Operational Manual

Energy Efficiency and Renewable Energy for Municipal Pump Station of Solomon Water

CTCN Technical Assistance Ref. 2017000039
Solomon Water- Energy Efficiency and Self-Generation Plan

OPERATIONAL MANUAL

Energy Efficiency and Renewable Energy for Municipal Pump Stations

Prepared for

Solomon Water

Under the project

Technical Assistance to Solomon Water on Energy Efficiency and Self-Generation Options

Prepared by

pwc

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Foreword

Solomon Islands 95% electricity generation is based on fossil fuels. The electricity tariff of Solomon Islands is one of the highest in the Pacific (and the World). Solomon Islands is using diesel-based electricity generators to meet its electricity requirements, this leads to higher GHG footprint. The expense towards energy consumption is more than 35% for Solomon Water. In addition, low importance is provided to efficiency in selection of equipment related to water services. Therefore, it is vital for Solomon Water to explore sustainable energy solutions that would help reducing energy consumption and contribute towards national GHG emission reduction targets

The Climate Technology Centre and Network (CTCN), the implementation arm of the United Nations Framework Convention on Climate Change (UNFCCC) Technology Mechanism, promotes the accelerated transfer of technologies for energy-efficient, low-carbon and climate-resilient development. As nations around the world seek to fulfil their development goals in an increasingly sustainable and environmentally sound manner, the CTCN aims to serve as a trusted partner by providing expert policy and technology support. At the request of National Designated Entities (NDEs), the Centre harnesses the expertise of its global network of over 400 institutions to deliver tailored assistance and capacity building in a broad range of sectors including agriculture, energy, transport, water and waste management.

In response to Solomon Islands request for technical assistance (TA) for energy efficiency and self-generation options Solomon Water in Solomon Islands, the CTCN, collaborated with Solomon Islands NDE (Climate Change Department, Ministry of Environment, Climate Change, Disaster Management and Meteorology), and other key national counterparts including the Energy Division of the Ministry of Mines, Energy and Rural Electrification, and Solomon Islands Water Authority (Solomon Water) to execute the technical assistance through PricewaterhouseCoopers (PwC), India.

We congratulate the team from PwC for putting such valuable information together in one place. We are confident that Solomon Water will take advantage of this publication and lead the sector towards sustainable and resource efficient production.

Sincerely,

Rose Mwebaza
Director, Climate Technology Centre and Network

Preface

Solomon Islands primarily uses fossil fuels to meet its electricity requirements. Solomon Water is one of the major electricity consumers in the country (~10%). The energy consumption is further expected to increase to cater the projected escalation of demand pertaining to increasing population and to reach out to un-serviced population. Considering present practices and inadequate knowledge, the level of energy efficiency in Solomon Water is quite low. The overarching goal of the technical assistance by CTCN is to create and showcase successful energy efficiency cases and providing with self-generation option, which can be implemented by Solomon Waters to reduce their GHG footprint.

PricewaterhouseCoopers (PwC) followed a systematic approach in the preparation of the manual on Energy Efficiency and Renewable Energy for Solomon Water. Detailed energy audit and renewable feasibility assessment of the 7 pump stations of Solomon Waters was conducted. The study helped in arriving at the baseline energy and performance indicators as well as in identifying energy efficiency improvements and self-generation options. The identified technology and self-generation option were further validated through consultation with sector and local experts. A two-day training programme was organized to build capacity and transfer knowledge on the findings from the study. Hands-on-training was provided to select employees of Solomon Water, who are expected to implement the proposed recommendations.

The operational manual on Energy Efficiency and Renewable Energy for Solomon Water offers comprehensive guidance to stakeholders looking to get insights in energy efficiency and renewable energy management in Municipal pump stations. The manual provides introduction to key energy performance indicators. Data management and analysis is presented in depth, followed by energy management with reference to technology, retrofits and best operating practices which is further followed by Solar rooftop systems assessment and models. The manual further describes financial analysis important for selecting energy efficiency and solar rooftop systems for implementation.

Solomon Waters and other key stakeholders such as government departments, technology suppliers and experts would find this Operational Manual on Energy and Water Management for Municipal Pump Stations useful for promoting resource efficiency.

Sincerely,

Amit Kumar
Partner, PricewaterhouseCoopers India

Acknowledgement

PricewaterhouseCoopers (PwC) expresses its sincere gratitude to Climate Technology Centre & Network (CTCN) and United Nations Industrial Development Organization (UNIDO) for vesting its confidence in PwC for carrying out this prestigious "*Technical Assistance to Solomon Water on Energy Efficiency and Self-Generation Options*". We express our sincere thanks to Mr. Rajiv Garg (Regional Manager, CTCN) and Mr. Sambit Nayak (Mitigation Specialist, CTCN) for coordinating and steering the project.

PwC is indebted to Mr. Ian Gooden, Chief Executive Officer, Solomon Island Water Authority for showing keen interest in the study and thankful to the progressive management of Solomon Water for their wholehearted support and cooperation for the technical assistance. It is well worthy to mention that the efforts being taken, and the enthusiasm shown by all the personnel towards energy efficiency was admirable. A special thanks to Mr. Mark Waite (Strategic Projects Management Advisor), Mr. Shaun Kies-Ryan (Hydrogeologist), Mr. Noel Orudiana (Project Manager) and Mr. Danny Titiri (Electrical and Mechanical Team Lead) for coordinating the field visits. We would like to thank all the staff for support including Mr. Livingston, Mr. Sam and Mr. Moffat.

We take this opportunity to express our deep appreciation for the support and guidance extended by Mr. Hudson Kauhiona, Director Climate Change (National Designated Entity), Ministry of Environment, Climate Change, Disaster Management and Meteorology, Government of Solomon Islands.

Last but not the least, our sincere thanks to Mr. Adam Searancke, Project Manager, Solomon Island Water Authority for his full cooperation and support throughout the technical assistance.

Project Background

Brief about the project

Solomon Islands comprise hundreds of islands; of these, the main islands include Honiara (capital of Solomon Islands) and provincial urban centers of Auki, Noro and Tulagi. Solomon Islands Water Authority (SW), a state-owned enterprise, is mandated to operate as the provider of municipal water and wastewater services in Solomon Islands under the SIWA Act and State-Owned Enterprise Act. SW supplies and manages water only in these four main islands. It provides water services to an estimated population of about 100,000 in Honiara and over 8,000 in the provincial centers. The municipal wastewater services are provided to about 30,000 people in Honiara.[1] The Solomon Waters body reports to Minister of Mines, Energy and Rural Electrification and to the Minister of Finance of Solomon Islands.

The expense towards energy consumption were over 35% in year 2013-14 for Solomon Water. The energy consumption is further expected to increase to cater the projected escalation of demand pertaining to the increasing population and to reach out to un-serviced population. The main source of electricity generation in the island is fossil fuel and the increase in fuel cost would directly affect the operation cost and GHG footprint of Solomon Water. This in turn put upward pressure and wrongly influence the expansion plans of its services. In addition, low importance is provided to efficiency in selection of equipment related to water services. Therefore, it is vital for Solomon Water to explore sustainable energy solutions that would help reducing energy consumption and contribute towards national GHG emission reduction targets.[2]

Objectives of the Technical Assistance

The objective of the technical assistance is to support the planning and implementation of Energy Efficiency (EE) measures and Self-Generation Options (SGO) through renewable energy to reduce the reliance of Solomon Water on fossil fuel for energy requirements. The scope of work is divided in four parts:

Assessment of Energy Efficiency and RE options

- Field visit for measurement
- Identify energy conservation opportunities
- Identify self generation options

Capacity building through on-job training for Solomon Water

- Prepare training modules and operational modules
- On-the –job hands-on-mentoring on EE and RE implementation

Detail assessments of shortlisted EE and SGO options for Solomon Water

- Technical analysis
- Financial analysis

Monitoring of impact

- Monitoring and evaluation of Impacts
- Report on Gender co-benefits

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[1] *Terms of Reference, CTCN request ref: 2017000039*
[2] *Response Plan, CTCN request ID: 2017000039*

The assistance would lead to preparation of detailed feasibility reports covering technical and economic feasibility for EE and SGO options as well as support for selection of equipment and system by preparing tender specifications for procurement of energy efficient equipment/systems and implementation by Solomon Water.

Introduction to the manual

The operational manual is one of its kind and unique to the present needs of capacity building of the employees of Solomon Water. The purpose of this operational manual is to provide all employees of Solomon Island Water Authority with a reference manual containing of basics of operations & maintenance (O&M) with respect to energy efficiency and self-generation. The prime focus of this manual is on technical staff, O&M/ Energy managers and practitioners. However, an O&M program cannot be competent without everyone at the facility being involved. It is beneficial for everyone to understand the basic principles of O&M in order to support its cause.

1

The section one of the manual covers: introduction operations and maintenance, need of operation and maintenance, types of O&M, and steps for operational efficiency excellence. In addition, this section one covers introduction to energy related data management and analysis. It presents basics of energy key performance indicator for municipal pump station.

2

The section two of the manual focuses on energy performance assessment of major equipment and systems including electrical systems, pumps and motors. The section presents potential energy efficient technologies and retrofits for municipal pump stations. Further, the section presents best operating practices and trouble-shooting guide for these equipment.

3

The section three of the manual deliberates on potential self-generation option for municipal pump station, basics of grid connected solar rooftop systems, performance monitoring and maintenance of solar rooftop systems. It covers, various business models for setting up solar rooftop systems and policy and regulatory challenges.

4

The section four of the manual is dedicated to two topics i.e. financial feasibility assessment and measurement and verification (M&V). The section presents basics of financial analysis, life cycle cost analysis, and financial assessment of energy efficiency and renewable energy projects. The M&V protocol for pumps, motors and electrical systems is elaborated in detail.

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Abbreviations

BEE	Bureau of Energy Efficiency
BOO	Build Own Operate
BOOT	Build Own Operate Transfer
Btu	British thermal unit
CD	Contract Demand
CF	Cash Flow
CFM	Cubic feet per minute
CH_4	Methane
CHP	Combined Heat and Power
CIP	Census of Industrial Production
CO_2	Carbon Dioxide
CRAFT	Climate Resilience and Adaption Finance & Technology Transfer facility
CSI	Cement Sustainability Initiative
CT	Cooling Tower
CTCN	Climate Technology Centre & Network
DG	Diesel Generator
DISCOM	Distribution Company
DPP	Discounted Payback Period
DSM	Demand Side Management
ECM	Energy Conservation Measure
EE	Energy Efficiency
EHS	Environment, Health and Safety
EMI	Equal Monthly Installment
EnMS	Energy Management System
EnPI	Energy Performance Indicator
ESCO	Energy Service Company
ESI	Energy Savings Insurance
EU	European Union
FI	Financial Institution
FY	Financial Year
GEF	Global Environment Facility
GHG	Green House Gas
GIZ	The Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GRI	Global Reporting Initiative
GWh	Giga-Watt hour
HVAC	Heating, Ventilation and Air Conditioning
Hz	Hertz
IE	International Efficiency

IFC	International Finance Corporation
IRR	Internal Rate of Return
ISO	International Organization for Standardization
kcal	Kilo calories
kgoe	Kilogram of oil equivalent
KPI	Key Performance Indicator
kVA	Kilovolt ampere
kW	Kilo Watt
kWh	Kilowatt hour
LAN	Local Area Network
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
LED	Light Emitting Diode
LPH	Liters per hour
LPM	Liters per minute
m	meter
m^3	Cubic meter
MJ	Mega-Joule
MSME	Ministry of Micro, Small and Medium Enterprises
MU	Million Units of electricity
MW	Megawatt
NASA	National Aeronautics and Space Administration
NDE	National Designated Entity
NO_x	Nitrogen Oxide
NPK	Nitrogen Phosphorus Potash
NPV	Net Present Value
OEM	Original Equipment Manufacturer
O&M	Operation and maintenance
PAT	Perform Achieve Trade
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PV	Photovoltaics
rpm	Revolution per minute
ROI	Return on Investment
SASB	Sustainability Accounting Standards Board
SBD	Solomon Dollar
SCE	Specific Carbon dioxide Emission
SCM	Standard Cubic Meter
SDG	Sustainable Development Goal
SEC	Specific Energy Consumption
SGO	Self-generation options
SIEA	Solomon Islands Electricity Authority

SIWA	Solomon Islands Water Authority
SPC	Specific Power Consumption
SPP	Simple Payback Period
SPV	Solar Photovoltaic
SW	Solomon Water
TA	Technical Assistance
tCO_2	tonne of carbon dioxide
tCO_2e	tonne of carbon dioxide equivalent
TDS	Total dissolved solids
toe	tonne of oil equivalent
TR	Ton of refrigeration
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
VFD	Variable Frequency Drive
WACC	Weighted Average Cost of Capital
WB	World Bank

1 Introduction and Basics

1. Introduction and basics

1.1. Introduction to operation and maintenance

This chapter on operations and maintenance (O&M) will provide (O&M)/Energy managers and practitioners at Solomon Waters with useful information about O&M management, technologies, energy efficiency, and cost-reduction approaches.

Good maintenance practices in a facility can generate substantial energy savings in the facility. They can be accomplished immediately and very at low costs given there is proper cooperation, dedication and participation from everyone involved.

*Operations and Maintenance are the **decisions and actions** regarding the control and upkeep of property and equipment.*

These are inclusive, but not limited to, the following:

1. actions focused on scheduling, procedures, and work/systems control and optimization; and
2. performance of routine, preventive, predictive, scheduled and unscheduled actions aimed at preventing equipment failure or decline with the goal of increasing efficiency, reliability, and safety.

Operational Efficiency represents the lifecycle, cost-effective mix of preventive, predictive, and reliability-centered maintenance technologies, coupled with equipment calibration, tracking, and computerized maintenance management capabilities all targeting reliability, safety, occupant comfort, and system efficiency[3].

1.2. Why operation and maintenance?

Effective operation and maintenance is one of the most cost-effective methods for ensuring reliability, safety, and energy efficiency. Inadequate maintenance of the energy systems in a facility eventually leads to drop in efficiency and energy losses. The performance of any equipment or system deteriorate over its life. A good O&M practice can not only improve performance but also extend the service life of the equipment or system, same is depicted in **Figure 1**[3].

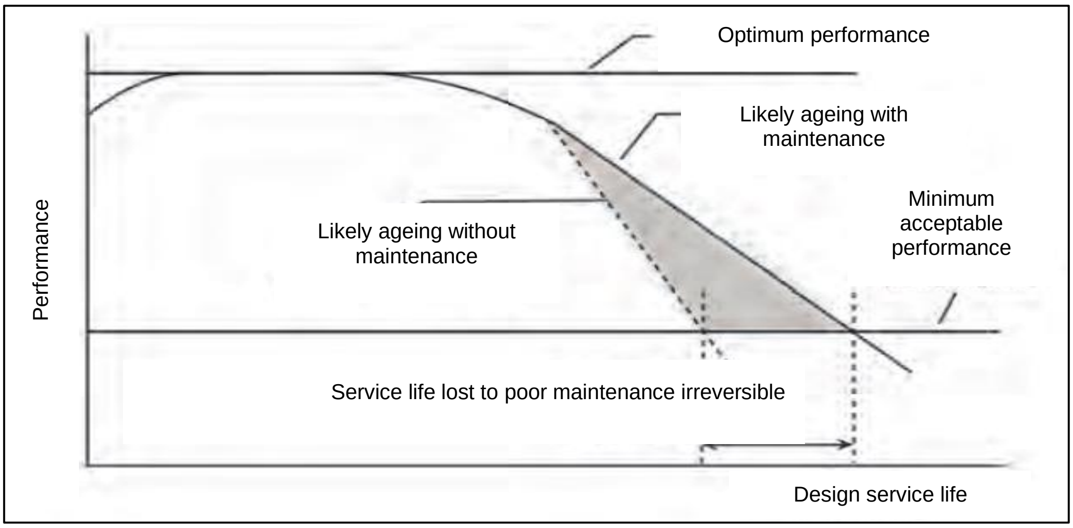


Figure 1 Operation & maintenance practice

[3] *Source: Operations & Maintenance Best Practices, US Dept. of Energy*

Figure 1 takes the case of a building wherein the performance of the components of building is degrading gradually with time. The two scenarios are elaborated, one where the building undergoes proper maintenance schedules and the other where it doesn't. The graph shows how the building has achieved prolonged life with the help of proper maintenance. This will also lead to reduced operating costs and increased operating life of the various electrical equipment's installed in the building (such as lighting, HVAC, ventilation, etc.).

O&M practices which target energy efficiency in their facilities can nearly save 5% to 20% of their total energy consumption. This is done by just applying good O&M practices with no significant capital investments. These practices lead to lowering of energy consumption which in turn ensures monetary savings. These savings on energy bills can range from hundreds to thousands of dollars depending upon the size of the site. A case example of O&M in government building is presented in **Box 1**.

Box 1: O&M of Government Building – Case Example

A demonstration focused on O&M-based energy efficiency was conducted at a government building. A significant component to this demonstration was metering and the tracking of steam use in the building. Within several months, $250,000 per year in steam leaks were found and corrected. These included leaks in a steam converter and steam traps. Because the building was not metered for steam and there was not a proactive O&M program, these leaks were not detected earlier, nor would they have been detected without the demonstrating. The key lessons learned from this example were:

- O&M opportunities in large buildings/facilities do not have to involve complex engineering analysis.
- Many O&M opportunities exist because building operators may not have proper documentation that hindered day-to-day actions.
- Involvement and commitment by building administrators is a key ingredient for a successful O&M program.

The failure rate over the time is explained by "*bathtub*" curve[3] (**Figure 2**). The initial infant mortality period of bathtub curve is characterized by high failure rate followed by a period of decreasing failure. Many of the failures associated with this region are linked to poor design, poor installation, or misapplication. The infant mortality period is followed by a nearly constant failure rate period known as useful life. There are many theories on why components fail in this region, most acknowledge that poor O&M often plays significant role.

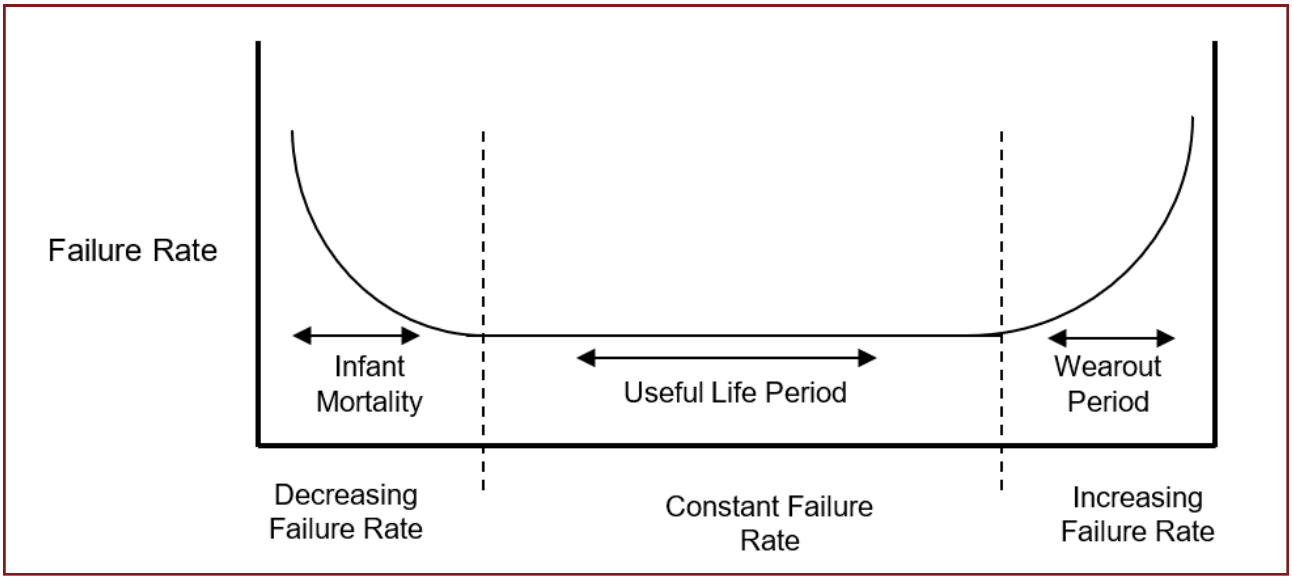


Figure 2 Component failure rate over time for component population

Management of O&M program in a manner that it binds the distinct functions of the program into one cohesive entity is a critical component. The five distinct functions involved in the program are explained in **Figure 3**.

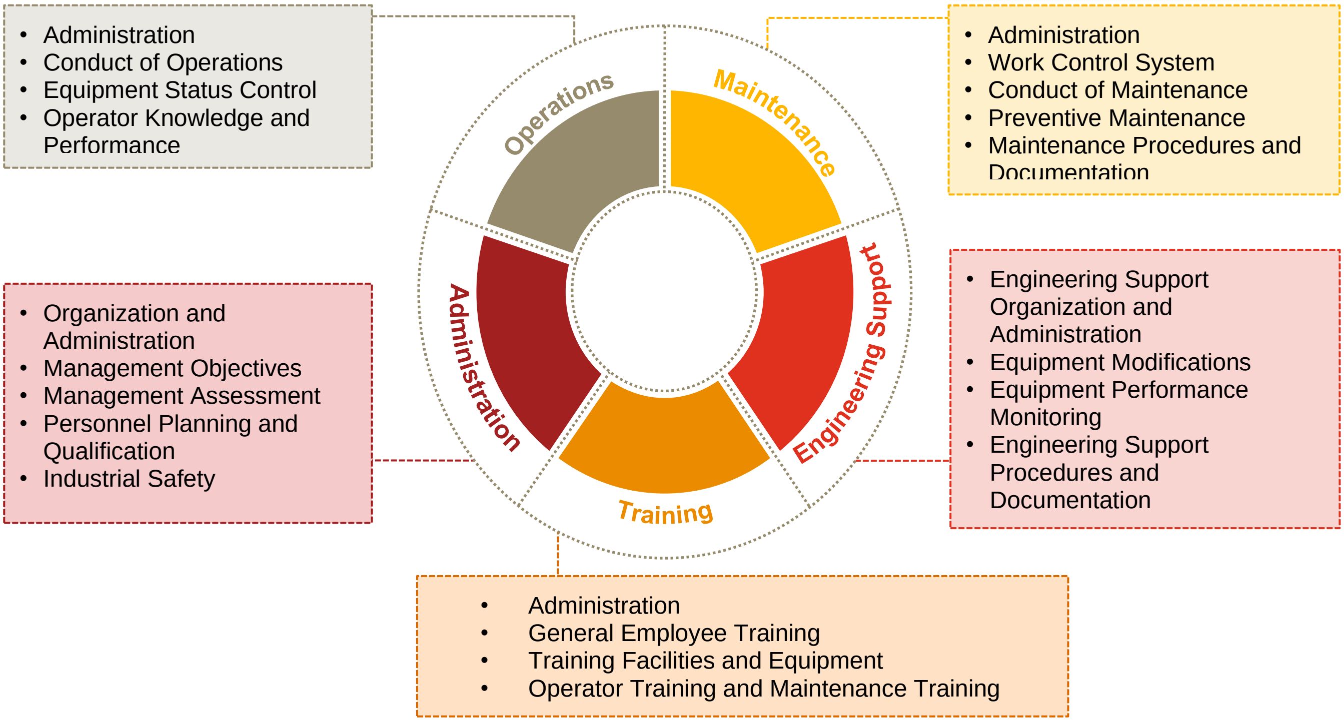


Figure 3 Components of O&M

1.3. Types of maintenance

Maintenance in simple terms is defined as the work done to keep something in proper condition. In most cases, facilities fail to undertake proper maintenance activities for their equipment. Privately or Government owned facilities are unwilling to spend necessary resources to maintain the equipment in proper working order. Rather, these facilities wait for equipment failure and then take necessary actions to keep operating.

Maintenance is predicated on actual or impending failure of the equipment. Without proper maintenance, equipment may not even operate efficiently for their design life. In case of pumping stations, regular maintenance of pumps will not only keep the pump operating at its best efficiency but may also increase its life.

In order to keep most equipment working efficiently proper maintenance is a necessary act that needs to be performed. Belts need to be adjusted, alignment needs to be checked, proper oiling on rotating motors and equipment is required, and so on. In some cases, certain components in an equipment need replacement, (e.g. impeller of a pump) to make sure that major equipment (in this case a pump) lasts for its design life. Failing to perform regular maintenance activities will only shorten the design life of the equipment. Maintenance can be classified into 4 categories, as shown in **Figure 4**.

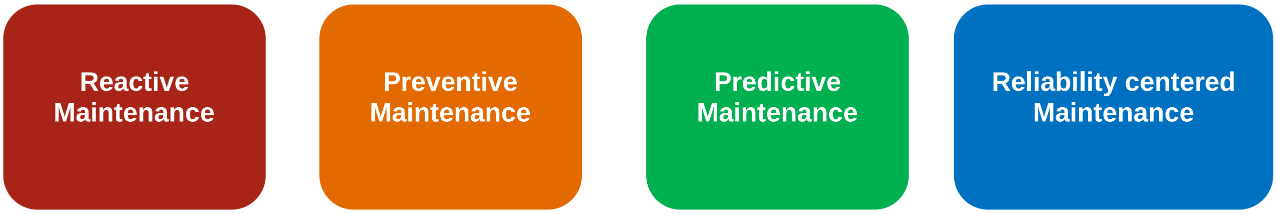


Figure 4 Types of maintenance

1.3.1. Reactive maintenance

Reactive Maintenance is the ‘run it till it breaks’ kind of maintenance mode. The designer of the equipment intends the product to run its full design life cycle without regular and scheduled maintenance. There are more disadvantages than advantages to a purely reactive maintenance program.

Initial stage for this type of maintenance, the facility owner will be saving on manpower costs or any capital costs until anything breaks. Since there are no maintenance costs involved, the facility owner will initially be saving money. In reality, the facility owner, while waiting for the equipment to break is shortening the life of the equipment. This means there will be more frequent replacements of the equipment, hence higher capital expenditure by the facility owner. There will be cases where failure of a single piece of component in a facility will lead to failure of a high cost component in an equipment. Such cases shall not occur if the maintenance of the equipment is more pro-active. Moreover, labor costs for repair will be much higher because the failure will require much more extensive repairs than have been required if the piece of equipment had not been run to failure Advantages and disadvantages of reactive maintenance are mentioned below.

+ Advantages	Limitations −
Low Cost Low staff	Increased cost due to unplanned downtime of equipment. Increased labor cost, especially if overtime is needed. Cost involved with repair or replacement of equipment. Possible secondary equipment or process damage from failure. Inefficient use of staff resources

1.3.2. Preventive maintenance

Preventive maintenance can be defined as schedule-based maintenance done in order to detect, preclude, or mitigate degradation of a component or system within a facility with the overall outcome of sustaining or extending its operating life by controlling degradation to an acceptable level.

Preventive maintenance has its edge over reactive maintenance in a manner that by performing preventive maintenance as the manufacturer has suggested. This will ensure the equipment to reach its design life, resulting in less frequent repairs and replacements. Preventive maintenance (such as lubrication, filter change) will enable equipment to perform more efficiently over its operating life, meaning energy and monetary savings. Minimizing failures in turn translate into and capital cost savings. Some of the advantage and limitations of preventive maintenance are shown below.

+ Advantages	Limitations −
Cost effective in many capital-intensive processes Flexibility on adjustment of maintenance periodicity Increased component life cycle Energy savings Reduced equipment or process failure ~10 – 18% cost savings over reactive maintenance	Catastrophic failures still likely to occur. Labor intensive. Includes performance of unneeded maintenance. Potential for incidental damage to components in conducting unneeded maintenance

1.3.3. Predictive maintenance

Predictive maintenance can be defined as follows: Measurements that detect the onset of system degradation (lower functional state), thereby allowing causal stressors to be eliminated or controlled prior to any significant deterioration in the component physical state.[3]

In simpler terms, predictive maintenance differs from preventive maintenance by basing the maintenance needs of the equipment on its current operating state rather than going by some preset schedule. Further it can be explained by considering a simple example of a car. A car owner will get his oil changed after every 10,000km travelled irrespective of the oil and lubricant condition, because its time. Another car owner gets his oil and lubricants checked at certain periodicities to determine its actual condition and is able to extend the oil change after around 15,000km. Former car owner is the simple case of preventive maintenance and the latter defines predictive maintenance Some advantages and limitations of predictive maintenance are given below.

Advantages	Limitations
Increased component operational life/availability Allows for preemptive corrective actions Decrease in equipment or process downtime Decrease in costs for parts and labor Improved worker and environmental safety Improved worker morale Energy savings ~8 – 12% cost savings over preventive maintenance	Increased investment in diagnostic equipment. Increased investment in staff training. Savings potential not readily seen by management

1.3.4. Reliability Centered maintenance

Reliability Centered Maintenance recognizes that all equipment present in the facility is not of equal importance to the system or the process in the facility. It has an edge over the other maintenance programs as it recognizes that equipment design and operation is different. Resources and personnel available at a facility are limited and the maintenance program needs to be structured in the most efficient way possible.

Reliability Centered Maintenance can in simpler terms is a systematic approach which evaluates the resources available with the facility and facility's equipment in a manner that it best utilizes the resources available at hand leading to higher cost effectiveness and reliability. This type of maintenance is highly reliant on predictive maintenance, but it also recognizes the fact that certain equipment which are inexpensive and do not contribute much to the process may best be left to reactive maintenance. Some of the advantages and limitations of reliability centered maintenance are presented below.

Advantages	Limitations
Can be the most efficient maintenance program Eliminating unnecessary maintenance or overhauls Minimize frequency of overhauls Reduced probability of sudden equipment failures Able to focus maintenance activities on critical components Increased component reliability Incorporates root cause analysis	Can have significant startup cost, training, equipment, etc. Savings potential not readily seen by management.

A representative maintenance priority matrix for the reliability centric maintenance is presented in **Table 1.** Reliability centric maintenance element application can be divided and categorized into reactive, preventive and predictive element applications. A distinctive reliability centered maintenance element applications hierarchy is presented in **Table 2.**[4]

[4] *NASA. 2000. Reliability Centered Maintenance Guide for Facilities and Collateral Equipment. National Aeronautics and Space Administration, Washington, D.C.*

Table 1 Sample priority matrix for reliability centric maintenance

Weighting	Description	Application
1	Emergency	Life, health, safety risk-mission criticality
2	Urgent	Continuous operation of facility at risk
3	Priority	Mission support/project deadlines
4	Routine	Prioritized: first come/first served
5	Discretionary	Desired but not essential
6	Deferred	Accomplished only when resources allow

Table 2 Reliability centered maintenance element applications

Reliability Centered Maintenance Hierarchy		
Reactive Element Applications	Preventive Element Applications	Predictive Element Applications
Small parts and equipment	Equipment subject to wear	Equipment with random failure patterns
Non-critical equipment	Consumable equipment	Critical equipment
Equipment unlikely to fail	Equipment with known failure patterns	Equipment not subject to wear
Redundant systems	Manufacturer recommendations	Systems which failure may be induced by incorrect preventive maintenance

1.3.5. Predictive maintenance technologies

Predictive maintenance attempts to detect the commencement of a degradation mechanism with the goal of correcting that degradation prior to significant deterioration in the equipment, component and/or system. Several predictive maintenance technologies are available in market with onset of breakthrough in sensor and information technology. It is important to identify relevant predictive maintenance technologies for a facility or equipment or system.

Training is of prime importance as the predictive maintenance technologies have become increasingly sophisticated and technology driven. The facility may decide to buy the technology for in-house use. However, a detailed cost benefit analysis must be carried out on the investment as some these technologies are expensive. On contrary, the facility may seek to contact outside vendors for specific equipment or systems.

Common predictive maintenance technologies for applications in municipal pump stations are presented in **Table 3**. These technologies cover major equipment and systems such as pumps, motors and electrical systems. This is an indicative list; proper application analysis and system knowledge is necessary to choose appropriate predictive maintenance technology for any facility.

Table 3 Common predictive technology applications

Technologies	Description	Pumps	Electrical motors	Electrical Systems
Vibration Monitoring/Analysis	Vibration monitoring is the process of monitoring machinery to identify vibrations which may indicate a developing failure, malfunction, or process restriction. It primarily applies to machinery that rotates such as pumps, motors, turbines, fans and compressors	Yes	Yes	No
Lubricant, Fuel Analysis	Lubricant/oil analysis is a routine activity for analyzing oil health, oil contamination and machine wear. The purpose of this analysis is to verify that a lubricated machine is operating according to expectations	Yes	Yes	No
Wear Particle Analysis	Wear particle analysis is a powerful technique for non-intrusive examination of oil-wetted parts of a machine. ... The particle characteristics are sufficiently specific so that the operating wear modes within the machine may be determined, allowing prediction of the imminent behavior of the machine	Yes	Yes	No
Bearing, Temperature/Analysis	Trending bearing temperatures over time will help identify the early stages of failure. The most common tools for doing this include thermocouples and resistance temperature detectors (RTDs)—both of which can be permanently mounted to locations on the bearing housing for continuous monitoring.	Yes	Yes	No
Performance Monitoring	Use of energy audit instrument such as ultrasonic water flow meter, three-phase power analyzer and pressure gauge.	Yes	Yes	No
Ultrasonic Noise Detection	Ultrasonic testing (UT) is an NDT test technique that interrogates components and structures to detect internal and surface breaking defects and measures wall thickness on hard (typically metallic or ceramic) components and structures.	Yes	Yes	No
Ultrasonic Flow	Ultrasonic flowmeters use sound waves to determine the velocity of a fluid flowing in a pipe. At no flow conditions, the frequencies of an ultrasonic wave transmitted into a pipe and its reflections from the fluid are the same. Under flowing conditions, the frequency of the reflected wave is different due to the Doppler effect. When the fluid moves faster, the frequency shift increases linearly. The transmitter processes signals from the transmitted wave and its reflections to determine the flow rate.	Yes	No	No

Technologies	Description	Pumps	Electrical motors	Electrical Systems
Infrared Thermography	Infrared thermography is the science of detecting infrared energy emitted from an object, converting it to apparent temperature, and displaying the result as an infrared image	Yes	Yes	Yes
Visual Inspection	Visual inspection is assessing the utilities in its environment by looking at it	Yes	Yes	Yes
Insulation Resistance	The insulation resistance is the resistance in ohms of wires, cables and electrical equipment. It is important to guard against electric shocks and avoid equipment damage from accidental discharges. The method of measuring the insulation resistance is to test and assess the state of the isolation (head and body.)	No	Yes	Yes
Motor Current Signature Analysis	Motor electrical current signature analysis (MCSA) is sensing an electrical signal containing current components that are direct by-product of unique rotating flux components. Anomalies in operation of the motor modify harmonic content of motor supply current	No	Yes	No
Motor Circuit Analysis	Motor Circuit Analysis is a simple 2-minute test that gives you a complete picture of your entire motor system's electrical health whether used for trouble-shooting or predictive maintenance.	No	Yes	Yes
Polarization Index	Polarization index (PI) testing is an extension of the insulation resistance test and is designed to check specific issues in a motor such as moisture and insulation deterioration	No	Yes	Yes
Electrical Monitoring	Electrical monitoring is used in a facility to measure the electrical consumption and its trend. It can be used to control and manage power consumption by facilities by carrying out different analytical tests from the electrical data.	No	No	Yes

1.4. O&M benchmarks

The philosophy of benchmarking is one of continuously and objectively seeking improvement[5]. Benchmarking is the practice of comparing performance metrics of an industry or sector or equipment against certain reference point, most often the industry/sector bests and best practices. Key performance indicators (KPI) are decision-making and monitoring tools, used to track performance of equipment and systems. Benchmarks and KPIs are used to identify opportunities for improving performance.[6] KPI and benchmarking analysis helps in:

Reduce costs | **Improve efficiency** | **Improve service** | **Save energy**

Some of the important operation & maintenance metrics and benchmarks are presented in **Table 4**.

Table 4 O&M benchmarks[3]

Metric	Variables and equation	Benchmark
Equipment availability	$\% = \frac{Hours\ each\ unit\ is\ available\ to\ run\ at\ capacity}{Total\ hours\ during\ the\ reporting\ time\ period}$	> 95%
Schedule compliance	$\% = \frac{Total\ hours\ worked\ on\ scheduled\ jobs}{Total\ hours\ scheduled}$	> 90%
Emergency maintenance percentage	$\% = \frac{Total\ hours\ worked\ on\ emergency\ jobs}{Total\ hours\ worked}$	< 10%
Maintenance overtime percentage	$\% = \frac{Total\ maintenance\ overtime\ during\ period}{Total\ regular\ maintenance\ hours\ during\ period}$	< 5%
Preventive maintenance completion percentage	$\% = \frac{Preventive\ maintenance\ actions\ completed}{Preventive\ maintenance\ actions\ scheduled}$	> 90%
Preventive maintenance budget/cost	$\% = \frac{Preventive\ maintenance\ cost}{Total\ maintenance\ cost}$	15 – 18%
Predictive maintenance budget/cost	$\% = \frac{Predictive\ maintenance\ cost}{Total\ maintenance\ cost}$	10 – 12%

1.5. Steps for operational efficiency excellence

The quality of operation and maintenance in a utility depends on various internal factors and policies. Operational excellence can be achieved when all these internal factors, policies and protocols are strictly followed by everyone involved. Operational excellence is a state of optimal performance by the utility, performing in its most efficient and cost-effective state.

Table 5 presents ten steps for operational excellence, which is an approach if followed can help Solomon Water achieve operational excellence.

[5] *Operation & Maintenance Benchmarking, https://www.bsria.com/uk/news/article/operation-maintenance-benchmarking-outputs-for-the-year/*
[6] *The Different Types of Benchmarking – Bernard Marr & Co. https://www.bernardmarr.com/default.asp?contentID=1753*

Table 5 Steps for operational efficiency excellence

Step 1: Strive to increase management awareness and appreciation of the operations and maintenance program / department.

- Consider developing a maintenance mission statement and requesting/requiring management sign-off.
- Consider developing a maintenance plan and requesting/requiring management sign-off.
- Begin the development of the OMETA linkages.
- Develop key points of contact within other departments that can participate in the O&M mission.

Step 2: Commit to begin tracking Operations and Maintenance activities

- Need to understand where O&M time is spent.
- Need to understand where O&M dollars are spent.
- Consider (strongly) purchasing or enhancing a Computerized Maintenance Management
- System and commit to its implementation and use.

Step 3: Through tracking begin to identify your troubled equipment and systems.

- Make a list of these systems and prioritize them

Step 4: Commit to addressing at least one of these troubled systems.

- Begin base lining/tracking this system.
- System operations and history.
- System maintenance and history.
- System costs, time to service, downtime, resulting overtime, etc.

Step 5: Commit to striving for Operational Efficiency of this system

- Strive to understand how to properly operate this system.
- Define and complete operator training needs.
- Strive to understand how to properly maintain this system.
- Define and complete maintenance training needs.

Step 6: Commit to purchasing or contracting for some form(s) of diagnostic, metering, or monitoring equipment.

Step 7: Commit to trending the collected tracking and diagnostic data

- Take to time to understand the data.
- Look for and develop "project opportunities."
- Develop appropriate cost justification metrics.

Step 8: Select, request funding for, and complete first "Operational Efficiency" project.

- Start small, pick a project that will be a winner.
- Carefully document all findings.
- Present success in terms management will understand

Step 9: Strive to highlight this success – capitalize on visibility opportunities

- Consider writing an internal success story/case study.
- Submit finding to trade publication or industry conference.

Step 10: Commit to choosing the next piece of equipment...go to Step 3.

1.6. Data management and analysis

Data consists of the basic structure for which information is created. ***Management*** is the orchestration of processes intended to carry out a task[7]. ***Data Management*** is the process of proactively reviewing and evaluating the data and its quality to ensure that it is fit for purpose[8]. ***Data analysis*** is a process of inspecting, cleansing, transforming, and modeling data with the goal of discovering useful information, informing conclusions, and supporting decision-making[9]. Data monitoring saves the organization time and money that would otherwise be spent to check and transform data before it is moved. Data monitoring promotes business agility because new initiatives involving data can be undertaken immediately without a time-consuming data preparation phase[10].

Metering of data is a technique used to monitor and collect certain data over a specified period of time. Data metering can be manual or automatic. ***Smart meters*** typically records consumption data and communicates the information to user either via. Local area network (LAN) or wirelessly. Data monitoring and analysis plays a crucial role and establishing the EnPIs/KPIs and achieving targets of improvement.

1.6.1. Analysis of energy consumption

Energy monitoring and targeting is primarily a management technique that uses energy information as a basis to eliminate waste, reduce and control current level of energy use and improve the existing operating procedures. It builds on the principle "you can't manage what you don't measure". It essentially combines the principles of energy use and statistics. The essential elements of monitoring and targeting system are presented in **Table 6**[11].

Table 6 Elements of monitoring and targeting

Parameter	Description
Recording	Measuring and recording energy consumption
Analyzing	Correlating energy consumption to a measured output, such as production quantity
Comparing	Comparing energy consumption to an appropriate standard or benchmark
Setting targets	Setting targets to reduce or control energy consumption
Monitoring	Comparing energy consumption to the set target on a regular basis
Reporting	Reporting the results including any variances from the targets which have been set
Controlling	Implementing management measures to correct any variances, which may have occurred
Checking	Accuracy of energy invoices
Allocating	Energy costs to specific departments
Determining	Energy performance/efficiency
Recording	Energy use, so that projects intended to improve energy efficiency can be checked
Highlighting	Performance problems in equipment or systems

[7] *What is Data Management? - Definition & Tools, Katherine Wenger, PhD, https://study.com*
[8] *Data Monitoring, https://www.edq.com/glossary/data-monitoring/*
[9] *Xia, B. S., & Gong, P. (2015). Review of business intelligence through data analysis. Benchmarking, 21(2), 300-311*
[10] *What is Data Monitoring? https://www.informatica.com/in/services-and-training/glossary-of-terms/data-monitoring-definition.html#fbid=66ipsJLg18w*
[11] *Energy monitoring and targeting, Guidebook 1, Bureau of Energy Efficiency*

1.6.1.1. *Electricity bill analysis*

The electricity bill analysis consists of understanding concepts of the electricity bill (explained in previous section) and review of energy consumption profile. Three most important parameters to be analysed are electricity consumption profile, maximum demand v/s contract demand and power factor profile. Sample analysis of the three parameters is presented below.

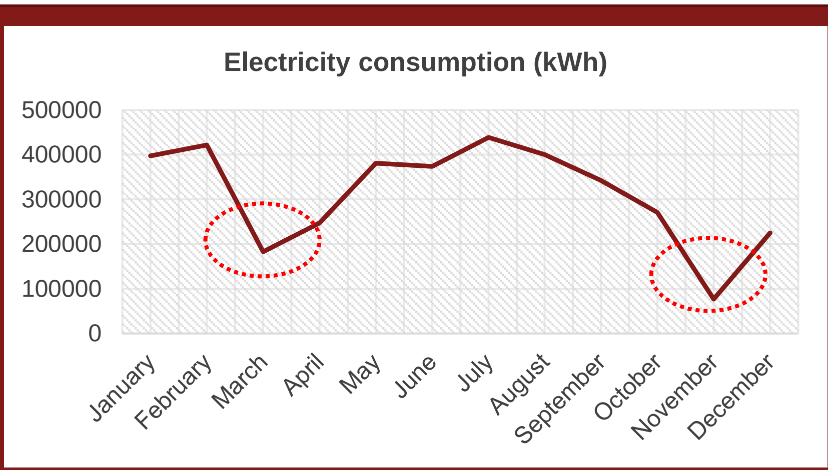


Illustration of monthly electricity consumption profile and variation in consumption.

It clearly shows the production in month of March and November was quite low

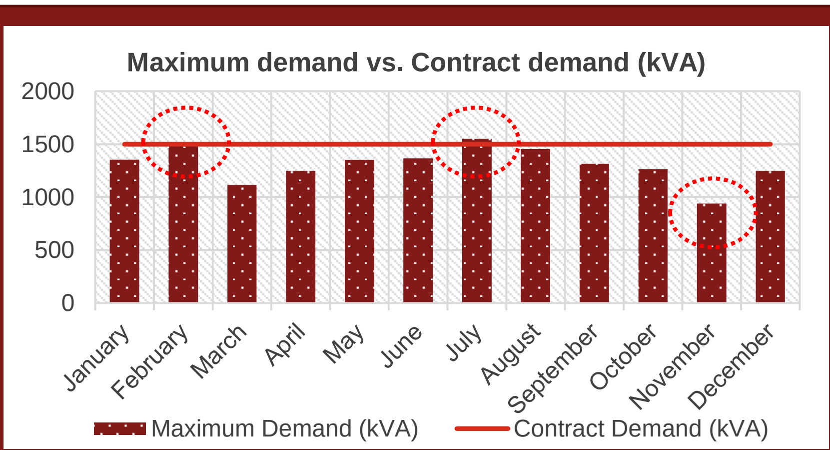


Illustration of monthly maximum demand vs. contract demand.

It can be seen in February & July the maximum demand has shot beyond contract demand whereas in November its less than 75% of CD

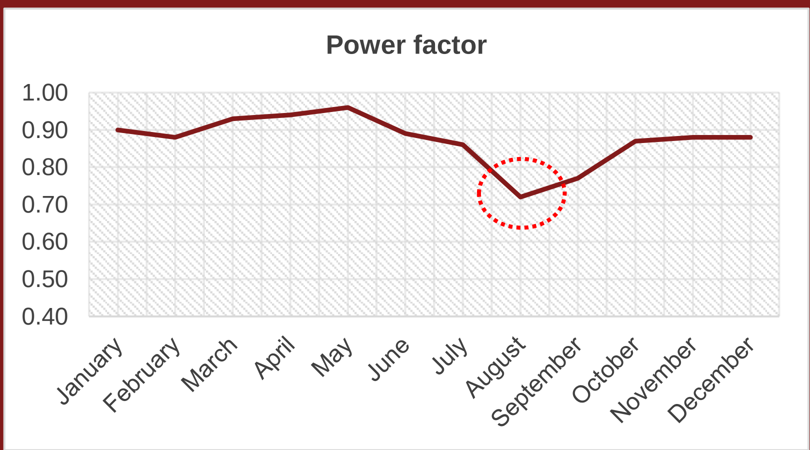


Illustration of monthly power factor of the industry.

The average power factor is 0.87. A good power factor is above 0.95 (ideally unity)

1.6.1.1. Energy tariff in Solomon Islands

The electricity tariff in Solomon Islands is one the most expensive in not just in Pacific but in the entire World. The typical pump stations of Solomon Water receive power from 415 V (volt) low tension industrial I3 connection of Solomon Island Electricity Authority (SIEA). The electricity tariff is three-part type, which are (a) Network access changes – NAC, (b) Fuel charge and (c) Non-fuel charges. The tariff varies every month. The basic tariff details of electricity for Solomon Water (average of last 12 months) are presented in **Table 7**.

Table 7 Energy source, availability and tariff details in Solomon Islands

Sr. No.	Energy Source	Availability	Tariff details
1	Electricity	Solomon Islands Electricity Authority	Connection type: Industrial / I3 NAC charge: SDB 3316 / month Fuel charge: SBD 2.65 / kWh I1 non-fuel charge: SBD 3.70 / kWh (up to first 1300 kWh) I2 non-fuel charge: SBD 3.18 / kWh (next 4700 kWh) I3 non-fuel charge: SBD 2.83 / kWh (remaining consumption) Average electricity charge: SBD 5.6 / kWh
2	Diesel	South Pacific Oil / Markwarth Oil Limited / Silent World	SBD $ 7 / /Litre

Average electricity tariff for Solomon Water is about SBD 5.6 per unit which is equivalent to US $ 0.68. The average electricity tariff in United States of America is US $ 0.12 per unit. It is substantially high in comparison with island nation such as Mauritius, where the average electricity tariff is US $ 0.16 per unit. This suggests need and importance of energy efficiency and self-generation to cut GHG footprint.

1.6.1.2. Specific energy consumption

The energy consumption is absolute quantity, it cannot be used as an index of comparison. The specific energy consumption is defined as energy consumption per unit of production i.e. cubic meter of water pumped or produced. The specific energy consumption (SEC) reveal interesting information for data analysis. Typically, SEC variation within one standard deviation range is acceptable. The specific consumption helps in evaluation of the performance of a facility by comparison with indicators.

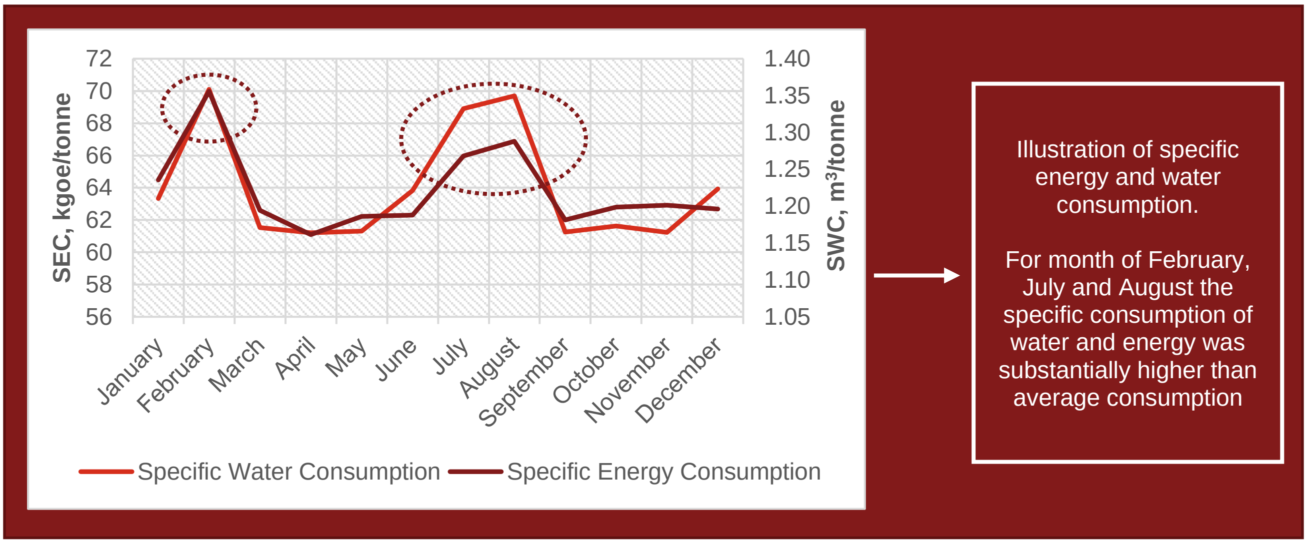
A sample energy consumption and production profile analysis for one of the Solomon Water municipal pump stations is presented in **Table 8**.[12]

Table 8 Sample specific energy consumption

Particular	Unit	Value
Energy consumption	kWh/day	789
Water production	m^3/day	1,591
Specific energy consumption	**kWh/m^3**	**0.496**
Specific energy cost	**SBD/m^3**	**2.78**

[12] *Detailed feasibility study, PwC Analysis part of Technical Assistance*

An illustration of variation in specific energy and water consumption of an industry against its production is presented below. The SEC data analysis clearly shows two months when the SEC is substantially higher. This would help management is further scrutinizing the data and arriving at root cause for a drop-in efficiency.



A detailed feasibility energy study is important step in effective management and use of the energy. A detailed energy audit is defined as the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption. The purpose/benefits of a detailed feasibility energy study is presented in **Figure 5**.

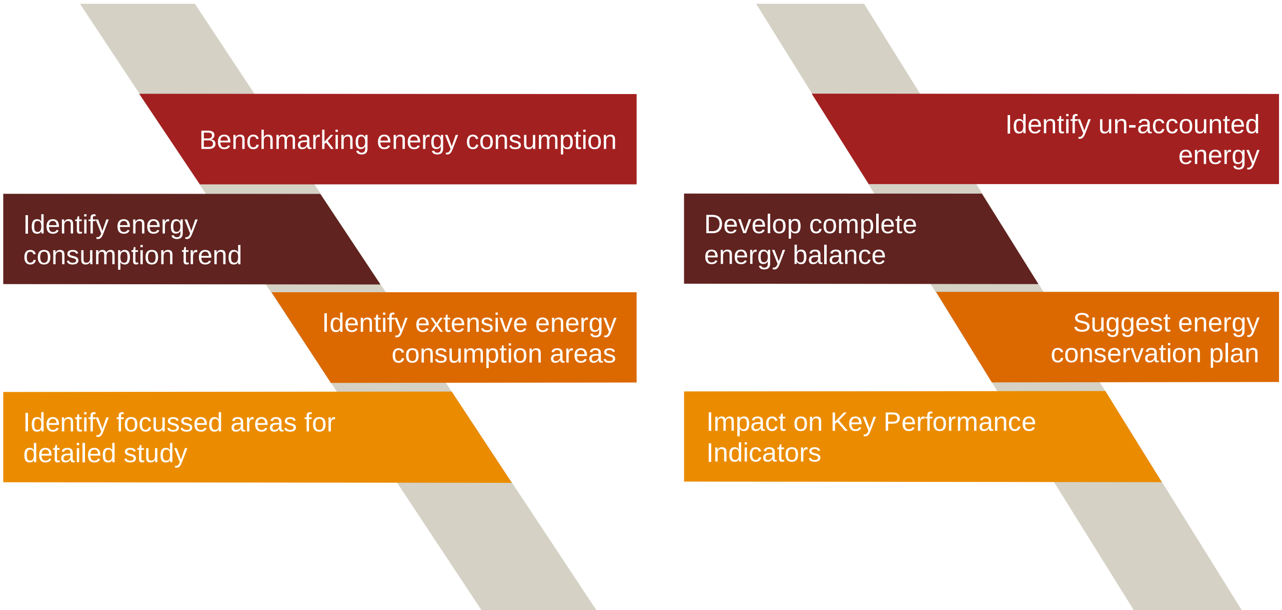


Figure 5 Purpose and benefits of detailed feasibility study

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2 Energy Performance Assessment


Solomon Water

2. Energy performance assessment

2.1. Energy basics

Energy is the ability to do work and work is the transfer of energy from one form to another. In practical terms, energy is what we use to manipulate the world around us, whether by exciting our muscles, by using electricity, or by using mechanical devices such as automobiles. Energy comes in different forms - heat (thermal), light (radiant), mechanical, electrical, chemical, and nuclear energy.

Energy efficiency is the ratio or a quantitative relationship between an output of performance and an input of energy. E.g. Conversion efficiency; energy required/energy used; output/input; theoretical energy used to operate/energy used to operate.[13] ***Energy management*** is defined as the judicious and effective use of energy to maximize profits. Energy management assists in strategizing for adjustment and optimization of energy usage.

This section focuses on addressing EE aspects of major energy systems in municipal pump station, which are pumps, motors and electrical systems. The coverage for each area is on (a) basics to equipment and systems, (b) energy performance assessment, (c) EE technologies and retrofits, and (d) best operating practices (BOP).

2.2. Energy management

Improving energy efficiency in facilities needs to be done within the context of an energy management system (EnMS). Within EnMS of existing set-up, the best way to maximise quantity of energy savings and minimising investment cost is to follow a five-stage process based on energy maturity matrix shown in **Figure 6**[14].

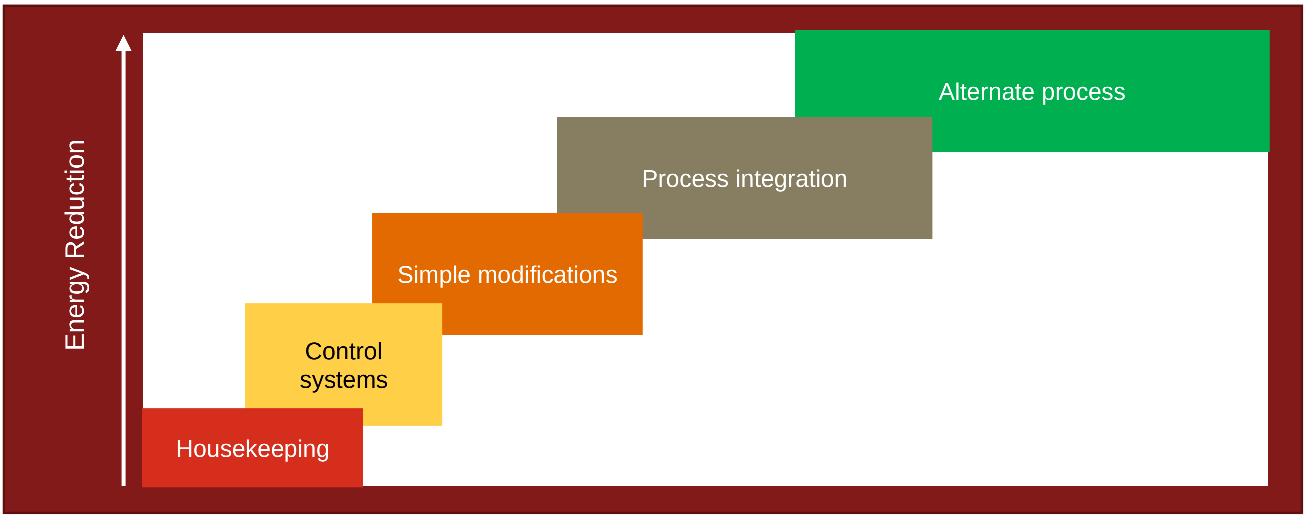

Figure 6 Energy maturity model

Good housekeeping

The first step is to prioritize housekeeping opportunities. Frequently, the opportunities that cost little or nothing include implementing good maintenance, turning things off when they are not needed, reinstating and improving insulation and leakage, idle time, production rate losses, and turning off taps & hoses when not needed. Benefit from steadfast and zero tolerance in good housekeeping is a reduction of energy consumption.

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[13] *International Standard, ISO 50001 - Energy Management Systems - Requirements with guidance for use, 1st edition 2011-06-15*

[14] *Fawkes, S., Oung et.al., Best Practices and Case Studies for Industrial Energy Efficiency Improvement, UNEP DTU Partnership*

Use of control systems

The introduction and tightening of the control systems of existing processes and utilities can further dampen variation in energy consumption and allow a process to operate closer to its designed control limits. Some small investment may be necessary to repair, reinstate, replace and/or introduce new control parameters.

Need for systems thinking

Integration of energy use is a more complex form of plant modification and retrofit but gives further energy savings. Some example includes recovering heat from one process to be reused in another process, thermal pinch analysis, process intensification, de-bottlenecking and uprating, and overall plant or site-wide optimization to minimize overall energy consumption.

Changes in process design and/or energy supply

The highest form of energy maturity, giving the biggest energy savings, comes from a step change either in process design, energy supply, or both. This is the costliest and carries the highest business risks compared to other projects in the energy maturity matrix.

2.3. Major energy consumpting equipment/systems

2.3.1. Pumps

Pumps serve a wide range of applications and are classified on their basic operating principle as dynamic or displacement pumps. Dynamic pumps are further sub-classified as centrifugal and special effects pumps. Displacement pumps are further subclassified as rotary or reciprocating pumps. In principle, any liquid can be handled by any of the pump designs. The most critical aspect of energy efficiency of a pumping system requires matching of the pumps to the loads. Even an efficient pump will operate inefficiently if it is a mismatch to the system.

Centrifugal pumps were chosen for Solomon Waters as they have proven to be the most economical pumps globally, so the focus of this chapter will be on centrifugal pumps. Centrifugal pumps are of a very simple design. The two main components of a centrifugal pumps are the impeller and the diffuser. Diffuser or the volute houses the impeller which is the only moving part of the pump. The impeller is attached to a shaft driven by a motor. Impellers are usually made up of bronze polycarbonate, cast iron, stainless steel as well as other materials. The diffuser captures and directs the water off the impeller.

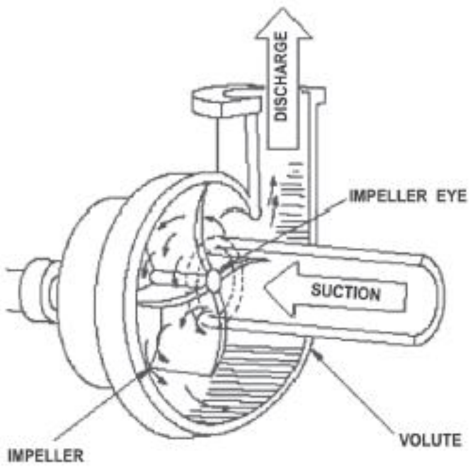


Figure 7 Centrifugal pump

Water enters the eye of the impeller and exits with the help of centrifugal force. As water leaves the impeller, because of centrifugal force and atmospheric pressure a low pressure is created around the eye of the impeller which causes more water to flow into the impeller. Velocity is developed as the water flows through impeller spinning at high speeds. This velocity is converted to pressure by the diffuser with the help of specially designed passageways which direct the water to the discharge of the pump, or the next impeller should the pump be in a multistage configuration. This can be further understood by **Figure 7**.[15]

Pump curves also indicate pump size and type, operating speed (in rpm) and impeller size (in mm or inches). They also show the pump's best efficiency point (BEP). The pump operates most cost effectively when the operating point is close to the BEP. A pump is generally oversized when it is not operated at or within 20% of its BEP, although it is normally considered acceptable if the duty point falls within 50% to 110% of the BEP flow

[15] *Pumps and pumping systems, Guidebook, Bureau of Energy Efficiency*

rate. This allows for a greater margin for error in the event that the system designer overestimated the actual resistance curve.[16] The performance of a pump can be expressed graphically as a representation of head against flow. The duty point of a pump is identified by the intersection of the system resistance curve and pump curve as shown in **Figure 8**. The pump operates at the duty point.

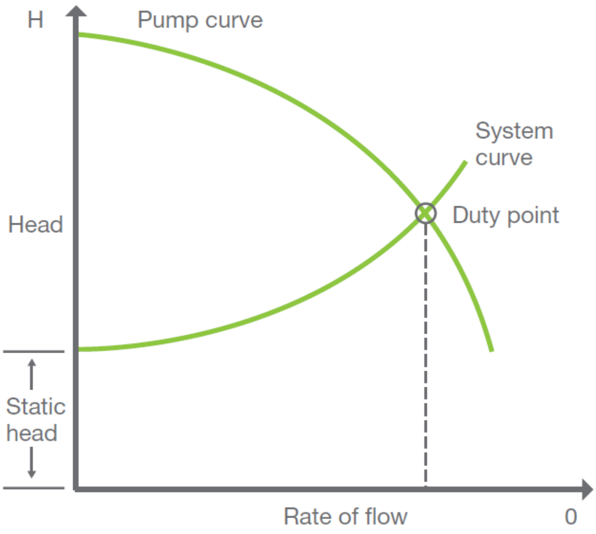


Figure 8 Duty point of the pump

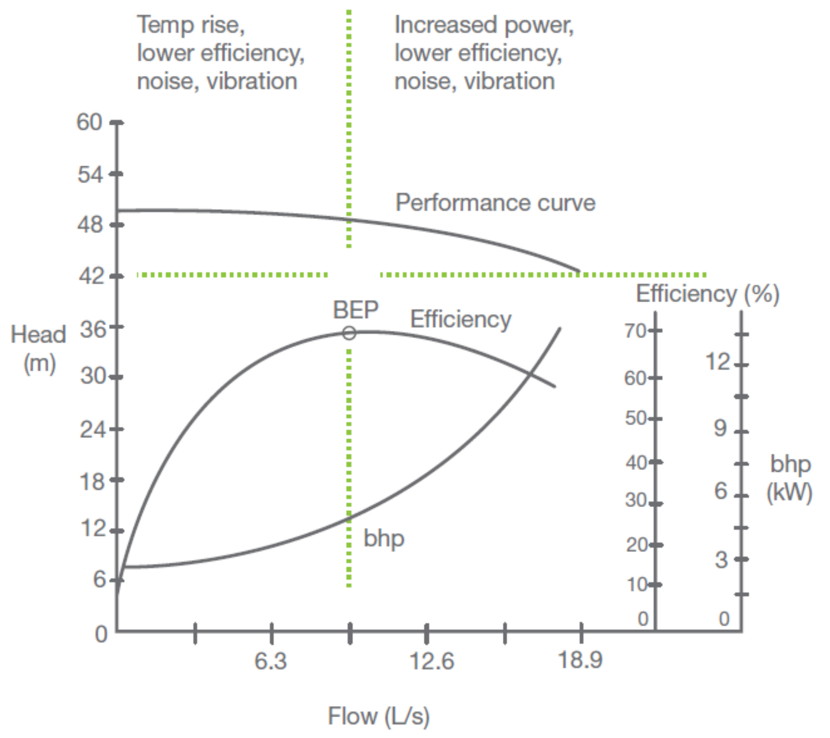
Any error in system curve calculations will lead to selection of a centrifugal pump which will not be a match for the pumping system and is less than optimal for actual system head losses. Adding safety margins to the calculated system curve will lead to selection of an oversized pump which will operate in a throttled condition leading to increased energy usage and shortening of pumps life. Studies indicate that the average pumping efficiency in municipal pump stations can be less than 50%. A pump's efficiency can also degrade during normal operation due to wear by as much as 10% to 25% before it is replaced.[17] A case example of BEP of a pump on performance curve is shown in Box 2[16].

Box 2: BEP in pump performance curve – Case Example

In the figure, the BEP of a pump, operating at 9.45 Litres per second at 36 meter differential head, is around 70% efficiency, and it consumes around 13.5 kW.

The likely effects of a pump operating at flow rates lower than the BEP (that is, to the left of the dotted line) are low efficiency, noise and vibration, giving reduced life due to increased radial loads on bearings and temperature rise due to dissipated energy created by low efficiency. Some of the common measures to rectify this are to use a smaller pump, a smaller multi-stage pump or to install bypass piping.

When operating a pump at flow rates higher than the BEP (that is, to the right of the dotted line), the effects are low efficiency, increased power needs, noise and vibration, giving reduced life due to increased radial loads on bearings.



[16] *Energy efficiency best practice guide for pumping systems, Sustainability Victoria 2009*
[17] *Pumping Tip Sheets, US Department of Energy –Energy Efficiency and Renewable Energy, US, September 2005 – May 2007*

2.3.1.1. Performance assessment of pumps

Pumping is the process of addition of kinetic and potential energy to a liquid for the purpose of moving it from one point to another. The most critical aspect of energy efficiency in a pumping system is matching of pumps to loads. Hence even if an efficient pump is selected, but if it is a mismatch to the system then the pump will operate at very poor efficiencies. In addition, efficiency drop can also be expected over time due to deposits in the impellers. Performance assessment of pumps would reveal the existing operating efficiencies in order to take corrective action.[18] The main purpose of performance assessment of a pumping system is twofold:

Main purpose of performance assessment of pumping system is twofold

Firstly, to arrive at pump efficiency in present operating condition

Secondly, to determine the system head and operating duty point of the pump

The operating efficiency of a centrifugal pump is ratio of actual hydraulic power in water delivered and input power to the shaft of pump. The hydraulic power of the pump can be calculated by measuring water flow rate, suction pressure and discharge pressure. Water flow rate can be measured using a non-intrusive type ultrasonic water flow meter and the pressures can be measured using digital or analog pressure gauge. The shaft power can be arrived at by measuring power drawn by the motor using a three-phase power analyser and multiplying the power with motor efficiency. The detailed formula is as follows:

$$\eta = \frac{P_h}{P_s} = \frac{\left({[Q \times (h_d - h_s) \times \rho \times g]}/{1000} \right)}{P_s}$$

Where,

Q	fluid flow rate (m^3/s)
h_d	discharge head (m)
h_s	suction head (m)
ρ	density of fluid (kg/m^3)
g	acceleration due to gravity
P_H	Hydraulic power
P_S	Shaft power
η	Efficiency


Water flow measurement

Pressure measurement

2.3.2. Motors

Electric motors convert electrical energy into mechanical energy by interaction between magnetic fields set up in stator and rotor windings. They are efficient at converting electrical energy into mechanical energy. An 80% energy efficient motor means that 80% of the electrical energy delivered to the motor is directly converted to mechanical energy, the rest is used up by the motor. An industrial electric motor can be broadly classified as induction motor, direct current motors or synchronous motors.

The operating efficiency of the motor varies according to its loading. The efficiencies of induction motors remain almost constant between 60-100% loading. However, a loading of motor has best efficiency at about 80% loading (see **Figure 9**). With motors designed to perform so efficiently; the opportunity for savings with motors remains chiefly in their selection and use. When a motor has a higher rating than that required by the equipment, motor operates at part load. In this state, the efficiency of the motor is reduced. Replacement of

[18] *Energy performance assessment of water pumps, Guidebook Bureau of Energy Efficiency*

under loaded motors with smaller motors will allow a fully loaded smaller motor to operate at a higher efficiency. This arrangement is generally most economical for larger motors, and only when they are operating at less than one-third to one-half capacity, depending on their size.[19]

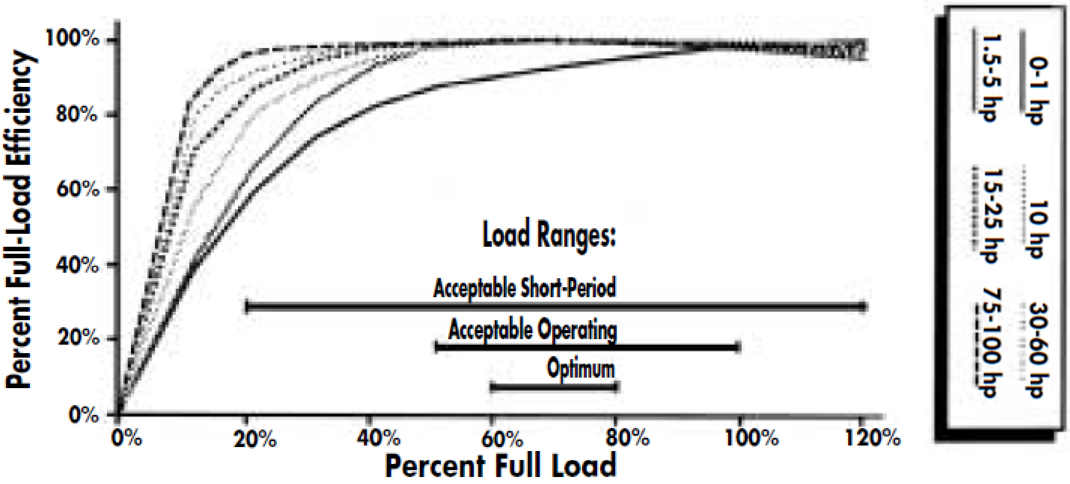
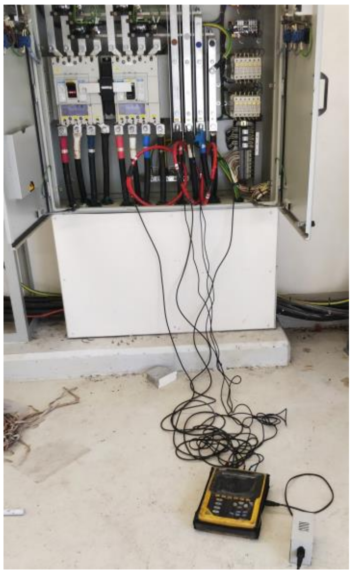


Figure 9 Motor efficiency vs. loading

Motor power measurement



The important performance parameters in a motor are efficiency, loading and power factor. The input power drawn by the motor can be measured using a three-phase power analyser directly or computed using the below formula after measuring voltage, current and power factor.

$$P_{in} = \frac{\sqrt{3} \times V \times I \times pf}{1000}$$

The loading of the electric induction motor can be estimated using the following formula:

$$Loading\ \% = \frac{P_{in}}{\left({P_r}/{\eta} \right)} \times 100$$

Where: P_{in} - Three Phase power in kW, V- RMS Voltage, mean line to line of 3 Phases, I- RMS Current, mean of 3 phases, PF- Power factor, P_r - rated power of motor (available on name plate of motor) and η - efficiency of motor (available in name plate of motor)

2.3.3. Electrical systems

Electric power supply system consists of power generation plants that generate electricity, high voltage transmission lines that transport electricity over long distances, distribution lines that deliver the electricity to the consumers and the substations that connect these parts of the system together.

In case of Solomon Water pump stations, the electrical system is the main receiving station at the pump station and the power distribution board dividing power to various equipment installed i.e. multistage vertical centrifugal pump, centrifugal borewell pump and lighting system.

The performance assessment of electrical systems main looks at power factor of the facility and utilization of contract demand (demand is not charged in Solomon Islands; hence only pf requires monitoring).

[19] *Energy performance assessment of motors and variable speed drives, Guidebook Bureau of Energy Efficiency*

The detailed methodology to be adopted for carrying out field measurement and the study of above-mentioned equipment including measurements to be conducted, instruments used, KPIs and remarks are presented in **Table 9**. Please refer the **annexure** for step by step process of energy audit.

Table 9 Equipment-wise performance assessment methodology

S. No.	Name of equipment	Measurements to be conducted	Instruments	Key Performance Indicators (EnPIs)	Remarks

1	**Electrical system** 	• Measurement of all electrical parameters
		  • Voltage (3 phases)
		  • Current (3 phases)
		  • Power factor
		  • Power (active, reactive and apparent)
			• Three phase power analyser
			• Thermal imager
				• Power factor
				• Demand utilization
					• Data logging for 24 hours

2	**Pumps** 	• Water flow rate • Suction pressure • Discharge Pressure • Input Power	• Pressure gauge • Ultrasonic water flow meter • Three phase power analyser	• Pump Efficiency - %	• Depending of mode of operation of pumps

3	**Electrical motors** 	• Measurement of all electrical parameters
		  • Voltage (3 phases)
		  • Current (3 phases)
		  • Power factor
		  • Power (active, reactive and apparent)
			• Three phase power analyser
			• Stroboscope
			• Thermal imager
				• Efficiency -%
				• Loading - %
					• All operating motors associated with pumps

4	**Lighting** 	• Lux Level • Power Input	• Lux Meter • Single phase power analyser	• Luminous efficacy – lux/W	• As per the standards provided by authorities

2.4. Energy efficency opportunities

2.4.1. Pumps

The efficiency of a pump may differ considerably from the installed efficiency for two main reasons.[20]

1	Most pumps are significantly overdesigned and therefore they will spend much of their operating time well below their design conditions

2	Pump efficiency deteriorates over time due to site-specific conditions effecting operating and maintenance costs.

Significant energy savings (typically 25-30%) in water pumping and distribution systems is possible. The study for improvement of pumps not only focuses on pumps but also on the driver, pipe installation and controls. If a pumping system is to be designed as an energy efficient system, the first aspect is to guarantee the rated efficiency of the pump and associated motors are as high as possible. In addition, each pump must be made to operate as close to its BEP as possible. Moreover, it is important to avoid unnecessary energy being lost with balancing valves or orifices. Hence, it is often advisable to install more pumps in parallel, even if this is not common practice. From a careful and accurate assessment of the various sorts of designs it will become apparent which type can provide the best solution in terms of energy efficiency.[21] As per an American Society of Mechanical Engineers (ASME) publication there are 14 different ways to improve energy efficiency in pumping system, they are presented in **Table 10**[22].

Table 10 Energy efficiency opportunities in pumping system

1.	Maintenance	2.	Monitoring
3.	Controls	4.	Reduction in demand
5.	More efficient pumps	6.	Proper pump sizing
7.	Multiple pumps for varying loads	8.	Impeller trimming
9.	Variable speed drives	10.	Avoiding throttling valves
11.	Proper pipe sizing	12.	Precision casting, surface costings
13.	Replacement of belt drives	14.	Improvement of sealing

2.4.1.1. Maintenance

Effective, timely maintenance keeps pumps operating efficiently and allows for early detection of problems in time to schedule repairs and to avoid pump failures. Regular maintenance avoids losses in efficiency and capacity, which can occur long before a pump fails. Extending a pump's life can be easily increased with the right maintenance plan. The effective useful life of a pump can change depending on the pump type and application. Under normal conditions, water pumps can last as long as 15 years without needing to be replaced.

The main cause of wear and corrosion is high concentrations of particulates and low pH values. Wear can create a drop-in wire to water efficiency of unmaintained pumps by around 10–12.5%. Much of the wear occurs in the first few years, until clearances become similar in magnitude to the abrading particulates (see **Figure 10**).[16]

[20] *Source : http://www.pumpefficiencyorganization.com/education-and-training/*
[21] *Source : https://www.worldpumps.com/energy-efficiency/features/energy-savings-in-pump-systems/*
[22] *Edvard, 14 energy-efficiency improvement opportunities in pumping systems, Electrical Engineering Portal*

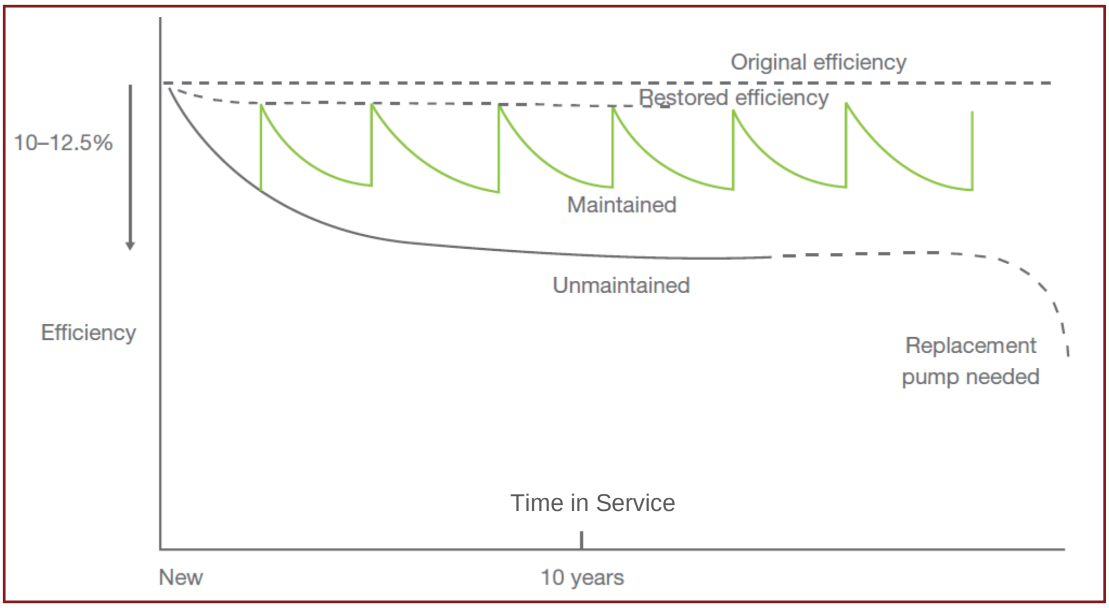


Figure 10 Average wear trends for maintained and unmaintained pumps

2.4.1.2. Monitoring

Monitoring in combination with O&M can be used to detect problems and identify solutions to create an efficient system. Monitoring can determine clearances that need be adjusted, indicate blockage, impeller damage, inadequate suction, operation outside preferences, clogged or gas-filled pumps or pipes, or worn out pumps.[22]

SCADA (Supervisory control and data acquisition) based monitoring system can not only monitor pump operating parameters such as suction and discharge pressure, water flow rate, and input power, but also remotely control the pump operations (**Figure 11**).[23]

Figure 11 Data monitoring center

2.4.1.3. More efficient pumps

Pump efficiency may degrade up to 25% over its lifetime. Experts point out that this drop in the performance is not principally due to the age of the pump but can also be due by modifications in the process which may have led to the mismatch between the pump capacity and its operation. However, it can sometimes be more efficient to buy a new pump, as newer models have higher efficiency levels. Older pumps were either mono-block or single/multi-stage horizontal end suction type centrifugal pumps. The latest vertical type end suction centrifugal pumps are about 10% more efficient than the horizontal ones.

Replacing a pump with a new efficient one decreases energy use by up to 10%. Moreover, one can choose higher efficiency motors (IE3 or IE4) to boost overall system efficiency by 2 – 5%.

2.4.1.4. Properly sized pumps

Matching pump size to the system requirements is one of the most importance aspect in operating pump efficiently. Consider a state-of-the-art technology-based high efficiency pump. The actual operating efficiency of the pump will be substantially (up to 30% lower than BEP) if the proper pump size is not selected (**Box 3**).

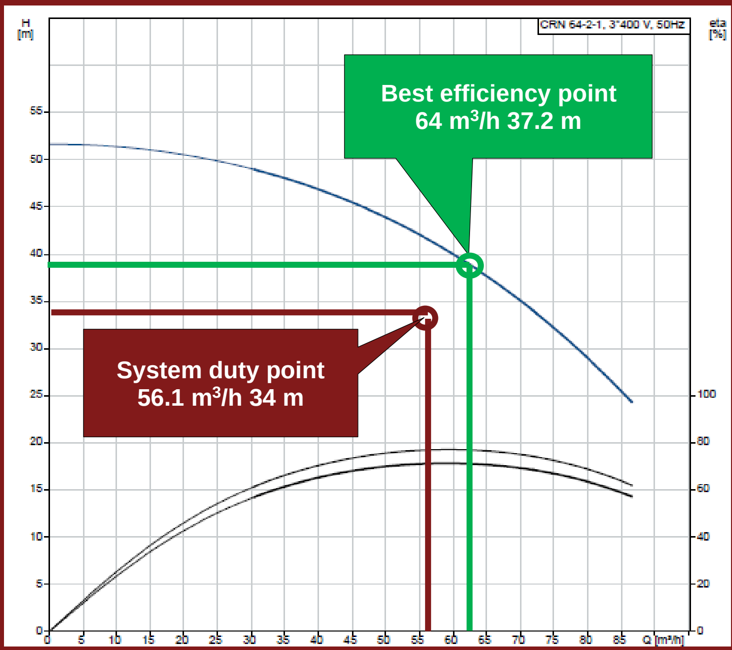
[23] *Photo source : https://www.wateronline.com/doc/scada-alternatives-for-remote-monitoring-0001*

Box 3: Improper pump sizing – Case Example

One of the Solomon Water pump stations is equipped with modern multi-stage vertical pump. The design best efficiency point of the pump is 78% while pumping 64 m^3 per hour of water at 37.2 meter head.

The actual system resistance is just 34 meter and the discharge from pump is 56.1 m^3 per hour. Leading to an operating efficiency of 65% which is 13% lower than the BEP of the pump. A properly sized pump would be able to meet the demand of system with much higher efficiency levels.

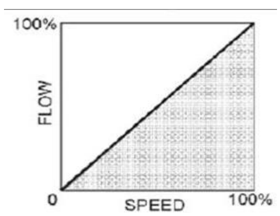
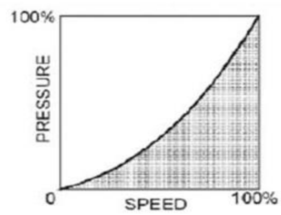
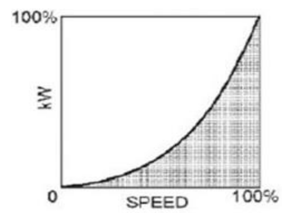
A proper pump selection can result in monetary saving by efficiency improvement of up to 15 thousand Solomon dollars.



2.4.1.5. Adjustable speed drives (ASD)

A centrifugal pump is a dynamic device with the head generated from a rotating impeller. There is therefore a relationship between impeller peripheral velocity and generated head. Peripheral velocity is directly related to shaft rotational speed, for a fixed impeller diameter and so varying the rotational speed has a direct effect on the performance of the pump. The relation between pump shaft speed with its discharge, head and power consumption is governed by affinity laws (**Table 11**).

Table 11 Pump affinity laws

Flow vs. Speed	Head vs. Speed	Power vs. Speed
		
$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$	$\frac{H_1}{H_2} = \frac{N_1^2}{N_2^2}$	$\frac{P_1}{P_2} = \frac{N_1^3}{N_2^3}$
Varying the RMP by 10% will decreases or increases water delivery by 10%	Reducing RPM by 10% decreases the static pressure by 19% and an increase in RPM by 10 % increases the static pressure by 21%	Reducing the RPM by 10% decreases the power requirement by 27% and an increase in RPM by 10% increases power requirement by 33%

There are several options for adjusting the speed of the pump shaft. One of the most convenient method is use of a variable frequency drive (VFD). A VFD is connected to the input supply to the motor of the pump. A pressure transducer is installed in the discharge side of the pump. A VFD has four components rectifier, intermediate DC link, inverter and controlling circuit. The rectifier converts AC mains supply to DC. The DC link smoothens the DC power. Inverter converts DC back to AC of required frequency. The controlling circuit gets feedback from transducer (mounted on discharge side of pump) and based on pre-set instructions, sends control signals to other components (**Figure 12**).

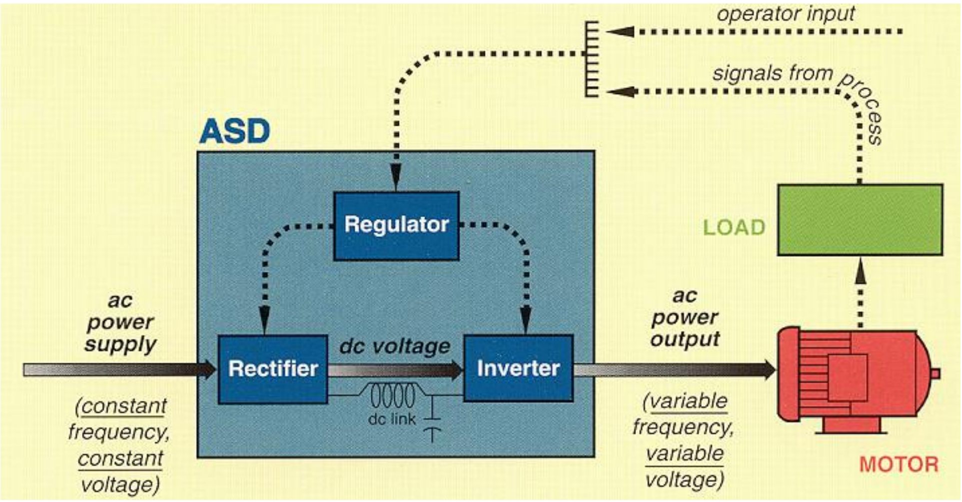


Figure 12 Working of VFD

A case study of VFD in pumping system is presented in **Box 4**[24].

Box 4: Large Municipal Wastewater Utility – Pump Station Improvements Case Study

Pump station consisting of two (2) 400 HP and two (2) 150 HP pumps operating at a constant speed to pump sewage out of the wet well. The energy retrofit project involved installation of (3) new 500 HP pumps with Variable Frequency Drives (VFDs). Substantial energy savings were achieved due to improved OPE, VFD installation and Pump Operational Optimization using the installed VFDs.

Energy Saved	Monetary Saving	Utility Incentive	Investment
(kWh)	(US $/year)	(US $/year)	(US $)
629869	94480	75380	1000000

2.4.2. Motors

According to a recent IEA study[25] electric motors are responsible for 53% of global electricity use. The energy efficiency of an electric motor is calculated as the ratio of the mechanical output power to the electrical input power. Typical losses in the motor includes friction & windage loss, core losses, stray load losses and copper loses. The first two losses are fixed and depend of design of the motor, this could be up to 2.5%. The next two losses are defined by design and increase with increase in loading of the motor.

[24] *Source : http://www.pumpefficiencyorganization.com/resources/*
[25] *IEA World Energy Outlook, Paris 2016*

The factors affecting the efficiency of an electric induction motor are as presented in **Figure 13**.

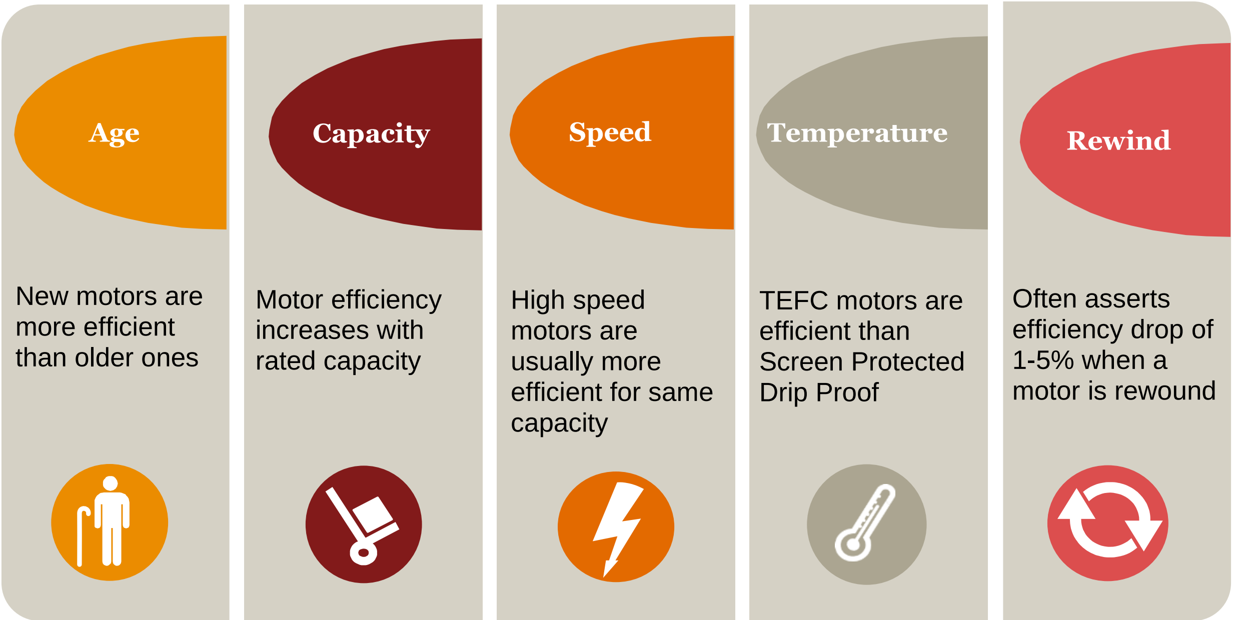


Figure 13 Factors affecting energy efficiency of electric motor

The poor efficiency of the sub-standard motors leads to higher energy consumption and energy costs. Hence, improvement in efficiency of the motor must be a part of any comprehensive energy conservation effort. Various measures to improve energy efficiency of the motor are presented in **Table 12.**

Table 12 Energy Efficiency measures in electric motors

Use high efficiency motors (IE3, IE4)	Avoid under-loading of motor
Optimum sizing of motor according to load	Proper rewinding of motor
Proper selection of capacity for variable load	Speed control of induction motor
Power factor correction by capacitors	

2.4.2.1. Rewinding of motors

The most common practice is to rewind burnt-out motors. The effect of rewinding can reduce the motor efficiency such as winding material, winding and slot design insulation performance, and operating temperature. For example, when the windings get heated, this can damage the insulation between lamination, which further raises the eddy current losses. However, proper measures such as using wires of greater cross section and slot size permitting etc. would result in a reduction of stator losses and thereby increasing efficiency. However, original design and structure of the motor should remain the same during the rewind, unless there are specific load---related reasons for redesign.[26]

With each rewinding electric motor loses 1-2% efficiency, depending the way motor is rewound.

[26] *Source: Energy Efficient Motors, CTC-N https://www.ctc-n.org/technologies/energy-efficient-motors*

2.4.2.2. Power factor correction by installing capacitors

In many applications the motors are often running at low power factors. In such cases, capacitor banks of appropriate capacity can be installed in parallel to motor to supply necessary reactive power. The benefits of power factor correction include: [26]

- reduced copper (I^2R) losses in cables upstream of the capacitor (and hence reduced energy charges),
- reduced kVA demand (and hence reduced utility demand charges),
- reduced voltage drop in the cables (leading to improved voltage regulation), and
- an increase in the overall efficiency of the plant electrical system.

2.4.2.3. Proper sized motor

Operating a higher capacity motor for lower loads reduces its energy efficiency, power factor and increase energy consumption. A case study of comparison of loading of motor on its energy consumption is presented in **Box 5**.

Box 5: Effect of oversized motor – A Case Study

A case of three motors each having same load, however the capacity of motor is different. The annual energy consumption and per cent energy consumption increase is presented in table.

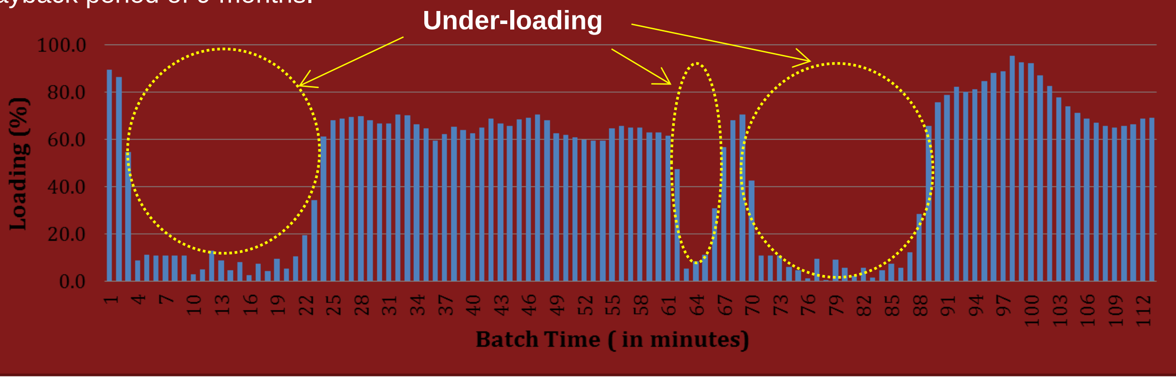
Particular	Case-1	Case-2	Case-3
Motor Load	7.5 kW (100% load)	11 kW (70% load)	15 kW (50% load)
Motor efficiency (%)	88.0	84.0	79.0
Motor input (kW)	8.5	9.0	9.5
Annual electricity consumption (kWh)	42,500	45,000	47,500
% increase in energy consumption	-	*5.8%*	*11.76%*

2.4.2.4. Star delta controller

When the operation cyclic in nature and there are periods of high load and low load on the motor, a start delta controller can be programmed to run motor efficiently. A case of star delta controller is presented in **Box 6**.

Box 6: Star delta controller – A Case Study

A motor of process equipment in metal processing industry had a batch operation. The motor loading was under 25% for about one third time. An automatic star delta controller was installed to run run motor in either star or delta depending on the actual load. This led to US $ 79,000 annual saving with a simple payback period of 9 months.



2.4.2.5. Higher efficiency motors

The efficiency of the motor is defined through an international Standard IEC 60034-2-1. The classification is in five levels, namely: IE1 – Standard Efficiency, IE2 – High Efficiency, IE3 – Premium Efficiency, IE4 – Super Premium Efficiency and IE5 – Ultra Premium Efficiency. Example of a 4-pole 50 Hz motor is shown in **Figure 14**.

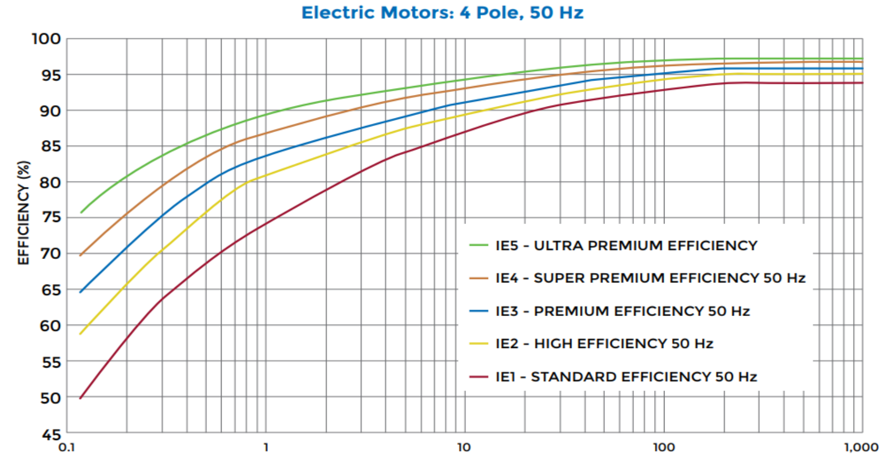


Figure 14 IEC efficiency levels for 4-pole motor operating at 50 Hz

Energy efficiency of induction motors can be improved by incorporating design advances shown in **Figure 15**, as well as by improved manufacturing practices. In practice, motor manufacturers typically take the lowest cost pathway to achieve the MEPS that has been adopted for a market. They use a combination of design improvements that depend on the prevailing costs of the materials.[27]

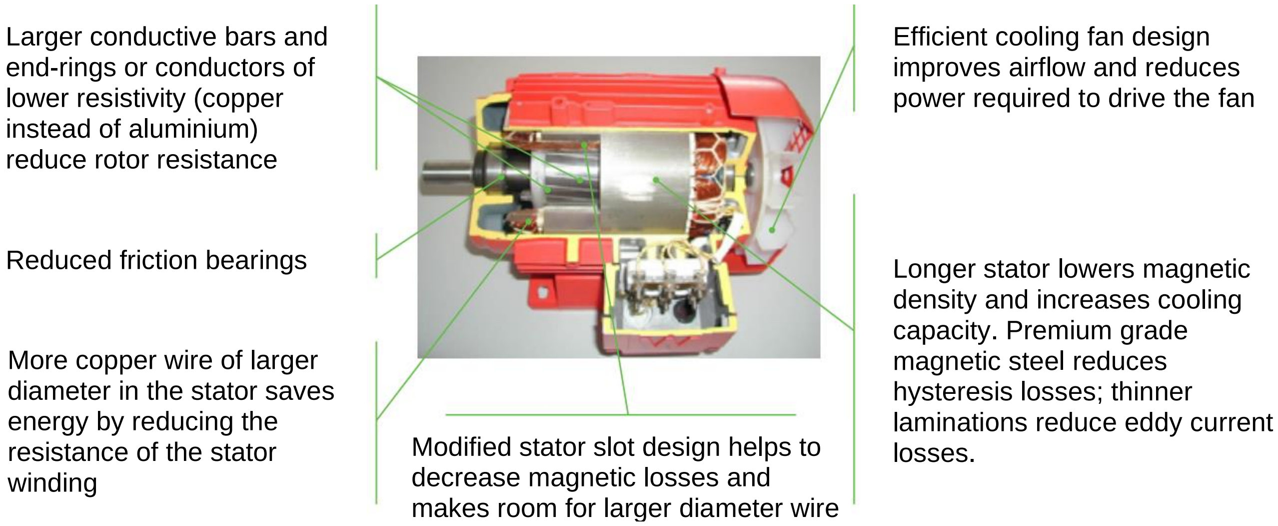


Figure 15 Induction motor design improvement for higher efficiency

A relatively small improvement in the energy efficiency is equivalent to a substantial reduction of energy losses. By way of illustration, in example of a 45 kW, 4 pole, 50 Hz motor, the difference in the efficiencies of IE4 and IE1 motors is only 3.7%, but this is equivalent to a 47% reduction in energy losses (**Table 13**).

Table 13 Comparison of efficiency classes for a 45 kW, 4-pole 50 Hz motor

Efficiency Class	Losses (W)	Loss reduction (%)	Energy Efficiency (%)
IE1	4073	0	91.7
IE2	3335	-18	93.1
IE3	2771	-32	94.2
IE4	2170	-47	95.4

[27] *Source: https://united4efficiency.org/wp-content/uploads/2017/09/U4E-MotorGuide-201709-Final.pdf*

Improvements in induction motor design have ensured a steady reduction of losses and increases in energy efficiency over the years. Motors have seen a loss reduction of 68% in last five decades. The minimum energy performance standard (MEPS) is defined as a mandatory minimum performance level that applies to all products sold in a market, whether imported or manufactured domestically. MEPS of electric motor are adopted by various countries across the world in past two decades (**Figure 16**). The MEPS is always defined around adoption of certain IE rating of the motors.

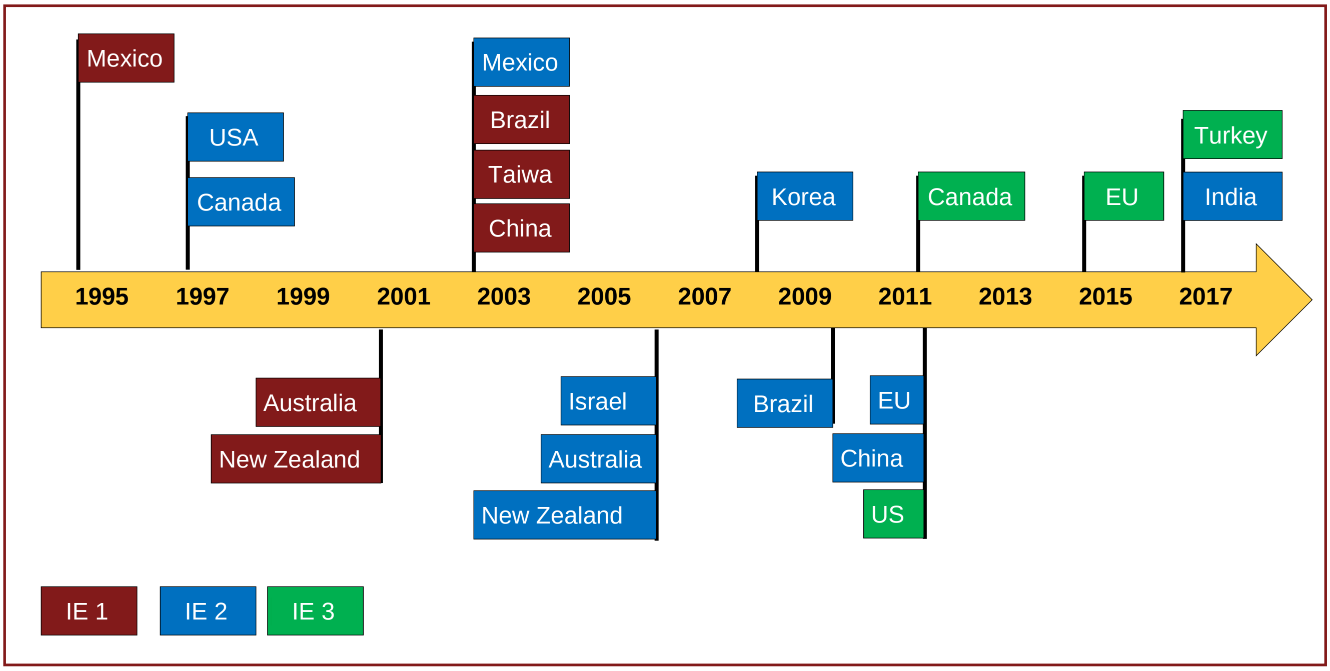


Figure 16 Worldwide motor MEPS timeline

A case example of energy efficient motor is presented in **Box 7**.

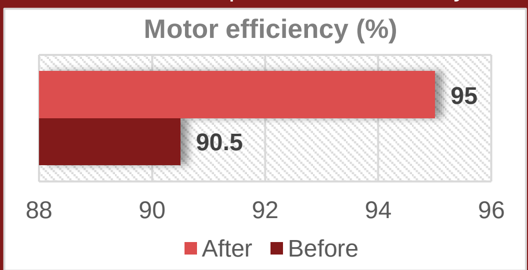
Box 7: Energy efficient motor (IE3)

Baseline scenario: A blower in a crusher industry was driven by a 75 kW electric induction motor. The motor was a standard motor with no rating. Moreover, motor was rewound twice. Operational hours: 6000.

Proposed solution: An IE3 rated motor was recommended to replace the standard motor. IE is "International Efficiency" with class 1, 2 & 3 i.e. IE1 & IE2 & IE3. The energy savings of IE3 motors are mainly based on lower nominal currents. IE3 motors are extremely sturdy and well designed.

Savings:

- Annual electricity saving – 13,830 kWh
- Annual monetary savings – US $ 1,820
- Simple payback – 4 years
- GHG reduction potential: 12 t CO_2/year



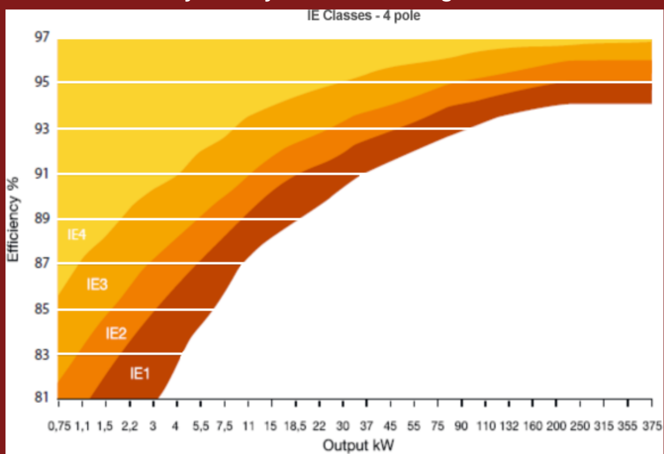


Figure 17 depicts an example of the redesign of a pumping system. The conventional design shown in the upper figure is operated to deliver 60 per cent of the rated fluid flow of the pumping system. The system efficiency is the product of the efficiencies of individual components, which in this example equals 31 per cent (e.g. 0.90 x 0.98 x 0.77 x 0.66 x 0.69 = 0.31). The lower figure shows a redesigned system for delivering the same fluid flow. A variable speed drive, rather than a mechanical throttle, varies the flow. The motor, the pump, the coupling and the pipes have been replaced with higher efficiency options. In the energy-efficient design, the input power required reduces from 100 to 43, thus giving a system efficiency of 72 per cent (31/43=0.72).[27]

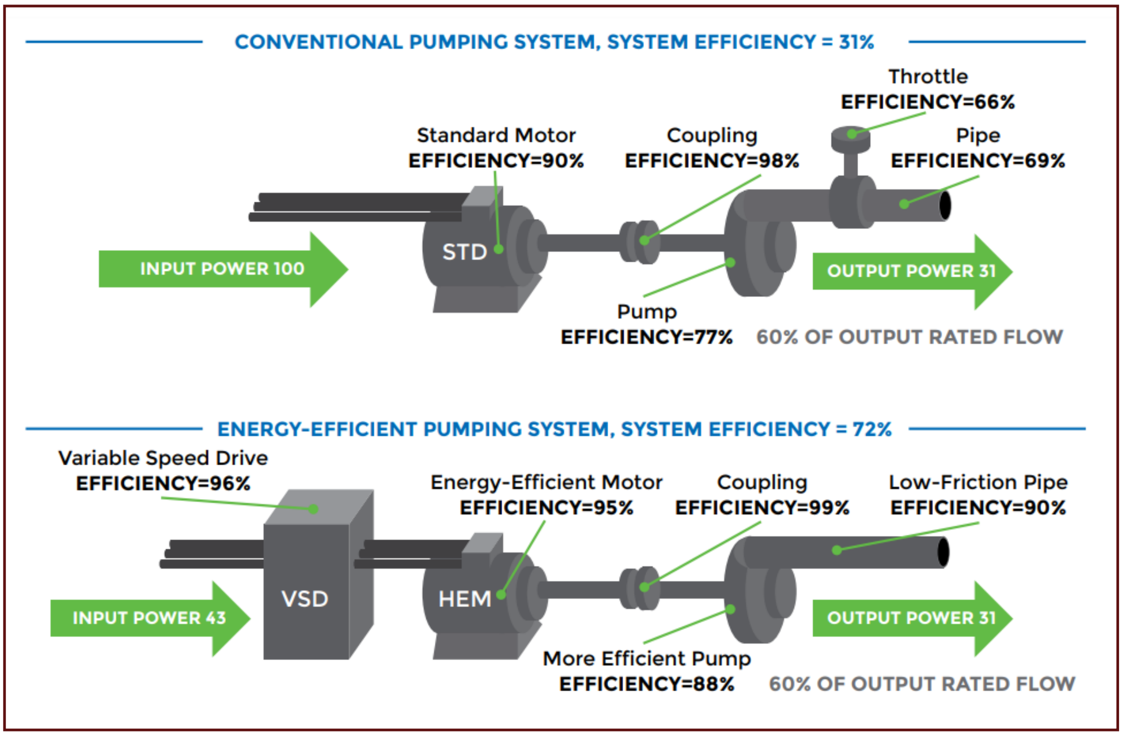


Figure 17 Energy saving potential of typical pumping system

2.5. Best operating practices

The operating and maintenance practices in play a vital role in improving energy efficiency of the systems. The best practices for electrical system, pumping system, electric motor and lighting system is presented below.

2.5.1. Best operating & maintenance practices for electrical system

The electrical distribution systems are often crudely designed and maintained, it can cause some problems in energy consumption and in safety. If a motor is operating at a lower voltage than it was designed for, it is probably using more amperage than was intended and is causing unnecessary losses in transmission lines. If the wires are too small for the load, line losses can be large, and fi re hazards increase significantly. Other problems that can create unnecessary energy loss are voltage imbalance in three-phase motors and leaks from voltage sources to ground. The problems and solutions for the electrical systems are shown in **Table 14**[28].

Table 14 Electrical system - Problems and solutions

Component	Problem	Initial Maintenance Action
Transformer	Leaking oil	Have electric company check at once
	Not ventilated	Install ventilation or provide for natural ventilation
	Dirt or grease in control room	Install air filtering system to insure clean contacts
	Water on control room floor	Install drainage or stop leaks into control room

[28] *Wayne C Turner, Steve Doty, Energy Management Handbook, Sixth Edition*

Component	Problem	Initial Maintenance Action
Contact	Burned spots	Indicates shorting; repair immediately
	Frayed wire	May cause shorting; use tape to secure frayed ends
Switch	Sound of arcing, lights flicker	Replace
Motors	Noisy	Check bearings
	Too hot	Check voltage on both legs of three-phase input
	Vibrates	Check mounting

2.5.2. Best operating & maintenance practices for pumps

The best operating practices of the pump is presented in seven categories[29].

Practice 1: Use Efficient Flow Control Methods
• Adapt to wide load variation with variable speed drives or sequenced control of multiple units. • Stop running multiple pumps - add an auto-start for an on-line spare / add booster pump in problem area. • Use booster pumps for small loads requiring higher pressures. • Flow control by control valves should be avoided. • Proper checking for valve passing of recirculation line should be done.
Practice 2: Avoiding Cavitation in Pump
Cavitation is the formation of bubbles or cavities in liquid, developed in areas of relatively low pressure around an impeller. The imploding or collapsing of these bubbles trigger intense shockwaves inside the pump, causing significant damage to the impeller and/or the pump housing. It may cause damage to pump vanes and hull loss may happen to pump. It can be prevented by following methods: • Ensure adequate Net Positive Suction Head (NPSH) at suction end. • Reduce motor RPM if possible. • Increase the diameter of the eye of the impeller. • Use an impeller inducer. • Use two lower capacity pumps in parallel. • Use a booster pump to feed the principal pump. • Design the pump suction piping and routing to avoid excess turbulence • Take precaution while fixing the pump suction line size to avoid turbulence and have sufficient NPSHa • Respect the maximum allowable flow limit of the pumps.
Practice 3: Location of pump
The location of pump plays a significant role in energy consumption pattern for pumping unit. Guidelines for efficient pumping system are: • Ensure adequate Net Positive Suction Head (NPSH) at site of installation • Operate pumps near best efficiency point. • Avoid pumping head with a free-fall return (gravity); • Reduce system resistance by pressure drop assessment and pipe size optimization
Practice 4: Proper monitoring and controlling of system
The pump efficiency can be determined by regular monitoring of key performance parameters like pressure, discharge flow etc. • Check for regular vibration checking for pumps

[29] *Source : https://beeindia.gov.in/sites/default/files/BOP-Coimbatore.pdf*

- Ensure availability of basic instruments at pumps like pressure gauges, flow meters.
- Modify pumping system and pumps losses to minimize throttling.
- Repair seals and packing to minimize water loss by dripping.
- Balance the system to minimize flows and reduce pump power requirements.

Practice 5: Avoid friction in line

Friction losses should be as minimum as possible in the pumping system. There are various factors which causes high power consumption with respect to same flow.

- Reduce system resistance by pressure drop assessment and pipe size optimization
- Checking for valves for full opening
- Minimum number of elbows and turns in the piping
- Cleaning of in line filters

Practice 6: Avoid oversizing of pump

Characteristics of an Oversized Pump	***Description***
Excessive flow noise	Oversized pumps cause flow-induced pipe vibrations, resulting in excessive noise and increased damage to pipework (including flanged connections, welds and piping supports)
Highly throttled flow control valves	Pumps tend to remain in more restrictive positions in systems with oversized pumps; this increases backpressure, further decreasing efficiency
Frequent replacement of bearings and seals	Increased backpressures from increased flow rates creates high radial and thrust bearing loads as well as high pressures on packing glands and mechanical seals
Heavy use of bypass lines	A system that heavily uses bypass lines indicates that the system has either oversized pumps, is not balancing properly, or both
Intermittent pump operation	Pumps being used for purposes such as filling or emptying tanks that run very intermittently indicate oversizing and hence suffer increased start/stop inefficiencies, wear, as well as increased piping friction

Practice 7: Pumping system design consideration

- Ensure availability of basic instruments at pumps like pressure gauges, flow meters.
- Operate pumps near best efficiency point.
- Modify pumping system and pumps losses to minimize throttling.
- Stop running multiple pumps - add an auto-start for an on-line spare or add a booster pump in the problem area.
- Use booster pumps for small loads requiring higher pressures.
- Balance the system to minimize flows and reduce pump power requirements.
- Avoid pumping head with a free-fall return (gravity); Use siphon effect to advantage
- Conduct water balance to minimize water consumption
- In multiple pump operations, carefully combine the operation of pumps to avoid throttling
- Provide booster pump for few areas of higher head
- Replace old pumps by energy efficient pumps
- In the case of over designed pump, provide variable speed drive, or downsize / replace impeller or replace with correct sized pump for efficient operation.
- Optimize number of stages in multi-stage pump in case of head margins

Pump wear and maintenance Effective, regular pump maintenance keeps pumps operating efficiently and allows for early detection of problems in time to schedule repairs and to avoid early pump failures. Regular maintenance avoids losses in efficiency and capacity, which can occur long before a pump fails. The main cause of wear and corrosion is high concentrations of particulates and low pH values. Wear can create a drop in wire to water efficiency of unmaintained pumps by around 10–12.5%. Much of the wear occurs in the first few years, until clearances become similar in magnitude to the abrading particulates.

Studies indicate that the average pumping efficiency in some municipalities can be less than 40%, with 10% of pumps operating below 10% efficiency. Oversized pumps and the use of throttled valves were identified as the two major contributors to the loss of efficiency. Energy savings in pumping systems of between 30% and 50% could be realized through equipment or control system changes. A pump's efficiency can also degrade during normal operation due to wear by as much as 10% to 25% before it is replaced. **Table 15** presents common problems and solutions in pumping system.

Table 15 Pumping - Problems and solutions

Common Problem	Potential Measures to Improve Efficiency
Vibration and Noise	a) Bearings failing or starting to fail b) bent shaft c) coupling misalignment d) damaged components: impeller, shaft, packing, coupling e) foreign material in pump causing imbalance f) foundation and/or hold down bolts loose g) loose components, valves, guards, brackets h) misalignment conditions i) piping inadequately supported j) pump cavitation due to vaporization in inlet line k) pump over or under rated capacity
Pump is not developing rated pressure	a) air or gas in liquid b) excessive lift on rotor element c) impeller diameter too small d) impeller installed backwards e) impeller speed too low f) leaking joints (well application) g) mechanical defects: wearing rings worn h) system head lower than anticipated i) wrong direction of rotation
Zero discharge of water	a) air leak in inlet or suction line or stuffing box b) broken line shaft or coupling c) bypass valve open d) closed suction valve
Sudden loss of suction of water	a) air or gas in liquid b) casing gasket defective c) clogging of strainer d) excessive well drawdown e) leaky suction line f) suction lift too high or insufficient NPSHa g) water seal plugged
Excessive Power Consumption	a) discharge pressure higher than calculated b) electrical or mechanical defect in motor c) higher fluid viscosity than specified d) improperly adjusted packing gland (too tight) causing drag

Common Problem	Potential Measures to Improve Efficiency
	e) incorrect lubrication of driver f) lubricant in shaft enclosing tube too heavy (vertical turbine) g) mechanical defects (shaft bent, rotating element binds) on shaft h) pump running too fast i) rotating element binding from misalignment j) speed too high k) stuffing boxes too tight, wearing rings worn l) system head higher than rating, pumps too little or too much liquid
Pump not able to discharge rated water	a) air leaking into pump b) broken valve springs c) capacity of booster pump less than displacement of power pump d) clogged suction strainer e) insufficient NPSHa f) bypass line passing g) makeup in suction line less than displacement of pump h) relief, bypass, pressure valves leaking i) speed incorrect, belts slipping, stuck foot valve
Lack of monitoring and/or documentation	Install monitoring and conduct survey

The summary of best practices for pumping system are as follows:

- Ensure adequate NPSH at site of installation.
- Ensure availability of basic instruments at pumps like pressure gauges, flow meters.
- Operate pumps near best efficiency point.
- Modify pumping system and pumps losses to minimize throttling.
- Adapt to wide load variation with variable speed drives or sequence control of multiple units.
- Stop running multiple pumps -add an auto-start for an on-line spare/add booster pump in the area.
- Use booster pumps for small loads requiring higher pressures.
- Increase fluid temperature to reduce pumping rates in case of heat exchangers.
- Repair seals and packing to minimize water loss by dripping
- Balance the system flows and reduce pump power requirements
- Avoid pumping head with a free return (gravity): Use siphon effect to advantage
- Conduct water balance consumption
- Avoid cooling water re-circulation in DG sets, air compressors, refrigeration systems, cooling towers feed water pumps, condenser pumps and process pumps.
- In multiple pump operations, carefully the operation of pumps to avoid throttling
- Provide booster pumps for few areas of higher head
- Replace od pumps by energy efficient pumps
- In case of over designed pump, provide variable speed drive, or downsize/replace impeller or replace with correct sized pump for efficient operation
- Optimize number of stages in multi-stage pump in case of head margins
- Reduce system resistance by pressure drop assessment and pipe size optimization

2.5.3. Best operating & maintenance practices for motors

The best operating practices of the motor is presented in seven categories[29].

Practice 1: Voltage should be equally balanced across motor terminals
A properly balanced voltage supply is essential for a motor to reach its rated performance. An unbalanced three-phase voltage affects a motor's current, speed, torque, and temperature rise. Equal loads on all three phases of electric service help in assuring a voltage balance while minimizing voltage losses. The options that can be exercised to minimize voltage unbalance include: • Balancing any single-phase loads equally among all the three phases • Segregating any single-phase loads which disturb the load balance and feed them from a separate line
Practice 2: Regular upkeep
Properly selected and installed motors can operate for many years with minimal maintenance. Nonetheless, regular care will extend their life and maximize their energy efficiency. A list of such practices and measures is presented below: • Clean motor surfaces and ventilation openings periodically. Heavy accumulations of dust and lint will result in overheating and premature motor failure. • Properly lubricate moving parts to avoid unnecessary wear. Be sure to apply appropriate types and quantities of lubricant. Applying too little or too much can harm motor components. • Check motor for over-heating and abnormal noises/sounds, sparking and ensure proper bedding of brushes. • Tighten belts and pulleys to eliminate transmission losses.
Practice 3: Replace, rather than rewind, motors when appropriate
Motors are generally repaired more than once, with a typical loss of nearly 2 % in efficiency at each rewind. These motors are generally less efficient than their nominal ratings and must be replaced appropriately. It is more common to rewind larger motors due to their high capital cost. But these motors usually operate at very high duty, and even a modest efficiency improvement may make it worthwhile to replace them with new, premium-efficiency motors rather than repair them.
Practice 4: Use appropriately sized motors for replacement
• Many motors are oversized for their applications, resulting in poor motor efficiency and excessive energy use. Always use motors sized according to the requirement of the load. It is good practice to operate motors between 75 -100 % of their full load rating because motors run most efficiently near their designed power rating. • When replacing motors, always buy energy efficient motors instead of conventional motors. The cost of energy consumed by a conventional motor during its life is far greater than the incremental cost of the energy efficient motor.
Practice 5: Reducing under-loading
Probably the most common practice contributing to sub-optimal motor efficiency is that of under-loading. Under-loading results in lower efficiency and power factor, and higher-than necessary first cost for the motor and related control equipment. • Carefully evaluate the load that would determine the capacity of the motor to be selected. • For motors, which consistently operate at loads below 40% of rated capacity, an inexpensive and effective measure might be to operate in star mode. A change from the standard delta operation to star operation involves re-configuring the wiring of the three phases of power input at the terminal box • Motor operation in the star mode is possible only for applications where the torque to speed requirement is lower at reduced load. • For applications with high initial torque and low running torque needs, Del-Star starters are also available in market, which help in load following derating of electric motors after initial start-up.

Practice 6: Install variable frequency drives
Motors frequently drive variable loads such as pumps, hydraulic systems and fans. In these applications, the motors' efficiency is often poor because they are operated at low loads. It is appropriate to use a Variable Frequency Drive (VFD) with the motor.
Practice 7: Install capacitor banks
Induction motors are characterized by power factors less than unity, leading to lower overall efficiency (and higher overall operating cost) associated with a plant's electrical system. • Install capacitors banks across motors with a high rating to reduce the distribution losses. • Capacitors connected in parallel (shunted) with the motor are typically used to improve the power factor. • The size of capacitor required for a particular motor depends upon the no-load reactive kVA (kVAr) drawn by the motor, which can be determined only from no-load testing of the motor. In general, the capacitor is selected to not exceed 90 % of the no-load kVAr of the motor. (Higher capacitors could result in over-voltages and motor burnouts)

In continues operation of motor many instances and events occur in which motor stop working or run ineffectively. Below table mention some cases with possible causes and corrective actions[30].

Possible Cause	Corrective Action
1. Motor fail to start	
Motor is wired incorrectly	Refer to the wiring diagram to verify the motor is wired correctly.
Motor damaged and rotor is striking stator	Rotate the motor's shaft and feel for rubbing.
Power supply or line trouble	Check the source of power, overload, fuses, controls, etc.
Motor bushes not connected	Press down the bushes, if motor runs remove bushes clean holders with sandpaper and fit bushes properly again
2. Motor does not start after stopping	
Fuse or circuit breaker is tripped	Replace the fuse or reset the breaker.
Stator is shorted or went to ground (Motor will make a humming noise and the circuit breaker or fuse will trip)	Check for leaks through the coils. If leaks are found, the motor must be replaced.
Motor overloaded or jammed	Inspect to see that the load is free. Verify the amp draw of motor versus the nameplate rating.
Capacitor (on single phase motor) may have failed	First discharge the capacitor. To check the capacitor, set the volt-ohm meter to RX100 scale and touch its probes to the capacitor terminals. If the capacitor is OK, the needle will jump to zero ohms, and drift back to high. Steady zero ohms indicates a short circuit; steady high ohms indicate an open circuit.
3. Motor stops suddenly	
Voltage drop	If the voltage is less than 90% of the motor's rating, contact your power company or check to see that another piece of equipment isn't taking power away from the motor.
Load increased	Verify that the load has not changed, and the equipment has not gotten tighter.
4. Motor accelerating at slow rate	

[30] *Source : https://www.groschopp.com/resources/troubleshooting-guide*

Possible Cause	Corrective Action
Defective capacitor	Test the capacitor
Bearing defect	Bearing to be replaced
Voltage fluctuation	Check for voltage
Connected Motor is of low power rating	Replace the motor with high power rated motor
5. Motor running in reverse direction	
Wiring defect	Rewire the motor according to the schematic provided with the motor
6. Motor tripping due to overheating	
Load too high	Locate and remove the source of excessive friction in the motor or pump. Reduce the load or replace the motor with one of greater capacity.
Improper ventilation	Check for proper cooling of motor
Unbalanced Voltage	Check the voltage at all phases
Rotor rubbing on stator	Tighten the thru bolts.
7. Motor Vibration	
Misalignment	Realign pump
Defective motor bearing	After checking motor on no load. Change the bearing
Pump running on less load	If the load on pump is low. Change the motor with smaller motor
Defective winding	Test the winding for shorted or open circuits. The amps may also be high. For defective winding, replace the motor.
8. Bearing Fail	
Load to motor may be excessive or unbalanced	Check the motor load and inspect the drive belt tension to ensure it's not too tight. An unbalanced load will also cause the bearings to fail.
High ambient temperatures	If the motor is used in an environment with high ambient temperatures, a different type of bearing grease may be required.
High motor temperatures	Check and compare the actual motor loads to the motor's rated load capabilities.
9. Capacitor Fail	
Ambient temperature too high	Verify that the ambient temperature does not exceed the motor's temperature rating
Possible power surge to the motor	Install surge protector
10. Motor running too fast	
High voltage	Regulate the same
Frequency too high	Check for power source
Wrong circuit connected to motor	Check from the circuit dig. Given by manufacturer

2.5.4. Best operating & maintenance practices for VFDs

The best operating practices of the variable frequency drives is presented in five categories[31].

[31] *Source : https://www.flowcontrolnetwork.com/pumps-motors-drives/article/15563782/best-practices-for-troublefree-vfd-operation*

Practice 1: Ensure proper ambient temperature
Minimum and maximum ambient temperature limits are specified for all frequency drives. Avoiding extreme ambient temperatures prolongs equipment life and maximizes system reliability. Component life is affected by heat, dust and humidity. Controlling these variables will extend component life and lead to longer drive life. In environments with extreme temperatures, additional steps may be needed to maintain the proper ambient temperature. Additional cooling fans, air conditioners or heaters may be required.
Practice 2: Checking for Altitude
Air cooling capability decreases at lower air pressure. Manufacturers provide guidelines on handling situations such as approaching higher elevations above sea level. E.g. below 3,300 feet (1,000 meters) altitude, no derating is necessary, but above 3,300 feet (1,000 meters) steps need to be taken. Typical steps are to de-rate (reduce the current rating) the drive or add additional cooling. In addition to the decreased cooling, the air gap between components becomes less and an arc can occur without proper spacing.
Practice 3: Input power — Distribution network, voltage & line disturbances
• Voltage level — Select the appropriate drive for that voltage and single-phase or three-phase. • Transformer configuration — Does the transformer have a solidly grounded secondary? If not, the drive may have metal oxide varistors or filter caps that need to be removed. • Do power quality issues exist? — This may require the use of a drive with a direct-current choke or line reactor built in or the use of an external reactor or isolation transformer. When wiring cables for input power, size wiring based on the AFD's input current and comply with local and national electrical codes. Because these cables carry high voltage, they should be kept away from control wiring, other power wires and motor wiring to avoid inducing voltages in other cables.
Practice 4: Motor wiring — Grounding, shielding
Wire used between the drive and the motor should be reviewed. In a retrofit when replacing a starter or contactor with the drive, consider that motor wiring in the past may have been individual conductors in a conduit. VSDs use insulated-gate bipolar transistors to the drive output to control a motor and vary speed. The cable must be sized correctly and designed for its installation location. Along with the cable, the right drive and motor combination is needed. Consider if the environment has moisture, oil or potential for the cable to be crushed to select the appropriate cable and if a specific conduit is needed.
Practice 5: Use of Proper Enclosure
A proper enclosure should be used to place the drive. It must be as per standards prescribed by the manufactures and must ensure proper heat disbursement and protection of drive from dust, rain and other outside particles which may damage the equipment. It is advisable to clean the drive during periodic maintenance. These fans are critical to the life of the drive. Remove dust off the heatsink and fans and clean the filter mats.

A regular and proper preventive maintenance is always required to keep VFD in a defect free and reliable operation mode. Without preventive maintenance, the probability of VFD failure increases drastically. The most common failures are due to component aging or operational conditions, such as varying ambient temperature, high humidity, excessive and heavy loads[32].

- **Clean properly**: Dust on an electronic device can cause malfunction or even failure by absorbing moisture. Discharging compressed air into the VFD is a viable option in some environments, but typical plant air contains oil and water. Oil-free, dry air requires a specialized, dedicated, and expensive air supply — and you

[32] *Source : http://www.vfds.org/basic-variable-frequency-drive-maintenance-tips-603781.html*

still run the risk of generating static charges. A non-static generating spray or a reverse operated ESD vacuum will reduce static buildup.

- **Keep VFD dry**: The presence of moisture will lead to VFD circuit board corrosion and condemn the VFD to failure or erratic operation. During the early design stages ensure that the VFD room is well located and that variable frequency drives are maintained in a dry area where moisture is not a problem.
- **Tighten of connections**: Heat cycles and mechanical vibration can lead to loose connections. Bad connections eventually lead to arcing and result in erratic operation, causing poor variable frequency drive quality, scrap, machine damage, or even personnel injury.
- When conducting a mechanical inspection, don't overlook internal VFD components. Check circulating fans for signs of bearing failure or foreign objects.
- Inspect DC bus capacitors for bulging/leakage, this could be signs of component stress or electrical misuse.
- Take voltage measurements while the VFD is in operation. Fluctuations in DC bus voltage measurements can indicate degradation of DC bus capacitors. Abnormal AC voltage on the DC bus indicates potential capacitor failure. Measurements of more than 4VAC may indicate a capacitor filtering problem or a possible problem with the diode bridge converter section. If you have such voltage levels, consult the manufacturer before taking further action.
- With the VFD in START and at zero speed, you should read output voltage of 40VAC phase-to-phase or less. Higher voltages could indicate transistor leakage. At zero speed, the power components should not be operating. Readings of 60VAC or more can indicate power component failure.
- Store spare VFDs in a clean, dry environment. Place this unit in your PM system so you know to power it up every six months to keep the DC bus capacitors at their peak performance capability. Otherwise, their charging ability will diminish significantly.
- Regularly monitor heat-sink temperatures. Most VFD manufacturers make this task easy by including a direct temperature readout on the keypad or display. Find this readout and check it weekly or monthly.

Troubleshooting for VFD systems is presented below[33]:

Possible Causes	Corrective Actions
1. High Bus Fault	
Overhauling load	Adjust deceleration time to match load capability
Input voltage level too high	Install isolation transformer, line filtering
Instantaneous voltage spike	Ensure ac power supply is consistent
2. Over current Fault	
Loose power connections or control wiring	Check all power and control connections and tighten loose connections or wiring
Incoming voltage too low	Stabilize/raise incoming voltage
Acceleration rate set too high	Decrease acceleration rate/lengthen acceleration time
Damage or excessive wear on mechanical load	Check load for damage/repair damage
Possible misalignments	Check and verify installation
Faulty motor	Repair or replace motor
Incorrect drive set up	Verify/adjust parameter settings
Drive/motor not matched to load	Verify application requirements
3. Over Temperature Fault	
Clogged filter	Clean, repair, or replace filter
Change in ambient temperature	Provide for additional cooling/ventilation
Fan blade damage or fan loss	Repair or replace fan

[33] *Source : https://www.plantengineering.com/articles/troubleshooting-vfds/*

Possible Causes	Corrective Actions
4. No Power in Drive	
Trouble with input ac power	Verify input ac power is connected and replace any blown fuses
Trouble with input control power	Verify input control power is connected %%POINT%% Check external conditions

2.5.5. Best operating & maintenance practices for lighting system

- Light levels decrease over time because of aging lamps and dirt on fixtures, lamps and room surfaces. Together, these factors can reduce illumination by 50% or more, while lights continue draw in full power.
- Regular maintenance is essential to ensure that facilities receive the desired quantity and quality of light, as well as energy efficiency, from their lighting systems. Periodic maintenance can produce a range of benefits, including a brighter and cleaner workplace, a higher level of security, and enhanced productivity.
- Basic maintenance includes cleaning of lamps & fixtures, cleaning and repainting interiors & re-lamping. Keep light-reflecting surfaces and lenses clean in order to maintain designed light levels (**Table 16**).

Table 16 Recommended illumination level

Area	Recommended Average Lux level
General factory area	
Canteens	150
Cloakrooms, change rooms, storages	100
Entrances	100
Factory outdoor areas	
Stockyards, main entrance,	20
Internal roads, exit roads, car parks	20
Assemble shop	
Rough work e.g. frame assembly	150
Medium work e.g. machined parts	300
Fine work e.g. Electronics assembly	700
Very fine work e.g. instrumentation assembly	1500
Boiler house	
Coal and ash handling	100
Boiler room	100
Outdoor plant	20
Control rooms	300
Inspection shops	
Rough work e.g. counting	150
Medium work e.g. sub-assembly	300
Fine work e.g. calibration and precision work	700
Very fine work e.g. critical parts	1500
Laboratories and test rooms	450
Office workspace	300

- Workers should take care not to touch the envelope of halogen bulbs because doing so leaves skin oils on the glass surface. As these bulbs heat and cool, the oils cause uneven stress, leading to glass cracking and shorter lamp life.

Tips for cleaning fixtures:

- Clean lighting fixtures whenever lamps are replaced. In areas where doors allow outside air or filtering is not adequate, clean at least twice a year.
- Wipe plastic lenses with damp, not dry cloth (a mild detergent may be needed). Small cell louver panels, including parabolic wedge louvers, should be removed and dipped in mild detergent solution, then air-dried.
- Do not wipe luminaire or lamps while fixture is energized.
- Line voltage should be checked at the fixture and compared with the ballast rating to be sure it is within the prescribed limits, so as to prevent lamps premature failure due to flickering caused by voltage fluctuation, hence if voltage controllers/stabilizers are present then its maintenance should also be done periodically.
- Replacement of old conventional magnetic ballast with new electronic ballast also reduces maintenance part of ballast repairing.
- To avoid damage to ballasts, lamps are replaced when it ceases operation unexpectedly, failed to light up after turning it on.
- Lamps should be replaced when they reach 70%-80% of their rated life. Your lamp supplier has additional information available regarding lamp maintenance procedures.
- Bulbs should be replaced not only when they break, but on a schedule according to how the brightness of the lamp decays over time. Some bulbs lose over a third of their initial brightness over a few years.
- Glass strips, running continuously across the breadth of the roof at regular intervals, can provide uniform lighting on industrial shop floors and storage bays, also maximum usage of daylights should be done in industries/factories by using transparent/translucent roofing sheets so as to minimize usage of electrical lighting in daytime.

3 Solar Rooftop Systems

3. Solar rooftop systems

3.1. Basics of solar rooftop systems

A solar photovoltaic (PV) cell converts sun's radiation directly into usable electricity. Electricity generated using Solar PV is a clean source of electricity and can be used directly, stored or even fed back to the power grid. There are numerous applications to this technology such as residential, industrial, agricultural, etc.

Solar power systems can be categorized in 3 types: on-grid, off-grid and hybrid. Details of the systems are shown in **Table 17**[34].

Solar PV can be characterized by:

- Electricity generation in daytime
- Low maintenance requirement
- Simple installation
- Easy scalability
- Robustness
- High upfront investment

Table 17 Types of solar systems

On-grid system
The rooftop solar system is integrated with the main grid supply. This system allows power to be used from the grid supply only when the rooftop solar system is unable to supply the required power. Thus, a well-planned rooftop system can efficiently supply power without using grid supply saving expenses otherwise incurred on using power from the grid. In fact, this system can earn revenues as any excess power generated can be fed to the grid for which DISCOMs pay compensation using 'net metering'.
Off-grid system
The rooftop solar system is not linked to the main grid. This system can run on its own with its own battery. The solar power generated from the rooftop solar system charges the battery which is then used to power various applications. This system is very useful when there is no grid supply or when the supply is very erratic with frequent breakdowns.
Hybrid system
Both on-grid and off-grid systems work in tandem. In this type of system, though a battery is used, the advantage here is that after the battery is fully charged the excess power generated is fed to the grid which generates additional revenues for the consumer.

For home solar rooftop systems, the nature of the roof is very important to determine its feasibility. The factors that need to be considered are as follows:

The availability of sunlight throughout the year and the area available on the rooftop is important to calculate the power that can be generated. A typical home solar panel can produce about 290 watts by harnessing one hour of direct sunlight. If sunlight falls for 8 hours, then the solar panel can produce 2320 watts electric power.

The orientation of the rooftop towards the sun is important. Exposure towards the north is the ideal orientation for the panel. If the roof is naturally sloping and facing north, then it is very ideal for installing rooftop solar panels. This is because Solomon Islands are situated in the southern hemisphere and north facing rooftops receive the maximum amount of sunlight as the earth rotates on its own axis at an inclination. However, if the roof is flat solar panels will need to be placed at an angle facing north to receive the maximum possible sunlight. Further, high rise buildings should not hinder the exposure of the solar panels to sunlight.

[34] *Solar rooftops: Everything you need to know before installing a solar rooftop system*

The decision on choosing a suitable type of rooftop solar system impacts the cost of the system. Each type involves different components and the costs could vary depending on them.

How much rooftop to use: Based on the availability of sunlight and the space available on the rooftop, the maximum power that can be generated can be determined. Further, based on the type of system the owner can decide on the space to be allocated on the rooftop for producing electric power.

3.2. Potential Assessment for Solar Rooftop[35]

Unlike energy generation from fossil fuels, renewable energy sources have comparatively low geographic density and are spread unevenly over large areas. Therefore, especially in cities, where space has greater value and opportunity costs, finding suitable spaces for implementing solar systems are essential to promote the use of solar technologies.

Increasing development of solar PV is mostly due to improving competitiveness and cost parity with other technologies, new government plans, increasing awareness of the potentials of this technology, and rising electricity demand. Substantial increases in rooftop solar PV installation resulted in buildings becoming the largest available urban source of space for deployment. In fact, globally, about half of the PVs presently installed capacity is composed of distributed PV systems. However, a large capacity is still untapped.

Considering a case of a typical 200 kWp grid connected solar rooftop plant, it will have the following outputs:
- Generation of around 25,300 units of electricity in a month (average);
- Consist of 800 – 1,200 PV panels occupying 2000 m^2 (50m x 40m) roof space. As thumb rule the area requirement for SPV system is 10 m^2/kW (considering thin film technology);
- Generates 303,600 kWh in a year;
- Payback in 4-10 years considering a 15% rebate on initial cost. However, the system will last for ~20 years;
- The solar output can be supplied to the grid and earn revenue if the SPV system produces in excess of electricity requirement or when the building is vacant.

3.2.1. Basics of Grid Connected Solar Rooftop Plant

In grid connected rooftop or small SPV system, the DC power generated from SPV panel is converted to AC power using power conditioning unit/Inverter and is fed to the grid either of 440/220 Volt three/single phase line or of 33 kV/11 kV three phase lines depending on the capacity of the system installed at residential, institution/commercial establishment and the regulatory framework specified for respective States. These systems generate power during the daytime which is utilized by powering captive loads and feed excess power to the grid as long as grid is available. In case, where solar power is not sufficient due to cloud cover etc., the captive loads are served by drawing balance power from the grid. The main components of a grid connected solar rooftop system are as presented in **Table 18**.

Table 18 Main components of grid connected solar rooftop system

Component	Description
PV modules 	PV modules comprise of PV cells which are the devices that actually convert solar energy into usable electricity. They are commonly manufactured using silicon, but there are other materials as well such as cadmium telluride (CdTe), copper indium gallium selenide/sulfide (CIGS) from which they are being manufactured. Silicon based PV cells are relatively higher in cost but have a higher efficiency of around 15% to 20% as compared to 5% - 10% for other materials used. Good quality PV modules have an operating life of around 20 – 30 years depending on multiple factors.

[35] *Evaluating solar energy technical and economic potential on rooftops in an urban setting: https://link.springer.com/article/10.1007/s40095-018-0289-1*

Component	Description
Mounting Structures 	The mounting structure of the Solar panel is the support structure which is responsible for holding the solar PV modules. PV modules are mounted on these support structures in a manner that they are able to generate more by capturing more solar insolation. These structures can be either fixed or tracking or floating. Fixed solar mounting structures have the lowest cost as they require the least maintenance, the choice of type of mounting structure depends on the resources available with the facility
Inverter 	PV modules generate DC power from the solar radiation. However, in order to be used to feed the power grid or for the operation of most electrical equipment it needs to be converted to AC, which is predominantly performed by the inverters. For Grid connected Solar rooftops inverters come in standard sizes ranging from a few hundred watts to a few hundred kilowatts, depending on system size. Selection of an inverter is based on factors such as application, size, cost, usage and functions (some inverters also perform energy monitoring functions), etc.
Balance of System 	Components such as cables, switchboards, junction boxes, meters, etc. are classified under balance of system Electricity meters are used to record the amount of electricity that is generated or consumed in a facility.

A simple pictorial representation of a grid connected Solar PV setup is shown in **Figure 18** and **Figure 19**[36].

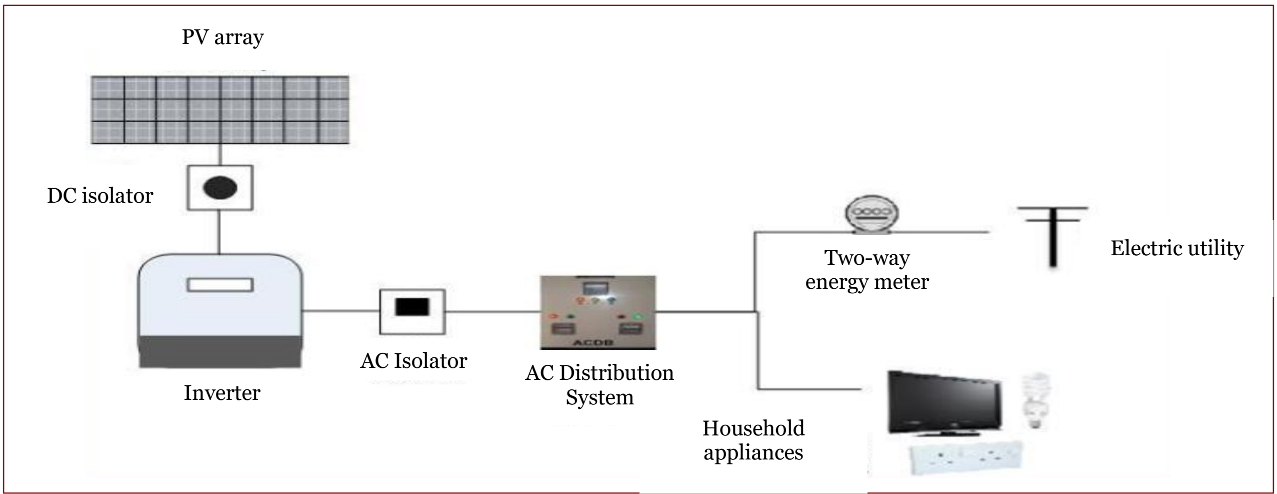


Figure 18 Pictorial representation of grid connected solar PV setup

Net-metering:
The grid connected rooftop system can work on net metering basis wherein the beneficiary pays to the utility on net meter reading basis only. Alternatively, two meters can also be installed to measure the export and import of power separately. The mechanism based on gross metering at mutually agreed tariff can also be adopted.

[36] *Source: Technical Manual for Banks & FIs on Grid Connected Rooftop Solar PV (MNRE India)*

In gross metering the energy generated from the SPV plant is feed to the grid. In lieu to the energy fed to the grid, they are paid a feed in tariff.

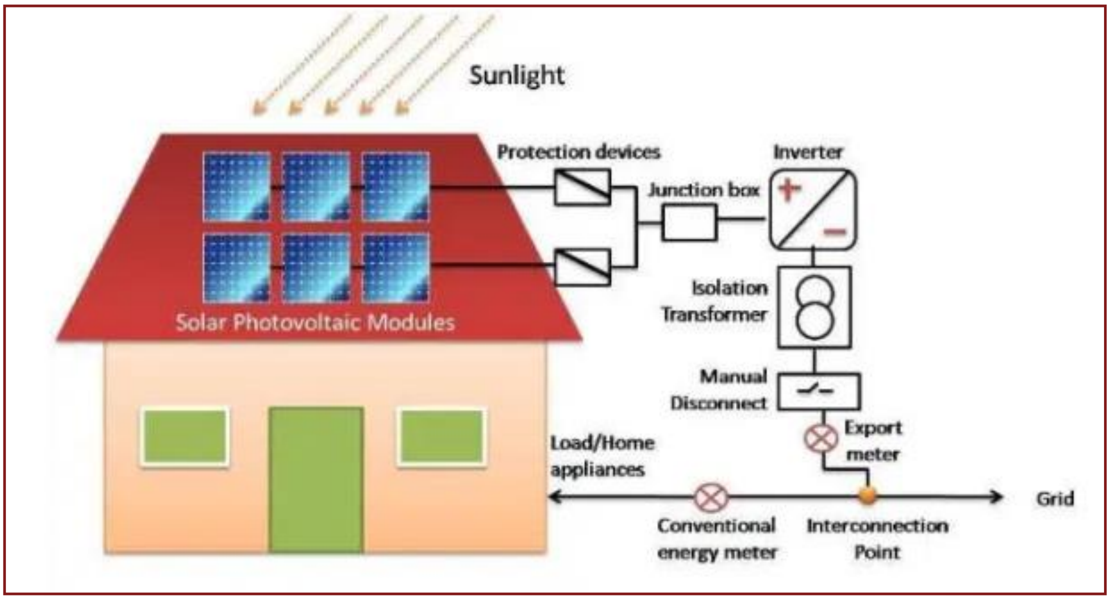


Figure 19 Pictorial view of solar PV rooftop system

3.3. Quality Standards and Benchmarks

Solar PV systems have certain international standards and quality specifications. These standards and benchmarks are necessary as they bring in confidence to invest in the technology. There are a number of standards concerning safety, performance, product quality, durability, grid interconnection, efficiency, harmonics, surge protection, power quality, etc. A list of standards, as per different components of the solar PV system, defined by IEC (International Electrotechnical Commission) is shared in **Table 19**[36].

Table 19 Quality standards for solar PV systems

S.No.	Standard	Brief Description
Solar PV Modules/Panels		
1.	IEC 61215	Design Qualification and Type Approval for Crystalline Silicon Terrestrial Photovoltaic (PV) Modules
2.	IEC 61646	Design Qualification and Type Approval for Thin-Film Terrestrial Photovoltaic (PV) Modules
3.	IEC 62108	Design Qualification and Type Approval for Concentrator Photovoltaic (CPV) Modules and Assemblies
4.	IEC 61701	Salt Mist Corrosion Testing of Photovoltaic (PV) Modules
5.	IEC 61853- Part 1	Photovoltaic (PV) module performance testing and energy rating –: Irradiance and temperature performance measurements, and power rating
6.	IEC 62716	Photovoltaic (PV) Modules – Ammonia (NH3) Corrosion Testing
7.	IEC 61730-1,2	Photovoltaic (PV) Module Safety Qualification – Part 1: Requirements for Construction, Part 2: Requirements for Testing
8.	IEC 62804 (Draft Specifications)	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation. IEC TS 62804-1: Part 1: Crystalline silicon

S.No.	Standard	Brief Description
9.	IEC 62759-1	Photovoltaic (PV) modules – Transportation testing, Part 1: Transportation and shipping of module package units
	Solar PV String Inverters/PCUs	
10.	IEC 62109-1, IEC 62109-2	Safety of power converters for use in photovoltaic power systems - Part 1: General requirements, and Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters. Safety compliance (Protection degree IP 65 for outdoor mounting, IP 54 for indoor mounting)
11.	IEC/IS 61683 (For Standalone System)	Photovoltaic Systems – Power conditioners: Procedure for Measuring Efficiency (10%, 25%, 50%, 75% & 90-100% Loading Conditions)
12.	BS EN 50530 (Will become IEC 62891) (For Grid-connected System)	Overall efficiency of grid-connected photovoltaic inverters: This European Standard provides a procedure for the measurement of the accuracy of the maximum power point tracking (MPPT) of inverters, which are used in grid-connected photovoltaic systems. In that case the inverter energizes a low voltage grid of stable AC voltage and constant frequency. Both the static and dynamic MPPT efficiency is considered.
13.	IEC 62116/ UL 1741/ IEEE 1547	Utility-interconnected Photovoltaic Inverters - Test Procedure of Islanding Prevention Measures
14.	IEC 60255-27	Measuring relays and protection equipment - Part 27: Product safety requirements
15.	IEC 60068-2 (1, 2, 14, 27, 30 & 64)	Environmental Testing of PV System – Power Conditioners and Inverters a) IEC 60068-2-1: Environmental testing - Part 2-1: Tests - Test A: Cold b) IEC 60068-2-2: Environmental testing - Part 2-2: Tests - Test B: Dry heat c) IEC 60068-2-14: Environmental testing - Part 2-14: Tests - Test N: Change of temperature d) IEC 60068-2-27: Environmental testing - Part 2-27: Tests - Test Ea and guidance: Shock e) IEC 60068-2-30: Environmental testing - Part 2-30: Tests - Test Db: Damp heat, cyclic (12 h + 12 h cycle) f) IEC 60068-2-64: Environmental testing - Part 2-64: Tests - Test Fh: Vibration, broadband random and guidance
16.	IEC 61000 Series	Electromagnetic Interference (EMI), and Electromagnetic Compatibility (EMC) testing of PV Inverters (as applicable)
	Fuses	
17.	EN 50521	General safety requirements for connectors, switches, circuit breakers (AC/DC): a) Low-voltage Switchgear and Control-gear, Part 1: General rules b) Low-Voltage Switchgear and Control-gear, Part 2: Circuit Breakers c) Low-voltage switchgear and Control-gear, Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units d) EN 50521: Connectors for photovoltaic systems – Safety requirements and tests
18.	IEC 60269-6	Low-voltage fuses - Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems

S.No.	Standard	Brief Description
		Surge Arrestors
19.	IEC 60364-5-53	Electrical installations of buildings - Part 5-53: Selection and erection of electrical equipment - Isolation, switching and control
20.	IEC 60227, IEC 60502 (Part 1 & 2)	General test and measuring method for PVC (Polyvinyl chloride) insulated cables (for working voltages up to and including 1100 V, and UV resistant for outdoor installation)
21.	BS EN 50618	Electric cables for photovoltaic systems (BT(DE/NOT)258), mainly for DC cables
		Earthing/Lighting
22.	IEC 62561 Series (Chemical earthing)	IEC 62561-1 Lightning protection system components (LPSC) - Part 1: Requirements for connection components IEC 62561-2 Lightning protection system components (LPSC) - Part 2: Requirements for conductors and earth electrodes IEC 62561-7 Lightning protection system components (LPSC) - Part 7: Requirements for earthing enhancing compounds
		Junction boxes
23.	EC 529	Junction boxes and solar panel terminal boxes shall be of the thermo plastic type with IP 65 protection for outdoor use, and IP 54 protection for indoor use
		Energy meter
24.	As specified by the DISCOMs	A.C. Static direct connected watt-hour Smart Meter Class 1 and 2 — Specification (with Import & Export/Net energy measurements)
		Battery/ Electrical Storage
25.	IEC 61427-1	Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 1: Photovoltaic off-grid application
26.	IEC 61427-2	Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 2: On-grid applications
		Solar PV Roof Mounting structure
27.	DIN EN 1991-1-4	Actions on structures, Part 1-4: General actions – Wind actions

3.4. Performance monitoring of solar system

3.4.1. Maintenance

Good maintenance of solar PV plant will not only ensure proper efficiency in generation of electricity but will also lead to increased operating life of the power plant. When compared with other technologies solar PV plants have a relatively lower maintenance and servicing requirements.

Manufacturers and designers of Solar PV plants generally have set practices for PV system maintenance. Most of the equipment come with multiyear AMC's (Annual maintenance Contracts) that mandate the contractor to execute the required maintenance activities (including replacement or repair of equipment) inside the contracted period of the AMC (usually 2-5 years), without any cost to the facility owner.

A typical AMC for grid connected Solar PV includes following.

Scheduled maintenance activities

Supply & installation of spare parts

Maintenance of log sheets

Replacement or repair of defective modules, inverters, etc.

Logging complaints & its redressal

Insurances (machine breakdown insurance, earthquake, general insurance covering fire etc.)

A comparison of scheduled and unscheduled maintenance is presented in below.

Scheduled maintenance activities	Unscheduled maintenance activities
Checking module connection integrity	Tightening cable connections that have loosened
Checking junction / string combiner boxes	Replacing blown fuses
Module Cleaning	Repairing lightning damage
Inverter servicing	Repairing equipment damaged by intruders or during module cleaning
Inspecting mechanical integrity of mounting structures	Rectifying supervisory control and data acquisition (SCADA) faults
Vegetation control	Repairing mounting structure faults
Checking module connection integrity	Tightening cable connections that have loosened
Checking junction / string combiner boxes	Replacing blown fuses

3.4.2. Performance monitoring

Performance monitoring is a very important aspect of grid connected solar PV and is essential the successful operation and maintenance of the system. It provides the necessary data required for fault detection and performance analysis for the grid connected Solar PV.

For small scale Solar PV data gathered which may be gathered includes the data logged in inverters, switches and meters. In cases of large-scale MW solar PV systems data is acquired form sophisticated data acquisition systems (e.g. SCADA) to procure and assimilate data from a number of monitoring devices. Performance is monitored once in a day by the system operator in order to ensure timely detection of faults generation and deliver optimal performance.

3.4.3. System Operation and performance

The actual generation from a solar module follows a bell shape curve and is closely linked to the instantaneous solar irradiance falling on the surface of the module, starting in the morning and ending in the evening A typical energy generation curve under clear sky conditions is shown in **Figure 20**.

Energy generation calculations at a preliminary level for energy generated by a solar PV can be estimated using system size, solar resource and system losses. These calculations are only useful for preliminary project phase, for more accurate calculations sophisticated software products are used. These software products use location-specific weather data records, PV module configuration (angle, orientation, etc.), efficiency, losses, array design, cell temperatures, inverter characteristics and so on.

Preliminary calculations are quick and easy and can be done to check project feasibility by estimating the year wise generation data in the project life of the project. However, these calculations cannot be used in the design phase of the project as the design phase of project requires accurate detailed generation estimates, including month-wise, day-wise and hour-wise generation.

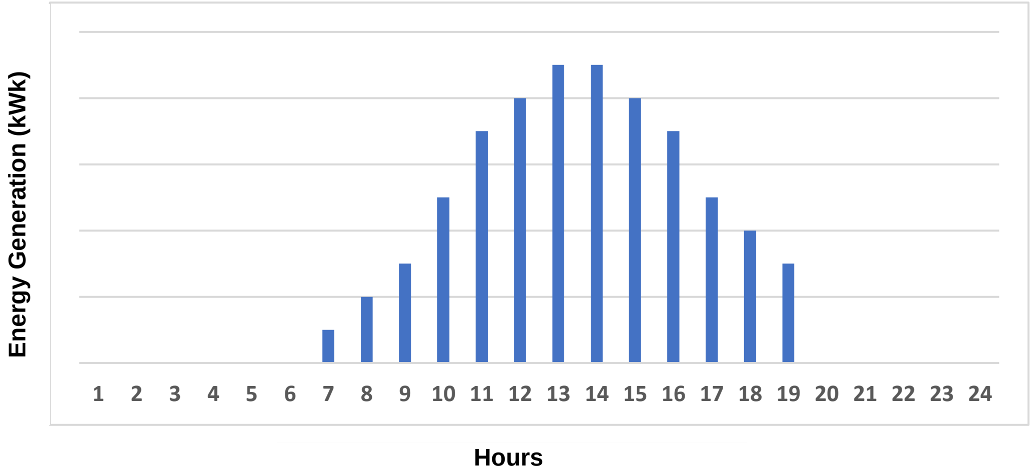


Figure 20 Typical energy generation curve under clear sky conditions

Typical PV system energy losses are presented in the Sankey diagram shown in **Figure 21**.

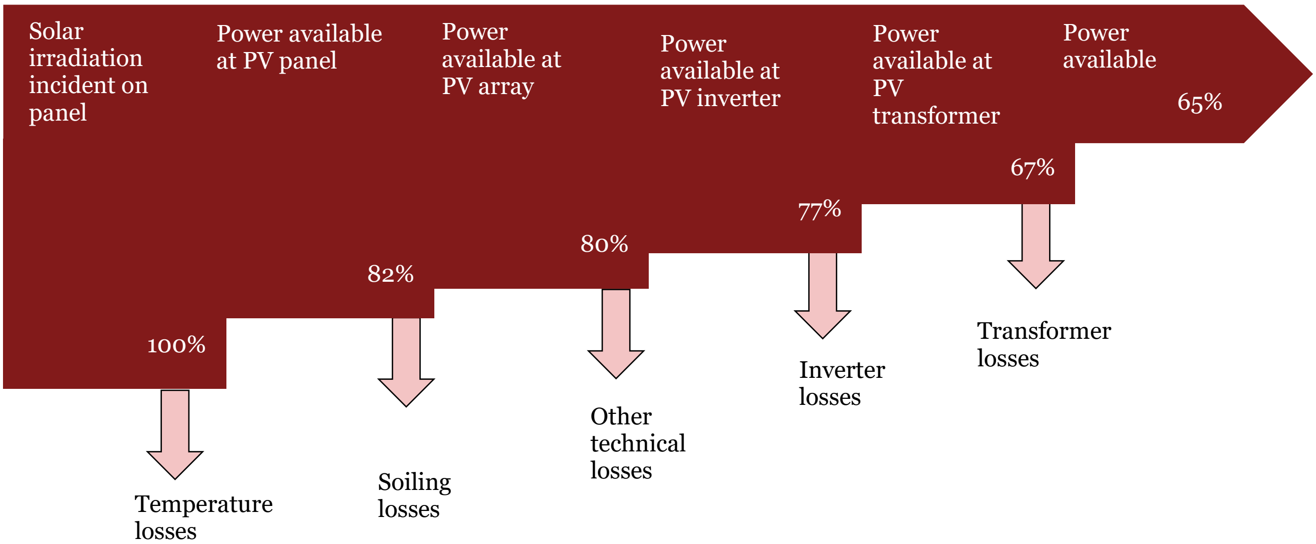


Figure 21 Typical energy losses in Solar PV system

3.5. Business models

In case of a Solar PV, design of an appropriate business model assumes a lot of significance due to their high costs of generation and high upfront cost of investment. Appropriately designing and deploying a solar PV setup in terms of business is the key to its success and should be the basis of policy and regulation formation.

Ownership and revenue structure are the two main determinants of a Solar PV plant. In most cases these two factors are determined by the policy framework in the market, electricity structure or tax policies prevalent.

CAPEX Model (Self Owned Business model)

The entire system is owned by the rooftop owners and he/she bears the cost of the Solar system. Responsibility of O&M for the system lifetime (25 years) is also with the rooftop owner. Developer is responsible for installing the system and initial 2 years O&M and five years warranty.

In most of the cases of self-owned business model, the owner usually invests in the equity component of the setup, while debt component left is financed by FI's such as commercial banks.

Captive off grid

The mechanism of a captive off-grid is presented in **Figure 22** and its application, advantages and disadvantages are presented in **Table 20**.

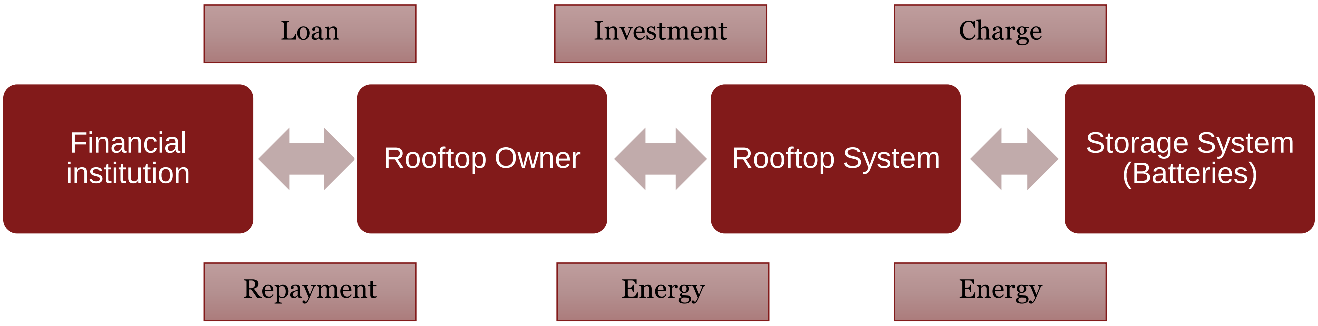


Figure 22 Captive off grid system model

Table 20 Captive off grid model application, advantage and disadvantage

Applications
This kind of business model is prevalent where there either is absence of proper power grid or reliability of the grid is very poor. Captive off grid Solar PV has huge applications in rural and remote areas which lack proper electricity distribution infrastructure. In such scenarios the power so generated is completely utilized by the owner.
Advantages
As stated in their applications, such kind of systems are usually deployed and developed in areas which lack proper power infrastructure. Most of these areas are energy deficient areas which lack clean energy technologies and are highly reliant on alternate expensive mode of power such as DG sets. Captive off-grid Solar PV is highly useful here.
Disadvantages
Added cost of energy storage options, such as batteries are needed, to service fluctuating demand requirements.

Gross feed

In this model the energy so generated by the solar modules is completely transferred to the grid, for which the consumer is paid feed in tariff (FiT). The owner of the SPV enters into a long-term agreement with the utility. The FiT setup provides a minimum rate of return to the investor on the investment. The mechanism of a gross feed model is shown in **Figure 21** and its application, advantages and disadvantages are shown in **Table 21**.

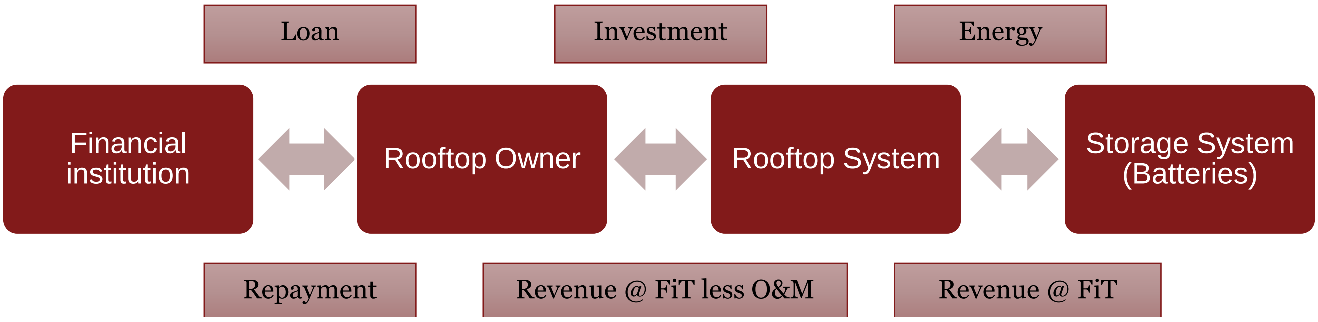


Figure 23 Gross feed model

Table 21 Gross feed model application, advantage and disadvantage

Applications
This kind of business model is prevalent in developed nation. The key markets which have adopted this type of business model are countries such as Japan, Italy, France, etc.
Advantages
One of the major advantages of this kind of business model is that they do not require any energy storage option to be coupled with, thereby bringing down the costs. It allows a number of new investors(customers) to enter the market, thereby increasing the investment base It safeguards the utilities against migration of high paying customers out of the utility ecosystem It allows consumers from different consumer categories, regardless of their tariffs, to participate in the solar program by installing optimally sized solar rooftops
Disadvantages
The main disadvantage of this kind of Solar PV is that it creates an apparent short-term cash flow burden on utilities balance sheet. Moreover, the high cost of procurement also leads to increase in consumers tariffs

RESCO Model (Third party owned business model)

Here, the entire system is owned by the developer. Responsibility of O&M for the system lifetime (say about 25 years) is also with the developer. Rooftop owners may consume the electricity generated, for which they have to pay a pre-decided tariff on a monthly basis. Excess generation may be exported to the grid, subject to availability of requisite state regulations. The developer may:

- lease the rooftop from the rooftop owner
- lease the system to the rooftop owner

The features of capex and opex models are presented in **Table 22**.

Table 22 Opex vs capex model

Capex	Opex
Project owned by roof owner/consumer	Project owned by project developer / supplier
Roof owner/consumer responsible for O&M of system after initial 1-2-year period	Roof owner/consumer not responsible for O&M; O&M is responsibility of project developer
Can't be converted to OPEX model at a later date Power to be used for captive consumption; surplus power can be sold to distribution utility	Can be converted into CAPEX at a pre-decided date (option to buy back) Power can be sold to roof owner; Power can be sold to distribution utility; Power can be sold to third party**

3.6. Policy and Regulatory Challenges

What Solomon Islands government schemes are in place to lower the cost of purchasing a solar PV system?

There are currently NO government assistance schemes in the Solomon Islands for the installation and operation of solar PV arrays

Renewable Energy Certificates

The Solomon Islands does NOT have a Renewable Energy Certificate Scheme.

Feed-in tariffs

Solomon Power does NOT purchase excess energy from a domestic or commercial photovoltaic system.

Standby Charges

Solomon Power DOES apply a daily standby charge for the operation of solar PV arrays that are connected to its network. This is 50% of the power that is generated by the array and consumed internally by the customer. The power generated by the array (in kWh) is assessed as being 4.4 times the nominal kW rating of the inverter.

The overview Process for Solar Grid Connect in Solomon Islands is presented in **Figure 24**[37].

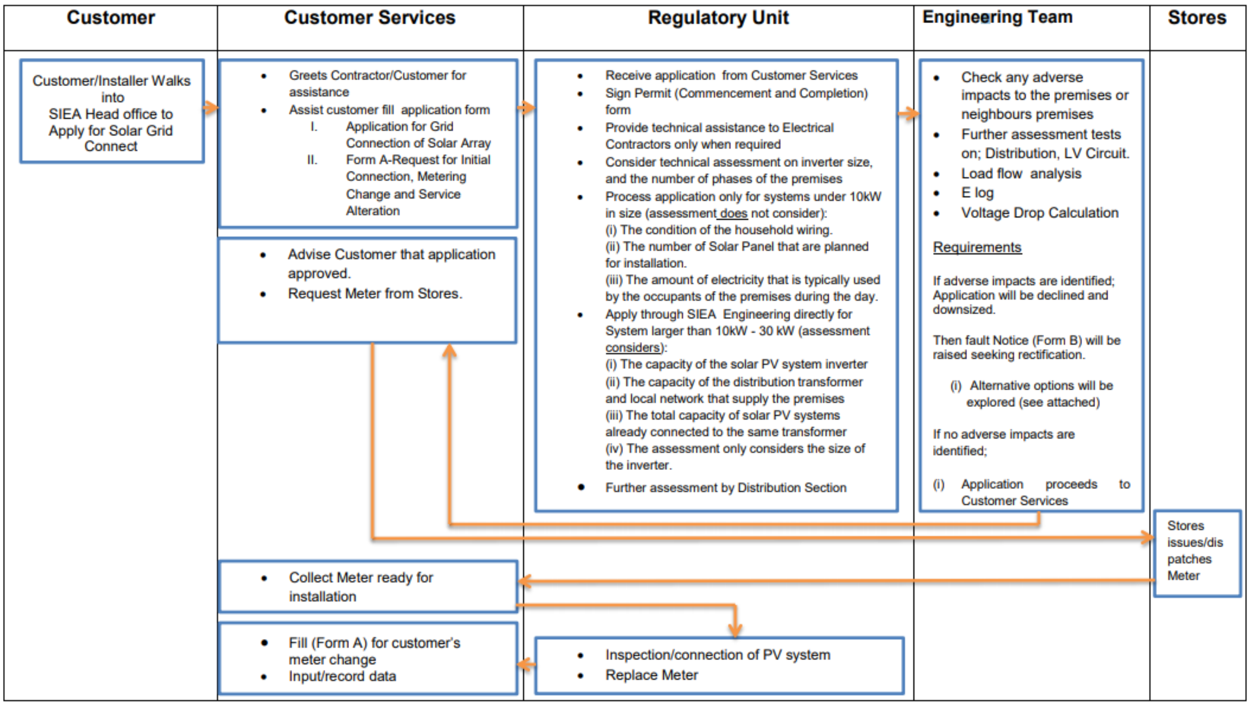


Figure 24 Process for Solar Grid Connect

Standards for Grid-Connected Photovoltaic (PV) Arrays – Solomon Power are as presented in **Table 23**[38]:

Table 23 Standards for grid-connected PV arrays - Solomon Power

Area	Standard	Title	Outline
Installation	AS/NZ 5033:2012	Installation and safety requirements for photovoltaic (PV) arrays	Sets out general installation and safety requirements for photovoltaic (PV) arrays, including DC array wiring, electrical protection devices, switching and earthing up to but not including energy storage devices, power conversion equipment or loads. The safety requirements of this Standard are critically dependent on the inverters associated with PV arrays complying with the requirements of IEC

[37] *Source: Solomon Power Website http://www.solomonpower.com.sb/sites/default/files/Regulatory/Process%20for%20Solar%20Grid%20Connect.pdf*
[38] *http://solomonpower.com.sb/wp-content/uploads/2019/08/6-Standards-for-Grid-Connected-Solar-Arrays.pdf*

Area	Standard	Title	Outline
			62109-1 and IEC 62109-2 and all power conditioning equipment complying with IEC 62109 series standards. PV arrays of less than 240 W and less than 50 V open circuit voltage at Standard Test Condition (STC) are not covered by this Standard.
Installation	AS4777.1:2005	Grid connection of energy systems via inverters - Installation requirements	Specifies requirements for the installation of inverter energy systems with ratings up to 10 kVA for single phase systems, or 30 kVA for three phase systems, onto the low-voltage electricity distribution network (grid).
Inverter	AS4777.2:2005	Grid connection of energy systems via inverters - Inverter requirements	Specifies requirements for inverters with ratings of up to 10 kVA for single-phase systems, or 30 kVA for three-phase systems, and intended for connection to the low-voltage electricity distribution network (grid).
Grid Protection Requirements	AS4077.3:2005	Grid connection of energy systems via inverters - Grid protection requirements	Specifies grid protection requirements for inverter energy systems with ratings up to 10 kVA for single-phase, or 30 kVA for three-phase, systems and intended for connection to the low-voltage electricity distribution network (grid).
General Wiring Standards	AS/NZS3000:2007/Amdt 2:2012	Electrical Installations	Known as the Australian/New Zealand Wiring Rules

4 Financial Feasibility and Measurement & Verification


RPS

4. Financial Feasibility and Measurement & Verification

4.1. Basics of financial analysis

Financial analysis is the process of evaluating projects or investment propositions and identifying the project or investment proposition with the highest potential. The investment would be required for modification, retrofitting and for incorporating new technology. It is imperative to adopt a comprehensive approach to for merit rating of various investment options vis-à-vis the anticipated saving. It is important to identify benefits of the identified measure not only to energy savings but also to other associated benefits like improved product quality, increased productivity and efficiency etc.[39]

Often, within a facility, the multitude & complexity of proposals that come up for consideration by management are from different sections of the facility. As a result, the genesis, objectives, results and needs of the proposals may be quite diverse. In case of investment proposals, the problem further intensifies as the management would like to invest the limited capital to the most attractive proposal which provides highest return on investment. Therefore, it is necessary to establish certain common evaluation criteria which can provide an indication of attractiveness of particular investment proposal as compared to the competing proposals.[40]

There are two common problems faced while considering investments in Energy proposals. The first problem is that organizations generally give preference to investing in their core or profitmaking activities in preference to energy efficiency. The second issue is that even when they do invest in energy efficiency, they tend to expect faster rates of return than they require from other kinds of investment.[39] In most respects, investment in EE project is no different from any other area of investment. Therefore, when facility management decides to invest in EE project, the same set of evaluation criteria must be applied to the EE investment proposal as would get applied to other investment considerations of the facility. Following are methods of financial analysis:

- Simple Payback Period (SPP)
- Discounted Payback Period (DPP)
- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- Return on Investment (ROI)
- Life Cycle Cost Analysis (LCCA)
- Sensitivity Analysis

4.2. Financial appraisal methods

4.2.1. Simple payback period

Simple payback period is a measure of the amount of time (in years) it takes to recover the initial investment in any project. With reference to resource efficiency, it is the amount of time (in years) taken to recover the initial investment in resource efficiency project considering only the net annual savings from the project. It is one of the simplest investment appraisal techniques. The simple payback period is usually calculated as follows:

$$Simple\ paybak\ period = \frac{First\ cost}{Yearly\ benefits - Yearly\ costs}$$

[39] *Financial Management, Book 1 Chapter 6, Bureau of Energy Efficiency Guidebooks*
[40] *Training manual for capacity building of banks, Financing Energy Efficiency at MSMEs, Prepared by PwC for SIDBI*

The advantages and limitations of simple payback period (SPP) method of financial appraisal are presented below. A case example is presented in **Box 8**.

Advantages	Limitations
It is simple, both in concept and application. Obviously, a shorter payback generally indicates a more attractive investment. It does not use tedious calculations. It favours projects, which generate substantial cash inflows in earlier years.	It fails to consider the time value of money. Cash inflows, in the payback calculation, are simply added without suitable discounting or compounding. It ignores cash flows beyond the payback period. This leads to discrimination against projects that generate substantial cash inflows in later years.

Box 8: Simple Payback Period Case Example

Problem: A copper smelting industry uses a smelting furnace. The furnace operates at mains frequency furnace and is an outdated design. Based on assessment of the furnace, the specific energy consumption of the furnace which is high considering process type and operation.

Solution: A high frequency induction furnace technology is proposed to replace the existing furnace. The specific energy consumption of the new furnace is expected to be 850 kWh per tonne as compared to 1362 per tonne for the conventional smelting furnace.

SPP calculation: The purchase and installation cost of new furnace is US $ 130,500, it is expected to save electricity equivalent to monetary saving of US $ 70,500 per year. The maintenance cost of the induction furnace is US $ 5000.

$$Simple\ paybak\ period\ = \frac{130{,}500}{70{,}500 - 5{,}000} = 2.0\ years$$

4.2.2. Discounted payback period

Discounted Payback period (DPP) is a measure of the amount of time (in years) it takes to recover the initial investment in any project considering the time value of money. The different between DPP and SPP is that DPP takes into account the time value of money while discounting the cash flows which is not the case in SPP. The discounted payback period is usually calculated as follows:

$$Discounted\ payback\ period\ = \frac{Actual\ cash\ inflow}{(1+r)^t}$$

Where: r - discount rate and t - period of cash flow

Hence, lower the DPP of the project, the faster the recovery of initial investment and thus better the project. The general rule is to accept projects which have a payback period less than the targeted period. The advantages and limitations of DPP method of financial appraisal are presented below. Case example is shown in **Box 9**.

Advantages	Limitations
It is simple, both in concept and application. Unlike SPP, it takes into account the time value of money while considering the cash flows.	It ignores cash flows beyond the payback period. This leads to discrimination against projects that generate substantial cash inflows in later years.

Box 9: Discounted Payback Period Case Example

Problem: A fertilizer industry had a number of toilets across the factory. Each was installed with standard flush of 13 - 16 litres per flush.

Solution: The low flush cisterns use as little as three liters of water for a short flush and six liters for a long flush, compared to regular cisterns that use 13 liters per flush. A significant amount of water can be saved by replacing all the conventional flushes with low flow flush systems.

DPP calculation: Let us consider a project of replacing regular toilet flushes with low flush cisterns which has the following cash flow stream. Initial cost of project is US $ 750. Savings in 1st, 2nd and 3rd years are US $ 600, 450 and 250. Assumption: Useful life is 3 years; Discount rate is 10%

Year	Cash flow (US $)	Present value (US $)	Cumulative (US $)
1	+600	545	545
2	+450	372	917
3	+250	187	1104

$$Simple\ paybak\ period\ = \frac{750}{600} = 1.25\ years$$

The investment is US $ 750, which falls in between 1st and 2nd year. (Somewhere 1year 7 months)

$$Discounted\ paybak\ period\ = 1.55\ years$$

4.2.3. Return on Investment

Return on Investment (ROI) is an indicator of the "annual return" from the project as a percentage of the capital cost involved in the project. The annual return takes into account the cash flows over the project life and the discount rate by converting the total present value of ongoing cash flows to an equivalent annual amount over the life of the project, which can then be compared to the capital cost.

ROI can be calculated using:

$$ROI = \frac{Annual\ net\ cash\ flow}{Capital\ cost} \times 100$$

This value should always be higher than the opportunity cost that is the cost of money (interest rate) in this case. The higher the value of ROI, better the investment. This metric can be used for evaluating investment opportunity with different time periods and capital costs. It helps in judging whether to go ahead with the investment opportunity or not.

The advantages and limitations of ROI method of financial appraisal are presented below. A case example is presented in **Box 10**.

Advantages

It is simple, both in concept and application.

Return expressed as percentage makes it easier to evaluate against borrowing interest. In general, if RoI is higher than the borrowing interest then it is a profitable investment.

Limitations

It doesn't consider the time value of money.

It also does not take into account variable annual cash flows which is often the more encountered case in real life analysis.

Box 10: Return on Investment Case Example

Problem: A beverage industry uses high quantity of water in ablution and cleaning process.

Solution: Use of high-pressure nozzles reduces quantity of water usage by increasing pressure. These nozzles can be retrofitted on existing cleaning water pipes.

ROI calculation: The industry adopted the high-pressure low floe nozzles at an investment of US $ 300 which led to annual monetary saving of US $ 75.

$$ROI = \frac{75}{300} \times 100 = 25\%$$

4.2.4. NPV and IRR

Net Present Value (NPV) gives the aggregate present value of all the cash flows associated with the project or investment opportunity. The NPV is calculated using the following formula:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{((1+r)^t)}$$

Where: r - discount rate, n - life of project, t - period (0, 1, ..., n), CF_t - cash flow occurring at end of period 't'

In general, higher the value of NPV, better the project. The investment proposition or project should be accepted if the NPV is positive and reject it if the NPV is negative. A negative NPV indicates that the project is not achieving the return standard and thus will cause a financial loss if implemented. It can be used for deciding between two different projects. The project with a higher NPV will be preferred over the project with lower NPV.

Internal Rate of Return (IRR) is the discount rate at which NPV of the project is zero. This method helps in calculating the rate of return that the investment is expected to yield. It is derived by the following equation:

$$0 = \sum_{t=0}^{n} \frac{CF_t}{((1+r)^t)}$$

Where: r - Discount rate at NPV=0 is IRR

The discount rate, r, in above formula is calculated by iterations. If this discount rate is greater than current interest rate, the investment is sound. The proposal with higher IRR is usually the preferred choice for investment. Calculation of IRR can be effectively done using a computer spreadsheet, otherwise it is a long iterative process.

IRR is used for comparing different investment alternatives. The project with a higher IRR has a higher rate of return and is thus a better alternative as compared to other projects.

The advantages and limitations of IRR method of financial appraisal are presented below. A case example is presented in **Box 11**.

Advantages	Limitations
It considers the time value of money while discounting cash flows. Unlike SPP and DPP, it considers all the cash flows of the project.	It does not distinguish between borrowing and lending. Therefore, a higher IRR may not necessarily be a better proposition.

Box 11: IRR Case Example

Problem: A fertilizer industry does not have rainwater harvesting system in place. Rainwater harvesting is the accumulation and storage of rainwater for reuse on-site, instead of allowing it to run off which happens most of the times. This leads to wastage of a large amount of reusable water.

Solution: Rainwater from the roofs can is directed into deep pits and reused with minimal filtration. The harvested rainwater can be used for gardening as well as in the toilets, with proper treatment it can be used for domestic purposes. Moreover, rainwater is simplest method of recharging groundwater.

NPV & IRR calculation: Initial cost of project is US $ 1000. Annual savings is US $ 300. Useful life 10 years. Calculate NPV at discount rate of 15%. Also calculate IRR for the proposal.

Year	Cash flow (US $)	Present value (US $)	Cumulative (US $)
0	-1000	-1000	-1000
1	+300	+260	-740
2	+300	+227	-513
3	+300	+197	-315
4	+300	+171	-143
5	+300	+149	+6
6	+300	+130	+136
7	+300	+112	+248
8	+300	+98	+346
9	+300	+85	+431
10	+300	+74	+505

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{((1+r)^t)} = 505$$

NPV is positive hence the project is recommended for implementation.

$$0 = \sum_{t=0}^{n} \frac{CF_t}{((1+r)^t)}$$

NPV @ 28% discount rate is -19.3 and NPV @ 27% discount rate is +9.3

IRR of the proposal is 27.3%.

4.2.5. *Life Cycle Cost Analysis*

The Life cycle cost (LCC) of any equipment is the total "lifetime" cost to purchase, install, operate, maintain and dispose of that equipment. LCC analysis can be performed easily using spreadsheet if we have access to all the cost values. The costs are either deterministic (such as acquisition costs, disposal costs etc.) or probabilistic (such as cost of failure repairs etc.).

LCCA is used for comparing and evaluating the costs involved in different equipment. It helps us in deciding which equipment to choose. Most of the organizations are unaware that the initial cost comprises a small portion of the cost while major cost comes from the energy consumption.

Life cycle cost is given by the following equation:

$$LCC = C_{ic} + C_{in} + C_e + C_o + C_m + C_s + C_{env} + C_d$$

Where: LCC - life cycle cost, C_{ic} - initial costs and purchase price,
C_{in} - installation and commission cost, C_e - energy costs,
C_o - operation costs, C_m - maintenance and repair costs
C_s - down time costs, C_d - decommissioning/disposal costs

For financial appraisal of project/proposal these costs can be simplified, and three costs can be considered and they are: (1) Investment cost (including commissioning), (2) Energy cost and (3) Service & maintenance cost. A typical case example of LCCA is presented in **Box 12**[41].

Box 12: Life Cycle Cost Analysis Case Example

Problem: The system is a single pump circuit that transports a process fluid containing some solids from a storage tank to a pressurized tank. The plant engineer is experiencing problems with a fluid control valve (FCV) that fails due to erosion caused by cavitation.

Solution: (a) Repair the control valve, (b) Change control valve (c) Impeller trimming and (d) Install VFD & remove control valve

LCCA calculation: The comparison of three potential solutions is done based on LCCA as shown below:

Particular	Repair control valve	Change control valve	Impeller trimming	VFD and remove control valve
Investment cost (US $)	0	5000	2250	21500
Energy cost (US $/year)	11088	11088	6720	5568
O&M cost (US $/year)	4500	500	500	1000
Repair cost US $/ 2 years)	2500	2500	2500	2500
Lifetime (years)	8	8	8	8
Present value LCC (US $)	113980	91827	59481	74313

Option C i.e. impeller trimming has the lowest life cycle cost, hence is the preferred solution for the problem.

The energy efficient equipment are typically more expensive to purchase initially as compared to standard equipment, but if viewed over the entire life span, the standard equipment are much more expensive because of high energy costs. Hence energy efficient equipment should be chosen based on LCCA not just initial cost.

4.2.6. Sensitivity analysis

The cash flows of the proposals are often based on assumptions that have a certain degree of uncertainty. The present-day cash flows, such as capital cost, energy cost savings, maintenance costs, etc. can usually be estimated accurately. Even though these costs can be predicted with some certainty, it should always be remembered that they are only estimates. Cash flows in future years normally contain inflation components which are often "guess-timates" at best. The project life itself is an estimate that can vary significantly.[39]

Sensitivity analysis is an assessment of risk. Because of the uncertainty in assigning values to the analysis, it is recommended that a sensitivity analysis be carried out - particularly on projects where the feasibility is marginal. How sensitive is the project's feasibility to changes in the input parameters? What if one or more of the factors in the analysis is not as favorable as predicted? How much would it have to vary before the project becomes unviable? What is the probability of this happening?[39]

[41] *Pump Life Cycle Cost - A Guide of LCC Analysis, US Department of Energy, https://www.energy.gov/sites/prod/files/2014/05/f16/pumplcc_1001.pdf*

Suppose, for example, that a feasible project is based on an energy cost saving that escalates at 10% per year, but a sensitivity analysis shows the break-even is at 9% (i.e. the project becomes unviable if the inflation of energy cost falls below 9%). There is a high degree of risk associated with this project - much greater than if the break-even value was at 2%[39].

Sensitivity analysis is undertaken to identify those parameters that are both uncertain and for which the project decision, taken through the NPV or IRR, is sensitive. Sensitivity and risk analysis should lead to improved project design, with actions mitigating against major sources of uncertainty being outlined. The various micro and macro factors that are considered for the sensitivity analysis are listed below.

Micro factors	Macro factors
• These are industry level variables that affect the operation of the industry in which the firm operates. • Some examples of micro factors which affect the analysis are as follows: • Capital structure • Operating expense • Changing of forms of finance • Changing the project duration	• These are economic variables that affect the operation of the industry in which the firm operates. • Some examples of macro factors are as follows: • Technology change • Change in interest rate • Change in energy price • Extension of various government subsidized projects

The advantages and limitations of sensitivity analysis as financial appraisal tool are as follows:

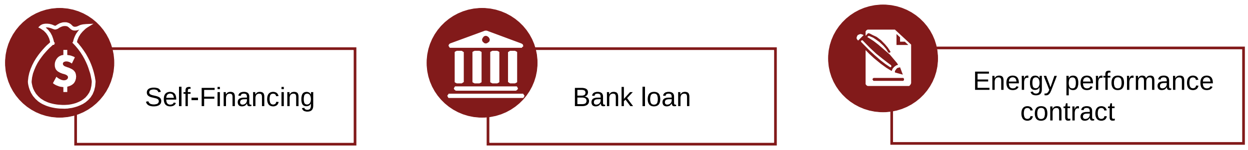
+ Advantages	Limitations −
In-depth analysis: Each independent and dependent variable is studied in detail. Strengthen weak spots: It helps in identifying variables that may act as weakness to the project. Decision making: Since all the variables are considered and outcomes are analyzed in detail, it is an extremely useful tool for future planning. Quality checks: It gives an idea of the variables which have a drastic or a substantial effect on success or failure of a project. Proper allocation of resources: It helps the organization in directing resources to variables that most require these resources.	It does not take into consideration the interrelationship between underlying independent variables. This method considers each variable individually and tries to determine the outcome. All variables are related to each other. It is based on historical data and assumptions made by the management. There are possibilities that these assumptions might itself be wrong. If the assumption is wrong, then the whole analysis is wrong.

The sensitivity analysis will bring changes in various items in the analysis of financial statements or the projects, which in turn might lead to different conclusions regarding the implementation of projects.

4.3. Financing options

Financing may be found from any of a variety of sources, including internal funds of industry and loans from financial institutions. For sustainable and sizable channels of financing, however, the local banking sector is ultimately the key in almost every country. Where the local banking sector is too weak, immature, or simply uninterested, any of a variety of arrangements may be worthwhile to provide initial resource efficiency project financing or begin to introduce the resource efficiency lending business into the market. These may involve other public institutions in a variety of ways. Ultimately, however, effective long-term solutions are bound to require large-scale, well-constructed involvement of the local banking system[42].

There are a number of financing options for resource efficiency projects, but the prominent ones are:



4.3.1. Self-financing

The industry can finance the energy and water saving proposals which have quick payback and or higher ROI. Self-financing has the following benefits:

- Assigning a proportion of energy savings to your energy management budget means you have a direct financial incentive to identify and quantify savings arising from your own activities.
- Separately identified returns will help the constituent parts of your organization understanding whether they are each getting good value for money through their support for energy management.
- If operated successfully, splitting the savings will improve motivation and commitment to energy management throughout the organization since staff at all levels will see a financial return for their effort or support.
- But the main benefit is on the independence and longevity of the energy management function.

4.3.2. Bank loan

The consumer can seek loan from a bank either nationalized or corporative or international. The form of capital is a term loan where is bank usually demands a collateral for mitigating risk of non-repayment of loan. The interest rate is variable which depends on repayment ability, size of loan amount & period of loan. The period of loan would depend on size of loan availed and repayment ability.

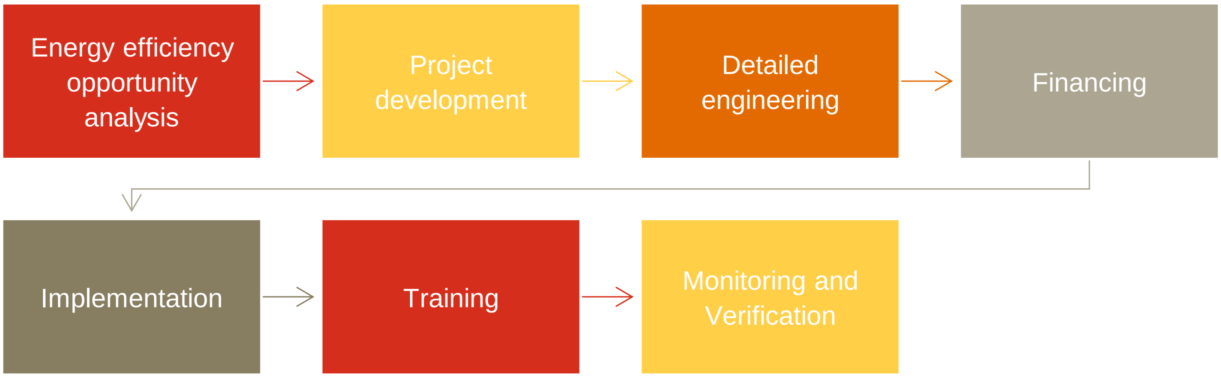
4.3.3. Energy Performance Contracting

If the project is to be financed externally, one of the attractive options for many organizations is the use of energy performance contracts delivered by energy service companies. Energy Services Company (ESCO) is a company who develops and implement Energy Efficiency (EE) projects to save energy and reduce energy costs for their customers. ESCO usually provides the following services:

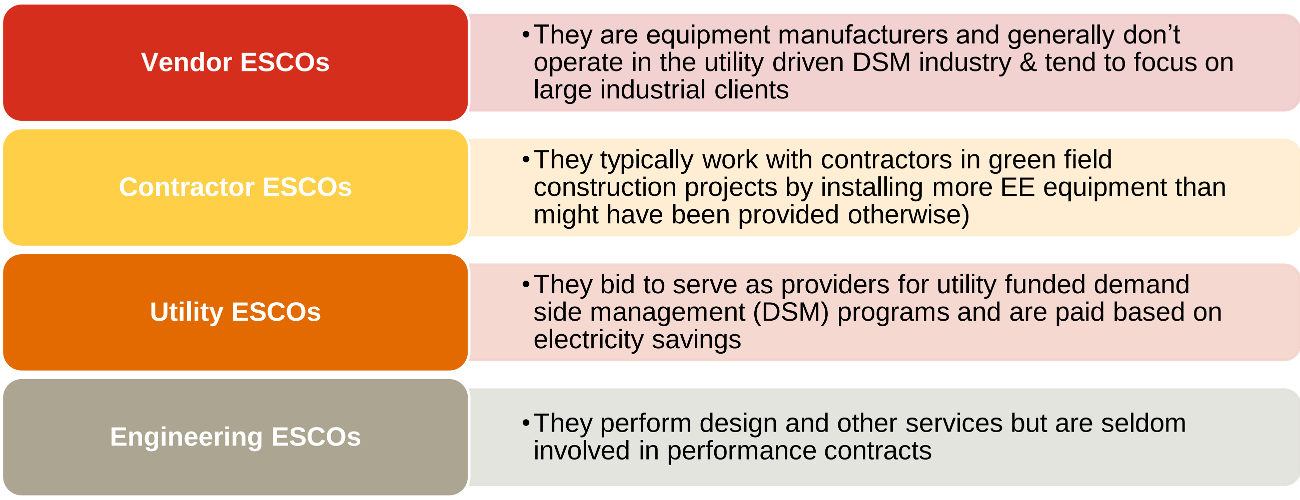
- Design, Develop, Finance Energy Efficiency projects
- Install, operate and maintain the energy efficient equipment
- Measure, monitor, and verify the project's energy savings
- Assume the performance and financial risk

[42] *Financing Energy Efficiency: Lessons from Brazil, China, India and beyond/ by Robert P Taylor, et. al. ESMAP*

Energy performance contracting is basically an agreement with an ESCO which involves a plethora of services including:



Performance contracting with an ESCO transfers the management and technology risks from the end-user to the ESCO.



There are five models for ESCO performance contracting, their features and model is presented below.

4.3.3.1. Shared Saving model

The features of the shared saving model are as follows:

a) ESCO finances the total upfront capital cost of the project.
b) ESCO receives major share of the achieved savings from the project.
c) Facility owner does not have any obligation to pay the loan.
d) ESCO assumes the performance and credit risk.

The model of shared saving ESCO is presented in **Figure 25.**

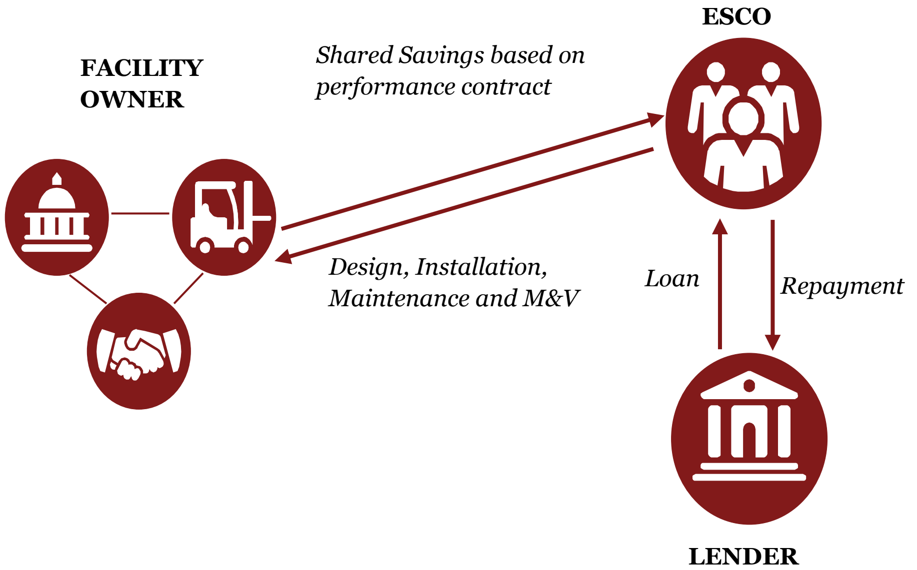


Figure 25 Shared saving model

4.3.3.2. Guaranteed Savings Model

The features of guaranteed savings model are as follows:

a) Facility owner takes loan from financial institution and finances the project
b) ESCO bears no obligation for repayment of loan
c) ESCO guarantees energy savings performance to facility owner
d) Any shortfall in the energy savings from the guaranteed is compensated by the ESCO
e) Savings exceeding the guaranteed level are shared with the ESCO

The model of guaranteed saving ESCO is presented in **Figure 26**.

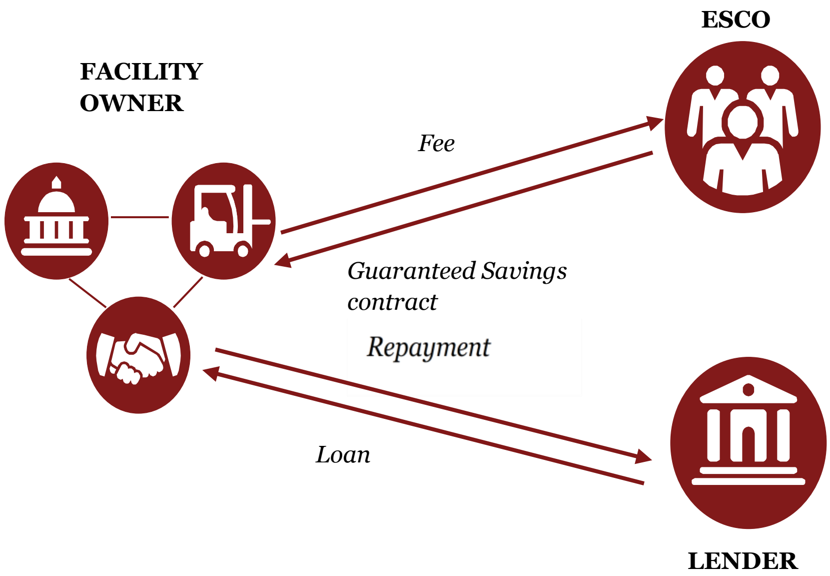


Figure 26 Guaranteed saving model

4.3.3.3. Lease rental method

The supplier installs the equipment and may maintain it. The lease payments are financed by verified savings and the ownership is generally transferred at the end of a lease period. The client (lessee) makes payment of principal and interest; the frequency of payments depends on the contract. The stream of income from the cost savings covers the lease payment.

4.3.3.4. Build-own-operate-transfer (BOOT) model

The model may involve an ESCO designing, building, financing, owning and operating the equipment for a defined period of time and then the transferring this ownership over to the client. This model resembles a special purpose enterprise created for a particular project. Clients enter into long term supply with the BOOT operator and are charged according to the service delivered. The service charge includes capital and operating cost recovery and project profit.

4.3.3.5. Build-own-operate (BOO) model

A new public private partnership (PPP) project model for ESCO business named BOO (Build-own-operate) has been emerging in which a private organization builds, owns and operates the energy efficiency of a facility. The government doesn't provide direct funding in this, but it may offer financial incentives like tax-exempt status.

A comparison of various ESCO models is provided in **Table 24**.

Table 24 Comparison of ESCO models

Contract type	Whose balance sheet	Who takes performance risk	Project specific financing
Guarantee savings	Industry	ESCO	Yes
Shared savings	ESCO	ESCO	No
Lease rental	Industry	ESCO	Yes
BOOT model	ESCO	ESCO	Yes

4.4. Measurement & Verification

Three terms are often used when one speaks about measurement and verification. These three terminologies are M&V i.e. measurement & verification, M&E i.e. Monitoring & Evaluation and MVR i.e. Monitoring, Reporting & Verification. These three terminologies are unique and have different meaning. **Figure 27** presents the basics of these terms.

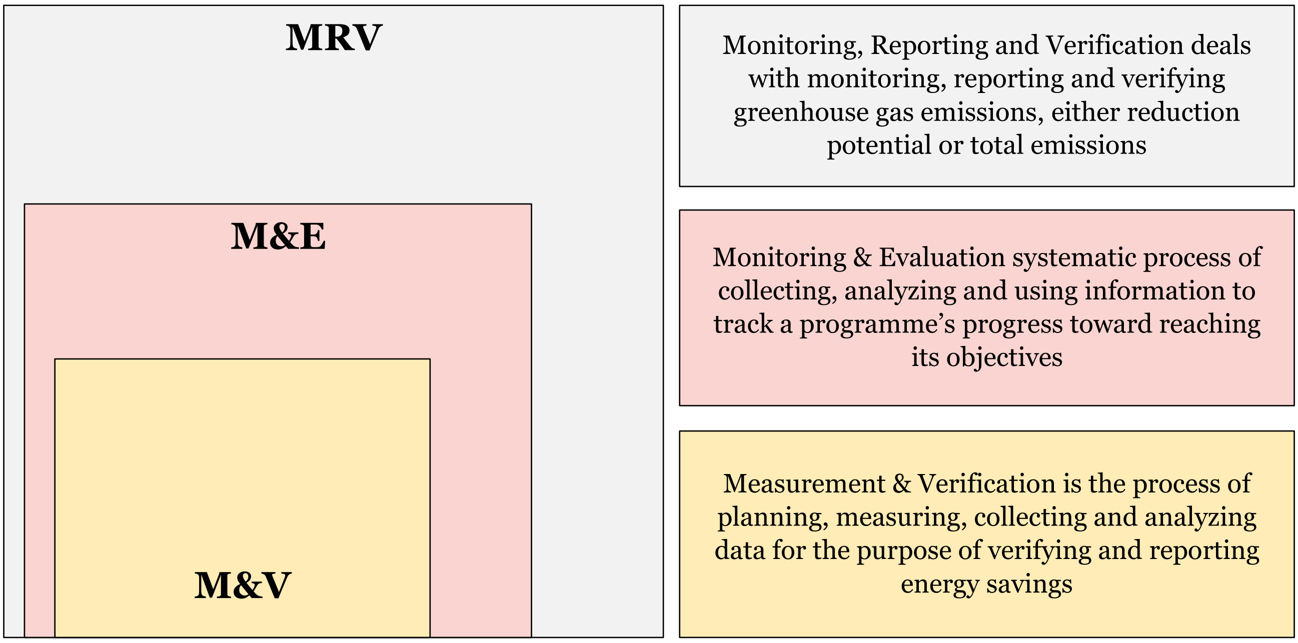


Figure 27 Definition of M&V, M&E and MRV

"Measurement and Verification" (M&V) is the process of planning, measuring, collecting and analyzing data to determine actual savings for energy demand, energy cost and corresponding greenhouse gases within a site by an Energy Conservation Measure (ECM).

Measurements are used to verify savings, rather than applying deemed savings or theoretical engineering calculations, which are based on previous studies, manufacturer provided information or indirect data. Savings are determined by comparing post-retrofit performance against a 'business as usual' forecast. M&V enables:

- calculation of savings for projects that have high uncertainty or highly variable characteristics
- verification of installed performance against manufacturer claims
- a verified result which can be stated with confidence and can prove return on investment
- demonstration of performance where a financial incentive or penalty is involved
- effective management of energy costs
- the building of robust business cases to promote successful outcomes

The measurement & verification process has five parts: understanding the M&V, getting started, M&V design and planning, data collection and modelling, and finishing M&V project. The most important step in the process is M&V designing and planning[43].

4.4.1. Understanding M&V concepts

Some of the key terms that are used in the following chapters and are important for the understanding of measurement and verification are explained in **Table 25**.

Table 25 M&V concepts

M&V terms	Definition	Example
Measurement Boundary	A hypothetical boundary that defines the physical scope of a M&V project. The effects of an ECM are determined at this boundary.	Pumping facility, sub facility, lighting circuit, mechanical plant room, switchboard, individual plant and equipment etc.
Energy Use	Energy used within the measurement boundary	Electricity, diesel, LPG, kerosene, biomass etc.
Key Parameters	Data sources relating to energy use and independent variables that are measured or estimated which form the basis for savings calculations	Instantaneous power draw, metered energy use, efficiency, operating hours, temperature, humidity, performance output etc.

[43] *Source: Measurement and verification operational guide, NSW Government*

M&V terms	Definition	Example
M&V options	Four generic approaches for conducting M&V which are defined within the IPMVP.	These are known as Options A, B, C and D.
Routine adjustment	Routine adjustments to energy use that are calculated based on analysis of energy use in relation to independent variables.	Energy use may be routinely adjusted based on independent variables such as ambient temperature, humidity, occupancy, business hours, production levels, etc.
Non routine adjustments	Once-off or infrequent changes in energy use or demand that occur due to changes in static factors	Energy use may be non-routinely adjusted based on static factors such as changes to building size, facade, installed equipment, vacancy, etc. Unanticipated events can also temporarily or permanently affect energy use. Examples include natural events such as fire, flood, drought or other events such as equipment failure, etc.
Interactive effects	Changes in energy use resulting from an ECM which will occur outside our defined measurement boundary.	Changes to the HVAC heat load through lighting efficiency upgrades, interactive effects on downstream systems due to changes in motor speed/pressure/flow, etc.
Performance	Output performance affected by the ECM.	System/equipment output (e.g. compressed air), comfort conditions, production, light levels, etc.

The M&V process in a series of steps is presented in **Figure 28**.

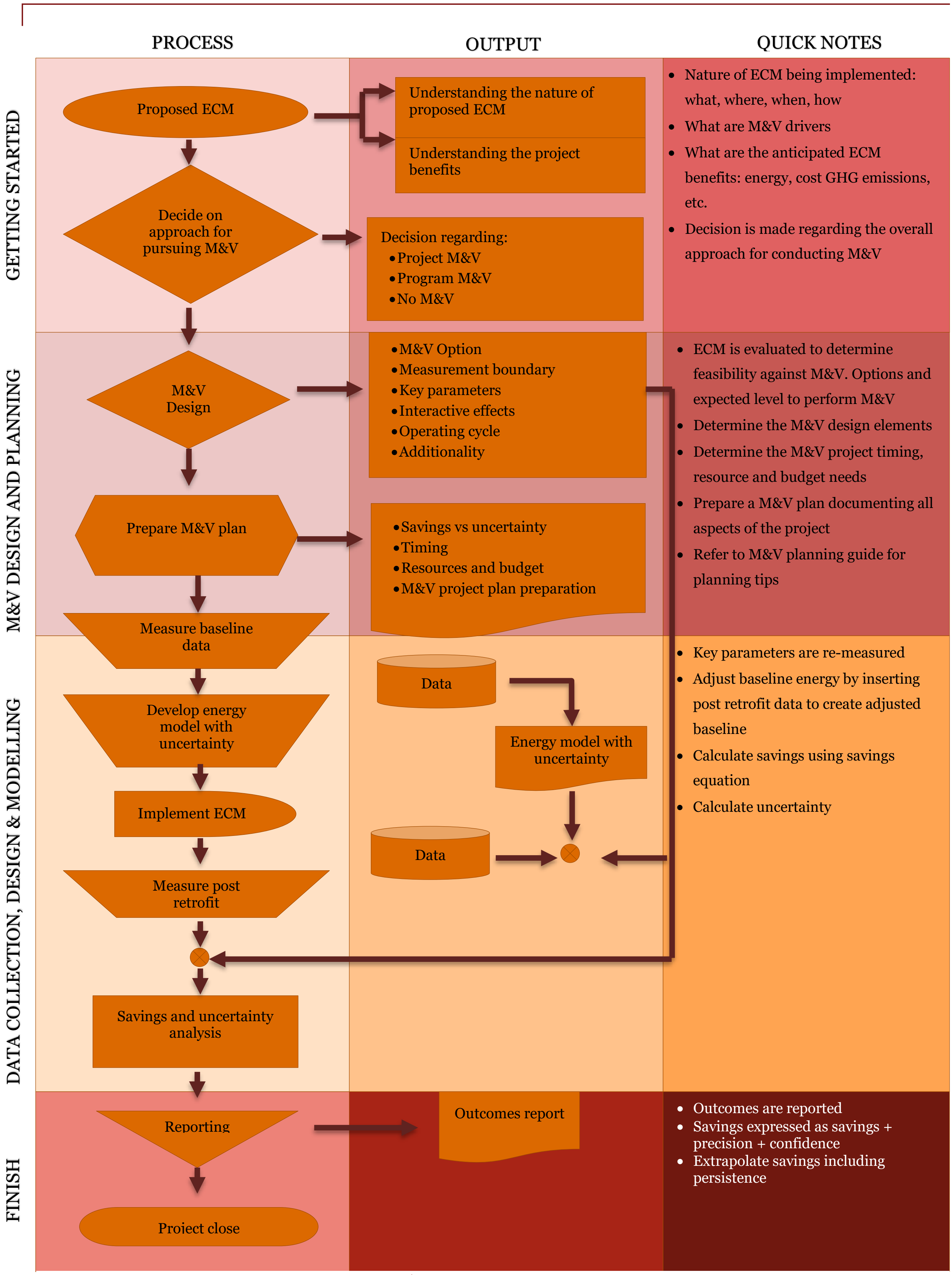


Figure 28 M&V process

4.4.2. M&V options

There are different ways to conduct M&V depending on the type of energy saving recommendation implemented. Two prominent documents present the options of M&V are the M&V guidelines from US Department of Energy[3] and M&V guideline from International Performance Measurement and Verification Protocol (IPMVP). The options with overview and example from the M&V guideline of the US Department of Energy is presented in **Table 26** and the options for M&V as per IPMVP guideline along with type of saving calculation is presented in **Table 27**.

Table 26 M&V options, overview and example (US DOE)

Options	Overview	Example
Option A Retrofit Isolation with Key Parameter Measurement	This approach is designed for projects where potential to generate savings must be verified, and the actual savings can be determined from limited data collection, engineering calculations, and stipulated factors.	Lighting retrofit projects. The key parameters are the power draws of the baseline and retrofit light fixtures. The operating hours are estimated based on facility use and occupant behavior. Energy savings are calculated as the difference in power draw multiplied by the operating hours
Option B Retrofit Isolation with All Parameter Measurement	Option B is very much similar to option A but for the fact that it involves measurement of all the relevant parameters. This method is intended for retrofits with performance factors and operational factors that can be measured at the component or system level. Short-term periodic measurements can be used when variations in the measured factor are small and may be sufficient to characterize the baseline.	Installation of a variable-speed drive and associated controls on an electric motor. Electric power is measured with a meter installed on the electrical supply to the motor. Power is measured during the baseline period to verify constant loading. The meter remains in place throughout the post-retrofit period to measure energy use. Energy savings are calculated as the pre-retrofit energy use (adjusted to correspond to the length of the reporting period) minus the measured energy use during the reporting period
Option C Whole-Facility Measurement	Option C verification methods determine savings by studying overall energy use in a facility. The whole-building or facility-level metered data are evaluated using techniques that range from simple billing comparison to multivariate regression analysis	Replacement of a pump in a pumping station. Using billed electricity data for 12 months during the baseline period, a baseline regression model is developed of monthly electricity use. Given monthly pumping data in a year at the site, the baseline model is used to determine baseline electricity use. Annually during the post-retrofit period, a similar regression model is developed using billed electricity and pumping data from the previous 12-month period. Savings are defined as the normalized baseline electricity use minus the normalized reporting-period electricity use.
Option D Calibrated Computer Simulation	Option D is primarily a whole-building method but can be used at the component level. Savings are based on the results of a calibrated computer simulation model. Estimated savings may vary during the contract term if real weather data are used.	Multifaceted energy management program affecting many systems in a building but where no base year data are available. Post-retrofit period energy use is measured by gas & electric utility meters. Base year data is determined by simulation using the post-retrofit period utility data.

Table 27 M&V options IPMVP

M&V option	Brief	Saving calculation
Option A	Based on measured equipment performance, measured or stipulated operational factors and Annual Verification of potential to perform	Engineering calculations
Option B	Based on periodic or continuous measurements taken through the tern of contract at the system level	Engineering calculations using measured data
Option C	Based on whole building or facility level factors	Analysis of utility meter data
Option D	Based on Computer Simulation of building or process simulation is calibrated with measured data	Comparing different models

4.4.3. Risk, responsibility, and performance matrix[3]

A project specific risk, responsibility and performance matrix is essential for an effective monitoring of an energy efficiency project. This matrix details risks, responsibilities, and verification requirements that should be considered when developing performance contracts. The matrix is developed to help identify the important project risks, assess their potential implications, and clarify the party responsible for managing the risk. The **Table 28** presents energy efficiency project risks and responsibility. The implementer must give their approach to mitigate the risk.

Table 28 Energy efficiency project risk, responsibilities and matrix

Responsibility/Description
Financial
Interest rate: Neither the contractor nor the customer has significant control over prevailing interest rates. Higher interest rates will increase project cost, financing/project term, or both. The timing of the task order (TO) signing may impact the available interest rate and project cost.
Energy prices: Neither the contractor nor the customer has significant control over actual energy prices. For calculating savings, the value of the saved energy may either be constant, change at a fixed inflation rate, or float with market conditions. If the value changes with the market, falling energy prices place the contractor at risk of failing to meet cost savings guarantees. If energy prices rise, there is a small risk to the customer that energy saving goals might not be met while the financial goals are. If the value of saved energy is fixed (either constant or escalated), the customer risks making payments in excess of actual energy cost savings.
Construction costs: The contractor is responsible for determining construction costs and defining a budget. In a fixed-price design/build contract, the customer assumes little responsibility for cost overruns. However, if construction estimates are significantly greater than originally assumed, the contractor may find that the project or measure is no longer viable and drop it before TO award. In any design/build contract, the customer loses some design control. Clarify design standards and the design approval process (including changes) and how costs will be reviewed.
M&V confidence: The customer assumes the responsibility of determining the level confidence that it desires to have in the M&V program and energy savings determinations. The desired confidence will be reflected in the resources required for the M&V program, and the ESCO must consider the requirement before submitting the final proposal. Clarify how project savings are being verified (e.g., equipment performance, operational factors, energy use) and the impact on M&V costs.
Energy related cost saving: The customer and the contractor may agree that the project will include savings from recurring and/or one-time costs. This may include one-time savings from avoided expenditures for projects that were appropriated but will no longer be necessary. Including one-time cost savings before the

Responsibility/Description
money has been appropriated may involve some risk to the customer. Recurring savings generally result from reduced operations and maintenance (O&M) expenses or reduced water consumption. These O&M and water savings must be based on actual spending reductions. Clarify sources of non-energy cost savings and how they will be verified.
Delays: Both the contractor and the customer can cause delays. Failure to implement a viable project in a timely manner costs the customer in the form of lost savings and can add cost to the project (e.g., construction interest, remobilization). Clarify schedule and how delays will be handled.
Major changes in facility: customer controls major changes in facility use, including closure. Clarify responsibilities in the event of a premature facility closure, loss of funding, or other major change.
Operational
Operating hours: The customer generally has control over operating hours. Increases and decreases in operating hours can show up as increases or decreases in savings depending on the M&V method (e.g., operating hours multiplied by improved efficiency of equipment vs. whole facility/utility bill analysis). Clarify whether operating hours are to be measured or stipulated and what the impact will be if they change. If the operating hours are stipulated, the baseline should be carefully documented and agreed to by both parties.
Load: Equipment loads can change over time. The customer generally has control over hours of operation, conditioned floor area, intensity of use (e.g., changes in occupancy or level of automation). Changes in load can show up as increases or decreases in "savings" depending on the M&V method. Clarify whether equipment loads are to be measured or stipulated and what the impact will be if they change. If the equipment loads are stipulated, the baseline should be carefully documented and agreed to by both parties.
Performance
Equipment performance: The contractor has control over the selection of equipment and is responsible for its proper installation, commissioning, and performance. The contractor has the responsibility to demonstrate that the new improvements meet expected performance levels, including specified equipment capacity, standards of service, and efficiency. Clarify who is responsible for initial and long-term performance, how it will be verified, and what will be done if performance does not meet expectations.
Operations: Performance of the day-to-day operations activities is negotiable and can impact performance. However, the contractor bears the ultimate risk regardless of which party performs the activity. Clarify which party will perform equipment operations, the implications of equipment control, how changes in operating procedures will be handled, and how proper operations will be assured.
Preventive maintenance: Performance of day-to-day maintenance activities is negotiable and can impact performance. However, the contractor bears the ultimate responsibly regardless of which party performs the activity. Clarify how long-term preventive maintenance will be ensured, especially if the party responsible for long-term performance is not responsible for maintenance (e.g., contractor provides maintenance checklist and reporting frequency). Clarify who is responsible for performing long-term preventive maintenance to maintain operational performance throughout the contract term. Clarify what will be done if inadequate preventive maintenance impacts performance.
Repair and maintenance: Performance of day-to-day repair and replacement of contractor-installed equipment is negotiable; however, it is often tied to project performance. The contractor bears the ultimate risk regardless of which party performs the activity. Clarify who is responsible for performing replacement of failed components or equipment replacement throughout the term of the contract. Specifically address potential impacts on performance due to equipment failure. Specify expected equipment life and warranties

Responsibility/Description
for all installed equipment. Discuss replacement responsibility when equipment life is shorter than the term of the contract.

4.4.4. M&V baseline parameters and conditions

The baseline parameters and conditions for the measurement and verification are presented in **Table 29**.

Table 29 Baseline parameters for M&V

S. No.	Energy conservation measure	Baseline parameters	Baseline conditions
1	Replacement of existing pump with energy efficient pump	▪ Water flow rate in m^3/hour ▪ Total head in meters ▪ Power input in kW	▪ Daily production in m^3/day or operating hours
2	Retrofitting of Variable Frequency Drive on a pump to run it close to system duty point	▪ Water flow rate in m^3/hour ▪ Total head in meters ▪ Power input in kW	▪ Daily production in m^3/day or operating hours ▪ Operating frequency in Hz
3	Replacement of existing motor with IE4 motor	▪ Rating of motor (IE1, IE2, IE3 and IE4)	▪ Loading in % ▪ Pump duty in m^3/hour and head in meters
4	Replacement of existing lighting system by efficient lighting system	▪ Existing lamps type and rating	▪ Operating hours

4.4.5. M&V protocol

The parameters and proposed protocol for the measurement and verification are presented in **Table 30**.

Table 30 M&V protocol

S. No.	Energy conservation measure	Parameters to be measured after implementation		Adjustment/ variable factors
1	Replacement of existing pump with energy efficient pump	▪ Estimation of pump efficiency	▪ 3 samples	▪ Operating pressure
2	Retrofitting of Variable Frequency Drive on a pump to run it close to system duty point	▪ Estimation of pump efficiency ▪ Examine the operation of VFD	▪ 3 samples ▪ 1 sample	▪ Operating pressure
3	Replacement of existing motor with IE4 motor	▪ Motor input power	▪ 3 samples	▪ Motor loading
4	Replacement of existing lighting system by efficient lighting system	▪ Physical inspection	▪ One time	▪ NA

Annexure

Pump and motor step-by-step energy audit process

1. **Pre audit phase**

- Check that the pump is operating on usual cycle and there is no abnormality
- Prepare energy audit instruments i.e. power analyzer, pressure gauge and ultrasonic water flow meter.

2. **During audit**

- Clean a clear section of pipe (i.e. remove over paint, clean any dirt or dust). Make sure the section of pipe for measurement is straight and nearest bend is at-least 5 times the diameter of pipe away on either side (upstream and downstream)
- Set-up ultrasonic flow meter, by feeding proper pipe material, dimensions, lining (if any), circumference
- Select fluid as clear water, set wedge temperature at 25°C
- Based on spacing displayed in flow meter, set up the sensor stand
- Connect sensors using strap-on stand and conduct measurements
- Repeat the measurement for at-least three consistent values
- In parallel with each reading note the discharge pressure of the pump
- Check the reservoir level
- Conduct power measurement with each sample of flow measurement
- Note the following power parameters: voltage, current, power factor, power and harmonics
- Repeat the measurement for at-least three consistent values

3. **Post audit**

- Calculate the power input using formula given in section 2.3.2.
- Calculate the overall head of pump by adding suction and discharge head. If the suction water level is above the center point of pump, in that case subtract the suction head from discharge to arrive at total head
- Compute the efficiency of pump using formula given in section 2.3.1.
    - Otherwise input the power, flow, and head parameters in the model excel spreadsheet to arrive at pump efficiency.

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