | Tape measure | 1 | 10,000 | 10,000 | 4.5 | 5 |
| 13 | Wire stripers | 1 | | | 0 | 5 |
| 14 | Potentiometers | 1 | | | | |
| 15 | Pyrometers | 1 | | | | |
| 16 | Solar panel 3 Wp poly | 2 | | | | |
| 17 | | | | | | |

| Item Number | Items | Quantity | Unit Cost (TZS) | Total Cost (TZS) | Total Cost (Euro) | Total Needed for 5 workstations |
|---|---|---|---|---|---|---|
| 1 | Solar panel 50 Wp poly | 2 | 120,000 | 240,000 | 108 | 10 |
| 2 | Pure sine wave inverter Victron 350VA/12V | 1 | 400,000 | 400,000 | 180 | 5 |
| 3 | Charge controller ProSolar 20A/12V PWM Digital with LEDs | 1 | 200,000 | 200,000 | 90 | 5 |
| 4 | Battery deep cycle GEL 40 Ah/12 V | 2 | 180,000 | 360,000 | 162 | 10 |
| 5 | Cables, lot | 1 | 150,000 | 150,000 | 67.5 | 5 |

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**Solar Photovoltaic Accreditation Training Program**

**Guidance Document**

# Solar Photovoltaic Accreditation Training Program

Mwongozo wa uga wa hatua kwa hatua kwa ajili ya kubuni mfumo Photovoltaic na makisio ya gharama

Step-by-Step Field Guide for Photovoltaic System Design and Cost Estimate

# Mwongozo wa uga wa hatua kwa hatua kwa ajili ya kubuni mfumo Photovoltaic na makisio ya gharama *(Step-by-Step Field Guide for Photovoltaic System Design and Cost Estimate)*

Hatua ya 1: Kukadiria mzigo kutendeka (kWh/siku) *Step 1: Estimate the Daily Energy Load to be Served (kWh/day)*

Hatua ya 2: Makisio yanayohitajika inveta ukubwa (W) *Step 2: Estimate required inverter size (W)*

Hatua ya 3: Makisio yanayohitajika betri ukubwa (kWh; Volti; Amp-HOURS) *Step 3: Estimate required battery size (kWh; Volts; Amp-hours)*

Hatua ya 4: Makisio yanayohitajika mfumo photovoltaic ukubwa (W; m2) *Step 4: Estimate required photovoltaic system size (W; $m^2$)*

Hatua ya 5: Bainisha Mdhibiti wa malipo *Step 5: Specify Charge Controller*

Hatua ya 6: Kuweka wiring ya mfumo *Step 6: Sizing system wiring*

Hatua ya 7: Kukadiria gharama ya mfumo (TZS) *Step 7: Estimate System Cost (TZS)*

## Hatua ya 1: Kukadiria mzigo kutendeka (kWh/siku)

## Step 1: Estimate the Daily Energy Load to be Served (kWh/day)

Identify all the electric appliances that will be served by the photovoltaic energy system. Consider any new loads that are not currently in place but that will be added soon.

Determine the power consumption of each one of the electric appliances in Watts (W). Count the number of identical appliances. Record whether each appliance is Direct Current (DC) or alternating current (AC). Record the voltage that each appliance requires. Multiply Voltage and Current (volts x amps) to get power.

Determine how many hours per day each electric appliance will operate. Determine how many days per week each appliance will operate.

Multiply by hours per day and days per week to get Wh/week, then divide by 7 days/week to get average daily energy (Wh/day) for both AC and DC appliances.

Divide the AC Power (W) by inverter efficiency to get DC power into the inverter. Similarly, divide Daily AC Energy (kWh/day) by inverter efficiency to get DC energy into the inverter- add this to the Daily DC Energy to get the total amount of DC that will have to come from the battery to power both the DC loads directly and the AC loads through the inverter. This is the Daily DC Energy Load (Wh/day)

## Load Summation Worksheet

| Sr.No | Individual Loads | Quantity | X | Volts | X | Current | = | Watts | | X | Use | X | Use | ÷ | 7 | = | Watt hours | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | AC | DC | | hrs/day | | days/wk | | days | | AC | DC |
| 1 | | | | | | | | | | | | | | | 7 | | | |
| 2 | | | | | | | | | | | | | | | 7 | | | |
| 3 | | | | | | | | | | | | | | | 7 | | | |
| 4 | | | | | | | | | | | | | | | 7 | | | |
| 5 | | | | | | | | | | | | | | | 7 | | | |
| 6 | | | | | | | | | | | | | | | 7 | | | |
| 7 | | | | | | | | | | | | | | | 7 | | | |
| 8 | | | | | | | | | | | | | | | 7 | | | |
| 9 | | | | | | | | | | | | | | | 7 | | | |
| 10 | | | | | | | | | | | | | | | 7 | | | |
| 11 | | | | | | | | | | | | | | | 7 | | | |
| 12 | | | | | | | | | | | | | | | 7 | | | |
| 13 | | | | | | | | | | | | | | | 7 | | | |
| 14 | | | | | | | | | | | | | | | 7 | | | |
| 15 | | | | | | | | | | | | | | | 7 | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | AC loads Connected Power (Watts) | DC loads Connected Power (Watts) | | | | | | | | AC Total Daily Energy (Wh/day) | DC Total Daily Energy (Wh/day) |
| | | | | | | | | Divide AC power by inverter efficiency | | | | | | | | | Divide AC energy by inverter efficiency | |
| | | | | | | | | DC Total Connected Power (W) | | | | | | | | | DC Total Daily Energy (Wh/day | |

## Electrical Appliance Typical Energy Consumption Table

| Appliance | Consumption (Watts) | Appliance | Consumption (Watts) |
|---|---|---|---|
| Toaster | 800-1500 | Television - 25" color | 150 |
| Popcorn Popper | 250 | Television - 19" color | 70 |
| Blender | 300 | Television - 12" black and white | 20 |
| Electric cooker with oven | 1000-2500 | VCR | 40 |
| Microwave | 600-1500 | CD player | 35 |
| Waffle Iron | 1200 | Stereo | 20 |
| Hot Plate | 1200 | Clock radio | 1 |
| Frying Pan | 1200 | AM/FM auto cassette player | 8 |
| Dishwasher | 1200-1500 | Satellite dish | 30 |
| Sink waste disposal | 450 | CB radio | 5 |
| Washing machine - Automatic | 500 | Electric clock | 3 |
| Washing machine - Manual | 300 | Radiotelephone - Receiving mode | 5 |
| Vacuum cleaner - High Power | 1600-2000 | Radiotelephone - Transmitting mode | 40-150 |
| Vacuum cleaner - Upright | 200-700 | Lights:100 watt incandescent | 100 |
| Vacuum cleaner - Hand | 100 | Lights:25 watt compact fluorescent | 28 |
| Sewing machine | 100 | Lights:50 watt DC incandescent | 50 |
| Iron | 1000 | Lights:40 watt DC halogen | 40 |
| Clothes dryer - Electric | 4000 | Lights:20 watt DC compact flourescent | 22 |
| Clothes dryer - Gas heated | 300-400 | Lights: Compact fluorescent 40 watt Incandescent equivalent | 11 |
| Heater - Electric water heater | 4000 | Lights: Compact fluorescent 60 watt Incandescent equivalent | 16 |
| Heater - Engine block | 150-1000 | Lights: Compact fluorescent 75 watt Incandescent equivalent | 20 |
| Heater - Portable | 1500 | Lights: Compact fluorescent 100 watt Incandescent equivalent | 30 |
| Heater - Waterbed | 400 | Electric mower | 1500 |
| Heater - Stock tank | 100 | Hedge trimmer | 450 |
| Furnace blower | 300-1000 | Weed eater | 500 |

| | | | |
|---|---|---|---|
| Air conditioner - Room | 1000 | 1/4" drill | 250 |
| Air conditioner - Central | 2000-5000 | 1/2" drill | 750 |
| Garage door opener | 350 | 1" drill | 1000 |
| Ceiling fan | 40 | 9" disc sander | 1200 |
| Table fan | 20 | 3" belt sander | 1000 |
| Electric blanket | 200 | 12" chain saw | 1100 |
| Blow dryer | 1000 | 14" band saw | 1100 |
| Shaver | 15 | 7-1/4" circular saw | 900 |
| Waterpik | 100 | 8-1/4" circular saw | 1400 |
| Well Pump (1/3-1 HP) | 480-1200 | Refrigerator/Freezer - 20 cu. ft. (AC) | 1412 watt-hours/day |
| Laptop | 20-60 | Refrigerator/Freezer - 16 cu. ft. (AC) | 1205 watt-hours/day |
| PC | 80-150 | Freezer - 15 cu. ft. (Upright) | 1239 watt-hours/day |
| Charger: mobile phone charger | 1 | Freezer - 15 cu. ft. (Chest) | |

*These are estimates. Please check the national average and the name plate data.

## Hatua ya 2: Makisio yanayohitajika inveta ukubwa (W

## Step 2: Estimate required inverter size (W)

From Table 1 above, add up all the AC loads which might be expected to operate simultaneously. This is the AC Power Required (W).

Consider that to run all AC appliances at the same time would take a larger inverter and discuss with the purchaser of the system the cost of inverter capacity.

If any of the appliances have an electric motor or involve a surge of power upon start-up, multiply those by a factor of 3 (or other factor determined another way) to estimate AC Surge Power Required (W). As a rough "rule of thumb" minimum surge requirements for stand-alone inverters of a load can be calculated by multiplying the required watts by 3.

Specify the DC voltage available to the inverter.

Specify the AC voltage, frequency and number of phases for the utility circuit that the inverter will power. Choose an inverter that can provide the required AC Voltage and frequency. For Tanzania the is 230 V at 50 Hz.

Specify any special features of the inverter such as waveform quality (sine wave versus modified sine wave); faceplate displays of power generation and energy delivered; operational indicators such as error lights.

| Inverter Sizing Worksheet | | | | |
|---|---|---|---|---|
| AC Power Required Watts (Watts) | AC Surge Power Required (W) | DC System Voltage (V) | AC System Voltage (V) and number of phases (1 or 3) | Listed Desired Features (true sine wave or modified sine wave, efficiency, display of power and energy on faceplate; operational indicators) |
| | | | | |

## Hatua ya 3: Makisio yanayohitajika betri ukubwa (kWh; Volti; Amp-HOURS)

## Step 3: Estimate required battery size (kWh; Volts; Amp-hours)

Take DC Average Daily Load (Watt-hours/day) from the load estimate (including both DC loads served directly and AC loads powered through an inverter) and divide by battery efficiency (e.g. 85%) and wiring efficiency (e.g. 95%) to get the amount of DC energy that must be put into the batteries each day to provide that load out of the battery.

Determine Battery System Voltage (e.g. 12V, 24V, 48V).

Divide DC Average Daily energy to Batteries (Watthours/day) by Battery System Voltage (V) to get Average Amp-hour/day (Ah) of battery capacity associated with the load.

Multiply Average Amp-hour/day (Ah) required by number of days of autonomy (e.g. 3 days), and divide by the fraction of the battery capacity that you can actually use. For example, a lead acid battery might only use 60% of its capacity, so divide by 0.6.

Choose a particular battery and get the A-H capacity off the label from the manufacturer.

Divide by the amp-hours rating of each battery unit to determine the number of parallel battery strings required to provide the desired amps.

Divide the DC System Voltage (V) by the voltage of each battery unit to determine the number of battery units in series in each string.

The total number of battery units required is the number connected in series in each string multiplied by the number of parallel strings.

| | | Battery Sizing Worksheet | | | | | | |
|---|---|---|---|---|---|---|---|---|
| DC Average Daily Load (Watt-hours/day) | ÷ | Battery efficiency and wiring efficiency | (=) | DC Average Daily energy to Batteries (Watthours/day) | ÷ | DC System Voltage (V) | (=) | Average Amp-hour/day (Ah) required |
| | ÷ | | (=) | | ÷ | | (=) | |
| | | | | | | | | |
| Average Amp-hour/day (Ah) required | x | Days of Autonomy | ÷ | Discharge Limit (minimum left in battery, fraction) | ÷ | Capacity of Each Battery (Ah) | (=) | Batteries in Parallel |
| | x | | ÷ | | ÷ | | (=) | |
| | | | | | | | | |
| DC System Voltage (V) | ÷ | Battery Voltage (V) | (=) | Batteries in Series | x | Batteries in Parallel | (=) | Total Number Batteries |
| | ÷ | | (=) | | x | | (=) | |

## Hatua ya 4: Makisio yanayohitajika mfumo photovoltaic ukubwa (W; m2)

## Step 4: Estimate required photovoltaic system size (W; m2)

Take the "Average Amp-hour/day (Ah) required" from the battery sizing step, and divide by charge controller efficiency, to determine "Average Amp-hours/day (Ah/day) from Solar". This is the amount of current that the photovoltaic system will have to provide, considering losses in inverter, battery, and wiring efficiency. For example, a charge controller might be 90% efficient.

The PV array can operate at a voltage higher than the battery, and the charge controller will convert the higher array voltage to the the desired battery voltage. Multiply the "Average Amp-hours/day (Ah/day) from Solar" by the battery voltage to get the energy required to go into the battery each day, and divide by the PV array voltage to get the number of Amp hours going into the charge controller from the PV array every day.

Divide the number of amp-hours provided by the PV array each day by number of "sun hours" (same as kWh/m2/day) in the location to get the "Rated amps of photovoltaic capacity required (Amps)". In Tanzania, Sun Hours varies from 4.2 hours per day in Songea, to 4.9 hours per day in Dar Es Salaam, to 5.9 hours per day in Dodoma. See solar resource data for the location and for the orientation of the PV modules.

The rated amps provided above are the "maximum power" or "operating" current (amps) of the solar collector as listed on the name-plate of the PV module. Divide the "Rated amps of photovoltaic capacity required (Amps)" by the Operating current (amps) of each PV module to determine the number of parallel strings of PV modules required.

Divide the DC PV Array voltage by the voltage of each PV module to determine the number of PV modules in series in each string.

The total number of PV modules will be the number in series in each string times the number of strings.

| Array Sizing Worksheet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Average Amp-hour/day (Ah) Required | x | Battery Voltage (V) | = | Average Daily Energy Required into battery (Wh) | | | | |
| | x | | = | | | | | |
| Average Daily Energy Required into battery (Wh) | ÷ | PV Array Voltage (V) | ÷ | Charge Controller Efficiency (eg. 0.9) | = | Average Daily Amp-hours/day (Ah) from Solar | | |
| | ÷ | | ÷ | | = | | | |
| Average Daily Amp-hours/day (Ah) from Solar | ÷ | Peak Sun Hrs/day | (=) | Array Max Power or Operating Amps | | | | |
| | ÷ | | = | | | | | |
| | | | | | | | | |
| Array Operating Amps | ÷ | Operating Amps per module | (=) | Modules in Parallel | | | | |
| | | | | | | | | |
| | | | | | | | | |
| PV Array Voltage (V) | ÷ | Nominal Module Voltage (V) | (=) | Modules in Series | x | Modules in Parallel | (=) | Total Modules |
| | ÷ | | (=) | | x | | (=) | |

## Hatua ya 5: Bainisha Mdhibiti wa malipo

## Step 5: Specify Charge Controller

Determine the short circuit current Isc (Amps) of each of the PV modules and multiply 1.25 and then by the number of strings in parallel to determine the maximum number of amps of current that the PV array could provide. The 1.25 is multiplied because the short circuit current could be greater than the value on the PV module nameplate if more sunlight is reflected toward the PV module by clouds, snow, or shiny objects. The controller must be rated to handle this many amps of current on the side of the PV Array.

Similarly, determine the maximum number of amps that could occur on the battery-side of the charge controller. Take the maximum number of solar amps above, multiply by PV Array Voltage (V); and then divide by battery voltage (V) to get the maximum amps on the battery side of the charge controller. The controller must be rated to handle this many amps of current on the battery side too.

| Controller Sizing Worksheet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Module Short Circuit Current (Isc) | x | Modules in Parallel | x | 1.25 | (=) | Array Short Circuit Amps (Isc) | Controller Array Amps | Listed Desired Features |
| | x | | x | 1.25 | (=) | | | |
| | | | | | | | | |
| Array Short Circuit Amps (Isc) | x | PV Array Voltage (V) | ÷ | Battery Voltage (V) | = | Maximum Amps into Battery (A) | Controller Load Amps | |
| | x | | ÷ | | = | | | |

# Hatua ya 6: Kuweka wiring ya mfumo

# Step 6: Sizing system wiring

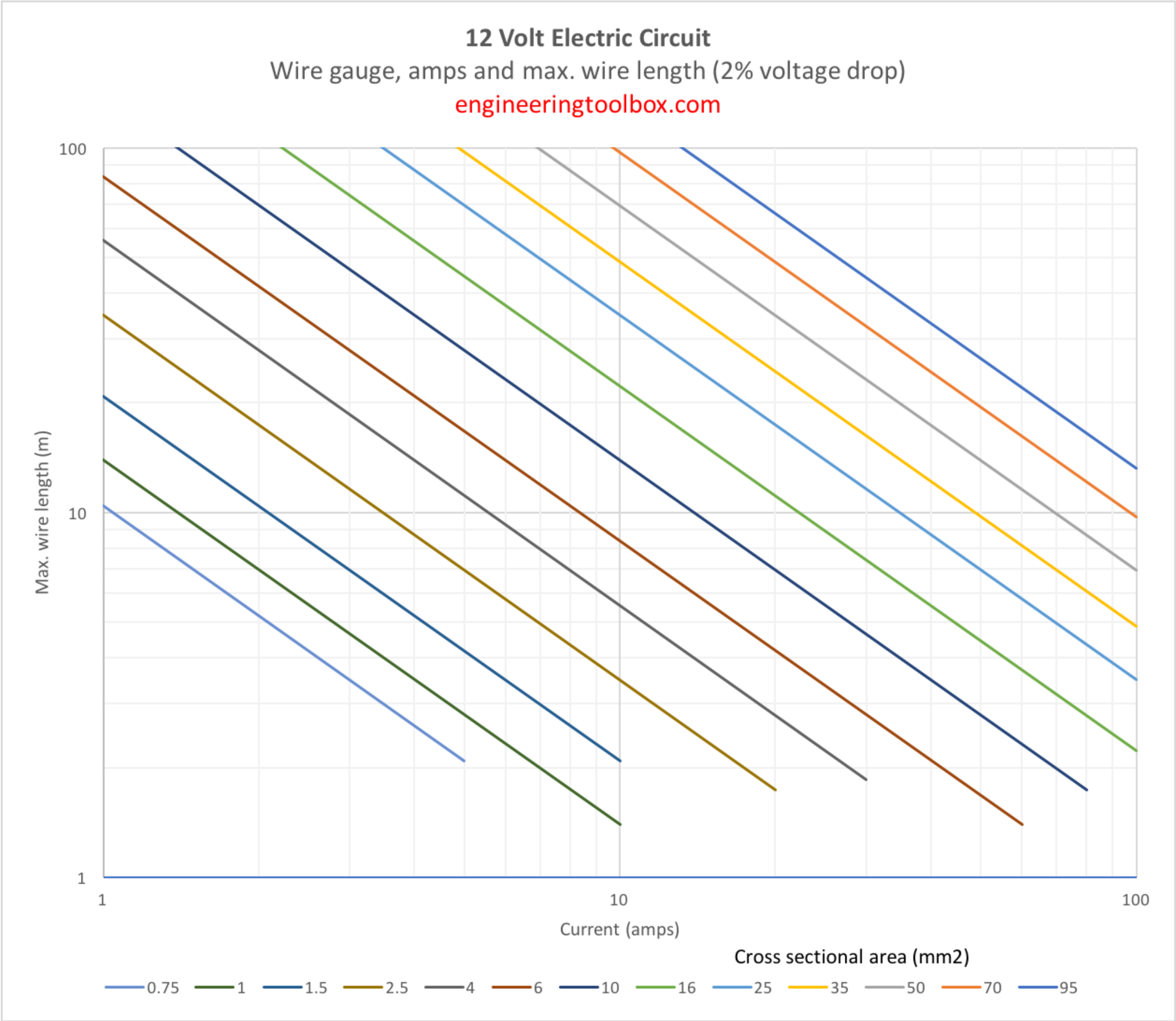
Select solid or stranded wire based on required flexibility of wire. Stranded conductors increases its flexibility and is recommended choice when a large wire size is required.

Select wire with Insulation covering that can provide protection from heat, abrasions, moisture, ultraviolet light and/or chemicals, depending on the circumstances of the installation.

Select color of wire covering coded to designate its function and use. Technicians should understand the color-coding of conventional electrical wire to ensure safe and efficient operation, troubleshooting, and repair. Large conductors usually have only black colored insulation. Therefore, it is allowable to use colored electrical tape or paint to color code the wire ends where electrical connections are made.

There are two important criteria for selecting wire size: Ampacity and Voltage drop. There are on-line calculators such as http://photovoltaic-software.com/DC_AC_drop_voltage_energy_losses_calculator.php that gives the AC and DC Power, Voltage Drop, wire energy losses, resistive heating, for three phase and single phase wiring. The chart on the following page also shows length of wire that results in acceptable voltage drop for each wire diameter size for a 12 V system. Other charts are available for other system voltages.

The wires in different parts of the PV system may be different sizes depending on how much current they must carry. For the wire run from the PV panels to the controller or battery, use the module short circuit current (Isc) multiplied with number of modules in parallel to size the wire. For the wire from battery to the DC service panel, use the total load amperes. For the wire to each individual load, use the amps that load requires to size the wire.



12 Volt Electric Circuit
Wire gauge, amps and max. wire length (2% voltage drop)
engineeringtoolbox.com
Max. wire length (m)
100
10
1
1
10
100
Current (amps)
Cross sectional area (mm2)
0.75
1
1.5
2.5
4
6
10
16
25
35
50
70
95

## Hatua ya 7: Kukadiria gharama ya mfumo (TZS)

## Step 7: Estimate System Cost (TZS)

Create a “Bill of Materials” that includes all the components that will need to be purchased for the installation.

Add cost of installation labor including other costs such as travel to the location.

Add costs for project management and sales of future systems.

Include contingency costs for any unknown circumstances.

Require a deposit- earnest money to confirm the commitment of the customer.

Specify terms of payment, such as 50% when equipment is ordered and the remaining 50% due upon completion.  Specify number of days within payment is due.

| Items | Quantity | Unit Cost (TZS) | Total Cost (TZS) |
|---|---|---|---|
| Solar panel 50 Wp poly | 2 | 120,000 | TZS 240,000.00 |
| Pure sine wave inverter Victron 350VA/12V | 1 | 400,000 | TZS 400,000.00 |
| Charge controller ProSolar 20A/12V PWM Digital with LEDs | 1 | 200,000 | TZS 200,000.00 |
| Battery deep cycle GEL 40 Ah/12 V | 2 | 180,000 | TZS 360,000.00 |
| Cables, lot | 1 | 150,000 | TZS 150,000.00 |
| Installation accessories (conduit, nails, wire clips, witches, lamp holders and lamps), lot | 1 | 100,000 | TZS 100,000.00 |
| Wooden board, soft wood | 1 | 100,000 | TZS 100,000.00 |
| Metal panel pole mount (pipe and aluminium angle iron) | 1 | 200,000 | TZS 200,000.00 |
| Fuses or breakers | 2 | 10,000 | TZS 20,000.00 |
| Installation Labor | 8 | 20,000 | TZS 160,000.00 |
| Project Management | 2 | 40,000 | TZS 80,000.00 |
| | | | |
| | | | |
| | | Total | TZS 2,010,000.00 |

# Climate Technology Centre & Network
# Solar Photovoltaic Accreditation Training Program

# Module Descriptions

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

| |
|---|
| **Module 1: Introduction** |

## II. Training Details

Location (VETA Facility, Morogoro, Tanzania):

Date (month, date, year): 11/6/17

Start Time: 9:00 am Day 1

End Time: 9:30 am Day 1

## III. Total Hours and Minutes

| | |
|---|---|
| **Hours:** 0 | **Minutes:** 30 |

## IV. Number of Academic Credits or Continuing Education Credits Awarded

| |
|---|
| **CEUs:** 0.05 CEU's (1/2 hour of classroom overview with pre-exam) |

## V. Module Level (Choose one.)

☒ Introductory level (101)

☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply)

☒ Course Overview
☐ Solar Resource Assessment
☐ Photovoltaics Devices
☐ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☐ Wire Type and Size
☐ Sizing of Components (PV, battery, inverter, etc.)
☐ PV Module Inspection
☐ PV System Inspection and Commissioning
☐ Operations and Maintenance
☐ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☐ Hands on Exercise

## VII. Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

**This module introduces: Overview of the course**

Learning Objectives – Description of the objectives of the pilot course and how it will be taught

- Describe the objective of the training course. The training will focus on the off-grid solar photovoltaic and battery systems up to the size of a community center
- Describe the way the course will be delivered. Lectures will be held in the morning and hands-on activities in the afternoon.
- Participants will include technicians and students (10 technicians and 20 students)
- Technicians will be available to help with the training during the calculations and hands-on activities.

## VIII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

Instructor should be experienced with PV system design and installation, and be familiar with the worksheets and methods used in the instructional material for this course for both the lectures and the hands-on activities

## IX. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.

This Introduction module seeks to give an overview of what the course will cover and how it will be taught.

## X. Target Audience

***Describe the target audience.***

1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.
3) The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the

training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.

**Number of Students Expected to Participate:** 30

## XI. Sequence of Course Content

***Please provide an outline of the course.***

1) Objective of the training
2) Participants
3) Outline of the training course and material that will be covered
4) Training course methodology (Background & Technical Theory in the morning /Hands-on labs in the afternoon
5) Training implementation
6) Materials delivered including equipment needed for the hands-on activities
7) Translation of the slides and course will be provided in Swahili

## XII. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Power point presentation and books and information on PV fundamentals

**Facility Requirements:** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes; class-room style seating

## XIII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:** No known issues

☒ Confirm that any parameters and constraints have been rectified

## XIV. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Survey of Expertise** (to be given at the beginning of the course)

**Problem #1**
Which is a typical value of insolation (irradiance) for full-sun (no clouds) and measured perpendicular to the Sun's rays (cosine of incident angle=1)?

a. *100 W/m2*
b. *1000 W/m2*
c. *1000 kW/m2*
d. *1000 W/cm2*

*Solution:* b

**Problem #2**
What type of output current do you get from Solar panels?

a. *AC*
b. *DC*
c. *Both*

*Solution:* b

**Problem #3**
What is the major element semiconductor found in a photovoltaic (PV) cell?

a. *Hydrogen*
b. *Nitrogen*
c. *Silicon*
d. *Carbon*

*Solution*: c

**Problem #4**
What is the purpose of an inverter in an active PV system?

a. *Convert alternating current (AC) to direct current (DC)*
b. *Convert direct current (DC) to alternating current (AC)*
c. *Change the flow of electrons from positive to negative*
d. *Change the flow of electrons from negative to positive*

*Solution:* b

**Problem #5**
When PV Solar panels are added in series, what happens to voltage and current respectively?

a. *Voltage Increases and Current Remain same*
b. *Voltage Decreases and Current Increases*
c. *Voltage Remain same and Current Increases*
d. *Voltage Decreases and Current Decreases*

*Solution*: a

**Problem #6**
Which wire combination would allow me to power a device that needs 6 volts?

a. *Two 3 volt solar panels wired in parallel*
b. *Two 2 volt solar panels connected in series.*
c. *Two 3 volt solar panels wired in series*
d. *Two 2 volt solar panels connected in parallel*

Solution: c

**Problem #7**
What is the purpose of a complete PV charge controller:

a. *Controls the amount of current flowing into a battery from the PV panel*
b. *Controls the current flowing out of the battery to the load*
c. *Monitors and regulates the voltage of a battery*
d. *All of the above*

Solution: d

**Problem #8**
What is the formula for calculating Power?

a. *V x I*
b. *V ÷ I*
c. *V+ I*
d. *V – I*

Solution: a

## XV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits.

## XVI. Approval

☐ Planning Document Approved by Stakeholders (funding agency, partners, educational institution>

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

| |
|---|
| **Module 2: PV Technology** |

## II. Training Details

Location (facility name, city, state, if applicable):

Date (month, date, year): 11/6/17

Start Time: 10:00 am Day 1

End Time : 11:00 pm Day 1

## III. Total Hours and Minutes

| | |
|---|---|
| **Hours:** 1 | **Minutes:** 0 |

## IV. Number of Academic Credits or Continuing Education Credits Awarded

| |
|---|
| **CEUs:** 0.1 CEU's (1 hour of classroom instruction) |

## V. Module Level (Choose one.)

☒ Introductory level (101)

☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply.)

☐ Loads Assessment, Efficiency and Load Control
☐ Solar Resource Assessment
☒ Photovoltaics Devices
☒ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☐ Wire Type and Size
☐ Sizing of Components (PV, battery, inverter, etc.)
☐ PV Module Inspection
☐ PV System Inspection and Commissioning
☐ Operations and Maintenance
☐ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☐ Hands on Exercise

## VII. Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

**This module introduces: Principles of Solar Power; Characteristics of PV Cells and PV Module Performance**

Learning Objectives – Description of tangible objectives and activities the learner will be able to accomplish/master as a result of participation in the training module

- Describe how sunlight may be converted to electricity using the photovoltaic effect, using Silicon/Boron/Phosphorous material system as example.
- Apply elementary circuit theory (Kirchoff's Current Law and Kirchoff's Voltage Law) to explain the origin of the i-v curve (current voltage curve).
- Describe how the current and voltage characteristics change with sunlight and temperature.
- Describe how power and efficiency change with temperature
- Observe limit on open circuit voltage at lowest possible temperature
- List other types of photovoltaic devices and their efficiency; pros and cons of each
- Understand Standard Test Conditions (STC) and how to read module nameplate and data sheet
- List different rating systems other than STC such as PTC, LIC, LTC, HIC, NOCT
- Review of PV Market in terms of market volume for different technologies and which countries lead manufacturing and consumption of solar (e.g. China market)

## VIII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

Instructor should be experienced with PV system design and installation, and be familiar with the worksheets and methods used in the instructional material for this course.

## IX. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.

This module on PV Fundamentals seeks to de-mystify how photovoltaics convert sunlight into electricity and from that very description provide explanations of how the characteristics change with sunlight and temperature. There is also a need to explain that there are different types of PV technology and how they can be compared in terms of standard rating systems.

## X. Target Audience

***Describe the target audience.***

1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.
3) The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.

**Number of Students Expected to Participate:** 30

## XI. Sequence of Course Content

***Please provide an outline of the course.***

1) Semiconductor effect
2) Doping to create a positive/negative junction
3) Equivalent circuit model with voltage and current equations
4) I-v curve and how it changes with sunlight and temperature
5) Maximum voltage limits and minimum temperature
6) How efficiency and power change with sunlight and temperature
7) Standard Rating Conditions
8) How to read nameplate and data sheet for module
9) Review of PV Market Data

## XII. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Books or printed information on PV fundamentals

**Facility Requirements:** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes; class-room style seating

## XIII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:** No known issues

☒ Confirm that any parameters and constraints have been rectified

## XIV. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Please check to ensure that the course contains an assessment.**
☒ Multiple Choice Test/Quiz: 5 questions

**Problem #1**
In a Silicon Solar Cell, Boron dopant is on which side of the p-n junction:

a. *Boron is the p-type semiconductor*
b. *Boron is the n-type semiconductor*

<u>*Solution:*</u> *a*

**Problem #2**
As temperature increases, the open circuit voltage (Voc) of a PV cell:

a. *Increases linearly*
b. *Decreases linearly*
c. *Decreases exponentially*
d. *Stays the same*

<u>*Solution:*</u> *b*

**Problem #3**
As insolation Ic (W/m2) increases, current of a PV cell:

a. *Increases linearly*
b. *Increases logrithmically*
c. *Stays the same*
d. *Decreases linearly*

<u>*Solution:*</u> *a*

**Problem #4**
The voltage that a PV cell operates at depends on:

a. *The band gap of the semiconductor material*
b. *The temperature of the cell*
c. *The resistance of the load*
d. *All of the above*
e. *None of the above*

<u>*Solution:*</u> *d*

**Problem #5**

What is the specified difference between Standard Test Condition (STC) and PVUSA Test Conditions (PTC)?

*a.* *STC specified 1000 W/m2 whereas PTC specifies 800 W/m2 insolation*
*b.* *STC specifies cell temperature whereas PTC specifies surrounding air temperature*
*c.* *STC is used in government whereas PTC is used in industry applications*
*d.* *STC specifies 1 m/s wind speed whereas PTC specifies zero wind speed*

Solution: *b*

## XV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits.

## XVI. Approval

☐ Planning Document Approved by Stakeholders (funding agency, partners, educational institution>

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

| |
|---|
| **Module 0:** PV Inspections |

## II. Training Details

Location (VETA Facility, Morogoro, Tanzania):

Date (month, date, year): 11/06/17

Start Time: 11:00 am Day 1

End Time: 12:00 noon Day 1

## III. Total Hours and Minutes

| | |
|---|---|
| **Hours:** 1 | **Minutes:** 0 |

## IV. Number of Academic Credits or Continuing Education Credits Awarded

| |
|---|
| **CEUs:** 0.1 CEU's (1 hour of classroom instructions) |

## V. Module Level (Choose one.)

☒ Introductory level (101)

☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply.)

☐ Loads Assessment, Efficiency and Load Control
☐ Solar Resource Assessment
☐ Photovoltaics Devices
☐ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☐ Wire Type and Size
☐ Sizing of Components (PV, battery, inverter, etc.)
☒ PV Module Inspection
☐ PV System Inspection and Commissioning
☐ Operations and Maintenance
☐ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☐ Hands on Exercise

## VII. Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

| **This module introduces:** |
|---|
| Learning Objectives – Description of tangible objectives and activities the learner will be able to accomplish/master as a result of participation in the training module<br>▪ How to visually inspect used/new solar photovoltaic (PV) modules for major defects.<br>▪ Inspection Procedure<br>▪ Undersatnd the severity of a particular defect on performance and/or reliability of used/new solar photovoltaic (PV) modules |

## VIII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

Instructor should be experienced in identifying and explaining the major defects that occurs with solar photovoltaic (PV) modules.

## IX. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.
This module on solar photovoltaic (PV) inspection will describe the major defects that occur with modules and how to visually identify those defects. This module also provides checklist of used/new solar photovoltaic (PV) modules which will help to identify if the module is good or bad.

## X. Target Audience

***Describe the target audience.***

1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.

The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.

**Number of Students Expected to Participate:** 30

## XI. Sequence of Course Content

***Please provide an outline of the course.***

1) Why do we need inspection?
2) Terminology
3) Severity Rating
4) Inspection Procedure
5) Accept and Reject Criteria
6) Checklist: New Module
7) Checklist: Used Module
8) Catalogue Of Defects: New Modules
9) Catalogue Of Defects: Used Modules

## XII. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Books or printed information on PV Inspection.

**Facility Requirements:** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes and make calculations using worksheets; class-room style seating

## XIII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:**

☒ Confirm that any parameters and constraints have been rectified

## XIV. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Problem #1**

What is severity of Faulty Electrical Connection?

a. 1
b. 2
c. 3
d. 5

*Solution:* d

**Problem #2**
If there are any burn marks, should the module be used?

a. Yes
b. No

*Solution:* b

**Problem #3**
All used modules can also have all defects that new modules have, but the converse is not true

a. True
b. False

*Solution:* a

**Problem #4**
Does incorrect spelling on the name plate of a module affects its performance?

a. Yes
b. No

*Solution:* b

**Problem #5**
Under no conditions should a module that risks the safety of an installer or end user be considered acceptable.

a. True
b. False

*Solution:* a

## XV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits.

## XVI. Approval

☐ Planning Document Approved by Stakeholders (funding agency, partners, educational institution>

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

| |
|---|
| **Module 4: Applications of PV in Remote Areas** |

## II. Training Details

Location (VETA Facility, Morogoro, Tanzania):

Date (month, date, year): 11/7/17

Start Time: 8:00 am Day 2

End Time: 9:00 am Day 2

## III. Total Hours and Minutes

| | |
|---|---|
| **Hours:** 1 | **Minutes:** 0 |

## IV. Number of Academic Credits or Continuing Education Credits Awarded

| |
|---|
| **CEUs:** 0.1 CEU's (1 hour of classroom instruction) |

## V. Module Level (Choose one.)

☒ Introductory level (101)

☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply.)

☐ Loads Assessment, Efficiency and Load Control
☐ Solar Resource Assessment
☐ Photovoltaics Devices
☒ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☐ Wire Type and Size
☐ Sizing of Components (PV, battery, inverter, etc.)
☐ PV Module Inspection
☐ PV System Inspection and Commissioning
☐ Operations and Maintenance
☐ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☐ Hands on Exercise

### Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

| **This module introduces: The basic application of a remote stand-alone PV system and components** |
|---|
| Learning Objectives – Description of tangible objectives and activities the learner will be able to accomplish/master as a result of participation in the training module<br>▪ Give an overview of the PV stand-alone systems and how they can be used.<br>▪ Describe the different componets that make-up a PV stand-alone system.<br>▪ Provide examples of applications for PV + battery systems in remote off-grid areas<br>· Water pumping, solar lighting and health care systems<br>▪ Provide example one-line diagrams of typical off-grid and PV+battery systems |

## VII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

Instructor should be experienced with PV system design and basic components of a typical PV stand-alone system.

## VIII. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.

This module provides an overview of PV stand-alone systems and how they can be used in remote, off-grid areas.  A list of the componets is presented that are required to make up a PV + battery system along with the one-line schematic diagrams for each example application.

## IX. Target Audience

***Describe the target audience.***

1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.
3) The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.

**Number of Students Expected to Participate:** 30

## X. Sequence of Course Content

***Please provide an outline of the course.***

1) Overview of PV stand-alone system components
2) Applications of PV stand-alone systems
3) PV Water Pumping-components and one-line diagram
4) PV Solar Lighting- components and one-line diagram
5) Health care and refrigeration applications

## XI. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Power point presentation

**Facility Requirements: :** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes; class-room style seating

## XII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:** No known issues

☒ Confirm that any parameters and constraints have been rectified

## XIII. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Problem #1**
Which of the following components are found in a PV stand-alone sytem that is capable of serving AC loads?

a. *PV*
b. *Batteries*
c. *Inverter*
d. *Charge controller*
e. *All of the above*

*Solution*: e

**Problem #2**
What are examples of uses of PV stand-alone systems?

a. *lighting*
b. *cell phone charger*
c. *refrigeration*
d. *televisions and radios*
e. *all of the above*

*Solution:* e

**Problem #3**
What is the purpose of an inverter in an active PV system?

a. *Convert alternating current (AC) to direct current (DC)*
b. *Convert direct current (DC) to alternating current (AC)*
c. *Change the flow of electrons from positive to negative*
d. *Change the flow of electrons from negative to positive*

*Solution:* b

**Problem #4**
All PV stand-alone systems require batteries

a. *True*
b. *False*

*Solution:* b

## XIV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits.

## XV. Approval

☒ Planning Document Approved by Stakeholders (funding agency, partners, educational institution)

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

| |
|---|
| **Module 5: Solar Resource** |

## II. Training Details

Location (facility name, city, state, if applicable):

Date (month, date, year): 11/6/17

Start Time: 9:00 am Day 2

End Time: 10:00 am Day 2

## III. Total Hours and Minutes

| | |
|---|---|
| **Hours:** 1 | **Minutes:** 0 |

## IV. Number of Academic Credits or Continuing Education Credits Awarded

| |
|---|
| **CEUs:** 0.1 CEU's (1 hour of classroom instruction) |

## V. Module Level (Choose one.)

☒ Introductory level (101)

☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply.)

☐ Loads Assessment, Efficiency and Load Control
☐ Solar Resource Assessment
☒ Photovoltaics Devices
☒ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☐ Wire Type and Size
☐ Sizing of Components (PV, battery, inverter, etc.)
☐ PV Module Inspection
☐ PV System Inspection and Commissioning
☐ Operations and Maintenance
☐ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☐ Hands on Exercise

## VII. Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

**This module introduces: Hour Angle; Declination; Location of Sun in the Sky; Diffuse, Direct and Total Radiation; Maps and Sources of Solar Resource Data**

Learning Objectives – Description of tangible objectives and activities the learner will be able to accomplish/master as a result of participation in the training module

- Describe the spectal nature of solar radiation (ultraviolet, visible, and infrared)
- Describe the magnitude of solar radiation inside and above the atmosphere
- Describe the position of the sun in the sky as a function of time of day, day of year, and latitude
- Describe the effects of tilt and azimuth orientation of fixed tilt; one axis tracking; and two axis tracking on solar exposure of a PV module.
- Describe maps and sources of solar resource data for use in Solar Energy studies.

## VIII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

Instructor should be able to calculate sin and cosine functions; internet access will be required to access on-line solar maps and data.

## IX. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.

This module on Solar Resource explains the magnitude of the solar resource; how the position of the sun in the sky varies with time-of-day; day of year; and latitude; how the solar radiation available varies with the position of a fixed solar collector; how tracking can improve solar gains on a module; maps and sources of solar resource data.

## X. Target Audience

***Describe the target audience.***

1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.
3) The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the

training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.

**Number of Students Expected to Participate:** 30

## XI. Sequence of Course Content

***Please provide an outline of the course.***

1) Solar Spectrum
2) Hour Angle
3) Declination
4) Fixed tilt orientation
5) Tracking: single axis; dual axis
6) Solar Maps and Data

## XII. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Books or printed information on PV fundamentals

**Facility Requirements:** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes; class-room style seating

## XIII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:** No known issues

☒ Confirm that any parameters and constraints have been rectified

## XIV. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Problem #1**

Full sun measured directly toward the sun with no shade is approximately:

*a. 10 W/m2*
*b. 100 W/m2*
*c. 1000 W/m2*

*d. 10,000 W/m2*
*e. 100,000 W/m2*

<u>Solution:</u> *c*

**Problem #2**
The location of the sun in the sky depends on:

a. *Time of day*
b. *Day of Year*
c. *Latitude*
d. *None of the above*
e. *All of the above*

<u>Solution:</u> *e*

**Problem #3**
The month with the highest solar resource in Tanzania is:

a. *December*
b. *March*
c. *June*
d. *July*
e. *September*

<u>Solution:</u> *a*

**Problem #4**
The orientation of a solar panel that maximizes solar gain is

a. *Flat horizontal*
b. *South-facing vertical*
c. *Tilt=local latitude and facing toward the equator*
d. *East facing*
e. *West facing*

<u>Solution:</u> *c*

**Problem #5**
Which of the following locations in Tanzantia has the best solar resource?

a) *Iringa*
b) *Morogoro*
c) *Songia*
d) *Kigoma*
e) *Mtwara*

<u>Solution:</u> *a*

## XV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

| |
|---|
| Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits. |

## XVI. Approval

| |
|---|
| ☐ Planning Document Approved by Stakeholders (funding agency, partners, educational institution> |

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

| |
|---|
| **Module 6: PV Installation Safety** |

## II. Training Details

Location (facility name, city, state, if applicable):

Date (month, date, year): 11/7/17

Start Time: 10:30 am Day 2

End Time: 11:00 am Day 2

## III. Total Hours and Minutes

| | |
|---|---|
| **Hours:** | **Minutes:** 30 |

## IV. Number of Academic Credits or Continuing Education Credits Awarded

| |
|---|
| **CEUs:** 0.05 CEU's (.5 hour of classroom instruction) |

## V. Module Level (Choose one.)

☒ Introductory level (101)

☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply.)

☐ Loads Assessment, Efficiency and Load Control
☐ Solar Resource Assessment
☐ Photovoltaics Devices
☐ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☐ Wire Type and Size
☐ Sizing of Components (PV, battery, inverter, etc.)
☐ PV Module Inspection
☐ PV System Inspection and Commissioning
☐ Operations and Maintenance
☒ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☐ Hands on Exercise

## VII. Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

**This module introduces: Safety issues encountered in PV system design and installation: fire hazard; electrocution hazard; arc flash hazard; and falls from roofs and ladders. The module describes measures to mitigate these hazards; arc flash protection; lock out tag out.**

Learning Objectives – Description of tangible objectives and activities the learner will be able to accomplish/master as a result of participation in the training module

- Describe the hazards inherent in PV system installation and maintenance
- Describe the measures to protect personnel and property from hazards

## VIII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

Instructor should be familiar with the hazards inherent in PV system installation and maintannce and should be able to identify unexpected hazards. Instructor should be able to specify measures to mitigate hazards to protect personnel and property from harm.

## IX. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.

This module on Safety explains the hazards associated with falls from heights; fires caused by overheating wires or sparks; electrocution; arc flash. The module explains measures to be taken to mitigate the hazard and protect personnel and property from such hazards.

## X. Target Audience

***Describe the target audience.***

1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.
3) The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.

**Number of Students Expected to Participate:** 30

## XI. Sequence of Course Content

***Please provide an outline of the course.***

1) Fall from heights
2) Fire caused by sparks or overheated wires
3) Arc flash
4) Electrocution hazard and lock-out-tag-out

## XII. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Books or printed information on PV fundamentals

**Facility Requirements:** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes; class-room style seating

## XIII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:** No known issues

☒ Confirm that any parameters and constraints have been rectified

## XIV. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Problem #1**

Which of the following present hazard due to fall from heights

*a) A ladder sliding sideways against a roof eave*
*b) The bottom of a ladder kicking out from underneath it*
*c) A roof collapsing due to excessive weight*

d) *Sliding off of a wet and slippery roof*
e) *All of the above*

<u>Solution:</u> *e*

**Problem #2**
Fires due to overheaing wires may be prevented by:
a) *Dousing with water*
b) *Pack wires in dirt*
c) *Fasten wires to walls*
d) *Proper overcurrent protection (fuses and circuit breakers)*
e) *None of the above*

<u>Solution:</u> *d*

**Problem #3**
True or False: Electrocution is not possible with solar power because the current is too small

<u>Solution:</u> *False*

**Problem #4**
***Which of the following can reduce hazards at a PV workplace: Flat horizontal***
a) *A clean and orderly work area*
b) *Proper equipment and training in its use*
c) *Awareness of potential hazards and how to avoid them*
d) *Periodic reviews of safety procedures*
e) *All of the above*

<u>Solution:</u> *e*

**Problem #5**
True or False: It is OK to work on a PV system alone if you have proper safety training

<u>Solution:</u> *False*

## XV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits.

## XVI. Approval

☐ Planning Document Approved by Stakeholders (funding agency, partners, educational institution>

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

| |
|---|
| **Module 7⁚ Electrical Load Analysis** |

## II. Training Details

Location (VETA Facility, Morogoro, Tanzania):

Date (month, date, year): 11/07/17

Start Time: 11:00 am Day 2

End Time: 12:00 noon Day 2

## III. Total Hours and Minutes

| | |
|---|---|
| **Hours:** 1 | **Minutes:** 0 |

## IV. Number of Academic Credits or Continuing Education Credits Awarded

| |
|---|
| **CEUs:** 0.1 CEU's (1 hour of classroom instructions) |

## V. Module Level (Choose one.)

☒ Introductory level (101)
☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply.)

☒ Loads Assessment, Efficiency and Load Control
☐ Solar Resource Assessment
☒ Photovoltaics Devices
☐ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☐ Wire Type and Size
☐ Sizing of Components (PV, battery, inverter, etc.)
☐ PV Module Inspection
☐ PV System Inspection and Commissioning
☐ Operations and Maintenance
☐ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☒ Hands on Exercise

## VII. Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

**This module introduces:**

Learning Objectives – Description of tangible objectives and activities the learner will be able to accomplish/master as a result of participation in the training module

- Describe the basic priciples and different types of load available in the house
- Read the nameplate data of equipments
- Calculate the load estimate of the house for PV application

## VIII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

Instructor should be experienced with different types of loads, and be familiar with the worksheet for load estimation

## IX. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.

This module on electric load analysis will describe the different types of load.The participant of this module will also learn how to calculate the load required for PV stand-alone power systems

## X. Target Audience

***Describe the target audience.***

1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.

The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.

**Number of Students Expected to Participate:** 30

## XI. Sequence of Course Content

***Please provide an outline of the course.***

1) Using Energy Efficiently
2) Electrical Load Requirements
3) Refrigeration
4) Lighting
5) Calculating Load Estimates

## XII. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Books or printed information on electric load analysis

**Facility Requirements:** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes and make calculations using worksheets; class-room style seating.One or two equipments to show on how to read the nameplate data for load calaculation.

## XIII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:**

☒ Confirm that any parameters and constraints have been rectified

## XIV. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Problem #1**

Loads influence the size and cost of photovoltaic system

a. True
b. False

*Solution:* a

**Problem #2**

A ____ is the percentage of time an appliance that is "on" is actually drawing power.

a. Load
b. Duty Cycle

c. Efficiency

*Solution:* b

**Problem #3**

As a rough rule of thumb, Surge requirements ≈ Operating watts x ___

a. One
b. Two
c. Three
d. Four

*Solution:* c

**Problem #4**

A 20- watt fluorescent light is controlled by a photocell. The average daily on-time is 12 hours per day.

How many watt-hours are consumed by the light on an average day?

a. 8
b. 1.6
c. 32
d. 240

*Solution:* d

**Problem #5**

How many types of basic options of refrigeration available?

e. One
f. Two
g. Three
h. Four

*Solution:* c

## XV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits.

## XVI. Approval

☐ Planning Document Approved by Stakeholders (funding agency, partners, educational institution>

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

| |
|---|
| **Module y: Photovoltaic Electric Principles** |

## II. Training Details

Location (VETA Facility, Morogoro, Tanzania):

Date (month, date, year): 11/08/17

Start Time: 8:00 am Day 3

End Time: 9:30 am Day 3

## III. Total Hours and Minutes

| | |
|---|---|
| **Hours:** 1.5 | **Minutes:** 0 |

## IV. Number of Academic Credits or Continuing Education Credits Awarded

| |
|---|
| **CEUs:** 0.15 CEU's (1.5 hour of classroom instructions) |

## V. Module Level (Choose one.)

☒ Introductory level (101)

☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply.)

☐ Loads Assessment, Efficiency and Load Control
☐ Solar Resource Assessment
☒ Photovoltaics Devices
☐ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☐ Wire Type and Size
☐ Sizing of Components (PV, battery, inverter, etc.)
☐ PV Module Inspection
☐ PV System Inspection and Commissioning
☐ Operations and Maintenance
☐ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☐ Hands on Exercise

## VII. Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

| **This module introduces:** |
| --- |
| Learning Objectives – Description of tangible objectives and activities the learner will be able to accomplish/master as a result of participation in the training module<br>▪ Describe the basic electric principles (voltage, current, power etc)<br>▪ Understand the series and parallel configuration |

## VIII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

> Instructor should be experienced with PV + battery system design and installation, and be familiar with the worksheets for battery bank sizing.

## IX. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

> The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.
>
> This module on photovoltaic electric principles batteries will describe the basic electrical terms and formulas. The participant of this module will also learn about series and parallel configuration

## X. Target Audience

***Describe the target audience.***

> 1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
> 2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.
>
> The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.
>
> **Number of Students Expected to Participate:** 30

## XI. Sequence of Course Content

***Please provide an outline of the course.***

1) Terminology
2) Matching Appliances to the System
3) Electrical Circuits
4) Series and Parallel Circuits in Power Sources
5) Series and Parallel Circuits in Electrical Loads
6) Series and Parallel Circuits Exercises

## XII. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Books, power-point slides or printed information on fundamental of electrical

**Facility Requirements:** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes and make calculations using worksheets; class-room style seating

## XIII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:**

☒ Confirm that any parameters and constraints have been rectified

## XIV. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Problem #1**

The power a system is measured in __

a. Watts/kilo-Watts
b. Voltage
c. Current
d. Resistance

*Solution:* a

**Problem #2**
What are the two different types of current?

*Solution:* Alternating Current (AC) and Direct Current (DC)

**Problem #3**
Energy = Watt-hours (Wh) = Watts (W) x Time (Hours)

a. True
b. False

*Solution:* a

**Problem #4**
What are the advantages of series wiring?

a. High voltage
b. Need smaller wire
c. Less line losses
d. All of the above

*Solution:* d

**Problem #5**
In series connection, current remains same and voltage increases.

In parallel connection, voltage remains same and current increases.

a. True
b. False

*Solution:* a

## XV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits.

## XVI. Approval

☐ Planning Document Approved by Stakeholders (funding agency, partners, educational institution>

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

| |
|---|
| **Module ɸ: Inverters** |

## II. Training Details

Location (VETA Facility, Morogoro, Tanzania):

Date (month, date, year): 11/7/17

Start Time: 10:00 Day 3

End Time: 10:30 Day 3

## III. Total Hours and Minutes

| | |
|---|---|
| **Hours:** 0 | **Minutes:** 30 |

## IV. Number of Academic Credits or Continuing Education Credits Awarded

| |
|---|
| **CEUs:** 0.05 CEU's (1/2 hour of classroom instruction) |

## V. Module Level (Choose one.)

☒ Introductory level (101)

☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply.)

☐ Loads Assessment, Efficiency and Load Control
☐ Solar Resource Assessment
☒ Photovoltaics Devices
☐ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☐ Wire Type and Size
☒ Sizing of Components (PV, battery, inverter, etc.)
☐ PV Module Inspection
☐ PV System Inspection and Commissioning
☐ Operations and Maintenance
☐ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☐ Hands on Exercise

## VII. Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

| |
|---|
| **This module introduces: the inverter, component to convert Direct Current to Alternating Current** |
| Learning Objectives – Description of tangible objectives and activities the learner will be able to accomplish/master as a result of participation in the training module<br>▪ Describe the basic priciples of inverters and how they are used in PV stand-alone systems.<br>▪ Present an overview and background of inverters and how they are used in grid-tied systems<br>▪ Describe some of the advanced features of inverters<br>▪ Calculate the inveter size in a stand-alone PV system |

## VIII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

Instructor should be experienced with PV system design and installation, and be familiar with the worksheets for inverter sizing.

## IX. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.

This module on inverters will seek to explain how the Direct Current (DC) output from PV panels is converted to Alternating Current (AC) to operate common household appliances. The module will describe different features of inverters and how they are used both on off-grid and on-grid applications. The participant of this module will also learn how to calculate the size of an inverter for PV stand-alone power systems.

## X. Target Audience

***Describe the target audience.***

1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.
3) The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.

**Number of Students Expected to Participate:** 30

## XI. Sequence of Course Content

***Please provide an outline of the course.***

1) Operating principles of inverters
2) Inverter types
3) Inverter issues
4) Advancements in inverter arrangements
5) Advancements in inverter features
6) Inverter sizing calculations

## XII. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Books or printed information on inverter fundamentals

**Facility Requirements:** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes and make calculations using worksheets; class-room style seating

## XIII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:**

☒ Confirm that any parameters and constraints have been rectified

## XIV. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Problem #1**
What is the purpose of an inverter in an active PV system?

a. *Convert alternating current (AC) to direct current (DC)*
b. *Convert direct current (DC) to alternating current (AC)*
c. *Change the flow of electrons from positive to negative*
d. *Change the flow of electrons from negative to positive*

Solution: b

**Problem #2**
What are the 3 types of inverter classification?

a. *Grid-tied, Grid-tied for wind turbine, stand-alone inverter*
b. *Grid-tied, Grid-tied with battery backup, stand-alone inverter*
c. *Grid-tied, Off-grid, and stand-alone inverter*

Solution: b

**Problem #3**
Which of the following are types of inverter arrangements?

a. *Central inverter*
b. *Grid-tied*
c. *String inverters*
d. *Micro-inverters*
e. *DC optimizers*
f. *a,c,d,and e*
g. *All of the above*

Solution: f

**Problem #4**
True or False: Surge capacity is calculated by multiplying the peak wattage by 4.

Solution: *False*

**Problem #5**
Which of the following are types of advanced inverter features?

a. *low votage and frequency ride through*
b. *real power control functions*
c. *supply reactive power and voltage support*
d. *communications*
e. *All of the above*

Solution: e

## XV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits.

## XVI. Approval

☐ Planning Document Approved by Stakeholders (funding agency, partners, educational institution>

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

**Module 10: Photovoltaic System Wiring**

## II. Training Details

Location (VETA Facility, Morogoro, Tanzania):

Date (month, date, year): 11/09/17

Start Time: 10:30 am Day 3

End Time: 12:00 noon Day 3

## III. Total Hours and Minutes

**Hours:** 1.5 **Minutes:** 0

## IV. Number of Academic Credits or Continuing Education Credits Awarded

**CEUs:** 0.15 CEU’s (0.15 hour of classroom instructions)

## V. Module Level (Choose one.)

☒ Introductory level (101)
☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply.)

☐ Loads Assessment, Efficiency and Load Control
☐ Solar Resource Assessment
☐ Photovoltaics Devices
☐ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☒ Wire Type and Size
☐ Sizing of Components (PV, battery, inverter, etc.)
☐ PV Module Inspection
☐ PV System Inspection and Commissioning
☐ Operations and Maintenance
☐ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☒ Hands on Exercise

## VII. Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

| **This module introduces:** |
|---|
| Learning Objectives – Description of tangible objectives and activities the learner will be able to accomplish/master as a result of participation in the training module<br>▪ Calculate the wiring size in a PV stand-alone power system<br>▪ An overview of Overcurrent Protection and it's sizing<br>▪ An overview of Grounding and it's types<br>▪ An overview of Surge Supression and it's wiring |

## VIII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

Instructor should be experienced with PV system wiring and protection sizing, design and installation

## IX. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.

This module on photovoltaic system wiring describes wiring terminology and the participant of this module will learn how to size the wire based on applications. This module also gives an overview about overcurrent protection, disconnectors, and surge suppression.

## X. Target Audience

***Describe the target audience.***

1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.

The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.

**Number of Students Expected to Participate:** 30

## XI. Sequence of Course Content

***Please provide an outline of the course.***

1) Introduction
2) Wire Sizing
3) Overcurrent Protection
4) Overcurrent Protection Sizing
5) Disconnects
6) Grounding
7) Surge Suppression

## XII. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Books or printed information on PV Wiring and PV Electrical Safety

**Facility Requirements:** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes and make calculations using worksheets; class-room style seating

## XIII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:**

☒ Confirm that any parameters and constraints have been rectified

## XIV. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Problem #1**

Any material that allows electric current to pass through is called

a. Conductor

b. Insulator

*Solution:* a

**Problem #2**

Using too small diameter wire or too many wires within conduit will result in overheating and damage to the wire's protective insulation

a. True
b. False

*Solution:* a

**Problem #3**

What are the important criteria for selecting wire size?

a. Ampacity
b. Voltage drop
c. Minimum size required by codes and standards
d. All the above

*Solution:* d

**Problem #4**

For the wire run from the PV panels to the controller or battery, size the wire to accommodate: Total Amps x 1.25 x 1.25.

Where total amps=Isc x Number of modules in parallel

a. True
b. False

*Solution:* a

**Problem #5**

_______ is a device for diverting and/or diminishing of excessive current and voltage from the AC power line or PV Array wiring, which can damage sensitive electronic equipment.

a. Current
b. Voltage
c. Surge Supression

*Solution:* c

## XV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits.

## XVI. Approval

☐ Planning Document Approved by Stakeholders (funding agency, partners, educational institution>

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

| |
|---|
| **Module 11: Batteries** |

## II. Training Details

Location (VETA Facility, Morogoro, Tanzania):

Date (month, date, year): 11/09/17

Start Time: 8:00 am Day 4

End Time:  10:00 am Day 4

## III. Total Hours and Minutes

| | |
|---|---|
| **Hours:** 2 | **Minutes:** 0 |

## IV. Number of Academic Credits or Continuing Education Credits Awarded

| |
|---|
| **CEUs:** 0.2 CEU's (2 hour of classroom instructions) |

## V. Module Level (Choose one.)

☒ Introductory level (101)

☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply.)

☐ Loads Assessment, Efficiency and Load Control
☐ Solar Resource Assessment
☒ Photovoltaics Devices
☐ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☐ Wire Type and Size
☒ Sizing of Components (PV, battery, inverter, etc.)
☐ PV Module Inspection
☐ PV System Inspection and Commissioning
☐ Operations and Maintenance
☐ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☐ Hands on Exercise

## VII. Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

**This module introduces:**

Learning Objectives – Description of tangible objectives and activities the learner will be able to accomplish/master as a result of participation in the training module

- Describe the basic priciples of batteries and how they are used as storage in PV stand-alone systems.
- Introduce the different types of batteris and their specifications
- Understand Battery Safety
- Apply basic circuit theory for battery wiring configurations to include parallel and series wiring
- Calculate the battery size in a PV stand-alone power system

## VIII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

Instructor should be experienced with PV + battery system design and installation, and be familiar with the worksheets for battery bank sizing.

## IX. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.
This module on batteries will describe the basic features and types of batteries used in a PV + battery stand-alone power system. This module will describe different specifications of batteries and how they configured in off-grid applications. The participant of this module will also learn how to calculate the size of a battery bank for PV stand-alone power systems.

## X. Target Audience

***Describe the target audience.***

1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.

The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.

**Number of Students Expected to Participate:** 30

## XI. Sequence of Course Content

***Please provide an outline of the course.***

1) Battery types and features of operation
2) Battery Specifications
3) Battery Safety
4) Battery wiring configurations
5) Battery sizing calcuations

## XII. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Books or printed information on PV with batteries stand-alone power systems

**Facility Requirements:** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes and make calculations using worksheets; class-room style seating

## XIII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:**

☒ Confirm that any parameters and constraints have been rectified

## XIV. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Problem #1**

Which of the following are types of batteries used in PV systems?

- *a. Lead-acid (deep cycle) batteries*
- *b. Vented lead-acid (VLA)*
- *c. Lithium-Ion batteries*
- *d. Valve regulated Lead-acid (VRLA)*

  e. *Car batteries*
  f. *All of the above*
  g. *a,b,c, and d*

*Solution: g*

**Problem #2**
True or False: Batteries store energy in alternating current (AC) form.

*Solution: False*

**Problem #3**
True or False: Battery capacity is measured in Watt-hours (Wh)

*Solution: False*

**Problem #4**
The life expectancy of a battery is dependent on

  a. *Depth of discharge (DOD)*
  b. *Environmental conditions (increases with colder temperatures)*
  c. *Rate of discharge*
  d. *All of the above*

*Solution: d*

**Problem #5**
True or False: Batteries wired in series and parallel are similar to PV modules in that the series battery connections increases voltage and parallel battery connections increases current.

*Solution: True*

## XV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits.

## XVI. Approval

☐ Planning Document Approved by Stakeholders (funding agency, partners, educational institution>

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

| |
|---|
| **Module 12: PV Controllers** |

## II. Training Details

Location (VETA Facility, Morogoro, Tanzania):

Date (month, date, year):

Start Time: 10:30 am Day 4

End Time: 11:00 am Day 4

## III. Total Hours and Minutes

| | |
|---|---|
| **Hours:** 0 | **Minutes:** 30 |

## IV. Number of Academic Credits or Continuing Education Credits Awarded

| |
|---|
| **CEUs:** 0.05 CEU's (.5 hour of classroom instructions) |

## V. Module Level (Choose one.)

☒ Introductory level (101)

☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply.)

☐ Loads Assessment, Efficiency and Load Control
☐ Solar Resource Assessment
☒ Photovoltaics Devices
☐ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☐ Wire Type and Size
☒ Sizing of Components (PV, battery, inverter, etc.)
☐ PV Module Inspection
☐ PV System Inspection and Commissioning
☐ Operations and Maintenance
☐ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☐ Hands on Exercise

## VII. Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

| **This module introduces: The battery charge controller; component in PV + battery power system** |
|---|
| Learning Objectives – Description of tangible objectives and activities the learner will be able to accomplish/master as a result of participation in the training module<br>▪ Describe the basic priciples of battery charge controllers and how they are used in PV stand-alone systems.<br>▪ Introduce the different features of PV charge controllers<br>▪ List the main basic features recommended in a PV + battery stand-alone system.<br>▪ Calculate the PV charge controller size in a PV stand-alone power system |

## VIII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

Instructor should be experienced with PV + battery system design and installation, and be familiar with the worksheets for charge controller sizing.

## IX. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.

This module on battery charge controllers will describe the basic features on how the battery charge is controlled so as not to damage the battery. This module will describe different specifications of the charge controller and how they are used in off-grid applications. The participant of this module will also learn how to calculate the size of a charge controller for PV stand-alone power systems.

## X. Target Audience

***Describe the target audience.***

1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.
3) The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.

**Number of Students Expected to Participate:** 30

## XI. Sequence of Course Content

***Please provide an outline of the course.***

1) Features of battery charge controllers
2) Charge controller specifications
3) Charge controller sizing calculations and worksheet

## XII. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Books or printed information on PV with batteries charge controller fundamentals

**Facility Requirements:** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes and make calculations using worksheets; class-room style seating

## XIII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:** No known issues

☒ Confirm that any parameters and constraints have been rectified

## XIV. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Problem #1**

What is the purpose of a charge controller in an active PV system?

a. *To prevent reverse current from flowing into a battery*
b. *To prevent overcharging batteries*
c. *To prevent over discharging the batteries*
d. *To monitor the battery voltage*
e. *All of the above*

<u>*Solution:*</u> e

**Problem #2**
True or False: Charge controllers are only essential in PV + battery stand-alone systems

*Solution:* *False*

**Problem #3**
True or False: Maximum Power Point Tracking (MPPT) is an algorithm that is included in some charge controllers to extract the maximum amount of power from the PV modules.

*Solution:* *True*

**Problem #4**
When calculating the size of the charge controller minimum current required, the PV array's short circuit current is determined by?

a. *Multiplying the number of PV modules in series with the Isc of each module*
b. *Multiplying the number of PV modules in parallel with the Isc of each module*
c. *Multiplying the number of PV modules in parallel with the Isc of each module and multiplying by 125% safety factor*
d. *All of the above*

*Solution:* c

**Problem #5**
True or False: The Charge controller DC current rating must be greater than the maximum DC load current.

*Solution:* *True*

## XV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits.

## XVI. Approval

☐ Planning Document Approved by Stakeholders (funding agency, partners, educational institution>

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

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| **Module 13: PV and Battery System Sizing** |

## II. Training Details

Location (facility name, city, state, if applicable):

Date (month, date, year): 11/9/17

Start Time: 11:00 am Day 4

End Time: 12:30pm Day 4

## III. Total Hours and Minutes

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|---|---|
| **Hours:** 1 | **Minutes:** 30 |

## IV. Number of Academic Credits or Continuing Education Credits Awarded

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| **CEUs:** 0.15 CEU's (1.5 hours of classroom instruction) |

## V. Module Level (Choose one.)

☒ Introductory level (101)

☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply.)

☐ Loads Assessment, Efficiency and Load Control
☐ Solar Resource Assessment
☐ Photovoltaics Devices
☐ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☐ Wire Type and Size
☒ Sizing of Components (PV, battery, inverter, etc.)
☐ PV Module Inspection
☐ PV System Inspection and Commissioning
☐ Operations and Maintenance
☐ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☐ Hands on Exercise

## VII. Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

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| **This module introduces:** This module introduces simple hand calculations to estimate a recommended size for the major components of a system: PV module, charge controller, batteries, and inverter. |
| Learning Objectives – Description of tangible objectives and activities the learner will be able to accomplish/master as a result of participation in the training module<br>▪ Collect information:<br>▪ Estimate or measure load<br>▪ Get best solar resource (weather) data<br>▪ Photovoltaic capacity ($kW_{rated}$ or $m^2$)<br>▪ Inverter capacity (kW)<br>▪ Battery capacity (kWh)<br>▪ Charge controller capacity |

## VIII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

Instructor should be familiar with sources of solar resource data; means to ascertain the load for an application, and calculations for the size of system components which can adequately meet the load given the resource but no incur un-necessary cost for the customer.

## IX. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.

This module on Component Sizing describes calculations to determine the recommended size of major system components: PV array, charge controller, batteries, and inverter.

## X. Target Audience

***Describe the target audience.***

1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.
3) The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the

training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.

**Number of Students Expected to Participate:** 30

## XI. Sequence of Course Content

***Please provide an outline of the course.***

1) Collect information:
    - Estimate or measure load
    - Get best solar resource (weather) data
2) Photovoltaic capacity ($kW_{rated}$ or $m^2$)
3) Inverter capacity (kW)
4) Battery capacity (kWh)
5) Charge controller capacity

## XII. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Books or printed information on PV fundamentals

**Facility Requirements:** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes; class-room style seating

## XIII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:** No known issues

☒ Confirm that any parameters and constraints have been rectified

## XIV. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Problem #1**

The amount of energy required of a end-use per day is:

a) *Power divided by run time in hours*
b) *Power plus by run time in hours*
c) *Power minus by run time in hours*
d) *Power multiplied by run time in hours*
e) *None of the above*

*Solution:* *d*

**Problem #2**

To determine the rated power (kW) of a required photovoltaic array, the required amount of energy (alternating current) in kWh/day is divided by:

a) *The solar resource in hours-of-full-sun-per-day*
b) *The round-trip efficiency of the batteries*
c) *The efficiency of the charge controller*
d) *The efficiency of the inverter*
e) *All of the above*

*Solution:* *e*

**Problem #3**

True or False: In an off-grid application, the daily load is divided by the minimum daily resource to determine PV system component sizes.

*Solution:* *True*

**Problem #4**

Inverter efficiency is on the order of:

a) *10%*
b) *45%*
c) *65%*
d) *90%*
e) *101%*

*Solution:* *d*

**Problem #5**

True or False: Because PV modules are rated at a sunlight level of 1 kW/m2, a solar resource of 5 kWh/m2/day means that a PV module will deliver its rated capacity for 5 hours per day.

*Solution:* *True*

## XV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

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|---|
| Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits. |

## XVI. Approval

| |
|---|
| ☐ Planning Document Approved by Stakeholders (funding agency, partners, educational institution> |

# Climate Technology Centre & Network Solar Photovoltaic Accreditation Training Program - Module Description

## I. Module Sequence and Title

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|---|
| **Module 14: Commissioning** |

## II. Training Details

Location (facility name, city, state, if applicable):

Date (month, date, year): 11/10/17

Start Time: 8:00 am Day 5

End Time: 10:00 am Day 5

## III. Total Hours and Minutes

| | |
|---|---|
| **Hours:** 2 | **Minutes:** |

## IV. Number of Academic Credits or Continuing Education Credits Awarded

| |
|---|
| **CEUs:** 0.2 CEU's (2 hours of classroom instruction) |

## V. Module Level (Choose one.)

☒ Introductory level (101)

☐ Advanced level (301)

## VI. What topic(s) from the course does this module address? (Choose all that apply.)

☐ Loads Assessment, Efficiency and Load Control
☐ Solar Resource Assessment
☐ Photovoltaics Devices
☐ Photovoltaics Components and System Diagrams (batteries, charge controller, inverter, overcurrent protection)
☐ Wire Type and Size
☐ Sizing of Components (PV, battery, inverter, etc.)
☐ PV Module Inspection
☒ PV System Inspection and Commissioning
☐ Operations and Maintenance
☐ Installation and Maintenance Safety
☐ Economic Analysis/Proposal
☐ Hands on Exercise

## VII. Description and Learning Objectives

***Detailed description of the training module, including learning objectives.***

**This module introduces:** Commissioning procedures to safely bring into service a photovoltaics system.

Learning Objectives – Description of tangible objectives and activities the learner will be able to accomplish/master as a result of participation in the training module

- Safely put the plant into operation.
- Identify any deficiencies in the products or installation
- Ensure plant performs as expected.
- Prepare commissioning report.

## VIII. Instructor/Subject Matter Expert Information

***Please include instructor(s) qualifications for instruction.***

Instructor should be familiar with installation and test procedures associated with photovoltaics systems. Instructor should have experience with the kinds of problems commonly found in PV systems and how to identify and rectify them.

## IX. Needs Assessment/Analysis

***Document the reason/need for the course being offered. Course needs can include government requirements, independent analyses and reports, meeting notes, interest from potential participants, etc.***

The need for this course is to prepare installers of small, generally off-grid photovoltaic systems to spot counterfeit products and ensure quality in the design, sizing, installation and maintenance of solar electric systems.

This module on Commissioning includes descriptions of the inspections and testing required to confirm that a system has been properly installed and to safely bring the system into production. This module describes the important elements of a commissioning report.

## X. Target Audience

***Describe the target audience.***

1) The recipients will be Tanzanian youth that had/have no opportunity of attending formal VETA training on solar photovoltaic that in any case does not exist.
2) The expected education level/ entry requirements for the PV training include VETA electrician courses and this course will be aligned with VETA standards and progression through classes.
3) The level of education is primary school (standard VII) and form IV. The aim is offering employment opportunities to the youth who could not continue with formal education to the high levels. In addition, there is a great number of youth who have received training informally and are already working in the field of solar photovoltaic. Such group will have to attend the training that can be able to attend interview with VETA for accreditation when VETA starts doing so for renewable energy artisans.

**Number of Students Expected to Participate:** 30

## XI. Sequence of Course Content

***Please provide an outline of the course.***

4) Safely put the plant into operation.
5) Ensure plant performs as expected.
6) Increase efficiency and energy delivery (kWh/kW/year).
7) Decrease down-time (hours/year).
8) Extend system lifetime.
9) Reduce cost of O&M ($/kW/year).
10) Correct commissioning is required for warranty.

## XII. Equipment/Materials

***Budget Requirements***

☒ Fits within planned budget

☐ Other

***Technology Requirements***

☒ On-site facilities will provide necessary technology for a successful training event in accordance with Facility Requirements below

☐ Other

If other, please explain:

**Reference Materials for Course:** Books or printed information on PV fundamentals

**Facility Requirements:** Computer to project PowerPoint Slides; Overhead projector; student desks with pen and paper to take notes; class-room style seating

## XIII. Parameters and Constraints

**Budget Constraints:** No known issues

**Facility Constraints:** No known issues

**Legal Constraints:** No known issues

☒ Confirm that any parameters and constraints have been rectified

## XIV. Assessment Methodology (if applicable)

***An assignment and testing schedule to verify the learning objectives.***

**Problem #1**
Which of the following are involved in commissioning of a PV system:

a) *Visual Inspection*
b) *Electrical Testing*
c) *Whole-system performance testing*
d) *All of the above*
e) *None of the above*

*Solution: d*

**Problem #2**
Electrical testing includes:

a) *Open circuit voltage*
b) *Operating current*
c) *Resistance of insulation system*
d) *Resistance of grounding system*
e) *All of the above*

*Solution: e*

**Problem #3**
True or False: Commissioning is only for safety and reduce the output of a PV system

*Solution: False*

**Problem #4**
Whole-system performance testing requires the following insturments:

a) *Voltmeter*
b) *Amp (current) meter*
c) *Energy meter and pyranometer (to measure sunlight)*
d) *None of the above*
e) *All of the above*

*Solution: c*

**Problem #5**
True or False: A commissioning report should confirm that the number of PV modules actually installed matches the number of modules in the design.

*Solution: True*

## XV. Criteria for Successful Completion (if applicable)

***Describe the criteria for successfully completing the assessment and course objectives. FEMP requires 80% correct answers on all assessments.***

Students are expected to attend the entire workshop and finish the test with 80% (4/5) correct answers in order to receive a course certificate and credits.

## XVI. Approval

☐ Planning Document Approved by Stakeholders (funding agency, partners, educational institution>