Feasibility of Energy-Efficient Distribution Transformer Manufacturing in Namibia

LEAPFROGGING TO ENERGY EFFICIENT APPLIANCES AND EQUIPMENT (REFRIGERATORS AND TRANSFORMERS) IN NAMIBIA

Draft Version

Basel Agency for Sustainable Energy (BASE)

International Copper Association (ICA)

Southern African Development Community's (SADC) Centre for Renewable Energy and Energy Efficiency (SACREEE)

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List of Abbreviations

BASE	Basel Agency for Sustainable Energy
CO_2	Carbon Dioxide
CRGO	Cold Rolled Grain Oriented
CTCN	Climate Technology Centre & Network
DEA	Department of Environmental Affairs
DT	distribution transformer
ECB	Electricity Control Board
EE	Energy efficiency
GCF	Green Climate Fund
GHG	Greenhouse Gas
ICA	International Copper Association
IEC	International Electrotechnical Commission
IPP	Independent Power Producer
ISO	International Organization for Standardization
kV	kilovolt
kWh	kilowatt-hour
LL	Load Losses
MW	Megawatt
MEFT	Ministry of Environment and Tourism
MEPS	Minimum Energy Performance Standards
MME	Ministry of Mines and Energy
NamPower	Namibia Power Corporation
NDA	National Designated Agency
NDE	National Designated Entity
NLL	No Load Losses
PCB	Polychlorinated Biphenyls
PV	Photo Voltaic
PWG	Policy Working Group
RED	Regional Electricity Distributor
SACREEE	SADC Centre for Renewable Energy and Energy Efficiency
SADC	Southern African Development Community
CO	Total Cost of Ownership
U4E	United for Efficiency

UNEP	United Nations Environment Programme

1 Background

Namibia is among the eight countries[1] in Southern Africa that have embraced a common approach for the implementation of the Green Climate Fund (GCF) Readiness projects on "Developing a national framework for leapfrogging to energy efficient refrigerators and distribution transformers". The network partners, comprising Basel Agency for Sustainable Energy (BASE), International Copper Association (ICA), and Southern African Development Community's (SADC) Centre for Renewable Energy and Energy Efficiency (SACREEE), are providing technical services for the implementation of the GCF Readiness project entitled *National framework for leapfrogging to Energy Efficient Appliances and Equipment in Namibia (Refrigerators and Distribution Transformers) through regulatory and financing mechanism*. The technical assistance has been executed with the Climate Technology Centre and Network (CTCN) through the United Nations Environment Programme (UNEP) as implementing institution, and United for Efficiency (U4E) as the technical partner on national frameworks for leapfrogging to energy-efficient appliances and equipment in Namibia through regulatory and financing mechanisms. The GCF Readiness project has been implemented under the guidance of the Ministry of Environment and Tourism (MEFT), the National Designated Agency (NDA) for the Green Climate Fund (GCF), and the Department of Environmental Affair (DEA) under MEFT which acts as the National Designated Entity (NDE) for CTCN and also the National Focal Point for GCF.

The objectives of the GCF Readiness project in Namibia are to improve the country programming process regarding refrigerators and distribution transformers (DTs) and strengthen climate finance strategies. Specifically, the project aims to put in place mandatory Minimum Energy Performance Standards (MEPS) and a labelling scheme, which will create an enabling policy and regulatory environment for refrigerators and DTs in Namibia. In addition, the project will include key components such as national policy roadmaps and enabling environments for the implementation of standards and labels, appropriate financing mechanisms to accelerate deployment of energy-efficient refrigerators and DTs, and strengthen national capacity to develop standards and labels for other appliances in future. This will transform the market to energy-efficient refrigerators and DTs and ultimately reduce the strain on the electricity grid, increase disposable income for householders and potentially reduce greenhouse gases (GHG) emissions.

The report aims to summarize needs of the local DT industry in Namibia in design and manufacture of energy-efficient DTs in line with international best practices and feedback from the local industry during the training session organized on 20th September 2022.

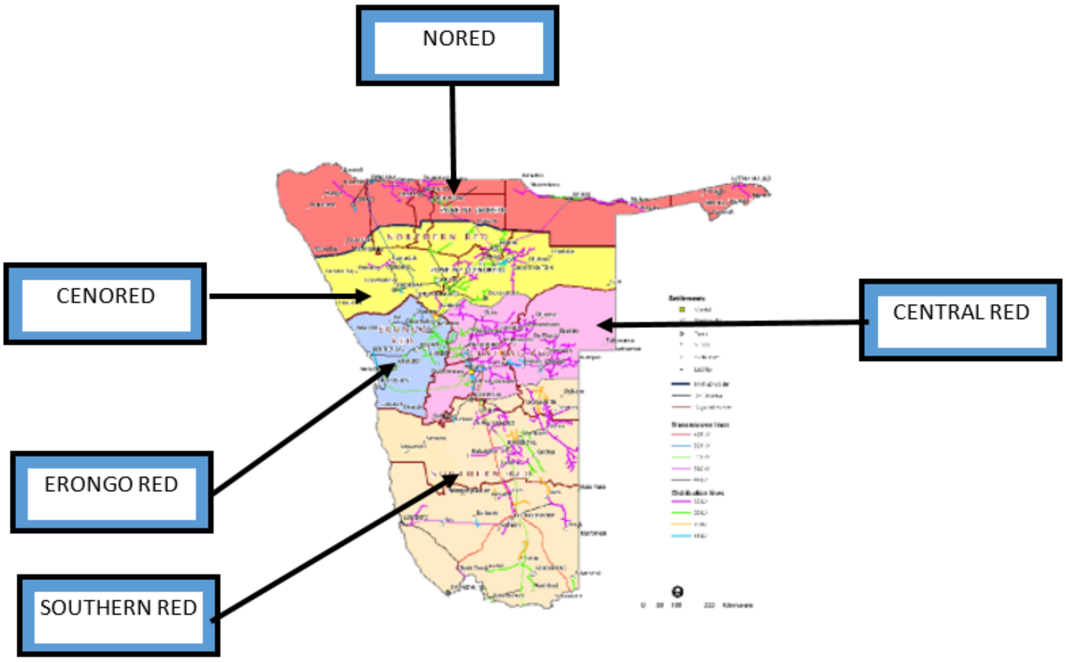
[1] Botswana, Eswatini, Lesotho, Namibia, Namibia, Tanzania, Zambia and Zimbabwe

2 Power Industry in Namibia

Over the past two decades, Namibia's power sector has undergone numerous important developments and changes, including improvements in the institutional and regulatory framework, electricity generating capacity addition, network expansion, and cross-border power interconnection (with South Africa and Zambia). The sector has a weload-developed regulatory framework with a mandate for oversight of the responsibility of the regulator, the Electricity Control Board (ECB). The Ministry of Mines and Energy (MME) has a key role to develop sectoral policies, strategies, and plans including implementing the Government's rural electrification program (grid and off-grid) and monitoring electrification progress.

The main stakeholders include the Namibia Power Corporation (NamPower), responsible for generation, transmission, import, export, trading, and power supply as well as distribution for most of the Central and Southern regions of Namibia. Electricity distribution is also the responsibility of the three Regional Electricity Distributors (REDs) – NORED, CENORED and ERONGO RED, in their respective service areas. There are several local authorities and municipality distributors responsible for distribution and supply to certain consumers. In addition, several Independent Power Producers (IPPs) have come on board as generators of renewable energy.

Shown in Figure 2-1 are areas covered by NamPower and the three REDs.



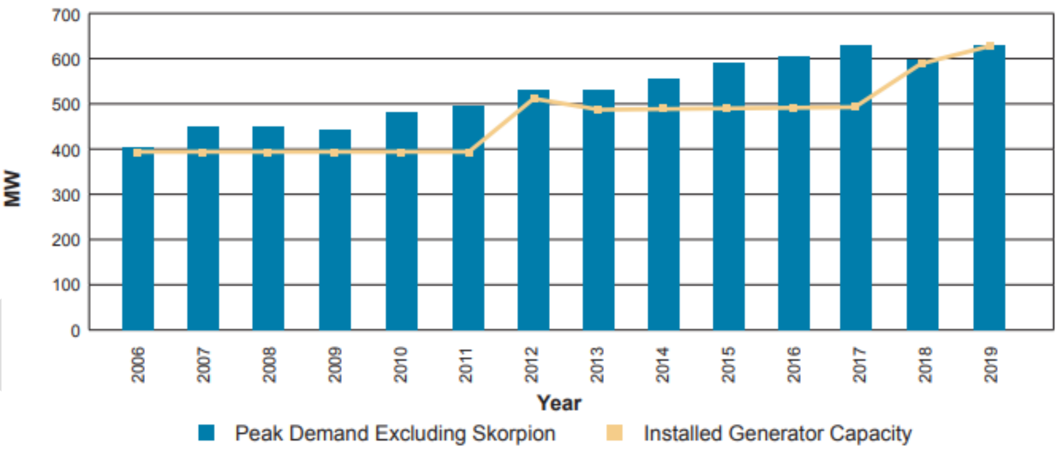
Source: Electricity Control Board

Figure 2-1: Regional Electricity Distribution in Namibia

The Government of Namibia has been committed to supporting and actively promoting rural electrification. MME's electrification programme focuses mainly on the provision of grid electricity infrastructure to connect Government assets in rural areas to the national grid and renewable energy solutions in remote rural areas, while urban electrification has largely been the domain of REDs or local authority entities. Policy, planning and strategic coordination for scaling up connectivity to electricity in rural areas has been the primary remit of the MME; informed by Rural Electricity Distribution Master Plans (REDMPs) and the Off-grid Electrification Master Plan (OGEMP). The original REDMP was adopted by the MME in 2000, with updates in 2005 and 2010 [REDMP, 2010].

At the project level for rural areas and public institutions that benefit from subsidized electrification projects, as well development of mini-grids, MME conducts annual planning processes in consultation with regional councils, other local stakeholders and NamPower in order to determine priority projects to receive funds from Development Finance Institutions (DFIs), Government or NamPower's rural electrification budget. NamPower is responsible for executing some projects before handover to a distributor (or NamPower Distribution) for operation, while MME implements the bulk of rural electrification before handover to the REDs for operation for grid electrification only. However, the containerized solar systems and mini-grids are handed over to the Ministry of Works and Transport for operation.

Namibia's installed power capacity is about 640 MW (hydro 54 %, coal 14 %, diesel 3.5 % and solar and wind 28 %). This includes NamPower power stations and IPPs, while peak demand is 632 MW, excluding Skorpion Zinc mine which is connected to the NamPower grid but gets supplied power directly from ESKOM (South Africa), with a peak demand of 52 MW (ECB, 2019).



Source: Electricity Control Board

Figure 2-2: Installed Capacity and Peak Demand in Namibia, 2006-2019

3 Distribution Transformer Industry in Namibia

3.1 Demand-Side and Key Players

Namibia's transmission network is composed of 66-400 kV and 350 kVDC of overhead lines spanning more than 11,704 km, connecting generation sites and major demand centres, as shown in Figure 7 below. Some 400 kV lines are planned to extend the transmission grid into north-eastern and north-western Namibia, as well as additional transmission infrastructure associated with regional interconnection projects with South Africa to the South, Angola to the North and Botswana to the East. The distribution network covers most of the densely populated areas in Namibia, as well as many rural areas. In total, the 11- 33 kV medium-voltage network extends more than 45,000 kilometres across the country, with approximately 306 distribution and transmission substations.

Source: Namibia: Geospatial Least Cost Electrification Plan, 2021

Figure 3-1: Transmission and Distribution Networks in Namibia

NamPower and REDs are the major buyers of DTs in Namibia and all DTs are imported. Currently, over 1,000 DT are procured each year, with NORED procuring about 90% of the total. The estimated total market size for DTs would be 1,900 units in 2021. This figure includes about 870 units procured to replace end-of-life equipment only. Subsequently, the estimated stock level would be 27,000 units in 2021. With an average DT cost of USD 9,300 or NAD 137,000 per unit; the total market value for distribution transformers would be about USD 18 million (NAD 265 million) in 2021.

If the market size projections of the DTs were to follow the government strategy to reach full electrification by 2030, country's electrical load demand forecasts, economic growth, stock replacement at end-of-life, the projected market size will increase to 2,600 units by 2030 with the estimated total stock of 38,265 DTs. This would correspond to a annual market value of USD 24.7 million (NAD 363 million).

It is envisaged that, beyond 2030, a significant drop in demand for DTs would be expected following the completion of the full electrification goal. Market demand would then be mainly driven by economic growth for commercial and industrial customers, population growth in the residential sector, as well as replacement of end-of-life equipment, which would not compensate for the end of large-scale electrification investment by the Government. This would justify both the sudden drop in market size and value in 2031 onwards.

3.2 Supply-Side and Key Players

All DTs in Namibia are imported mainly from South Africa. There is also a small number of DTs imported from India and from other parts of the world, depending on the specifications of the tenders. At least nine companies in Namibia have been identified as suppliers and service providers of DTs (see Table 3-1). The main leading supplier of the distribution transformers active in the Namibian market is MegaTech Pupkewitz (Pty) Ltd (distributor for PCB Power Transformers) which has six branches across the country with the main office in Windhoek. Other suppliers include Actom Namibia (distributor for Actom transformers), Swanib Cables (Pty) Ltd, Megatron Engineering Namibia, Walfish Electric (Pty) Ltd, Swakop Electrical Supplies CC (SGB-Smit Power Matla distributors), Central Technical Suppliers, Ark Trading and HV Transformers. Note that only two companies, HV transformer (based in Erongo region) and Megatron Engineering Namibia (based in Windhoek), provide DT services nationwide.

Table 3-1: DT Suppliers and Service Providers in Namibia

Company	DT Brand	Portfolio of Products			Refurbishment/ Repair/ Rewinding
		Cooling type	Mounting type	Transformer Capacity range	
Walfish Electric (PTY)LTD	Actom and SGB-Smit Power Matla Transformers	Oil Natural Air Natural (ONAN)	Pole and Ground	16 kVA – 800 kVA	Supply only
Swakop Electrical Supplies CC	Actom, Trans Electron, SGB-Smit Power Matla Transformers	ONAN	Pole and Ground	16 kVA - 800 kVA	Supply only

Company	DT Brand	Portfolio of Products			Refurbishment/ Repair/ Rewinding
		Cooling type	Mounting type	Transformer Capacity range	
MegaTech Pupkewitz (PTY) LTD	PCB and Actom Transformers	ONAN	Pole and Ground	16 kVA - 2.5 MVA	Supply only
Swanib Cables (PTY) LTD	PCB, SGB-Smit Power Matla and Actom Transformers	ONAN	Pole and Ground	16 kVA - 2.5 MVA	Supply only
Actom Namibia	Actom and SGB-Smit Power Matla Transformers	ONAN	Pole and Ground	16 kVA – 800 kVA	Supply only
Central Technical Suppliers	PCB, Actom, Free State and SGB-Smit Power Matla Transformers	ONAN	Pole and Ground	16 kVA - 2.5 MVA	Supply only
Ark Trading	PCB, Free State and SGB-Smit Power Matla Transformers	ONAN	Pole and Ground	16 kVA - 2.5 MVA	Supply only
Megatron Engineering Namibia	SGB- Smit Power Matla and Actom, and others	ONAN	Pole and Ground	16 kVA- 800 kVA	refurbishment/ repair
HV Transformers	SGB- Smit Power Matla and Actom, and others	ONAN	Pole and Ground	16 kVA- 800 kVA	refurbishment/ repair

3.3 Procurement Practices

Namibia does not have its own national standards and regulations for distribution transformers and there is no uniformity in specifications. However, each electricity distributor and large non-utility users, such as mining companies, have developed their own specifications aligned with SANS 780 for transformers up to 3,150 kVA. The public procurement Act No.15, 2015 guides/governs the method of procuring or buying such transformers by distribution utilities. Note that all connections made at medium-voltage (MV) to or from the grid must comply with the distribution grid code promulgated under the Electricity Act, 2007 (Act No. 4 of 2007). The distribution grid code seeks for compliance to its provisions by all users of the distribution system such as entities, embedded generators, distributors and end-users with appliances/equipment connected to the national distribution system.

3.4 International Commitments on Distribution Transformer Efficiency

The amended version of the DT model regulation developed by United for Efficiency (U4E) was recommended for the implementation in all SADC GCF countries after significant PWG and TC consultations. The U4E Model Regulation Guideline 2019, on energy performance requirements for distribution transformers, requires that distribution transformers be reassessed for conformity as follows:

- Comply with minimum energy performance in terms of maximum allowed load and no-load losses
- Should not contain Polychlorinated biphenyls (PCB) contamination or other hazardous materials as defined in the relevant international, regional, and national regulations
- Product and technical information to include free access to websites of manufacturers and to durably mark on or near the rating plate of the distribution transformers
- Certification and registration to test transformer's energy performance in accordance with IEC 60076-1 and its fire performance in accordance with IEC 60076-11, for instance, for dry-type transformers and related reference test standards

4 Feasibility of Energy Efficient DT Manufacturing in Namibia

Energy-efficient transformers are more expensive compared with conventional, less-efficient transformers because of the higher costs associated with the use of either more or higher performance materials. The material cost of transformers is typically 80-90% of the selling price. Of the total material cost the core material cost contributes 35%-40%; conductor and insulation material costs (Including oil) contribute the remaining 25%-30% and 20% respectively[2]. In addition, a manufacturer's production costs will also be determined to some extent by the additional investments necessary. Production of energy-efficient transformers also raises issues about the capability of raw material suppliers, however, in case of Africa, it is understood that most raw materials are imported and capability of raw material suppliers should not be an issue in Namibia.

In addition to higher cost and availability of raw materials, capabilities of manufacturers in production of energy-efficient transformers will be determined by capacity of the following three aspects: 1) human resources; 2) machinery; and 3) knowledge in design and production of energy-efficient transformers. However, Namibia does not have any local DT manufacturing facilities, and it is assumed that the above-mentioned aspects of DT manufacturing capacity does not exist in Namibia.

To establish a DT manufacturing facility in Namibia, collaboration with the existing DT suppliers and/or service providers in Namibia in setting up a production line of energy-efficient DTs is recommended. It is estimated that the total investment required for setting up an energy-efficient DT production line is about US$4-5 million and this investment budget covers all necessary machineries, building facilities, and human resources training and capacity building.

[2] Determination Analysis of Standards & Labeling Program for Distribution Transformers in India, 2004

5 Online Capacity Building and Training Session

5.1 Summary of Online Capacity Building and Training Session

An online capacity building and training session was organized by the GCF Readiness project and SACREEE on 20th September 2022, and this online training session aimed to build capacity for utilities, non-utility market players, Ministries of Energy, Ministry of Finance and Ministry or entity responsible public procurement on the recommended Total Cost of Ownership (TCO) and technology upgrade options for manufactures of distribution transformers. The online capacity building and training session was participated by 39 participants including policy makers and DT industry representatives from Namibia. The presentations made during the training are included as Annexes to this report, and key points of the presentations and discussions are captured below.

Presentation on the Total Cost of Ownership (TCO)

- The training aims to build capacity for utilities, non-utility market players, Ministries of Energy, Ministry of Finance and Ministry or entity responsible for public procurement on the recommended Total Cost of Ownership (TCO) and technology upgrade options for manufacturers of distribution transformers.

- Transformers are made of different materials (e.g., steel, aluminum and copper) and as materials change, efficient levels also changes. While transformers are expensive to purchase, they are also more expensive to own but efficient transformers have lower cost of ownership.

- TCO is the financing mechanism which helps one to understand the savings versus incremental cost of energy efficient transformers. How the decision for buying energy efficient transformers can be made. The TCO approach minimizes the total investment in a transformer over its lifetime, considering purchase price and the value of future losses also called " loss evaluation".

- During the TCO procurement process, the electric utility declares its loss evaluation formula with A and B factors in a monetary value per watt, for example US$/Watt. "A" represents how much the utility values losses in the core (no load losses) and "B" represents how much the utility values losses in the coil (load losses). A is always greater than B. The A and B factors influence the transformer designs by suppliers in response to the tender, resulting in more energy efficient models, and the utility will benefit from the lower total cost of ownership.

- To help the utilities and buyers, IEC TS 60076-20 standard provides a TCO formula, and an Excel tool and a guide had been developed by U4E to promote use of TCO. U4E has also added a second TCO calculation methodology, which adds the price of a tonne of CO_2. Utilities can customize the inputs such as operating hours, life expectancy, load growth, fuel costs and O&M, load profile generation mix for peak power to calculate their own A and B factors.

Presentation on Capacity Building for Manufacturers of Distribution Transformers on Technology Upgrade Options

- DT customers can make orders with variation of requirements, and DTs are generally manufactured with a high degree of customization. Continuous optimization is necessary for DT manufacturers because the industry depends on materials and value additions. Important resources for DT manufacturing include skilled manpower, design skills, purchase skills, manufacturing skills, testing and quality assurance.

- The current DT manufacturing machineries in the market have improved drastically covering enhanced conductor winding / foil winding machine, core building / winding machine and testing set-up.

- To reduce no load losses, the magnetic circuit of DT, aka core, should provide a low reluctance flux path for the transformer to function. Design options for lower no load losses include the use of lower loss Cold Rolled Grain oriented (CRGO) steel sheets of high permeability and small thickness materials to reduce eddy current and hysteresis losses. Eddy current is further reduced by alloying the steel with silicon. The superior grades of CRGO are now available with losses up to 0.80, 0.75, 0.70 Watts/kg at 1.7 Tesla.

- Other materials used for transformer core is Amorphous metal, which is a non-crystalline substance formed as ribbons and has superior magnetic properties. Amorphous sheet is very thin compared to CRGO sheet, and the eddy current losses also are very low. However, the saturation flux density is low as compared to CRGO silicon steel and so is the case with mechanical strength against jerks during assembly and handling being softer than CRGO. Losses with Amorphous Alloy at 1.5 Tesla 50 Hz are as low as 0.325 Watts/kg, however, its saturation flux density is low as compared to CRGO and normally the designs never go beyond 1.38 to 1.4 Tesla for Amorphous core transformers, hence higher load losses.

- Old transformers have very high load losses, and, in Africa, old transformers are refurbished as opposed to getting new ones due to budgetary constraints.

- DT windings are made of high-grade copper or aluminum, which are designed to optimize thermal, mechanical and electrical stresses. The winding machines are equipped with different speed gears to ensure that proper tension is maintained on the windings. The conductors are suitably transposed at intervals to reduce the circulating current losses in winding. Different winding types are used in transformers, such as : Spiral / Layer Type winding; Helical winding; Cross-over winding; Continuous Disc winding; and Foil winding.

- Low voltage (LV) foil winding uses a single piece of thin strip as conductor with a width of the foil equal to length of the winding. This conductor strip (foil) wound along with a pre-impregnated interlayer insulation and during curing process foil and insulation are bonded together to form a rigid block. The LV coil becomes self-supporting against forces and later the coil is impregnated with resin for environmental protection. Eddy current losses in the thin foil are very small compared to thick rectangular wires, so windings made with foil are cooler than other types. Foil winding also minimizes the axial forces during short circuit, since currents in the winding are adjusted to the ampere turns in the high voltage winding.

- The construction of the Core and Coil Assembly (CCA) is significant from the performance point of the transformer. The CCA defines the insulation scheme, cooling, dynamic withstand capability, handling by providing sufficient radial and axial supports that prevents the stress from causing any damage to the windings. Clamping of the windings axially is necessary to hold the assembly firmly. Clamping structure of the assembly has supports to route the tap and line terminals, insulated vertical and horizontal strips of adequate thickness of a framework to assist the routing of terminals.

- Insulation scheme is categorized into major and minor insulation. Major insulation addresses the capability to withstand high voltages, isolation of the primary and secondary winding, clearances for voltage withstand, while minor insulation is the turn insulation, joint protection, etc. Both the major and minor insulation are equally important for the successful operation of the transformer. The thermal class of insulation depends on the Type of cooling medium.

- The significant part of the insulation used in oil immersed transformer is paper and wood based. This insulation material has high affinity to moisture which may weaken the insulation properties and reduce the insulation resistance to high voltages. Therefore, transformer windings and CCA have to undergo drying process at various stages depending on the rating and voltage class. There are two types of drying: Air drying and Vacuum drying. Air drying is used in DTs limited to voltage class below 33 kV, while Vacuum drying is predominantly used for all transformers of voltage class above 33 kV.

- The DT enclosure is generally referred to as tank and this is a fabricated structure constructed of mild steel of adequate thickness & generally rectangular shaped. The tank has two main functions: 1) To hold the CCA with proper clearances for voltage and oil flow; and 2) To facilitate cooling, safety and maintenance. The tank must be leak proof, and should withstand the specified pressure during all service as well as test conditions. Depending on heat dissipation requirements to keep the specified temperature rise requirements in test conditions and service, the transformer tank will either have corrugations or is fitted with pressed steel fin type radiator banks.

- After drying process, the CCA is inserted into the transformer tank. The CCA should stand freely inside the tank and inside clearances are to be maintained. The primary and secondary terminations are brought out through porcelain or epoxy cast bushing insulation. The transformer tank is also fitted with valves for oil filling, filtration, oil sampling, draining. Provision for safety devices like Buchholz relay, pressure relief valve, temperature recording and control instruments, neutral current transformer, protection and instrument transformer are customized features as per buyer's requirement. In a non-sealed transformers, conservator is provided for oil expansion and contraction during the operating cycle. For sealed type transformers DGPT Relay also is sometimes provided for protection. Terminal identification /marking are also done on/near the bushings.

- Transformer oil acts as cooling and insulating medium in a transformer. Generally mineral oil is used, however the mineral oil contains in transformers is environmentally harmful and synthetic and natural ester oils are also being used. The transformers being promoted in the U4E policy guidebook are the natural ester, which is derived from vegetable oil. Esters have a better insulating property and fire performance, and it is environmentally friendly and helps to make the transformer more resilient.

- The list of essential plant and machinery are presented which covers core assembly, winding, insulation cutting, core-coil assembly and processing, tank assembly, and test equipment for electrical, mechanical and final testing before dispatching.

5.2 Discussion, Conclusions and Next Steps

- There is need for countries to submit request to implement technology upgrade of DTs, and SACREEE has requested all partner countries to provide input on the needs for energy efficient DT manufacturing upgrade. Zimbabwe has requested the followings: assistance in training & acquiring design software for distribution transformers; financial support for product development (prototype development and testing); and financial support for tooling / machinery costs needed to produce low loss transformers. Other country participants are encouraged to provide inputs, that SACREEE together with BASE can assist in developing a proposal for funding considering country request for phase 2.

- A question on lifespan of high and low losses DTs was raised and it was clarified that the lifespan of DTs is not dependent on low loss or high loss but the working condition. However, Amorphous core material is very delicate and poor handling during transportation and installation may impacts Amorphous DTs' lifespan.

- SACREEE will send a formal request to DT manufacturers in participating countries to indicate technical and financial resources required to implement technology upgrades to meet the proposed minimum energy standards for DTs that are included in the National Policy Roadmaps.

6 Annexes

6.1 ANNEX A – Virtual Training on Total Cost of Ownership and Technology Upgrade Options for DTs

LEAPFROGGING TO ENERGY EFFICIENT APPLIANCES AND EQUIPMENT (REFRIGERATORS AND DISTRIBUTION TRANSFORMERS) in Malawi, Namibia, Zambia, Zimbabwe.

Agenda

Virtual Training on Total Cost of Ownership and Technology Upgrade options for Distribution Transformers

DATE: 20 September, 2022

TIME: 9h00 – 11h30 (CAT)

Meeting Format: Virtual

Zoom Meeting details:

https://us06web.zoom.us/j/85430710821?pwd=TWJVc2hPSW8rOSt3SXBoMUx1ZTM1dz09
Meeting ID: 854 3071 0821
Passcode: 707248

Objective of the meeting

This training aims to build capacity for utilities, non-utility market players, Ministries of Energy, Ministry of Finance and Ministry or entity responsible public procurement on the recommended Total Cost of Ownership and Technology Upgrade options for manufactures of distribution transformers. The training will include participants from Malawi, Namibia, Zambia and Zimbabwe.

Agenda

1.	**Welcome Remarks** by SACREEE	9:00 – 9:05
2.	**Objective of the training** by ICA	9:05 – 9:15
3.	**Presentation of the Total Cost of Ownership (TCO)** by ICA	9:15 – 9:45
4.	**Questions and discussions on the TCO** by ICA	9:45 – 10:00
5.	**Capacity building for manufacturers of Distribution Transformers on Technology Upgrade Options** by ICA	10:00 – 11:00
6.	**Questions and discussions** by ICA	11:00 – 11:30

Training on Total Cost of Ownership and Technology Upgrade options for Distribution Transformers.

(Leapfrogging to Energy Efficient Appliances and Equipment (refrigerators and transformers) in Malawi, Namibia, Zambia and Zimbabwe.)

Date: Sunday 20.09. 2022, 08:52 hrs.

Location:– online (zoom meeting)

Attendees:

1. Mr. Mzwandile Thwala – SACREEE
2. Mr. Aurélien Pillet - BASE – International Finance Expert
3. Mr. Mayur Karmarkar - ICA – International Policy Expert
4. Mr. Omar Abdelaziz- ICA – International Refrigerators Expert
5. Fenni Shidhika - SACREEE Local Policy expert, Namibia
6. Mr Izaiah Mulenga –SACREEE Local Policy expert, Zambia
7. Mr Tenda Marowa – SACREEE Local Policy expert, Zimbabwe
8. Mr James Tsumba – ESCO South Africa
9. Readlay Makaliki-SACREEE
10. Welton Saiwa-SACREEE
11. Abdul Rahim Hassan – Bureau of Standards Malawi
12. Alinafe Kasinja- Ministry of Energy Malawi
13. Bodrick Mwansa - Copperbelt Energy Corporation Plc
14. Brian Khoriyo - ESCOM Malawi
15. Carlos Siamalala- REA Zambia
16. Chasaya Mutambo- REA Zambia
17. Demetrius Jonas- Namibia
18. Enock Palapandu - Malawi Ministry of Energy
19. Fenni Shidhika- NEI/SACREEE
20. Fungai Nicholas Zowa - ZESA, Zimbabwe
21. Johnson Siamachira- SACREEE
22. James Tsumba- Malawi ESCOM
23. Joseph C Phiri- Mzuzu University
24. Arnold Kadziponye- MEGA Mini Grid (Mulanje, Malawi)
25. Kedrick Mulemwa
26. Kuunika Electricals
27. Lonjezo Bingalason-Churches Action in relief and Development (CARD)
28. Mwape CH – Copperbelt Energy Corporation
29. Moonga Muungo-REA Zambia
30. Odesi M Mwaamvwa-REA Zambia
31. Patrick Dongo-Rural Electrification Fund, Zimbabwe Harare
32. Sommai Phon-ICA
33. Susan Tise - MME Namibia
34. Tendayi Marowa- SACREEE
35. Tabby Moyo- SACREEE
36. Upile Kamoto- Ministry of ENERGY, Malawi
37. Robert Mbetewa- Journalist
38. Peter Makawa-Malawi Broadcasting Corporation
39. Jameson Chauluka Times – Journalist

Agenda

1. Welcome remarks by SACREEE
2. Objective of the training by ICA
3. Presentation on the Total Cost of Ownership (TCO) by ICA
4. Capacity building for manufacturers of Distribution Transformers on technology upgrade options by ICA
5. Questions and discussions
6. Closing remarks by SACREEE

Agenda item	Discussion	Decisions taken/ Action points
Welcoming remarks by Mr. Mzwandile Thwala – SACREEE	**Mr. Mzwandile Thwala called the meeting to order at 08:52 hours and welcomed participants attending the virtual meeting on Total Cost of Ownership and Technology Upgrade options for Distribution Transformers from Malawi, Namibia, Zambia and Zimbabwe.** • He explained that the meeting is one of the many meetings hosted by SACREEE, ICA and BASE under the project supported by Green Climate Fund focused on assisting eight SADC countries to leapfrog to energy efficient appliances and equipment. • The project aims to develop National Policy Roadmap for the eight countries. • He further explained that SACREEE, BASE and ICA are directly working with Malawi, Namibia, Zambia and Zimbabwe, and are at the stage where the project is concluding. • He said several meetings have been held with Policy Working Groups and Technical Committees on Minimum Energy Performance Standards as well as test Standards for refrigerator appliances and distribution transformers. • He also stated that recommendations have been made with regards to monitoring and verification enforcement framework. • Mr Thwala further explained that engagement have held around financing options for energy efficient equipment (refrigerators and Distribution transformers). • He also urged the participants, as key stakeholders to play a key role in providing information that would shape up the policy documents for the countries.	
Meeting Objective **By Mayur Karmarkar - ICA**	• Mr Karmarkar said the training aims to build capacity for utilities, non-utility market players, Ministries of Energy, Ministry of Finance and Ministry or entity responsible for public procurement on the recommended Total Cost of Ownership and Technology Upgrade options for manufacturers of distribution transformers.	

Agenda item	Discussion	Decisions taken/ Action points
Presentation on the Total Cost of Ownership (TCO) by Mr Mayur Karmarkar - ICA	• Making his presentation on Total Cost of Ownership (TCO), Mr Karmarkar started by explaining that transformers are used in electricity transmission and distribution system to adjust voltage and current. • He explained that electricity passes through transformers as it travels from the power plant to the consumer. • Further, he stated that energy efficient transformers can reduce transmission and distribution electricity losses. • He explained that electricity consumption for transformers could be increased by 49 percent by 2040 in Africa with demand to electrify the continent but noted that policies can reduce the losses to 23 percent. • However, with more stringent policies, this could be reduced further to 4 percent. • Mr Karmarkar further informed the meeting that annual electricity savings for transformers could reach almost 55 TWh in 2040, which is almost the same as current energy consumption of Singapore. • He added that energy efficient transformers could help reduce CO emissions by 45 million tons annually and save consumers US$7 billion on their electricity bills. • Globally, Mr Karmarkar noted that many countries do not have energy efficient policies for DT. • The biggest market for energy efficient DT is China, followed by the United States, India and the EU. • He emphasized that the project objective is to provide technical assistance to improve programming process regarding refrigerators and DT energy efficient and strengthen climate finance strategies. • Further the project aims to create an enabling policy and regulatory environment for the adoption of energy efficient refrigerators and DT through the development of mandatory Minimum Energy Performance Standards (MSPS) and a labeling scheme. • It also aims to develop a national policy roadmap for the implementation of standards and labels as well as suggest appropriate financing mechanisms to accelerate deployment of energy -efficient DT. • Additional, it will coordinate with similar GCF readiness projects in Botswana, Eswati, Lesotho, Malawi, Tanzania, Zambia, Zimambwe and the regional	

Agenda item	Discussion	Decisions taken/ Action points
	harmonization efforts coordinated by UNEP's United for Efficiency (U4E) initiative. • The project further aims to transform the market to energy -efficient refrigerators and distribution transformers by; ➢ Reducing the strain on the electricity grid ➢ Increase disposable income for households and potentially reduce greenhouse gases emissions. • Mr Karmarkar said the training will focus on Total Cost of Owners (TCO) and the manufacturer's capacity development. • TCO is the financing mechanism which helps one to understand the savings versus incremental cost. How the decision for buying energy efficient transformers can be made. • Further the manufacturer's capacity development looks at promoting the local industry by helping to create a healthy competition in energy efficiency market. • He further informed the meeting that despite having energy efficient DT, they are not utilized because others feel its too much work to buy a transformer while some are not familiar with this method. • Life cycle cost consideration works on (ISO55001)- Asset management works on the Initial cost that is purchase, transport and installation. • It also looks at; ➢ maintenance and inspection cost ➢ Cost of energy loss ➢ Salvage cost/ salvage value • He explained that during the initial purchase stage, the energy efficient DT may appear to be expense but the savings on the transformer pays off the cost during its saving life time. • Mr Karmarkar further informed the meeting that customers are faced with more challenges when they acquire a transformer with multiple design and efficiency. • He said transformers are made of different materials (Steel, Aluminum and Copper) and as materials change, efficient levels also changes. • Further, he noted that while transformers are expensive to purchase, they are also more expensive to own but efficient transformers have lower cost of ownership. • He further explained that the TCO approach minimizes the total investment in a transformer over its lifetime,	

Agenda item	Discussion	Decisions taken/ Action points

	considering purchase price and the value of future losses also called " loss evaluation"
	
	How does it work?
	
	• During the procurement process, the electricity utility declares its loss evaluation formulae-A and B factors-in terms of the value per watt example Rand/watt, or US$/Watt.
	• "A" represents how much the utility values losses in the core and "B" represents how much the utility values losses in the coil.
	• He explained that A is always greater than B (note: A=B means design for 100% load).
	• The A and B factors influence the designs created by suppliers in response to the tender, resulting in more energy – efficient models.
	• If the utility purchases those designs, the will benefit from lower total cost of ownership.
	• To help the utilities and buyers, there is the IEC TS 60076-20 standard that provides TCO formular.
	• Under the U4E, an excel tool and guide had been developed to promote use of TCO.
	• Mr Karmarkar said utilities can customize the inputs such as operating hours, life expectancy, load growth, fuel costs and O&M, load profile generation mix for peak power to calculate their own A and B factors.
	• many inputs calculated A and B factors can then be included in a call for tender
	• U4E has also added a second TCO calculation methodology, which adds the price of a tonne of CO2
	• Advantage is that utilities could start using this in their next tender and it would increase efficiency.
	• He stated that the software guide explains key principles and equations in the Excel model looking at:
	    ➢ Transformer losses
	    ➢ Loss evaluation
	    ➢ TCO carbon factors
	    ➢ Conclusions and
	    ➢ references
	• A calculation – an additional cost applied to the selling price to determine the lifetime cost.
	• TCO=IC+Ax(Po+Pco)+Bx(Pk+Pcs-Pco)
	• IC is the initial Cost of the transformer; this cost may include installation costs	

Agenda item	Discussion	Decisions taken/ Action points
	such as foundation and erection cost (this requires a more sophisticated evaluation); • Po is the no-load loss (kW) measured at the rated voltage and rated frequency, on the rated tap. • Pk is the load loss (kW) due to the load, measured at the rated currency and rated frequency on the rated tap at a reference temperature; • Pcs is the total cooling power(kw)needed for operation at the rated power (including three winding operation if any) note; this variable is set to zero for passively cooled transformer designs. • Pco is the cooling power (kW) needed for no-load operation (note: this variable is set to zero for passively cooled transformer designs. • A is the cost of capitalization of no-load losses in cost per kW and B is the cost of capitalization of the losses due to load in cost per kW. **A factor – Value of losses in the core** • Mr Karmarkar informed the meeting that Core losses are always present, 24 hours/365 days and do not vary with load. $A = \sum_{j=1}^{n} \frac{O_{0j} \times C_j}{(1+i_j)^j}$ Equation (A.2) • O_{0j} is the operating time of the transformer at year j in h; • C_j is the valorisation of the energy at year j in cost per KWh as losses are expressed in kW in the TCO formula; • I_j is the real discount rate at year j in per unit; • N is the life expectancy of the transformer in years. **B factor-Value of losses in the coil** • The coil loses increases with load and peak losses during the peak loading (most expensive electricity) $B = \sum_{j=1}^{n} \frac{\mu \times c_j \times (O_{aj} \times T_{aj} + O_{fj} \times T_{fj})}{(1+i_j)^j} (\frac{1+C_{\mu j}}{1+C_{aj}})^{2j}$ •	

Agenda item	**Discussion**	**Decisions taken/ Action points**
	➢ μ is the average load loss factor as defined in Equation (A.4) ➢ C_j is the total cost of the energy at year j in cost per kWh as losses are expressed in kilowatts; no CO2 price. ➢ C_j is the total cost of the energy at year j in cost per kWh as losses are expressed in kilowatts; including CO2 price. ➢ I_j is the real discount rate at year j in per unit; generally the weighted average cost of capital, provided by the regulator. ➢ O_{aj} is the operating time of the transformer at variable load during year j in h; ➢ O_{fj} is the operating time of the transformer at fixed load during year j in h, usually 8 760 h if the transformer is operated all year round; ➢ T_{aj} is the share of variable load in the total load loss factor at year j; ➢ T_{fj} is the share of fixed load in the total load loss factor at year j; ➢ n is the life expectancy of the transformer in years; ➢ $C_{\mu j}$ is the rate of load loss factor increase at year j; ➢ C_{aj} is the rate of installed power increase at year j. ➢ Further, Mr Karmarkar cited the following formulas as the most popular in distribution utilities. ➢ TOC = IC + (A*Wi) + B (Wc) ➢ Factor A = H * (Ec/1000) * $((1+r)^n-1)/(r * (1+r)^n$ ➢ Factor B = A * LLF ➢ LLF = A dimensionless ratio between average and peak values of load loss $LLF = \sum_{i=1}^{ni} Loadi2 \,/\, NI * Load^2_{peak}$ ➢ *NI* - total number of short intervals (there are 8760 hrs or 17,520 half-hrs per year ➢ $Loadi$ – Load during the short interval *I* ➢ $Load_{peak}$ - Peak load within the long interval (typically a year) $LLF = 0.35\ LF + 0.65\ LF^2$ LF for rural area < LF for urban area **A simplified approach to buy a transformer** • Mr Karmarkar explained that a simplified approach to buy a transformer is for the purchase managers of buildings or industry to specify loss requirements as per the standards. • He also stated that managers are to use a simple formula specifying A & B factors as below; **Ct = Purchase price + A * Po + B * Pk**	

Agenda item	**Discussion**	**Decisions taken/ Action points**
	$A = \frac{(1+i)^n - 1}{i \cdot (1+i)^n} \times C_{kWh} \times 8760$ $B = \frac{(1+i)^n - 1}{i \cdot (1+i)^n} \times C_{kWh} \times 8760 \times \left(\frac{I_l}{I_r}\right)^2$ ➢ I = interest rate 7 % ➢ N = lifetime 30 yrs ➢ C_{kWh} = cost / KWh (0.05 c) ➢ I_l/I_r = loading 50% • To summarise his presentation, Mr Karmarkar informed the meeting that MEPS give a good 'push' to the market: • He explained that the draft regulation is based on SAN 780 and a good starting point, but in the Africa region, more ambition is needed on the smaller kVA ratings. • He also stated that need for policy process to be adopted as they may take 2 years before there are in place. • Commenting on the TCO methodology, he explained that it offers a 'pull' based on IEC TS 60076-20 Annex A methodology. • TCOs allows utilities and industrial, commercial customers to calculate economic cost optimal for their situation and adds the option of including cost of CO_2 emissions. • There are also quick and easy to implement – potential fast-track.	
Presentation on capacity building for manufacturers of Distribution Transformers on technology upgrade options by Mr Muyur Karmarkar	• Making his presentation, Mr Karmarkar said SACREEE has asked all partner countries to provide input on the need for technology energy efficient upgrade. • He explained that request has been received from Zimbabwe for technology upgrade and this will involve: ➢ Assistance in training & acquiring design software for distribution transformers. ➢ Financing the product development (proto-type development & testing) ➢ Financing tooling / machinery costs needed to produce low loss transformers • He further encouraged the participants to provide inputs, that SACREEE together with BASE can assist to develop proposal for funding considering country request for phase 2. • He explained to the meeting that transformers are the principal medium for	

Agenda item	Discussion	Decisions taken/ Action points
	transferring energy from one circuit to another circuit by following the process of electromagnetic induction. • In general, transformers are responsible for supplying and regulating voltage levels by either increasing (step-up) or decreasing (step-down) it down. • He stated that distribution transformers are mainly used for lower voltage distribution networks for use in individual homes or commercial and industrial establishments. • The primary voltage is generally below 36 kV and secondary voltage can be 250 Volts or Less per phase. • He further explained that the basic classification of distribution transformers can be number of phases looking at single phase or three phase, design/Construction focusing on core type or shell type and cooling medium which can either be oil immersed or dry type. **Distribution Transformer manufacturing** • Mr Karmarkar explained that distribution transformers can be made with highest customization for each contract. Customer can make an order, with variation in requirements. • He also stated that continues optimization is necessary because the industry depends on material and value addition. • To manufacture DT, one needs resources that include skilled manpower, design skills, purchase skills, manufacturing skills, testing and quality assurance • He also noted that current DT machine on market has improved drastically covering enhanced conductor winding / foil winding machine, core building / winding machine and testing set-up. • Design options for efficient transformers should focus on no load losses such as use of lower-loss CRGO material. • Decreasing flux density by increasing core cross and decreasing flux path length by decreasing the conductor. • There is need to also decrease current path length by increasing volts/turn. • He explained that manufacturing process for oil filled transformer involves buying the core and sending it through the winding and convert that into the assembly, painting and tank outsourcing. **Major materials / Manufacturing Process** • Mr Karmarkar said the magnetic circuit of transformer, core provides a low	

Agenda item	Discussion	Decisions taken/ Action points
	reluctance flux path for the transformer to function. • Generally, it is made of Cold Rolled Grain oriented (CRGO) steel sheets of high permeability and small thickness coated with high temperature materials (Carlite or equivalent) to reduce eddy current losses and hysteresis losses. Their carbon content is maintained below 0.1%. Eddy current is further reduced by alloying the steel with Silicon. • Other materials used for transformer core is Amorphous metal, which is a non-crystalline substance formed as ribbons and has a superior magnetic properties. • It is very thin compared to CRGO Sheets, the eddy current losses also are very low. • However, the saturation flux density is low as compared to CRGO silicon steel and so is the case with mechanical strength against jerks during assembly and handling being softer than CRGO. • Various Cross-sections circular / rectangular, Core type / Shell Type may be opted depending on design. **Core – Cold Roller Grain Oriented Silicon steel** • These DT are manufactured by a few steel mills across the world with specialized material. • Mr Karmarkar noted that superior grades of CRGO are now available with Losses upto 0.80, 0.75, 0.70 Watts/Kg at 1.7 T. • He stated that losses with Amorphous Alloy at 1.5 Tesla 50 Hz are as low as 0.325 Watts/Kg, however, its saturation flux density is low as compared to CRGO and normally the designs never go beyond 1.38 to 1.4 Tesla for Amorphous core transformers. Hence higher load losses. • He also explained that old transformers have very high load losses and in Africa, there is a lot of refurbishing of old transformers as opposed to getting a new one due to budgetary constraints. • One can replace the core, which may not be the same as buying a new DT. • He explained that there are a few new technologies on the market with reduced losses below one. • He also stated that the steel industry has improved the steel grade, which has helped to make the transformers more efficient. • Mr Karmarkar said 3 D core is a new technology on the market that is becoming	

Agenda item	Discussion	Decisions taken/ Action points
	popular, reducing the flux path is the way to reduce losses in the transformer. • Wound core CRGO & AMT single Ph (a) Core Type (b) Shell Type are also energy efficient transformer that can help improve productivity as well reduce on labour. • Further, the meeting was informed of conducting material such as copper and alluminum **Conducting materials** • Mr Karmarkar said DT distribution windings are made of high grade electrolytic copper or aluminum, which are designed to optimize thermal, mechanical and electrical stresses. • The winding machines are equipped with different speed gears to ensure that proper tension is maintained on the windings. • Similarly, the conductors are suitably transposed at intervals to reduce the circulating current losses in winding. Axial and radial wedges and dove-tailed / T-spacers are provided as cooling ducts as per the design. • He highlighted that different winding types are used in transformers, such As : ➢ Spiral / Layer Type winding ➢ Helical winding ➢ Cross-over winding ➢ Continuous Disc winding ➢ Foil winding **LV Foil winding:** • LV foil winding uses a single piece of thin strip as conductor with a width of the foil equal to length of the winding. • This conductor strip (foil) wound along with a pre-impregnated interlayer insulation and during curing process foil and insulation are bonded together to form a rigid block. • Mr Karmarkar said the LV coil becomes self-supporting against forces and later the coil is impregnated with resin for environmental protection. • Eddy losses in the thin foil are very less compared to thick rectangular wires, so windings made with foil are cooler than other types. • Equally, foil winding minimizes the axial forces during short circuit , since currents in the winding are adjusted to the ampere turns in the high voltage winding. **Core Coil Assembly (CCA)**	

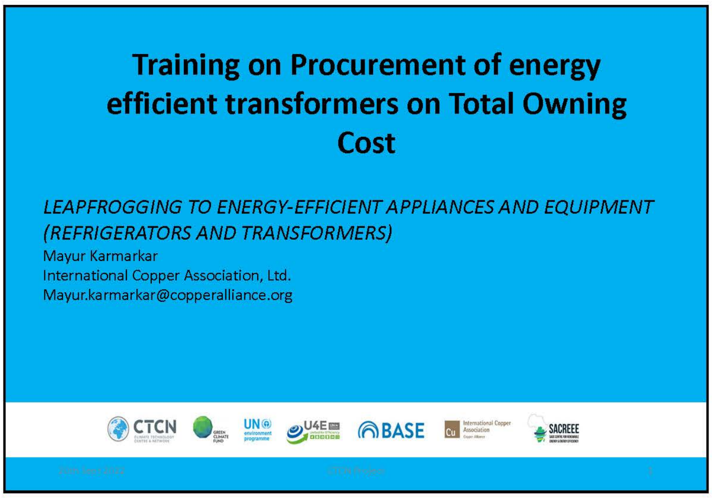
Agenda item	Discussion	Decisions taken/ Action points
	• He explained that the construction of the Core and Coil Assembly is significant from the performance point of the transformer. The CCA defines the insulation scheme, cooling, dynamic withstand capability, handling by providing sufficient radial and axial supports that prevents the stress from causing any damage to the windings. • He said clamping of the windings axially is necessary to hold the assembly firmly. Clamping structure of the assembly has supports to route the tap and line terminals, insulated vertical and horizontal strips of adequate thickness of a frame work to assist the routing of terminals. • Further, insulation scheme is categorized into major and minor insulation. • He explained that major insulation addresses the capability to withstand high voltages, isolation of the primary and secondary winding, clearances for voltage withstand while minor insulation is the turn insulation, joint protection etc. • Both the major and minor insulation are equally important for the successful operation of the transformer. • Further, the thermal class of insulation depends on the Type of cooling medium. **The drying process** • Mr Karmarkar highlighted that the significant part of the insulation used in oil immersed transformer is paper and wood based. • This insulation material has high affinity to moisture which may weaken the insulation properties and reduce the insulation resistance to high voltages. • For the above reasons, transformer windings and Core Coil Assembly undergo drying process at various stages depending on the rating and voltage class. • There are two types of drying: ➢ Air drying ➢ Vacuum drying. • **Air drying** is used in distribution transformers limited to voltage class below 33 KV, while **Vacuum drying** is predominantly used for all transformers of voltage class above 33 KV. **Tank & radiators** • The Transformer enclosure is generally referred to as tank and this is a fabricated structure constructed of mild steel of adequate thickness & generally	

Agenda item	Discussion	Decisions taken/ Action points
	rectangular shaped. The tank has two main functions: ➢ To hold the CCA with proper clearances for voltage and oil flow. ➢ To facilitate cooling, safety and maintenance. • The tank must be leak proof, and should withstand the specified pressure during all service as well as test conditions. • He stated that depending on heat dissipation requirements to keep the specified temperature rise requirements in test conditions and service, the transformer tank will either have corrugations or is fitted with pressed steel fin type radiator banks. **Final assembly & fitting** • After drying process, the CCA is inserted into the transformer tank. • The CCA should stand freely inside the tank and inside clearances are to be maintained. • The primary and secondary terminations are brought out through porcelain or epoxy cast bushing insulation. • Off circuit Tap Switch or OLTC connections are to be secured tightly and separated. • Mr Karmarkar said handling, jacking facility to lift the transformer or jack it for fixing detachable rollers is normally provided. • The transformer tank is also fitted with valves for oil filling, filtration, oil sampling, draining. • Provision for safety devices like Buchholz relay, pressure relief valve, temperature recording and control instruments, neutral current transformer, protection and instrument transformer are customized features as per buyer's requirement. • He explained that in a non-sealed transformers, conservator is provided for oil expansion and contraction during the operating cycle. • For sealed type transformers DGPT Relay also is sometimes provided for protection. Terminal identification /marking are also done on/near the bushings. **Oil plant** • Mr Karmarkar also highlighted that there is a programme of chemical management under the pop material management the world transformers in Africa.	

Agenda item	Discussion	Decisions taken/ Action points
	• He said the oil contains in transformers is environmentally harmful and the replacing of both power and oil disposable is a separate programme. • He further explained that the transformers being promoted in the policy right book are the natural ester, which is derived from vegetable oil • He noted that esters have a better insulating property, fire performance and mineral oil very wet. • It is environmental friendly and helps to make the transformer more resilient. **List of plant machinery (for testing oil immersed distribution transformers upto 25000 KVA)** ➢ Core assembly tables/platforms ➢ Core lifting/handling fixtures ➢ Mandrals ➢ Winding section ➢ Foil winding machines for LV Coil ➢ Cross over type HV Coil winding machines ➢ Rectangular Coil winding machines ➢ Decoilers/conductor feeding stands, ➢ Adjustable winding former ➢ Coil pressing jigs and fixtures ➢ Power supply source/generator ➢ Three phase variac/regulator ➢ Intermediate testing transformers for load tests /temperature rise test. ➢ High voltage testing transformer ➢ Double/triple frequency generator ➢ High accuracy three phase power analyzer ➢ Multiple range CTs and PT with high accuracy ➢ Noise level meter ➢ Vacuum test kits with gauges ➢ Pressure test kits with gauges etc. ➢ Oil BDV test kit ➢ Portable HV tester ➢ Paint thickness gauge • He further explained that other extra test equipment may also be installed depending on plant capacity as feasible.	

Agenda item	Discussion	Decisions taken/ Action points
Questions and discussions	• Opening up the floor for discussions, Mr Karmarkar said there is need for countries to submit request to implement technology upgrade of DTs. • He informed the meeting that participants will be communicated to via email for their formal submissions. • And Mr Tendayi Marowa noted that the need to engage key stakeholders like the manufacturers as countries draft the national roadmap policy. • Mr Marowa also stated as such as plans are underway by the project facilitate to host public consultations, those meeting will not be as detailed as the meeting held. • He called for future capacity building to include manufacturers who were absent in the meeting as they are key stakeholders. • Other participants sought clarity on the lifespan of the transformers considering the low losses and high losses	• In response to the query on the lifespan of the transformer, Mr Karmarkar said it is not dependent on low loss or high loss but the working condition, in the case of amorphous work material that is very delicate. • He explained the need to handle transformers very careful during transportation explaining that factors like the conductor life and paper insulation do not change
Closing remarks Mr.	• Closing the meeting, Mr Mzwandile Thwala thanked presenter and all the participants for attending the meeting. • Mr Thwala said the meeting was informative and believe that everyone had learnt a lot in procurement of energy efficient DTs. • He assured the meeting that a formal request will be sent to manufacturers from participating countries to provide an indicate of how much they would require to implement technology upgrade to meet the proposed minimum energy standards that are included in the National policy roadmaps	

6.2 ANNEX B – Training on Procurement of energy efficient transformers on Total Owning Cost Presentation



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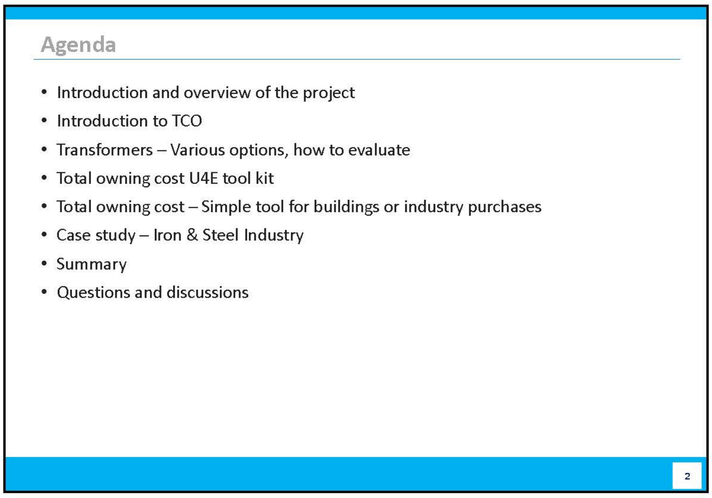

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1

Project overview

- **Objective:** Provide technical assistance to improve programming process regarding refrigerators and distribution transformers energy efficiency and strengthen climate finance strategies
- **Aims**
  - Create an enabling policy and regulatory environment for the adoption of energy-efficient refrigerators and distribution transformers through the development of mandatory Minimum Energy Performance Standards (MEPS) and a labeling scheme
  - Develop a national policy roadmap for the implementation of standards and labels
  - Suggest appropriate financing mechanisms to accelerate deployment of energy-efficient distribution transformers
  - Coordinate with similar GCF readiness projects in Botswana, Eswatini, Lesotho, Malawi, Tanzania, Zambia, Zimbabwe and the regional harmonization efforts coordinated by UNEP's United for Efficiency (U4E) initiative
- Transform the market to energy-efficient refrigerators and distribution transformers
  - Reduce the strain on the electricity grid
  - Increase disposable income for householders and potentially reduce greenhouse gases (GHG) emissions

3

3

How to buy a car?

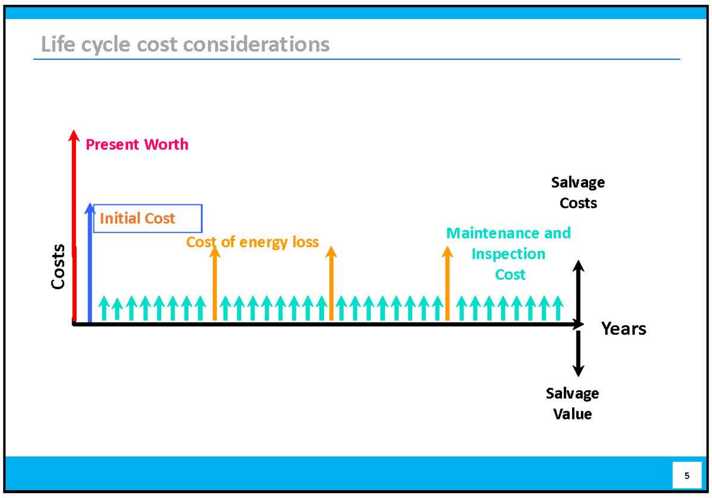
Let's presume you want to drive 25000 km per year during 5 years

Toyota Prius		VW golf	
Purchase price	25250	Purchase price	22875
Fuel price	6988	Fuel price	10075
Total price	32238	Total price	32950

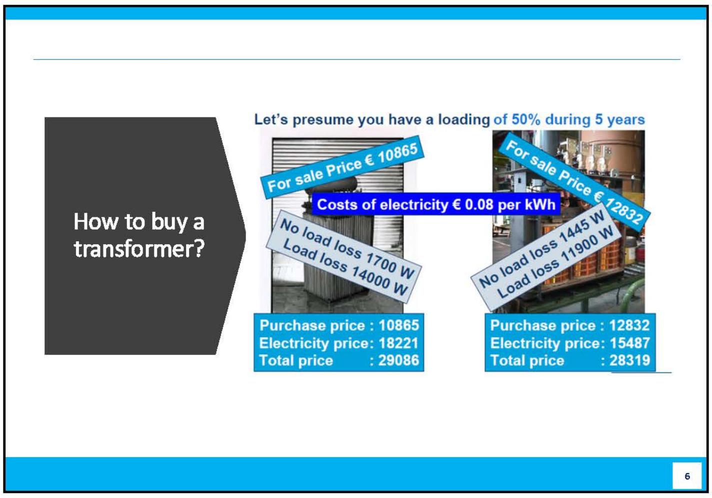
4

4

2


Life cycle cost considerations
Present Worth
Initial Cost
Cost of energy loss
Maintenance and
Inspection
Cost
Salvage
Costs
Costs
Years
Salvage
Value
5

5


How to buy a transformer?
Let's presume you have a loading of 50% during 5 years
For sale Price € 10865
For sale Price € 12832
Costs of electricity € 0.08 per kWh
No load loss 1700 W
Load loss 14000 W
No load loss 1445 W
Load loss 11900 W
Purchase price : 10865
Electricity price: 18221
Total price : 29086
Purchase price : 12832
Electricity price: 15487
Total price : 28319
6

6

3

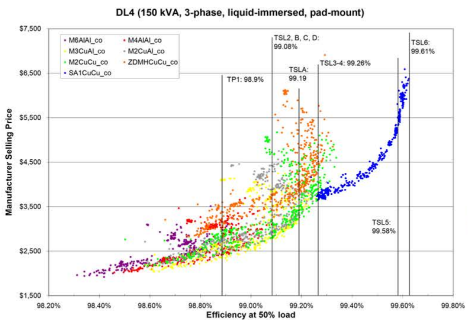
Why don't we use it if we are buying transformers?

- May be because:
  - We did not know it was that easy
  - It's too much work for buying a transformer
  - We are not familiar with this method
    - NEED MORE INFORMATION.....
  - We are not interested in energy or cost saving
    - How about your boss?
  - We are only interested for short time period
  - This method neglect a lot of aspects
    - Which aspects?
  - Others?

7

7

Transformer Designs – A Range of Efficiency Levels



- Improving grades of steel:
  - M6, M4, M3, M2
  - ZDMH
  - SA1
- Improving windings
  - Aluminum
  - Copper

How do we choose a transformer?

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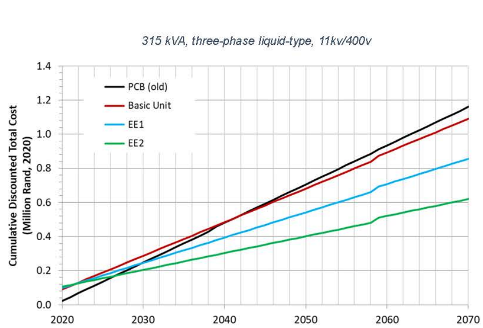
8

4

Life-Cycle Cost – Four Scenarios (2020 Rand)



- Cumulative, discounted cost of transformers in South Africa, including the transformer itself, the installation and the electricity cost (running cost)
- Transformers are expensive to purchase, but they are even more expensive to own
- Slope of the lines shows you a comparison of the cumulative LCC at any point in time
- Efficient transformers have lower total cost of ownership

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9

Total Cost of Ownership (TCO)

- The Total Cost of Ownership (TCO) approach **minimises the total investment in a transformer** over its lifetime, considering purchase price and the value of future losses (also called "loss evaluation")
- How does it work?
  - During the procurement process, the electric utility declares its **loss evaluation formulae – A and B factors** – in terms of the value per watt (e.g., Rand/Watt, or US$/Watt)
  - **"A"** represents how much the utility values **losses in the core** and **"B"** represents how much the utility values **losses in the coil**
  - A is always greater than B (note: A = B means design for 100% load)
  - The A and B factors influence the designs created by suppliers in response to the tender, resulting in **more energy-efficient models**
  - If the utility purchases those designs, they will benefit from lower total cost of ownership

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5

Total Cost of Ownership – IEC's Methodology

- The Transformer Technical Committee at the IEC Developed a standardised method for conducting TCO Calculation, published in Annex A of IEC TS 60076-20
- Informative Annex (not Normative)
- Contents:

Annex A (informative) Capitalisation of losses 26
A.1 General theory, concept of capitalisation 26
A.2 Impact of capitalisation values 27
A.3 Capitalisation formula 27
A.3.1 General 27
A.3.2 Calculation of factor *A* 28
A.3.3 Calculation of factor *B* 28
A.3.4 Use of *A* and *B* for tender evaluation 30
A.3.5 Determination of factors *A* and *B* 31

- Very few utilities in the SADC region use TCO

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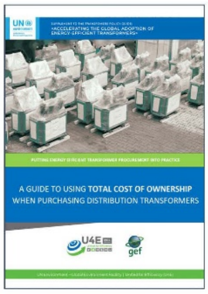
11

U4E Developed Excel Tool and Guide to Promote Use of TCO

- U4E developed an **MS Excel tool** and **software guide** following the IEC methodology
- Utilities can customize the inputs in the tool to calculate their own A and B factors
  - Many inputs – operating hours, life expectancy, load growth, fuel costs, O&M, load profile, generation mix for peak power…
- Calculated A and B factors can then be included in a call for tender tomorrow
- U4E added a second TCO calculation methodology which adds the price of a tonne of CO_2

- **Advantage: Utilities could start using this in their next tender, and it would increase efficiency**



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6

Total Cost of Ownership Guide

- Software guide explains key principles and equations in the Excel model

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1 INTRODUCTION AND CONTEXT 8
2 TRANSFORMER LOSSES 11
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3.1 DERIVATION OF THE A FACTOR (VALUATION OF FUTURE CORE LOSSES) 18
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4 TCO INCLUDING CARBON FACTOR 22
4.1 VALUATION OF CO_2 EMISSIONS 22
5 CONCLUSIONS 24
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Total Cost of Ownership Spreadsheet ... 1 of 2

- A calculation – an additional cost applied to the selling price to determine the lifetime cost

$$TCO = IC + A \times (P_0 + P_{C0}) + B \times (P_k + P_{CS} - P_{C0}) \quad \text{Eqn. A.1}$$

- IC is the initial cost of the transformer; this cost may include installation costs such as foundation and erection costs (requires a more sophisticated evaluation);
- P_0 is the no-load loss (kW) measured at the rated voltage and rated frequency, on the rated tap;
- P_k is the load loss (kW) due to the load, measured at the rated current and rated frequency on the rated tap at a reference temperature;
- P_{CS} is the total cooling power (kW) needed for operation at the rated power (including three winding operation if any) (note: this variable is set to zero for passively cooled transformer designs);
- P_{C0} is the cooling power (kW) needed for no-load operation (note: this variable is set to zero for passively cooled transformer designs);
- A is the cost of capitalisation of no-load losses in cost per kW;
- B is the cost of capitalisation of the losses due to load in cost per kW.

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Total Cost of Ownership Spreadsheet … 2 of 2

$$TCO = IC + A \times (P_0 + P_{C0}) + B \times (P_k + P_{CS} - P_{C0})$$ Eqn. A.1

16		Description:	315 kVA, 3 Phase Oil-filled; 11/0.4 kV DT							
17		*Calculation:*	Baseline	Option #1	Option #2	Option #3	Option #4	Option #5	Units	Description
18		*IC (price tendered)*	$ 4,500	$ 5,450	$ 6,350				USD	Initial Cost of the transformer
19		*P0 (core losses)*	0.84	0.64	0.42				kW	no-load losses (kW) at rated voltaged and frequency
20		*Pk (load losses)*	3.80	2.80	1.90				kW	load losses (kW) at rated current and frequency
21		*PCS (cooling losses)*	-	-	-	-	-	-	kW	total cooling power (kW) for operation at the rated power
22		*PC0 (cooling losses)*	-	-	-	-	-	-	kW	total cooling power (kW) for operation at no-load
23										
24	No CO2 Price	*A*	$ 4,102	$ 4,102	$ 4,102	$ 4,102	$ 4,102	$ 4,102	$/kW	cost of capitalisation of no-load losses
25		*B*	$ 1,536	$ 1,536	$ 1,536	$ 1,536	$ 1,536	$ 1,536	$/kW	cost of capitalisation of load losses
26										
27	With CO2 Price	*A*	$ 4,555	$ 4,555	$ 4,555	$ 4,555	$ 4,555	$ 4,555	$/kW	cost of capitalisation of no-load losses
28		*B*	$ 1,770	$ 1,770	$ 1,770	$ 1,770	$ 1,770	$ 1,770	$/kW	cost of capitalisation of load losses
29										
30										
31		TCO_{NoCO2}	$ 13,781	$ 12,375	$ 10,991	$ -	$ -	$ -	USD, total cost of ownership	
32										
33		$TCO_{withCO2}$	$ 15,050	$ 13,320	$ 11,625	$ -	$ -	$ -	USD, total cost of ownership	
34										

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A Factor – Value of Losses in the Core

- Core losses are always present, 24hr/365day
- Do not vary with load

$$A = \sum_{j=1}^{n} \frac{O_{0j} \times C_j}{(1 + i_j)^j}$$ Equation (A.2)

- O_{0j} is the operating time of the transformer at year j in h;
- C_j is the valorisation of the energy at year j in cost per KWh as losses are expressed in kW in the TCO formula;
- i_j is the real discount rate at year j in per unit;
- N is the life expectancy of the transformer in years.

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B Factor – Value of Losses in the Coil

- Coil losses increase with load
- Peak losses during peak loading (most expensive electricity)

$$B=\sum_{j=1}^{n}\frac{\mu \times c_j \times (O_{aj} \times T_{aj} + O_{fj} \times T_{fj})}{(1+i_j)^j}\left(\frac{1+C_{\mu j}}{1+C_{aj}}\right)^{2j} \quad (A.5)$$

- μ is the average load loss factor as defined in Equation (A.4)
- C_j is the total cost of the energy at year j in cost per kWh as losses are expressed in kilowatts; no CO2 price.
- C_j is the total cost of the energy at year j in cost per kWh as losses are expressed in kilowatts; including CO2 price.
- I_j is the real discount rate at year j in per unit; generally the weighted average cost of capital, provided by the regulator.
- O_{aj} is the operating time of the transformer at variable load during year j in h;
- O_{fj} is the operating time of the transformer at fixed load during year j in h, usually 8 760 h if the transformer is operated all year round;
- T_{aj} is the share of variable load in the total load loss factor at year j;
- T_{fj} is the share of fixed load in the total load loss factor at year j;
- n is the life expectancy of the transformer in years;
- $C_{\mu j}$ is the rate of load loss factor increase at year j;
- C_{aj} is the rate of installed power increase at year j.

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Most popular formula in distribution utilities

TOC = IC + (A*Wi) + B (Wc)

- Factor A = H * (Ec/1000) * $((1+r)^n-1)/(r * (1+r)^n$
- Factor B = A * LLF

LLF = A dimensionless ratio between average and peak values of load loss

$$LLF = \sum_{i=1}^{ni} Load_i^2 \,/\, NI * Load_{peak}^2$$

NI - total number of short intervals (there are 8760 hrs or 17,520 half-hrs per year

$Load_i$ – Load during the short interval I

$Load_{peak}$ - Peak load within the long interval (typically a year)

$$LLF = 0.35\ LF + 0.65\ LF^2$$

LF for rural area < LF for urban area

18

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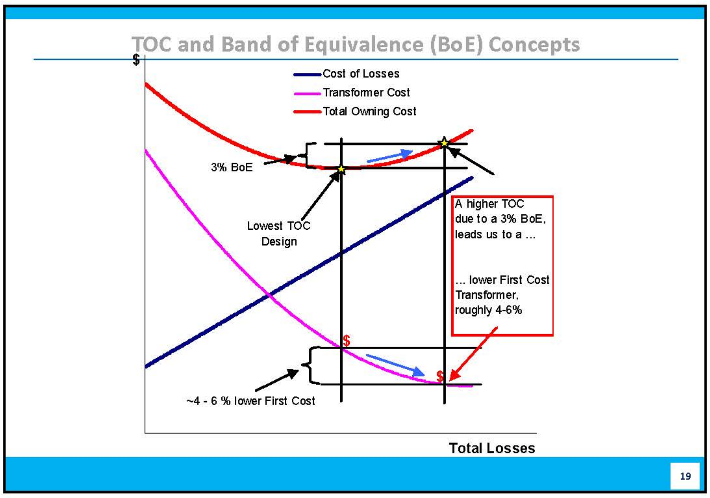
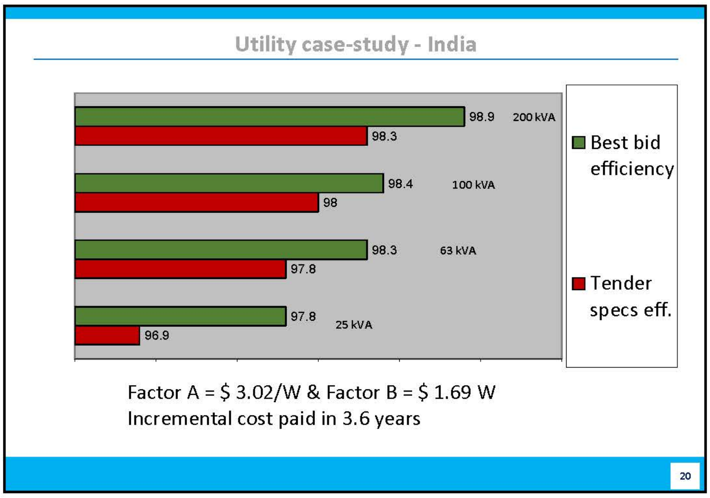

TOC and Band of Equivalence (BoE) Concepts
$
Cost of Losses
Transformer Cost
Total Owning Cost
3% BoE
Lowest TOC Design
A higher TOC due to a 3% BoE, leads us to a ...
... lower First Cost Transformer, roughly 4-6%
~4 - 6 % lower First Cost
Total Losses
19

19


Utility case-study - India
98.9
200 kVA
98.3
98.4
100 kVA
98
98.3
63 kVA
97.8
97.8
25 kVA
96.9
Best bid efficiency
Tender specs eff.
Factor A = $ 3.02/W & Factor B = $ 1.69 W
Incremental cost paid in 3.6 years
20

20

10

For purchase managers of buildings or industry

- A simplified approach to buy a transformer
  - Specify loss requirements as per the standards.
  - Use a simple formula specifying A & B factors as below;

Ct = Purchase price + A * Po + B * Pk

$$A = \frac{(1+i)^n - 1}{i \cdot (1+i)^n} \times C_{kWh} \times 8760$$

$$B = \frac{(1+i)^n - 1}{i \cdot (1+i)^n} \times C_{kWh} \times 8760 \times \left(\frac{I_l}{I_r}\right)^2$$

Here as an example
I = interest rate 7 %
N = lifetime 30 yrs
C_{kWh} = cost / KWh (0.05 c)
I_l/I_r = loading 50%

21

21

Case study – Iron steel plant in Europe

A typical rating – 1250 kVA

- Average loading of 65% with 6 pulse convertor
- Loading 24 hours a day & 7 days a week
- Average electricity price 40 Euro/MWh
- Average interest rate 7% PA
- Average age transformer 15 years but economic life time 10 years
- Plant used dry-type transformer

Based on above figures A = 2.46 Euro/W & B = 1.04 Euro/W

22

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Cost evaluation of 1250 kVA transformer

Vendor Name	Pn (Watts)	Pk (Watts)	Bid price (Euro)
A	2400	13568	12250
B	2200	11712	13000

Ct = Purchase price + A * Po + B * Pk

Vendor A Ct=12250+ 2400*2.46 + 13568*1.04 = 32265

Vendor B Ct= 13000+ 2200*2.46 + 11712*1.04 = 30592

Vendor B was cheaper on the life time basis with payback less than 2.50 years.

23

23

Key take-aways

- MEPS give a good 'push' to the market:
  - The draft Regulation is based on SAN 780
  - A good starting point, but in the Africa region, more ambition is needed on the smaller kVA ratings
  - Policy process to adopt, may take 2 years before in place
- TCO methodology offers a 'pull'
  - Based on IEC TS 60076-20 Annex A methodology
  - Allows utilities & industrial, commercial customers to calculation economic cost optimal for their situation
  - Adds the option of including cost of CO_2 emissions
  - Quick and easy to implement – potential fast-track...

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Information Resources on Transformers

- U4E Policy Guide for Transformers – Accelerating the Global Adoption of Energy-Efficient Transformers – click here
- U4E Model Regulation - Guidelines for Energy Performance Requirements for Distribution Transformers – click here
- U4E Procurement Guidelines: Model Liquid Immersed Distribution Transformer Technical Specification – click here
- IEC TR 60076-20: Power transformers - Part 20: Energy efficiency – click here
- PROPHET II: The potential for global energy savings from high-efficiency distribution transformers – click here
- SEAD Distribution Transformers - Internationally Comparable Test Methods and Efficiency Class Definitions – Four Part Study – click here
- IEA 4E Benchmarking Report for Distribution Transformers – click here
- Energy-efficient distribution transformers in Europe: impact of Ecodesign regulation – click here

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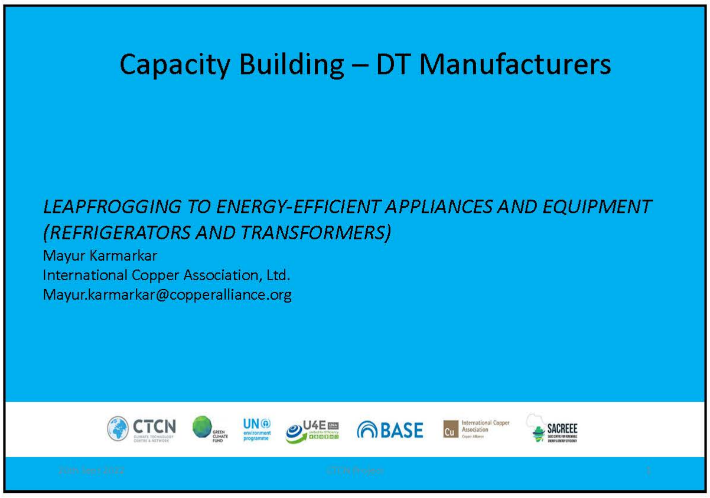
6.3 ANNEX C – Capacity Building – DT Manufacturers Presentation



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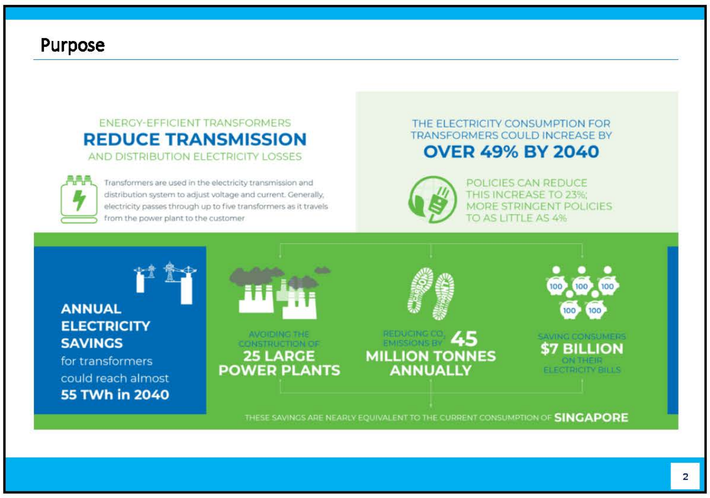

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1

Many countries in the world don't have national energy efficiency policies for DT

3

3

Total Cost of Ownership & capacity development of manufacturers

TCO

- Imperative to finance the incremental cost

Manufacturers' capacity development

- Helps to create a healthy competition in energy efficiency market

4

4

2

Requests received for technology upgradation (Zimbabwe)

- Assistance in training & acquiring design software for distribution transformers
- Financing the product development (proto-type development & testing)
- Financing tooling / machinery costs needed to produce low loss transformers

5

5

Estimate (Zimbabwe)

ITEM	DESCRIPTION	UOM	QTY	UNIT PRICE	TOTAL
	Product Development Phase				
1	**Benchmarking activities**	**Lot**	**1**	**USD 15,000.00**	USD 15,000.00
2	**Selection of tech transfer partner**	**Lot**	**1**	**USD 1,500,000.00**	USD 1,500,000.00
3	Transformer Design Software	Lot	1	USD 50,000.00	USD 50,000.00
4	Training for design software	Engineer	4	USD 3,000.00	USD 12,000.00
5	Hardware and tooling meeting MEPS	Lot	1	USD 720,000.00	USD 720,000.00
6	Prototype Tier 1-Tier 3 MEPS	Ea	12	USD 10,000.00	USD 120,000.00
7	Temporary export to SA + transportation	Lot	12	USD 1,800.00	USD 21,600.00
8	Type tests at NETFA (South Africa)	ea	15	USD 5,000.00	USD 75,000.00
9	**Estimated Subtotal for the transition**				**USD 2,513,600.00**

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Project overview

- **Objective:** Provide technical assistance to improve programming process regarding refrigerators and distribution transformers energy efficiency and strengthen climate finance strategies
- **Aims**
  - Create an enabling policy and regulatory environment for the adoption of energy-efficient refrigerators and distribution transformers through the development of mandatory Minimum Energy Performance Standards (MEPS) and a labeling scheme
  - Develop a national policy roadmap for the implementation of standards and labels
  - Suggest appropriate financing mechanisms to accelerate deployment of energy-efficient distribution transformers
  - Coordinate with similar GCF readiness projects in Botswana, Eswatini, Lesotho, Malawi, Tanzania, Zambia, Zimbabwe and the regional harmonization efforts coordinated by UNEP's United for Efficiency (U4E) initiative
- Transform the market to energy-efficient refrigerators and distribution transformers
  - Reduce the strain on the electricity grid
  - Increase disposable income for householders and potentially reduce greenhouse gases (GHG) emissions

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Introduction

Transformers are the principal medium for transferring energy from one circuit to another circuit by following the process of electromagnetic induction. In general, they are responsible for supplying & regulating voltage levels by either increasing (step-up) or decreasing (step-down) it down.

Distribution transformers are mainly used for lower voltage distribution networks for use in individual homes or commercial & industrial establishments. The primary voltage is generally below 36 kV and Secondary Voltage can be 250 Volts or Less per phase.

Basic Classification of Distribution Transformers can be :

No. of Phases	:	Single Phase or Three Phase
Design/Construction	:	Core Type or Shell Type
Cooling Medium	:	Oil Immersed or Dry Type

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Distribution Transformer manufacturing

Highest customization for each contract

- Make to order
- Variation in customer requirements
- Continues optimization
  - Higher material dependency, fluctuations in raw material cost

Resources

- Man – Skilled manpower
  - Design skills
  - Purchase skills
  - Manufacturing skills
  - Testing & Quality Assurance
- Machine – Updated manufacturing processes & machinery
  - Conductor winding / foil winding machine
  - Core building / winding machine
  - Testing set-up
- Money – Capital investment & working capital

9

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Design options for efficient transformers (1/2)

Loss reduction intervention		Effect on No Load Loss	Effect on Load Loss	Effect on material cost
Decrease No Load Loss	Use lower-loss CRGO material	Lower	No change*	Higher
	Decrease flux density by Increasing core Cross section area of core	Lower	Higher	Higher
	Decrease flux density by decreasing volts/turn	Lower	Higher	Higher
	Decrease flux path length by decreasing conductor Cross-section Area	Lower	Higher	Lower

* Amorphous core materials would result in higher load losses because flux density drops, requiring a larger core volume.

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Design options for efficient transformers (2/2)

Loss reduction intervention		Effect on No Load Loss	Effect on Load Loss	Effect on material cost
Decrease Load Loss	Use lower-loss conductor material	No change	Lower	Higher
	Decrease current density by increasing conductor cross-section area of core	Higher	Lower	Higher
	Decrease current path length by decreasing core cross-section area	Higher	Lower	Lower
	Decrease current path length by increasing volts/turn	Higher	Lower	Higher

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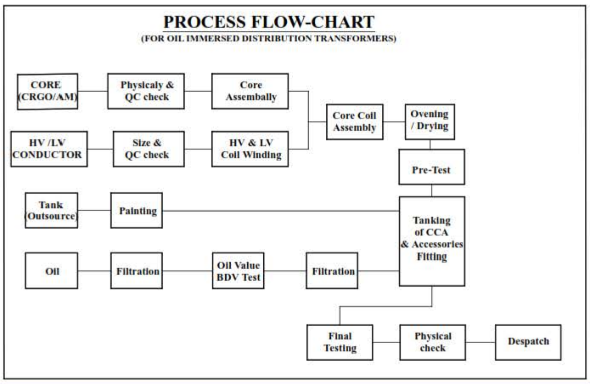
Manufacturing Process - Oil filled Transformer



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Major materials / Manufacturing Process

The magnetic circuit of transformer, core provides a low reluctance flux path for the transformer to function. Generally, it is made of CRGO (Cold Rolled Grain oriented) steel sheets of high permeability & small thickness coated with high temperature materials (Carlite or equivalent) to reduce eddy current losses and hysteresis losses. Their carbon content is maintained below 0.1%. Eddy current is further reduced by alloying the steel with Silicon.

Another material used for transformer core is Amorphous metal, which is a non-crystalline substance formed as ribbons. And has a superior magnetic properties. Also being very thin as compared to CRGO Sheets, the eddy current Losses also are very low. However, the saturation flux density is low as compared to CRGO silicon steel. And so is the case with mechanical strength against jerks during assembly & handling being softer than CRGO.

Various Cross-sections circular / rectangular, Core type / Shell Type may be opted depending on design.

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Core – Cold Roller Grain Oriented Silicon steel

- Manufactured by a few steel mills across the world
- Specialized material

Typical Losses of Various CRGO Core Grades

Grade of CRGO	Thickness in mm	Watts/Kg (1.7T 50Hz)
23ZDKH (or Equi)	0.23	0.85
23M0-H (or Equi)	0.23	0.9
23M0-H (or Equi)	0.23	0.95
23M0-H (or Equi)	0.23	1
M3 (or Equi)	0.23	1.1
27ZDKH (or Equi)	0.27	0.95
27M0-H (or Equi)	0.27	1

- Superior Grades of CRGO are now available with Losses upto 0.80, 0.75, 0.70 Watts/Kg at 1.7 T.
- Losses with Amorphous Alloy at 1.5 Tesla 50 Hz are as low as 0.325 Watts/Kg(Approx.)

However, its saturation Flux density is low as compared to CRGO & normally the designs never go beyond 1.38 to 1.4 Tesla for Amorphous core transformers. Hence higher load losses.

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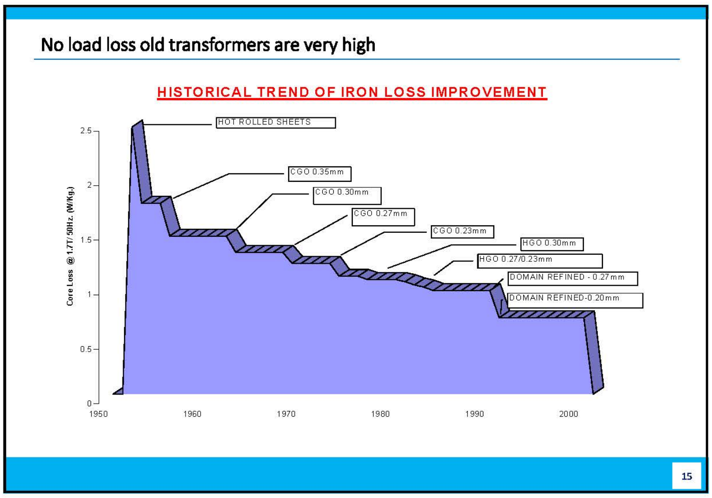
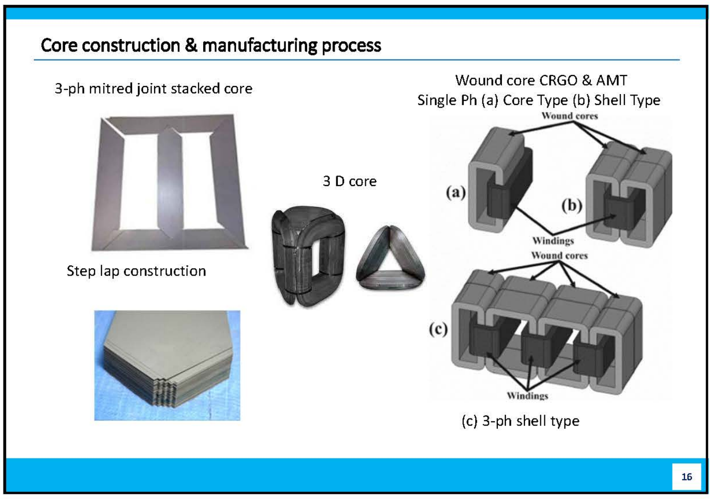

No load loss old transformers are very high
HISTORICAL TREND OF IRON LOSS IMPROVEMENT
HOT ROLLED SHEETS
CGO 0.35mm
CGO 0.30mm
CGO 0.27mm
CGO 0.23mm
HGO 0.30mm
HGO 0.27/0.23mm
DOMAIN REFINED - 0.27mm
DOMAIN REFINED-0.20mm
Core Loss @ 1.7T/ 50Hz. (W/Kg.)
0
0.5
1
1.5
2
2.5
1950
1960
1970
1980
1990
2000
15

15


Core construction & manufacturing process
3-ph mitred joint stacked core
Step lap construction
3 D core
Wound core CRGO & AMT
Single Ph (a) Core Type (b) Shell Type
Wound cores
(a)
(b)
Windings
Wound cores
(c)
Windings
(c) 3-ph shell type
16

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Automation

17

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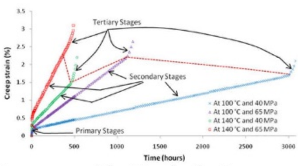
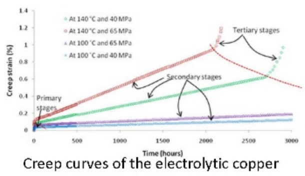
Conducting material

Properties	*Unit*	Aluminium (Al)	Copper (Cu)
Density	g/cm^3	2.70	8.94
Resistance	(Ωmm^2/m)x10^2	2.66	1.68
Thermal conductivity	cal/cm^2/cm°Cs	0.52	0.92
Thermal coefficient of linear expansion	(mm/mm°C)x10^{-6}	24.00	16.70
Melting temperature	°C	660.00	1083.00
Tensile strength	N/mm^2	91.50	220.50
Elongation	%	30.10	36.67
Hardness	HV	57.98	106.90



Creep curves of the EC grade Aluminum HV winding conductors



Creep curves of the electrolytic copper HV winding conductors

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Conductor windings

Distribution Windings are made of high grade electrolytic copper or aluminium, which are designed to optimize thermal, mechanical and electrical stresses. The winding machines are equipped with different speed gears to ensure that proper tension is maintained on the windings. The conductors are suitably transposed at intervals to reduce the circulating current losses in winding. Axial & Radial wedges and dove-tailed / T-spacers are provided as cooling ducts as per the design.

Using single / multiple winding conductors as per current & voltage Ratings, Different winding types are used in transformers, Such As :

- Spiral / Layer Type winding
- Helical winding
- Cross-over winding
- Continuous Disc winding
- Foil winding

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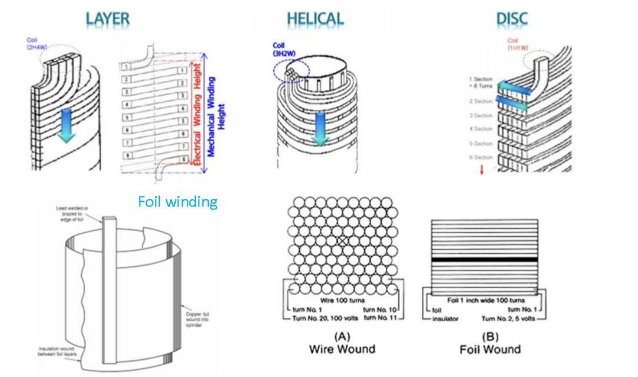
Winding types



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LV Foil winding

LV Foil winding:

- It uses a single piece of thin strip as conductor. Width of the foil is equal to length of the winding.
- This conductor strip (foil) wound along with a pre-impregnated interlayer insulation. During curing process foil and insulation are bonded together to form a rigid block. The LV coil becomes self supporting against forces.
- Later the coil is impregnated with resin for environmental protection.
- Eddy losses in the thin foil are very less compared to thick rectangular wires,so windings made with foil are cooler than other types.
- Foil winding minimizes the axial forces during short circuit , since currents in the winding are adjusted to the ampere turns in the high voltage winding.
- Is simple introduce cooling duct without decreasing the mechanical strength.
- It is easy and quick to manufacture this type of winding.

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Manufacturing – Core Coil Assembly (CCA)

The construction of the Core & Coil Assembly is significant from the performance point of the transformer. The CCA defines the insulation scheme, cooling, dynamic withstand capability, handling. The construction of the CCA by providing sufficient radial and axial supports prevents the stress from causing any damage to the windings. Clamping of the windings axially is necessary to hold the assembly firmly. Clamping structure of the assembly has supports to route the tap and line terminals. Insulated vertical and horizontal strips of adequate thickness of a frame work to assist the routing of terminals.

Insulation scheme is categorized into major and minor insulation. Major insulation addresses the capability to withstand high voltages, isolation of the primary and secondary winding, clearances for voltage withstand. Minor insulation is the turn insulation, joint protection etc. Both the major and minor insulation are equally important for the successful operation of the transformer. The Thermal class of insulation depends on the Type of cooling medium.

22

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Manufacturing – Core Coil Assembly (CCA)

3 D Core Coil Wining machine

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Drying

Significant part of the insulation used in oil immersed transformer is paper and wood based. This insulation material has high affinity to moisture which may weaken the insulation properties and reduce the insulation resistance to high voltages. It

For the above reasons, transformer windings & Core Coil Assembly undergo drying process at various stages depending on the rating and voltage class.

There are two types of drying: Air drying and Vacuum drying. Air drying is used in distribution transformers limited to voltage class below 33 KV, while Vacuum drying is predominantly used for all transformers of voltage class above 33 KV.

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Tank & radiators

The Transformer enclosure is generally referred to as tank. This is a fabricated structure constructed of mild steel of adequate thickness & generally rectangular shaped. The tank has two main functions:

i) To hold the CCA with proper clearances for voltage and oil flow.

ii) To facilitate cooling, safety and maintenance.

The tank must be leak proof, and should withstand the specified pressure during all service as well as test conditions.

Depending on heat dissipation requirements to keep the specified temperature rise requirements in test conditions & service, the transformer tank wall either has corrugations or is fitted with pressed steel fin type radiator banks.

Corrugated tank

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Final assembly & fitting

After drying process, the CCA is inserted into the transformer tank. The CCA should stand freely inside the tank & inside clearances are to be maintained. . The primary and the secondary terminations are brought out through porcelain or epoxy cast bushing insulation.

Off circuit Tap Switch or OLTC connections are to be secured tightly & separated.

Handling, jacking facility to lift the transformer or jack it for fixing detachable rollers is normally provided. The transformer tank is also fitted with valves for oil filling, filtration, oil sampling, draining. Provision for safety devices like Buchholz relay, pressure relief valve, temperature recording and control instruments, neutral current transformer, protection and instrument transformer are customized features as per buyer's requirement. In non-sealed transformers, conservator is provided for oil expansion and contraction during the operating cycle. For sealed type transformers DGPT Relay also is sometimes provided for protection. Terminal identification /marking are also done on/near the bushings.

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Transformer oil (Mineral PCB free)

Table 1 – General specifications, Type A (fully inhibited high-grade oils)

Property	Test method	Limits	
		Transformer oil	Low-temperature switchgear oils
1 – Function			
Viscosity at 40 °C	ISO 3104 a or ASTM D7042	Max. 12 mm^2/s	Max. 3,5 mm^2/s
Viscosity at –30 °C [b]	ISO 3104 a or ASTM D7042	Max. 1800 mm^2/s	–
Viscosity at –40 °C [c]	IEC 61868	–	Max. 400 mm^2/s
Pour point	ISO 3016	Max. – 40 °C	Max. – 60 °C
Water content	IEC 60814	Max. 30 mg/kg [d] / 40 mg/kg [e]	
Breakdown voltage	IEC 60156	Min. 30 kV / 70 kV [f]	
Density at 20 °C	ISO 12185 a or ISO 3675 or ASTM D7042	Max. 895 kg/m^3	
DDF at 90 °C	IEC 60247 a or IEC 61620	Max. 0,005	
Flash point	ISO 2719	Min. 135 °C	Min. 100 °C

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K Class liquid (Natural Ester)

FR3 fluid Acceptance Limits

	Standard test methods		ASTM D6871/IEEE C57.147	IEC 62770	FR3 fluid
PROPERTY	**ASTM**	**ISO/IEC**	**As-received new fluid property requirements**	**Unused new fluid property requirements**	**TYPICAL**
Physical					
Color	D1500	ISO 2211	≤1.0	–	0.5
Flash Point PMCC (°C)	D93	ISO 2719	–	≥250	260-270
Flash Point COC (°C)	D92	ISO 2592	≥275	–	320-330
Fire Point (°C)	D92	ISO 2592	≥300	>300	350-360
Pour Point (°C)	D97	ISO 3016	<-10	≤-10	-18 to -21
Density at 20°C (g/cm^3)	–	ISO 3675	–	≤1.0	0.92
Relative Density (Specific Gravity) 15°C	D1298	–	≤0.96	–	0.92
Viscosity (mm^2/sec)	D445	ISO 3104			
100°C			≤15	≤15	7.7 - 8.3
40°C			≤50	≤50	32 - 34
0°C			≤500	–	190
-20°C					650*
Visual Examination	D1524	IEC 62770 4.2.1	bright and clear	clear, free from sediment and suspended matter	clear, light green
Biodegradation	OECD 301B		readily biodegradable	readily biodegradable	readily biodegradable
Aquatic and Oral Acute Toxicity	OECD 202, 203, OECD 420		non-toxic	non-toxic	non-toxic
Electrical					
Dielectric Breakdown (kV)	D877	–	≥30	–	>45
Dielectric Breakdown (kV)					
1mm gap	D1816	–	≥20	–	>25
2mm gap	D1816	–	≥35	–	>50
2.5mm gap	–	IEC 60156	–	≥35	>55
Dielectric Breakdown under Impulse (kV) 25.4mm gap	D3300		>130		140
Gassing Tendency (µl/min)	D2300	–	≤0	–	-79
Dissipation Factor					
25°C (%)	D924	–	≤0.20	–	0.010 - 0.15
90°C (tan δ)	–	IEC 60247	–	≤0.05	0.01 - 0.03
100°C (%)	D924	–	≤4.0	–	1.00 - 3.85

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Manufacturing process

TRANSFORMER OIL:

Transformer oil acts as cooling & insulating medium in a transformer. Generally, mineral oil as per ISC-60296 is used. Oil is filtered under vacuum before filling into the transformer. In recent times, due to Health safety & Environmental concerns ester (synthetic as well as natural) oils are also being used in distribution transformers.

PAINTING :

Before Use, All fabricated steel tanks internally & externally cleaned thoroughly of all scales etc. For interior walls, anti-corrosive paint like Zinc chromate with excellent chemical resistance is used. For Exteriors, two coats of glossy, oil & weather resisting, non fading Epoxy paint is generally applied.

TESTING & DISPATCH :

Apart from in process checks as per QC plan, All routine tests as per IEC 60076 on each transformer are carried out. Type Tests and special tests forming part of acceptance tests as per customer requirement are also carried out.

Inspection before dispatch is required to ensure that the transformers are fitted with all accessories as per customer specification etc. The transformers need to be secured / locked against any possible damage/ defect during transportation to the consignee's storage area of installation site.

INSTRUCTION MANUAL:

An instruction manual containing, the guidelines for unloading, handling, storage, installation, commissioning, periodic diagnostics & maintenance etc is also provided.

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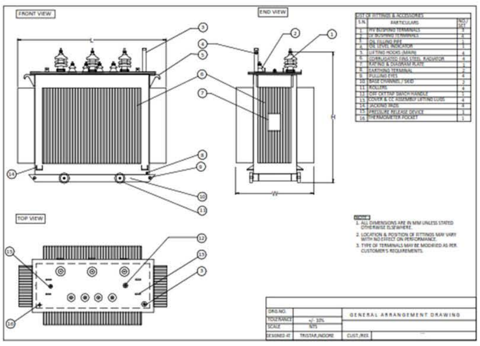
Documentation - General arrangement drawing



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List of plant machinery (1/3)

LIST OF ESSENTIAL PLANT & MACHINERY

(FOR MANUFACTURING OIL IMMERSED DISTRIBUTION TRANSFORMERS UPTO 2500 KVA)

S.No.	Description
1	Core Assembly Section
a	Core Assembly Tables / Platforms
b	Core lifting / Handling Fixures
c	Mandrals etc
2	Winding Section
a	Layer / Spiral / Disc Type Coil Winding Machines for LV Coil (can also wind HV coil over LV) - Circular Coils
b	Foil Winding Machines for LV Coil (can also wind HV coil over LV) - Circular Coils
c	Cross-over Type HV Coil winding Machines -Circular Coils
d	Rectangular Coil winding machines
e	Decoilers / Conductor Feeding Stands, Tenstioners etc
f	Adjustable winding formers
g	Coil Pressing Jigs & Fixures

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List of plant machinery 2/3

LIST OF ESSENTIAL PLANT & MACHINERY

(FOR MANUFACTURING OIL IMMERSED DISTRIBUTION TRANSFORMERS UPTO 2500 KVA)

S.No.	Description
3	Insulation Cutting Section
a	Paper Insulation Cutting / Sheering Machines
b	Spacer / Block puncing press machines
c	Multi Purpose Wood working & Sawing Machines
4	Core-Coil Assembly & Proceesing Section
a	Core-Coil Assembly Platforms / Tables / Floor space
b	Trolleys etc handling equipments
c	Air Drying Oven
d	Vacuum Oven (Optional)
e	Tools & Fixures, Workstations etc

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List of plant machinery (3/3)

LIST OF ESSENTIAL PLANT & MACHINERY

(FOR MANUFACTURING OIL IMMERSED DISTRIBUTION TRANSFORMERS UPTO 2500 KVA)

S.No.	Description
5	Tank Assembly Section & others (common)
a	EOT Crane/s
b	Trolleys, Fork lift etc handling equipments
c	Tools & Fixures, Workstations etc
d	High Vacuum Oil Filter Plant & pipelines
e	Oil Storage Tanks
f	Compressors, vacuum pumps etc
g	Painting booth with dust free environment

Any other Extra Machinery may also be installed depending on plant capacity & level of automation as feasible.

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Quality assurance - Testing equipment (1/2)

LIST OF ESSENTIAL TEST EQUIPMENTS

(FOR TESTING OIL IMMERSED DISTRIBUTION TRANSFORMERS UPTO 2500 KVA)

S.No.	Description
1	Electrical Tests (In Process / Final)
a	Winding Resistance meters
b	Turn ratio & Polarity test meters
c	Insulation Resistance Testers
d	Multimeters/ Clamp Testers
e	Oil BDV Test Kit
f	Portable HV tester
2	Mechanical Tests (In Process / Final)
a	Dimensional Check - Micrometers & verniers, Scales etc
b	Pressure Test kit with gauges
c	Vacuum Test kit with gauges
d	Paint Thickness Gauge

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Quality assurance - Testing equipment (2/2)

LIST OF ESSENTIAL TEST EQUIPMENTS

(FOR TESTING OIL IMMERSED DISTRIBUTION TRANSFORMERS UPTO 2500 KVA)

S.No.	Description
3	Final Testing before Dispatch (Additional to the above)
a	Power supply Source / Generator
b	Three Phase Variac / Regulator
c	Intermediate Testing Transformers (For Load tests/ Temperature Rise Test etc)
d	High Voltage Testing Transformer (For Separate Source high Voltage Test)
e	Double/Tripple Frequency Generator (For Induced Overvoltage Test)
f	High Accuracy Three Phase Power Analyser
g	Multiple Range CTs & PTs with high accuracy
h	Noise Level (dB) Meter
i	Thermometers / Multichannel Temperature Indicators
j	Integrated or classified Transformer Test Bench comprising of Indicators, Protection & Controls for various Tests
k	Tan Delta & Resistivity Test kit (Optional)

Any other Extra Test Equipment may also be installed depending on plant capacity as feasible.

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