ASIA POWER QUALITY INITIATIVE

International Copper Association India
Copper Alliance

Buyer's Guide for TRANSFORMER

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Copper Alliance

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Foreword

GBCI INDIA

August 29, 2022

At COP 26, our Honourable Prime Minister unveiled a "5 fold" strategy termed as Panchamrita to get to net zero emissions by 2070. This shall be achieved through a 5-pronged strategy, including, ramping up renewable energy production and mix in grid, improving energy efficiency and reducing energy and emission intensity. Reducing energy intensity shall require efficiency enhancements and loss minimization in several aspects of energy and electrical systems and Transformers form a critical part of this ecosystem. Transformer, like the human heart, is vital for keeping the 'Lights and Process on' and enable the smooth functioning of any facility, be it industry or building. Several techno-economic factors are considered before making the final decision on using an appropriate type of transformer, such operational parameters, capital and maintenance expenditure, and many more. The capital cost being significant, a lot of analysis is needed to select an appropriate transformer.

Considering the footprint that a building leaves on environment, the Government of India, through its apex body, BEE, has setup high performance standards through ECBC that covers transformers, among other systems and equipment. 'Net Zero' buildings today are more of an imperative than a choice, if we want to leave this world a better place for our future generations. Earlier, conventional mineral oil-immersed transformers were prevalent, in the buildings since outdoor space was never a constraint. But in an urban set up this is considered as unsafe due to the use of mineral insulating oil that has lower fire point temperature and is non-biodegradable.

Due to this, more and more buildings teams select dry type transformers, which are relatively safe from a fire hazard point of view. However, from an energy efficiency perspective, they cannot match sustained energy performance of mineral oil filled transformers. New technology like natural and synthetic ester-oil immersed type Transformers, despite more than three decades of successful global experience; are seldomly installed in India due to lack of awareness, perceived high first cost sensitivity, and user experience. These are not only non-hazardous with high fire point temperature but are also environment friendly.

In this guidebook on Transformer selection, we have tried to bring forward the pros and cons of each type of transformers. The checklist at the end of the book will help in ticking all the right boxes, before making the right choices. As transformers have more than 25 years of declared technical life it would be prudent to consider an environment-friendly and energy efficient transformer.

I am confident that this guidebook, shall help in enabling a well-informed choice.

Mili Majumdar

Mili Majumdar
Managing Director, GBCI India
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Message

I am indeed very pleased to go through this User Guide on Selection of Distribution Transformers being brought out by International Copper Association of India.

Customers today have quite a wide choice for buying distribution transformers; not only of various makes but also of various types such as traditional Mineral-Oil-Cooled or Dry-Type or the latest entry of Ester-Oil-Cooled transformers. Again there are few variations in each sub category including the choice of copper and aluminium winding.

With such numerous varieties comes the difficulty of choosing the right product. Transformer is the heart of any large building or any industrial plant that supplies the required electrical energy. A big addition to the existing users, is the new breed of hyper scale data centres being developed in India. Each of such large data centres consumes about 30 to 50 MW of power, thereby requiring much larger quantity of power and distribution transformers. It is also long life capital-intensive equipment that the owner makes a choice about.

Today being climate responsible and adopting visionary approach towards sustainability is an imperative for the buildings and the facility owners. But often they lack unbiased information and in-depth knowledge in the matter of choosing the right product at the beginning itself. It is therefore vital to consider cost-effective measures that could reduce losses in the transformer and alleviate these environmental impacts.

International Copper Association India, a member of Copper Alliance® and the Indian arm of the International Copper Association Limited, has been taking lead for spreading general awareness on the benefits of use of the energy efficient distribution transformer appropriate to the specific application.

I am sure that this buyer's guide, in easy to understand language would be immensely helpful for various stakeholders to make an informed choice for most capital intensive electrical asset in their premises.

N K Jain
Founder, N K Jain Consulting Engineers

Message

Transformer is a "Must" component of any medium to large electrical distribution system, may it be system installed by utility or consumer. This note is a very comprehensive collection of related information, which can prove to be a good guide for selection of type of the transformer from available options.

For utilities cost of transformer forms major part of the project, however recurring cost of losses is also major part of their operating expenses.

For industrial or commercial projects, cost of entire "Electrical system" is not even 6 to 7% of the total project cost, so judicious extra spent on energy efficient products does not leave major impact on project cost. Saving 1KW of transformer loss for 24 x 7 working saves almost Rs.70000 per year at today's average tariff.

This note also throws light on all other impacts on "sustainability" up to and after end of transformer life by selecting different types of transformers. All arguments related to "pros and cons" for each type are backed up with relevant data and convincing graphical representations of various parameters. At the end possible improvements in regulatory targets are also suggested as improved figures are already practiced in the industry.

Transformers usually have higher lead times for procurement and are "Single point of failure" in many systems. Transformer failures can prove to be quite dangerous and disastrous for human as well as property. The note discusses safety aspect of all three transformer types namely Dry type, Liquid filled Mineral oil type and liquid filled ester oil type.

Overall, this is a very well complied – unbiased guidance for transformer selection for any application. As it avoids electrical technicalities while advising rationally on selecting type of transformer, it is a useful tool and "Must Read" material for project owners and project managers.

Narendra Duvedi
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Acknowledgement

We are thankful to the following experts for their valuable suggestions for adding value to this guidebook

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Mr. N. K. Jain holds a Bachelor's Degree in Electrical Engineering from BITS, Pilani (1972) and Master's Degree from IIT, Mumbai (1973). He is a Life Member of Indian Nuclear Society and Fellow Life Member of Consulting Electrical Engineers Association of Maharastra, India (CEEMA). He has professional work experience of more than 49 years in design, installation, testing and commissioning of MEP services for industrial, commercial and IT facilities. He is running his own design consultancy firm by the name of N. K. Jain Consulting Engineers in Mumbai and has successfully designed and executed more than 500 projects comprising various types of IT facilities. Presently he is working as Lead Engineering Consultant to many hyper scale Co-Lo Data Centers and guiding a team of design engineers from concept to commissioning.

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Narendra Duvedi is a BEE Certified Energy Auditor, and Chartered Engineer. Currently he is the Executive Director of SAS POWERTECH Pvt. Ltd. Pune. He has served as thr President of Consulting Electrical Engineers Association of Maharashtra. He has been a syllabus adviser and member of the governing council of Pune University and various autonomous Institutes. He is particularly recognised for expertise in Energy Audits of large Industries and commercial establishments. He is also an expert in due diligence audits for Asset Transfers to validate electrical and other utility equipment. He has worked extensively across various markets including India and Israel, China, Germany, USA, Dubai, Abu Dhabi, Bahrain, Vietnam.

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About The Guide Book: (Background)

International Copper Association India, a member of Copper Alliance® and the Indian arm of the International Copper Association Limited, publishes technical handbooks, application guides, information booklets and brochures aimed at knowledge sharing and building capacity of users in understanding the benefits of use of specific type of electrical apparatus to achieve the objective of energy efficiency, power quality, electrical safety, and environmental sustainability. The Idea is to create 'an informed customer', while she/he makes the choice.

Technology has been the main driving force behind economic development all over the world. However now-a-days, there are concerns about achieving economic growth at the expense of environmental sustainability. When designing a machine, it is essential to ensure that technical aspects are met without adversely impacting the environment. Electrical industry is also playing its part in sustainable development by introducing “green alternatives” which, not only comply with environmental constraints, but also have better properties to offer.

The transformers, though the costliest equipment in the electrical system network, are indispensable for the power distribution in industrial, residential, commercial, agriculture, healthcare, mass transportation, etc... segments. After distribution lines, the distribution transformers are the second largest contributors to the losses in electric power distribution networks.

In India, since number of distribution transformers is very large, there are many untapped opportunities, which would contribute to vital issue of environmental protection by way of electrical energy conservation. Besides increasing the safety of the electrical installation by encouraging the use of appropriate type of distribution transformers is part of sustainable practice. However, the market forces are not always aligned in achieving this important national objective of reducing energy intensity or quick adaptation of techniques for climate risk mitigation.

Real estate sector, comprising residential and commercial building, has been main stay of economic activity in India for past few years and is expected to fuel growth in next two decades. At present, many users prefer installation of dry-type distribution transformers, seemingly maintenance free and fire safe, specifically in residential complexes, commercial complexes and healthcare facilities without proper consideration of its merits and demerits. There is a need to educate users and decision makers on various aspects of distribution transformers available in the market today, which will significantly impact on selection process, procurement and application strategies.

This Guidebook is intended for providing users the well-researched technical information and assisting in a balanced manner for selecting these transformers to suit their specific application need.

Improving the energy efficiency is the fastest, surest, cheapest and cleanest way to provide reliable power to sustain the economic activities.

1 Need for Application Oriented Approach

India is witnessing large scale development in Real Estate (High Rise Buildings), Commercial, Healthcare, Institutional and Mass Rapid Transportation (Metro Rail, Airports, etc...) sectors. Electric power distribution network is an essential support for sustaining the process of development in these sectors, and simultaneously, the growth of distribution transformer market runs hand in hand with this development.

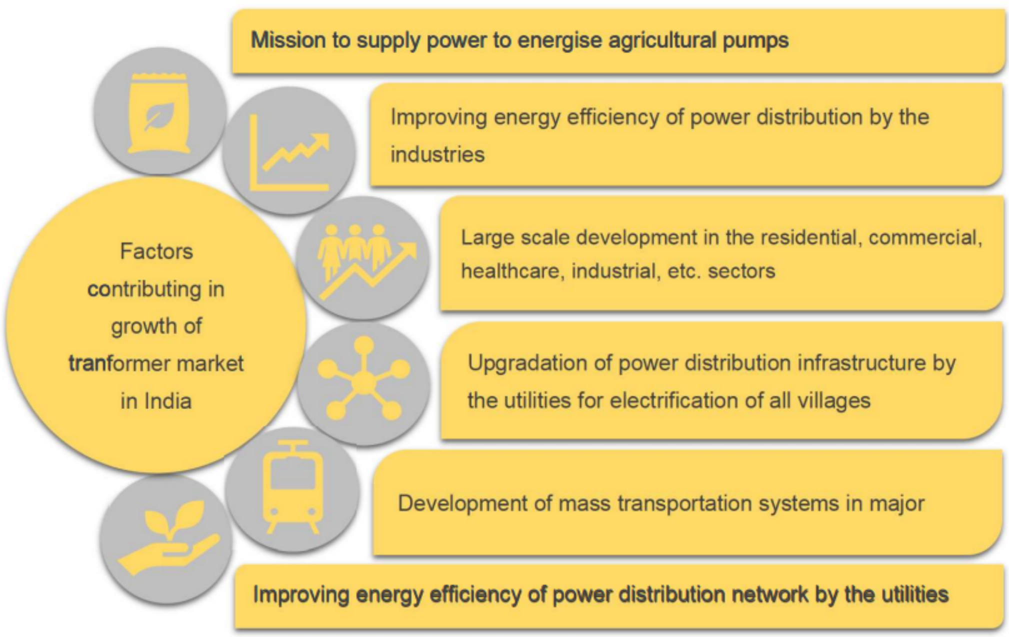


Fig. 1.1 Factors contributing to growth of transformer market

Today, Indian Transformer manufacturers are not only catering to the Indian markets, but around 25% of their production is exported to the other countries. There are sustainability related regulations being enforced in the European Union and other developed nations. These markets insist on eco-friendly design and promotion of circular economy; such concepts need to be adopted by more and more Indian manufacturers for credible presence in international markets.

In India, for maximizing available space on ground, the developers and builders, Architects, and MEP consultants, prefer to create a space for the installation of distribution transformers in the basement; instead of providing it at ground floor level or outdoor in the plot. In the urban areas, the Utility distribution is being preferred at an underground level, thus, service cables are laid instead of conventional overhead service lines from double pole structure and oil-immersed transformer installed at the consumers' premises. The installation of liquid-immersed transformers in the indoor areas, like basement, has been considered unsafe and hence is not permitted by the statutory safety regulations. However, stakeholders are not fully aware of other developments both in terms of technology and local regulations. Therefore, an available option remains of installing the dry-type transformers in the basement as they are allowed by Central Electricity Authority (Measures relating to Safety and Electric Supply) Regulations - 2010, National Building Code, 2016 and local regulations formulated by local bodies such as municipal corporations. as shown in Fig. 1.2.

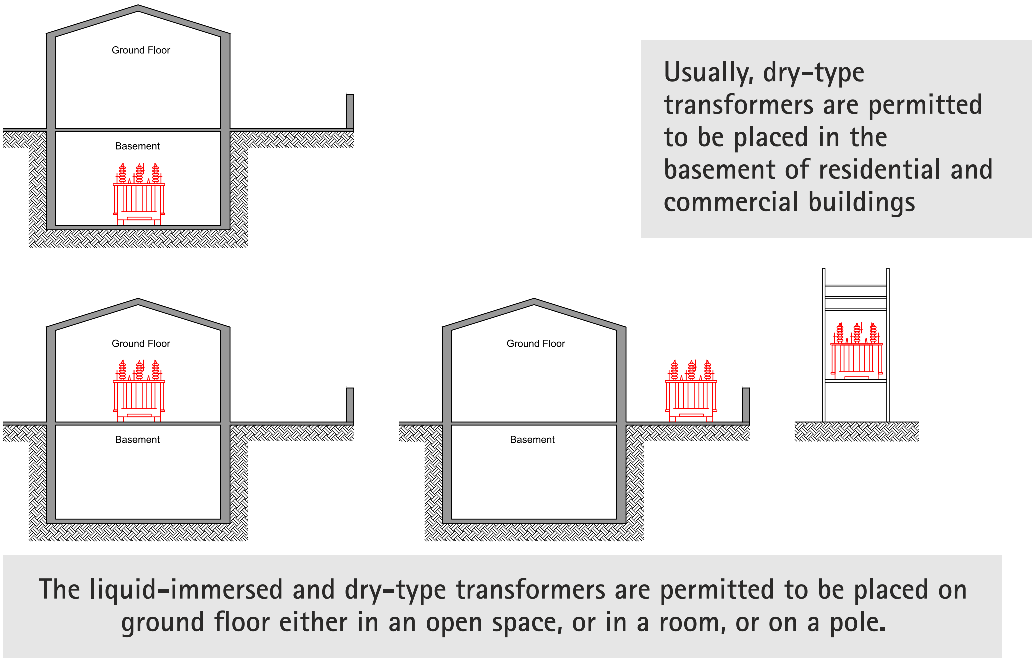


Fig. 1.2 Locations for installation of distribution transformers

In Maharashtra, the Chief Electrical Inspector, vide his communication ref: CEI/Tech/347/2018 dated 29/08/2018, has permitted installation of dry type transformers or transformers filled with insulating materials and qualifying under IS:16081-2013, IS:16099-2013 and IS:13503-2013 or sealed transformers filled with insulating liquids qualifying under IS:16659:2017 inside residential and commercial buildings with compliance to provisions made in IS:1646-2015 (reaffirmed 2020) - Code of Practice for Fire Safety of Buildings – General: Electrical Installations).In 2021, BIS published IS:1180 (Part 3) 'Outdoor/Indoor Type Liquid Immersed Distribution Transformers up to and including 2500 kVA, 33kV Specification – natural / synthetic organic ester liquid-immersed'. The other states need to take a cue from it and permit ester oil-filled transformers for the installation and use inside the indoor environment of residential and commercial buildings.

In India, two main types of distribution transformers, viz. liquid-immersed and dry-type, are mostly installed for different applications in the residential, commercial and healthcare facilities. The transformers are the most efficient electrical machines ever designed by man and expected to be reliable too with long technical life of over 30-40 years, being a static device.

The reliability of liquid-immersed transformers depends upon its complex three-dimensional insulation structure comprising of paper and pressboard wrapped around the winding conductors immersed in an insulating liquid. At present, mineral insulating oil has predominantly been used in liquid-immersed transformers since long. Since last two decades, natural and synthetic ester oils have also been used as the liquid insulating medium in the transformers due to their far better properties over mineral oils.

On the other hand, reliability of dry-type transformers depends upon type of insulation, viz. open wound, vacuum pressure impregnated; cast resin, applied over the winding conductors. In dry-type transformers, natural air or forced air is used as a cooling medium.

As conventional mineral oil-immersed transformers have been considered as unsafe due to use of fire-prone and non-biodegradable mineral insulating oil, the manufacturing techniques of distribution transformers are witnessing the shift from mineral oil-immersed units to other technologies, and besides dry-type, natural and synthetic ester-oil immersed type transformer units, that are non-hazardous and environment friendly, are gaining gradual acceptance in India too.

Though perceived to provide higher safety from electrical fire hazards point of view, the dry-type transformers provide lower efficiency as against liquid-immersed type. Dry type transformers, based on design adopted and experience from developed world, are environmentally hazardous due to grave problem of recycling or disposal upon completion of their useful life. Though in India the stock is low, but future growth would decide how much stock of dry-type would be embedded in the system adversely impacting landfill challenges and carbon footprint before such transition takes place at a usual slow pace of statutory regulatory intervention.

Now ester-oil immersed distribution transformers are also gradually finding favour for use in India. However, there are many mis-conceptions prevailing such as cost advantage, unsafe for indoor installation, difficult to maintain, etc..., which need to be clarified to the stakeholders.

Selecting an appropriate type of distribution transformer is vital for smooth functioning and safety of the facility. However, there are number of techno-economic factors to be considered before making the final decision on selection of appropriate type of transformer for the given project.

Operational requirements and constraints, maintenance and the lifetime costs of a transformer vary with every project. An investment in transformer is significant and hence, it is important to analyse the specific needs of a project to identify a type of transformer that best suits the needs.

In the European Union, there is growing awareness about sustainable manufacturing and useful life and end-of-life practices. And with "Circular Economy Action Plan" in place, emphasis is laid on both, energy efficiency and material efficiency for reducing environmental impact. This action plan aims to map the energy performance parameters as well as material efficiency parameters (which would measure recyclability potential and actual recycled contents of materials used in the product, without affecting technical performance parameters). So, the products can have dual nameplate approach for measuring its overall sustainable quotient. In future, products having same energy efficiency, but having improved efficiency would be labelled and preferred (by Users).

It is therefore, essential to provide understanding of all realities, like safety without compromise, market preparedness to offer energy efficient product, overall cost of ownership, disposal issues at end of useful life, environmental impact, reduced carbon footprint, sustainability and corporate responsibility towards climate change etc..., to all the stakeholders.

There is also an urgent need, as a part of our climate response, to enhance the efficiency of distribution transformers and adopt more "earth-friendly" options of insulations used in the transformer manufacturing. Continuous efforts are being made to use eco-friendly materials and reduce the energy losses with Star-labelling of distribution transformers by Bureau of Energy Efficiency (BEE). Energy Conservation and reduction of Carbon dioxide (CO2) emissions are in the spotlight for environmental sustainability.

2 Application Specific Distribution Transformer (Users' Preference)

The decision-making stakeholders for the installation of transformers are generally leading Electrical Engineering and MEP Consultants, Developers of Realty Schemes, Commercial Complexes, Healthcare Facilities, Institutions, users in Industries and Utilities. It is therefore, essential to know underlying reasons for preference of stakeholders towards choice of specific type of transformer/s and its basis and concerns, viz. space crunch, overall cost, statutory compliance, etc.

For compiling the data, the questionnaire containing specific questions was circulated among the concerned stakeholder. The replies were useful for understanding the stakeholder's preference for selecting specific type of transformer whether it is really a space crunch issue, or concern for the statutory compliance for electrical as well as environmental regulations, or only superficial level given lax enforcement of regulations, or finally the cost.

The findings of this desk analysis are used for preparing the recommendations for the techno-economic factors to be evaluated by the stakeholders and the procurement guidelines. All the concerns of the stakeholders are addressed individually with the support of technical clarifications and life-cycle cost analysis in a proper perspective.

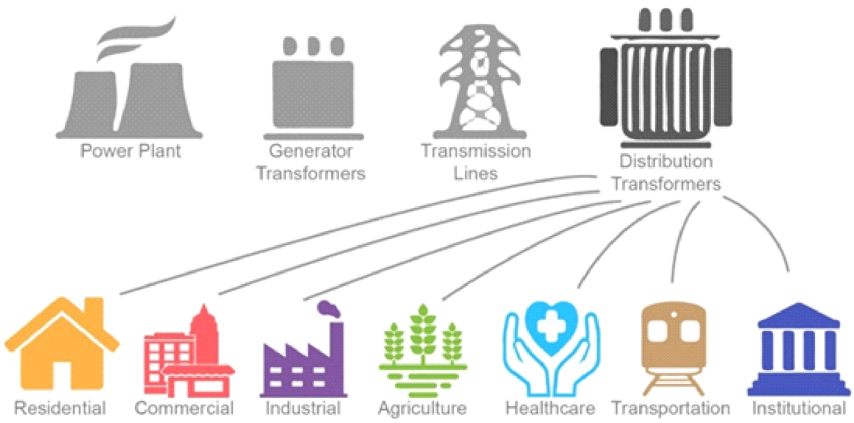


Fig 2.1 : Applications of Distribution Transformers

3 Distribution Transformers – Mineral-Oil Immersed, Dry-Type and Ester Oil-Immersed

Preamble:

In a long journey of almost 135 years in service to mankind, the transformers have grown in many aspects; technology, ratings, performance, eco-friendliness. In the beginning, air-cooled transformer had been used during 1886, followed by development of mineral oil-immersed transformers and ester oil-immersed transformers. This chapter describes the constructional features and their characteristics.

Types of Distribution Transformers and their Characteristics:

The types of distribution transformers and their sub-categories are as follows:

(i) Liquid-immersed type:

- Mineral oil-immersed
- Natural or synthetic ester oil-immersed

(ii) Dry-type:

- Open wound
- Vacuum pressure impregnated (VPI)
- Vacuum pressure encapsulated (VPE)
- Cast resin

(iii) Amorphous core type:

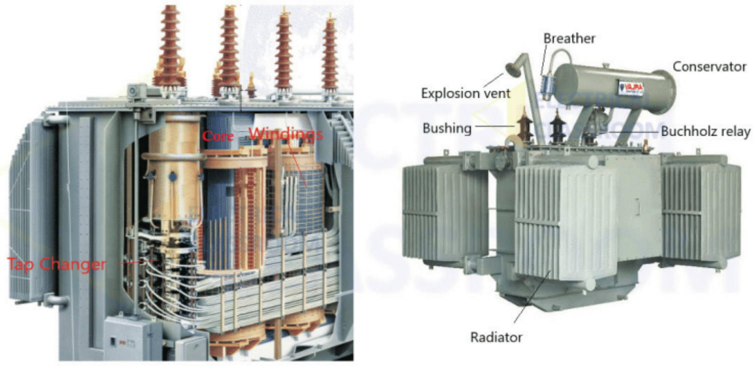
Common features of all types of transformers:

The transformers work on the fundamental principle of electromagnetic induction. The basic elements of transformers are the same and consist of magnetic core made of high permeability silicon steel laminations, high voltage (HV) and low voltage (LV) windings made of a copper or aluminium conductors. The windings are wrapped around the core and insulated with pressboard barriers and screens. The magnetic core provides a path for flow of magnetic flux, which is produced when voltage is applied to HV winding. Thickness of the winding insulation increases with voltage. Incoming and outgoing power supplies are connected to the respective winding via bushings.

Mineral Oil-immersed Transformers:

Population of mineral oil-immersed distribution transformers is largest due to mature and proven technology, and classical optimum efficiency, usually at around 50% load. Now-a-days transformers are also designed to deliver highest efficiency at higher loading say 75% for better asset utilisation.

The main tank of transformer, containing the core and winding assembly, is filled with mineral insulating oil. Besides providing vital insulation, the mineral oil also works as a cooling medium and diagnostic tool to monitor the health of the transformer. The solid insulation and mineral oil form an inseparable insulation system in the transformer. The reliability of liquid-immersed transformers depends upon its complex three-dimensional insulation structure comprising of kraft paper and pressboard wrapped around the winding conductors immersed in mineral insulating oil.



3.1 Liquid-immersed transformer – Outer and cutaway view

These transformers are more efficient than dry-types, and they usually have a longer life expectancy with proper maintenance and handling. Also, the oil is a more efficient cooling medium in reducing the hot spot temperatures in the winding and hence provides a better overload capability.

As for demerits, the mineral-oil is fire-prone and unsafe due to low flash point, as such adequate fire prevention measures, such as a containment trough for protection against possible leaks of the oil, are required to be implemented. It is even possible for an incorrectly protected transformer to explode.

The mineral oil is not eco-friendly and is also hazardous for the human beings, as it does not biologically degrade or disintegrate, and produces hazardous waste and hence cannot be disposed of easily without affecting the environment. It is a long-term pollutant for the environment.

The mineral oil, being highly hygroscopic medium, readily absorbs moisture from the air, which causes deterioration of its vital dielectric strength depending on proportion of moisture absorbed. If moisture content in kraft paper insulation doubles, transformer life expectancy is immediately halved. The World Health Organisation has classified the mineral oil used earlier under carcinogenic substance.

Installation of mineral-oil immersed transformers has not been permitted in the basement of any residential and commercial building by the statutory regulations late 1997 onwards.

Last but not least, the mineral oil is a by-product of crude oil refining process, and hence its availability will be difficult in near future due to depleted sources of basic natural petroleum, viz. crude oil, as this natural resource cannot be replenished. In order to prolong the availability of this non-replaceable natural source, rigorous research is in place to increase the efficiency of equipment, system, etc. in which different petroleum products are utilised.

Ester Oil-immersed Transformers:

Continuous research, going on for more than two decades, has led to the development of eco-efficient distribution transformers using natural ester oils (vegetable oil based) and synthetic organic ester oils, as an insulating liquid.

The constructional features of ester oil-immersed transformers are similar to the mineral oil-immersed units, as shown in Fig. 3.1.

Use of ester oils have found worldwide acceptance for their good "eco-friendly", "fire safe", "recyclable" and "bio-degradable" credentials. Ester oils are compatible with the existing mineral oil technology in terms of better dielectric properties, physio-chemical properties and thermal performance for use in the transformers. Natural Ester oils are biodegradable and easily disposable, and non-toxic, when exposed to the surroundings, and hence very well addresses the concern for environment.

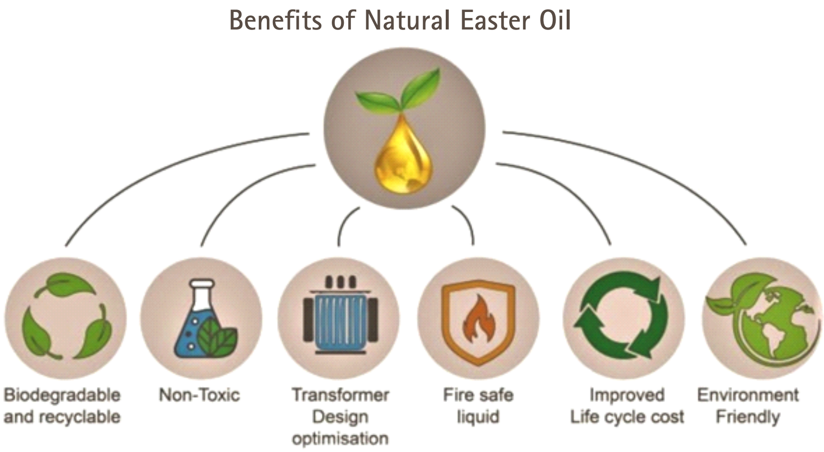


Fig. 3.2 Benefits of ester oil as insulating liquid

From fire safety perspective, the ester oils are safer than mineral oil, as they are classified as "K Class fire hazard" capable (fire temperature > 300 C) in IS:13503-2013/IEC 61039-2008. Need for fire-fighting measures is reduced for the ester oil-immersed transformers. Even if the transformer catches fire, it would extinguish soon due to low calorific value. Due to higher flash point, ester oil does not react heavily during any fault within the transformer. In absolute terms, total cost of damage resulting from ester oil-immersed distribution transformers is much lesser than that, from mineral oil transformers, considering the repair costs and damage to the surroundings. Data of flash point and fire point for mineral oil and ester oil, reproduced from referred standards, has been furnished under heading "Comparison of Characteristics of Insulating Liquids" (Ref. Table 3.1).

Dry-type (Non-liquid insulated and Air or Air/Gas Cooled):

Transformers with an air-cooling system are called dry-type transformers, available in the range of 500-2500 kVA. The dry-type transformers have been increasingly specified in India after enactment of regulations due to use of non-flammable winding insulation and uncertainty of availability of mineral insulting oils.

However, the dry-type transformers, generally available in the market presently, are less efficient as compared to the oil-immersed type transformers. Due to use of polyester resin based or cast resin insulating materials over the windings, the dry-type transformers are also not eco-friendly, as these resins are toxic, non-recyclable and non-biodegradable in nature.

The dry-type transformers are further divided into four sub-categories as follows as per the insulating material used and method of applying the insulation over the winding. These transformers are either installed in open or installed within ventilated steel enclosure. Method of cooling is either natural air circulation or fan forced air circulation through enclosure.

(i) Open wound:

This is a standard dry-type transformer, in which the winding is manufactured following a "dip-and-bake construction" method. In this method, the winding coils are preheated after applying initial insulation and then, when heated, are dipped in varnish at an elevated temperature. The coils are then baked in vacuum oven to cure the varnish.

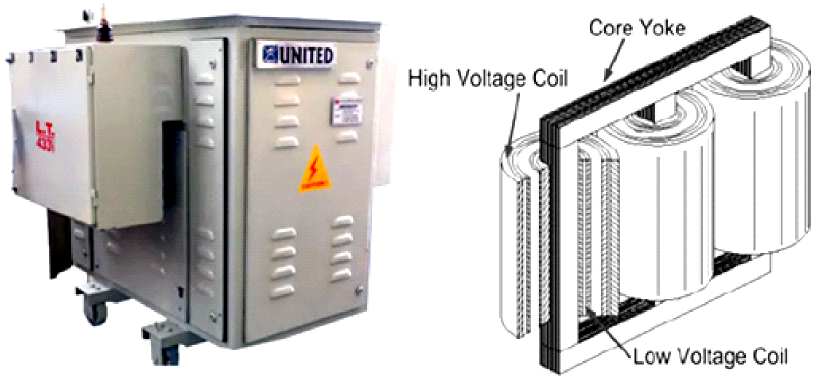


Fig. 3.3 Open wound dry-type in enclosure and cutaway view

These transformers are mostly used in residential and commercial complexes having moderate load and clean surroundings.

(ii) Vacuum pressure impregnated (VPI):

The VPI process uses polyester resin insulation, in which the varnish coating is applied to the winding in interchanging cycles of pressure and vacuum and then cured in an oven. This type of transformer is better than open wound transformer because the process includes pressure in addition to vacuum, which allows better penetration of the varnish in the winding. These units offer an increased resistance to corona and moisture ingress due to application of moisture-resistant polyester sealant over the winding. The materials used in VPI transformers can withstand high temperature.

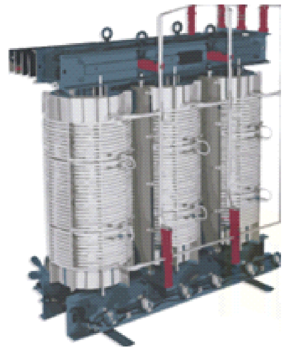


Fig. 3.4 VPI dry-type transformer (out of enclosure)

VPI dry-type transformers are commonly used for residential, commercial and industrial purposes.

(iii) Vacuum pressure encapsulated (VPE):

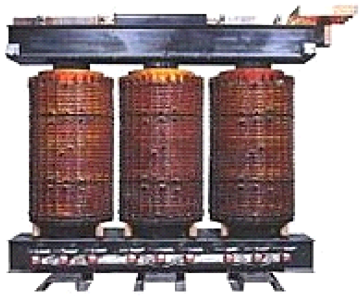


Fig. 3.5 VPE dry-type transformer (out of enclosure)

VPE transformers are comparable to VPI described above. After applying the varnish coating to the winding in interchanging cycles of pressure and vacuum and curing in an oven, a silicon-based resin is applied over the winding, which creates a thicker coating that is highly resistant to moisture and corrosive vapours, making it an excellent choice for harsher environments.

These types of transformers are preferred in the coastal areas and in the chemical industries, where the environment is susceptible to acids, chlorides and alkalis.

(iv) Cast resin (Moulded epoxy resin):

In this type of transformers, the winding coils are solidly cast in resin under a vacuum in a mould. The manufacturing process locks the windings in a strong epoxy resin with high dielectric strength, protecting the transformer from severe operating environments.

Fig. 3.6 Cast resin dry-type transformer in enclosure and out of enclosure

As the cast resin insulation is resistant to fire and reliable even in extreme weather, these transformers are preferred in the chemical industries with hazardous and corrosive processes, nuclear plants, mining facilities, on offshore platforms, and onboard ships.

As the dry-type transformers have low fire hazard characteristics, they are considered most suitable for installation in areas, where the power distribution system requires utmost safety.

These transformers require lesser maintenance in comparison to the liquid-immersed transformers in an ideal pollution free environment.

Due to more losses, typical full load efficiency of the dry-type transformers is around 95%. The operating cost or life-cycle cost of the dry-type transformers is in general higher than that of liquid-immersed units. The materials in open wound type transformer can be recycled. However, the materials in VPI and VPE are difficult to recycle because of their construction. As the entire winding of cast resin type is encapsulated in epoxy resin, the recycling is extremely difficult and uneconomical, and hence not preferred. Moreover, recycling or disposal of cast resin in every way is hazardous and disastrous to the environment and toxic. If buried underground, it will spoil the landfill site and surroundings over period of time due to its non-biodegradable characteristics.

Because air is the basic cooling medium, the dry-type transformers will be larger than liquid-immersed units for equivalent rating, but the first cost and installation cost would be less. When installed indoors, ventilation system needs to be sized for significant heat dissipation and provide proper cooling. These additional requirements increase the total ownership cost of dry-type transformers.

Amorphous Core Distribution Transformers:

Amorphous core distribution transformers (ACDT) offer low loss design due to core made of amorphous alloy, used in lieu of conventional cold roll grain oriented (CRGO) silicon steel core. Amorphous steel comprises of layers of thin foils of 0.025-0.03 mm thickness. Absence of a crystalline structure enables easy magnetisation, and combined with low thickness and high electrical resistivity enables a significant reduction in no-load losses as compared to CRGO core. The winding in ACDT transformer is either of copper or aluminium. The mineral oil is used as the liquid insulation and cooling medium in ACDT. A cutaway view of ACDT can be seen below in Fig. 3.7.

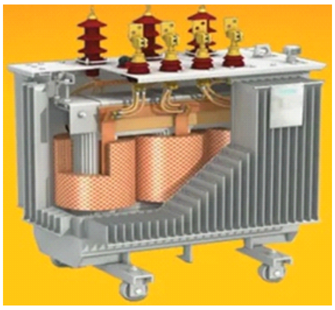


Fig. 3.7 Cutaway view of amorphous core distribution transformer

Due to use of more efficient core material and low magnetising current, the no-load losses are reduced. The temperature rise is also lower due to reduced losses. ACDT shows better tolerance to harmonics. These types of transformers are preferred by Utilities, as Distribution Transformers, where loading fluctuations are pronounced and unpredictable.

The degradation of efficiency over time is more due to less capability of brittle amorphous metal to withstand mechanical stresses. Once the small fragments of amorphous metal are broken off, it is impossible to repair the core. Amorphous core material cannot be and repaired or recycled upon burning of transformer. It is easy to over excite ACDT due to lower saturated flux of amorphous metal than CRGO, which lowers the overload capacity when compared to CRGO transformer.

As amorphous cores have a lower saturation point, they saturate at a lower flux density than CRGO, the larger winding coils and larger core are required for the same capacity and the ACDT require more footprint as compared to CRGO core transformers.

It may be noted that the finishing of the core assembly is very crucial for the amorphous core design, otherwise the noise level is higher than CRGO core transformers.

The cost of the same capacity of ACDT transformer is generally more than CRGO core transformers.

Comparison of Characteristics of Insulating Liquids:

Comparison of the important fire safety properties of insulating liquids is given in Table 3.1 below for reference.

Table 3.1:Characteristics of new insulating liquids

Properties	Mineral oil (IS:335)	Natural Ester oil (IS:16659 / IEC 62770)	Synthetic Ester oil (IS:16659 / IEC 62770)
Dielectric Strength (kV), 2.5mm gap	Min. 30	Min. 35	Min. 45
Dielectric dissipation factor, tan d at 90°C and 50 Hz	0.002	Max. 0.05	Max. 0.03
Kinematic viscosity at 40°C (mm2/s)	27 cSt (at 27°C)	Max. 50	Max. 35
Water content (ppm)	Max. 50	Max. 200	Max. 200
Total acidity (mg KOH/g)	Max. 0.6	Max. 0.6	Max. 0.6
Fire safety class*	O1	K3	K3
Flash point (°C)	140	Min. 250	Min. 250
Fire point (°C)	Limit 170	Min. 300	Min. 300
Calorific value MJ/kg	46	37.5	31.6

*Fire safety class as per IS:16081-2013 IEC 61099-2010

Due to high viscosity, the ester oil is an effective coolant and reduces the heat developed by thermal stress. The dielectric strength is not any way lower than that of mineral oil.

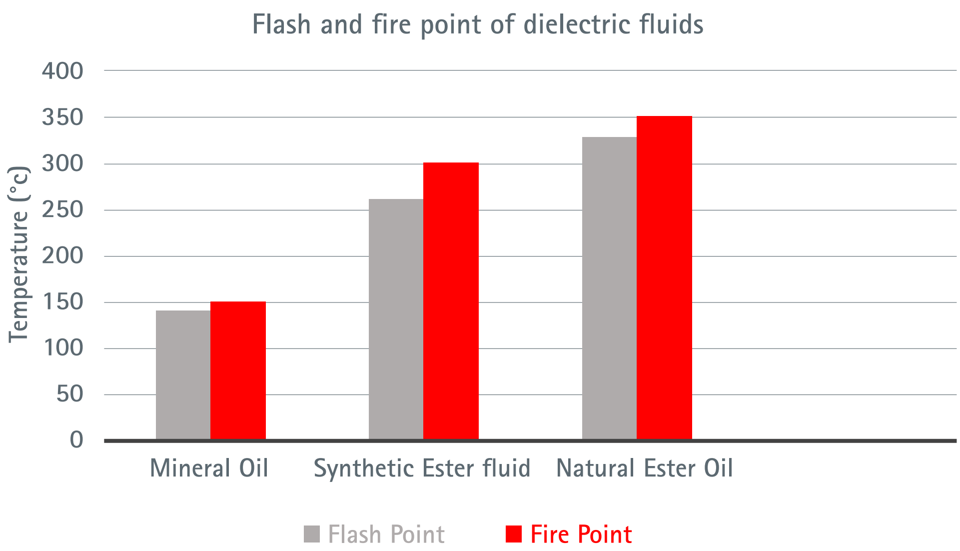


Fig. 3.8 Fire safety characteristics of liquid insulating liquids

The fire safety characteristics of insulating liquids are compared in the graph given in Fig. 3.8 for better understanding.

As for demerits, the natural ester oil has the tendency of getting oxidised more easily, however synthetic ester takes relatively more time for getting oxidised. During oxidation, the oil tends to form by products, such as acids and sludge, which may lead to faster ageing of transformer due to adverse effect of oxidation on the cellulose kraft paper insulation. Hence special care has to be taken while handling the natural ester oil to prevent from exposure to atmospheric conditions. Hence sealed type ester oil-filled transformers are preferred for their longevity and minimal need for oil replacement.

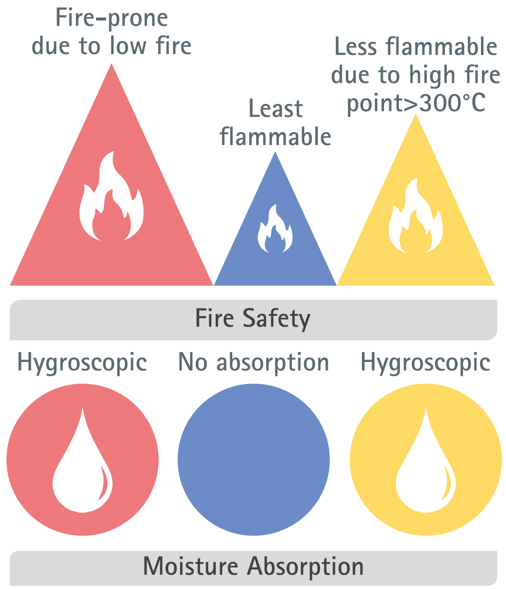
Concerns for environment sustainability are well addresses by the ester oil-immersed transformers as these units follow "Green Transformer" concept due to optimum use of eco-friendly materials, which are biodegradable and can be disposed without causing serious damage to the environment.

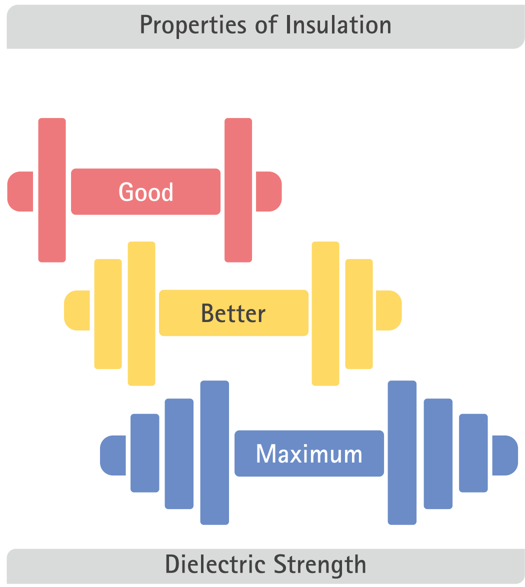
Summary of Transformer Characteristics:

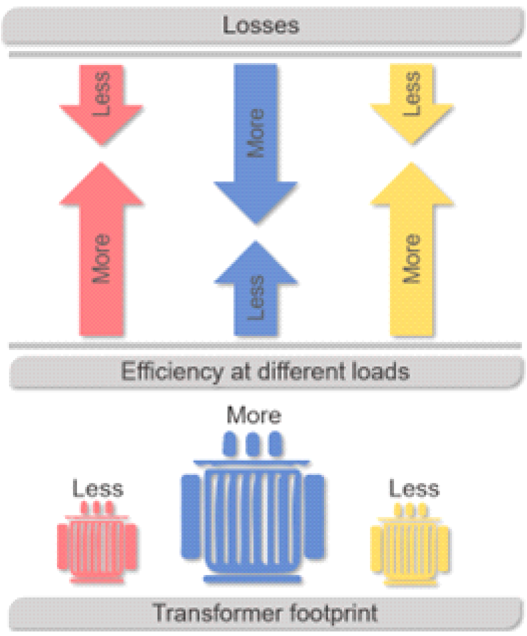
The important characteristics of three types of transformers have been summarised in Fig. 3.9below.

Legend

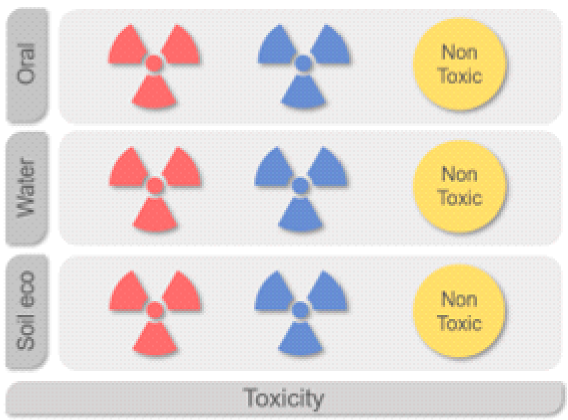
- Mineral Oil-Immersed Distribution Transformer
- Dry-type Distribution Transformer
- Ester Oil-Immersed Distribution Transformer

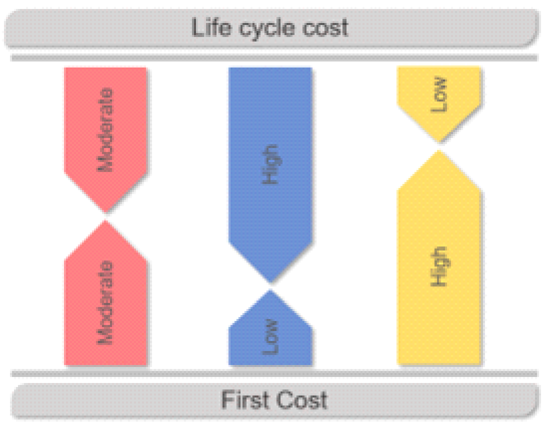

Fire-prone
due to low fire
Least
flammable
Less flammable
due to high fire
point>300°C
Fire Safety
Hygroscopic
No absorption
Hygroscopic
Moisture Absorption


Properties of Insulation
Good
Better
Maximum
Dielectric Strength


Losses
Less
More
Less
More
Less
More
Efficiency at different loads
More
Less
Less
Transformer footprint


More
Less
Moderate
Preventive
Maintenance
Repairing of damaged winding or core possible at reasonable cost
Repairing of damaged winding or core difficult, repairing cost very high. Repairing not possible for cast resin
Repairing of damaged winding or core possible at reasonable cost
Breakdown
Maintenance


Oral
Non
Toxic
Water
Non
Toxic
Soil eco
Non
Toxic
Toxicity


Life cycle cost
Moderate
High
Low
Moderate
Low
High
First Cost

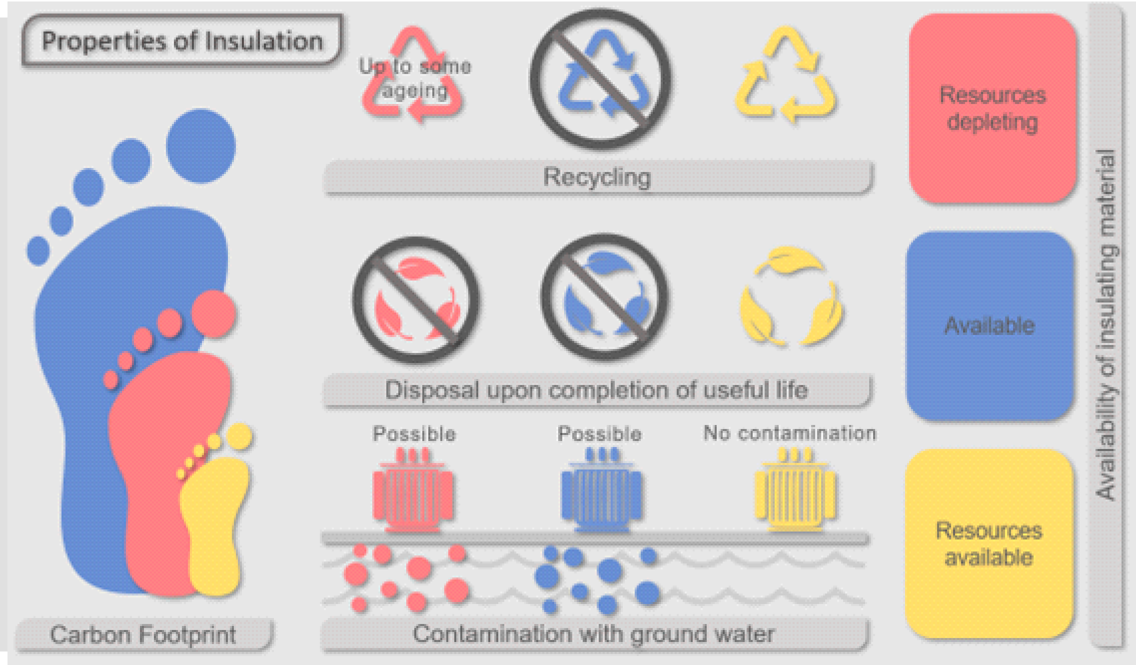


Fig. 3.9 Characteristics of three types of distribution transformers

Once the transformer capacity has been determined, criteria for selection of the transformer described in the succeeding chapter should be considered in order to techno-economically optimise the selection and to contribute to the efforts made for the environmental sustainability.

As seen from the summary of characteristics, the ester oil-immersed transformers appear to be the best option due to higher energy efficiency, better fire safety properties, excellent environment friendly properties due to biodegradability and recyclability of materials, low noise pollution, lower operational costs, lesser footprint, etc...Though dry-type transformers are selected over ester oil-immersed transformers, operating efficiency is often neglected and over long service life, the carrying cost of dry type transformers is high.

4 Energy Efficiency of Distribution Transformers

The criticality of energy efficiency has been explained in this chapter to emphasise an urgent need for selecting more efficient distribution transformers, so as to minimise the carbon footprint as well as to reduce operating costs. Brief discussion on the components within the transformer responsible for affecting the efficiency has been provided and comparative information has been presented for ease of understanding.

Energy efficiency of the distribution transformer has direct impact on its environment friendliness characteristics as well as the cost of electricity to the consumers. The transformer is expected to last for minimum 25-35 years with proper care in handling and maintaining, as it is a static equipment.

Though the dry-type transformers, for reasons discussed in preceding sections, are widely finding favour as replacement of the mineral-oil transformers in new residential, commercial, healthcare and institutional building projects, much attention is often not paid by the stakeholders towards energy efficiency. Typically, full load efficiency of dry-type transformers is around 95%, against plus 98% offered by the mineral oil transformers.

The transformers with marginally higher or incremental efficiency attract a significant premium on the cost. Recently, increasing number of Data Centres is being constructed all over the country, and preference is given to the dry-type transformers. Anticipating the requirement in large numbers, it would be prudent to make rigorous efforts to design the dry-type units offering highest efficiencies at full loads, near full load and also more importantly at part loads, so that they could compete with the liquid-immersed transformers.

On the other side, there is also an urgent need, as a part of our climate response, to adopt more "earth-friendly" options of insulations in the transformers, besides enhancing the energy efficiency. Continuous efforts are being made to use eco-friendly materials and to reduce the energy losses with Star-labelling of distribution transformers, specified by Bureau of Energy Efficiency (BEE). Energy conservation and reduction of CO2 emissions are in the spotlight for environmental sustainability.

Energy Losses in Distribution Transformers:

Let us understand how the major components, core and winding, within the transformer are responsible for the energy efficiency. The core and windings are the major contributors to the losses in the transformer as shown in Fig. 4.1.

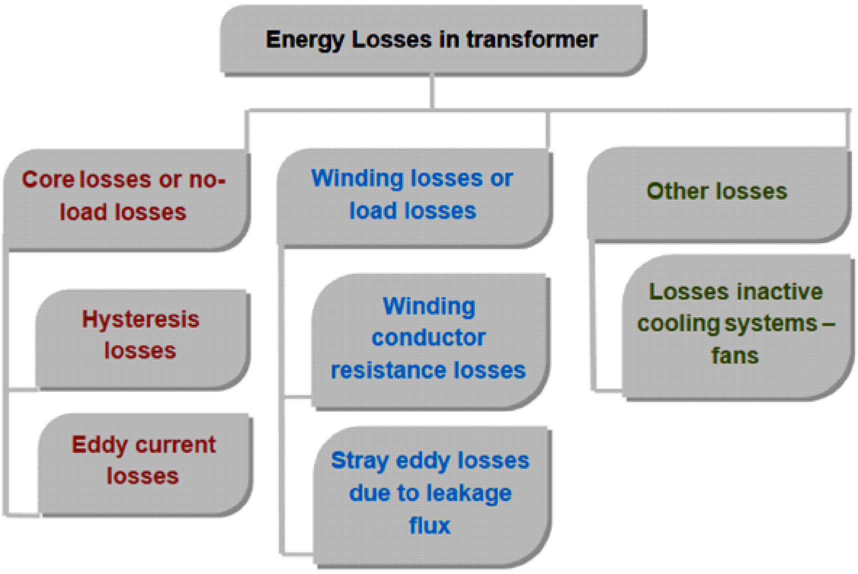


Fig. 4.1 Losses in transformers

(i) Core Losses:

The core losses, also known as no load losses or iron losses, consist of hysteresis and eddy current losses. Most transformer cores are constructed from low carbon cold-rolled grain oriented (CRGO) silicon steel laminations having low resistance to magnetic fields (also called permeability).
The hysteresis losses result due to heating of core due to resistance offered by the laminated steel core when AC power supply is applied to the transformer.

The eddy current losses on the other hand are caused due to heating of core due to circulating currents induced into the core laminations due to the magnetic flux leakage circulating around the core.
The no load losses occur as soon as the transformer is energised and remains constant irrespective of how much load is supplied by the transformer.

(ii) Winding Losses:

The winding losses, also known as load losses, are produced due to heating of winding due to resistance to the current offered by conductors. As the load losses are proportional to square of load current, these losses increase simultaneously with increase in the load. There are also stray eddy losses in small amount in the conductor that are caused by the leakage flux, which results into poor voltage regulation.

(iii) Other Losses:

Besides the core losses and the winding losses, certain transformers could have losses due to active cooling systems, if such systems are provided. Specifically in dry-type distribution transformers of higher capacities, the cooling fans are provided that start operating when the winding temperature rises above specified temperature for cooling. The energy used by such cooling systems is considered an operating loss of the transformer. Depending on the capacity and permissible temperature rise, one or more number of fans are provided.

Point of Maximum Efficiency:

When the transformer is not supplying load, the no load losses are more than load losses. As the load increases, the load losses also increase simultaneously, and at one point both types of losses become equal. The transformer offers maximum efficiency at the point where both losses cross each other. The relationship between load and efficiency is shown in the typical graph in Fig. 4.2 below.

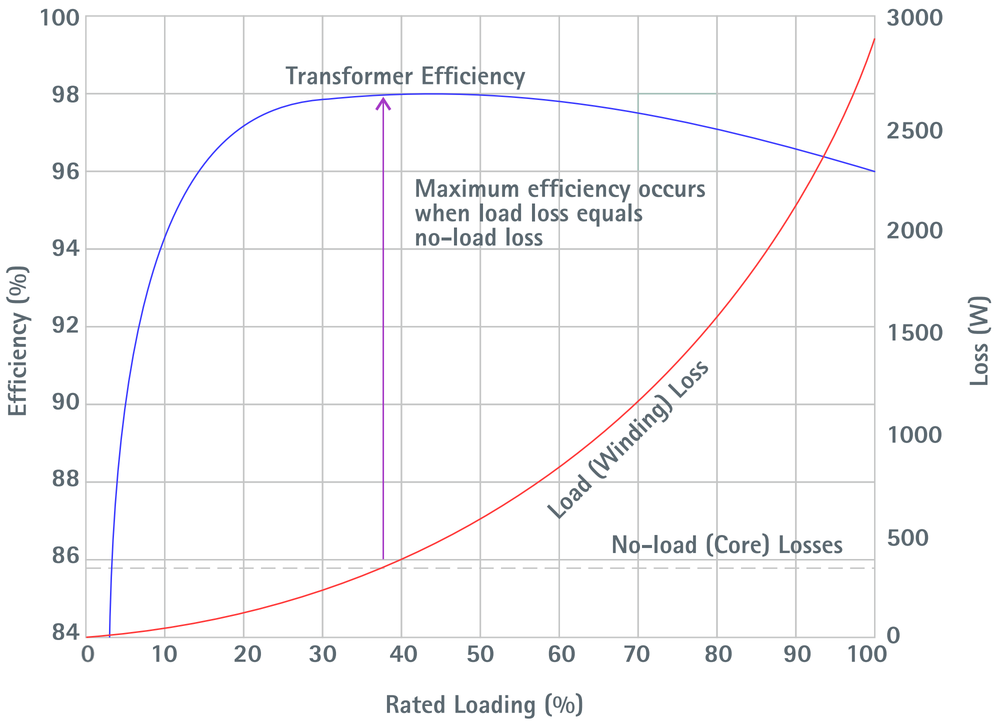


Fig. 4.2 Loss and Efficiency Relationship

Minimising Transformer Losses:

The transformer designer and user, both can contribute significantly for minimising the losses.

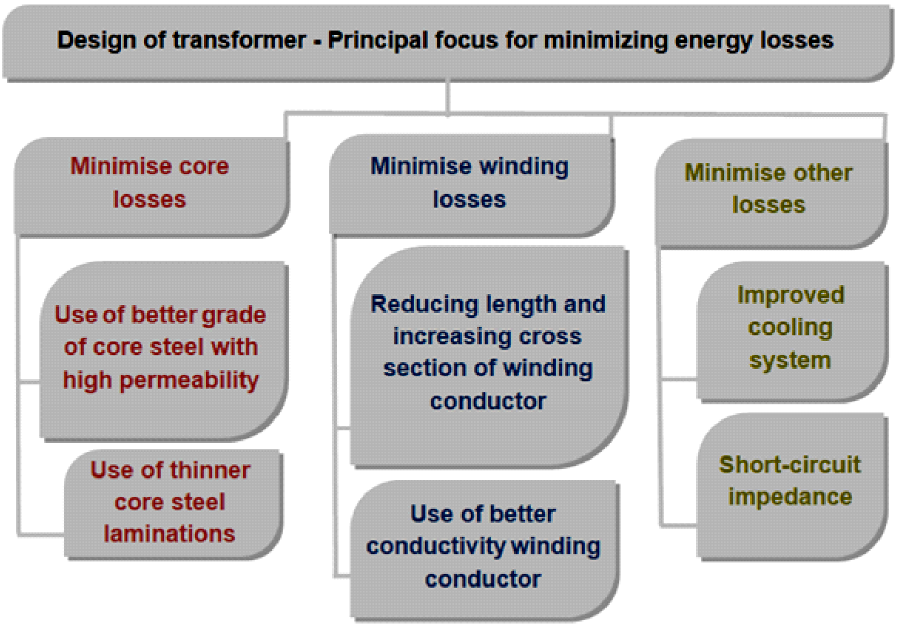


Fig. 4.3 Minimising losses in transformer

(I) Minimising the Core Losses:

For optimising transformer efficiency, core losses probably draw more attention as the losses remain constant independent of load. Therefore, transformer design and manufacturing could play an important role in reducing the core losses.

For reducing core losses, high-efficiency transformers are designed with a better grade of steel, which reduces the hysteresis losses due to lower resistance. The core construction allows two important energy saving features as follows:

(a) First, inherent linearity between lamination orientation and the magnetic field direction allows use of grain-oriented steel for transformer laminations.

(b) The eddy current losses can be significantly reduced by reducing the thickness of the laminations. The laminations are covered with thin layer of insulating varnish to prevent the eddy currents between laminations and confine them to narrow loops within each single lamination layer.

(ii) Minimising the Winding Losses:

The winding losses can be reduced by using conductor of higher cross section and by reducing length of winding conductor as an improved design. This reduces winding resistance. The load losses can also be reduced by using the conductor material with higher conductivity.

It may be noted that an arbitrary increase in cross section can increase eddy current losses. The designer can always make efforts to balance between minimum basic I2R and minimum eddy current losses for a given design. By keeping the leakage reactance and winding resistance within moderate value, better voltage regulation can be achieved for improving efficiency.

Trade-Off between Design and Cost:

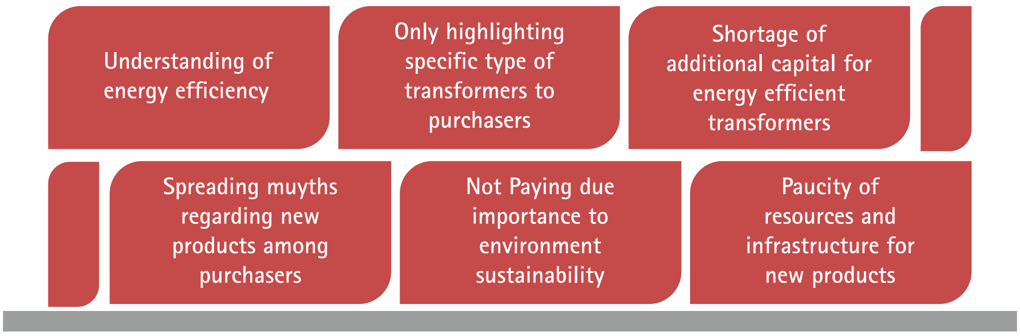
The design changes to reduce the transformer losses always involve trade-offs. While the winding losses can be reduced by varying the conductor cross section, the core losses would increase. If the cross-section of the transformer core will be modified for lowering no-load losses, the load losses would increase.
Variation in the conductor cross section and in the electric and the magnetic circuit path lengths in the core will affect losses in various ways, always leading the designer to seek a cost-effective balance.

However, the life-cycle cost analysis for both options will indicate overall carrying cost of transformer, taking into account energy savings by using the winding conductor of higher cross section. There are other design parameters, such as leakage flux, insulation, short-circuit impedance, cooling, etc... for improving the efficiency.

Roadblocks in attaining Transformer Efficiency:

Roadblocks for adoption of energy-efficient transformers must be addressed at the policy stage for ensuring a successful market transformation. Common roadblocks faced by the stakeholders are as under:

Roadblocks faced by the Manufacturers:



(i) The transformer manufacturers, in many cases, to be commercially competitive, do not prefer to offer their best technical designs (as the initial cost might go up); as they have a fear that the project owners would not offer any weightage for technical competency and for minimum environmental impact by better design.

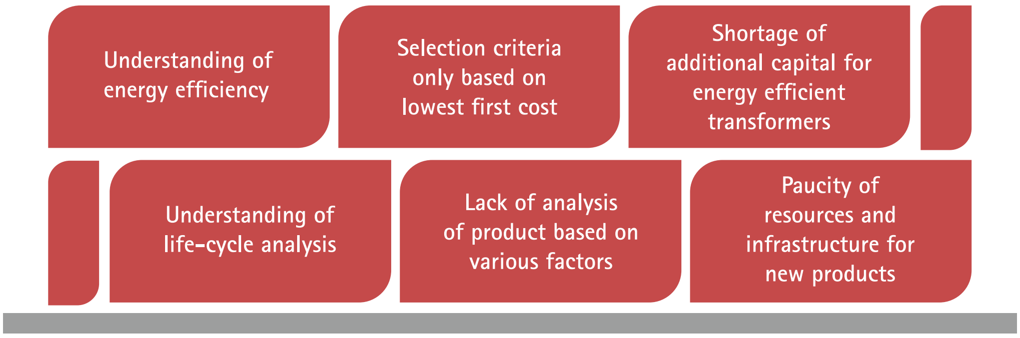
(ii) Usually, any deviation from the standard working procedure is mostly resisted. There are designs for different ratings of mineral-oil immersed units or standard dry-type units, that are readily available; however, usually marketing teams make all possible efforts for avoiding redesigning of high efficiency ester oil-immersed units; in case the user specifies such requirements.

(iii) The manufacturers usually desist from promoting the ester oil-immersed transformers by reasoning such as, higher first cost and maintenance costs, difficulties in maintaining the units, no permission for installation in basements and hence encroachment on outdoor areas, and difficulty in availability of ester oils, etc... are being communicated. All efforts are made to promote either mineral oil-immersed transformers or to the extent, dry-type transformers.

(iv) Most of the manufacturers do not like to acknowledge importance of irreversible impact on the environment due to lower efficiency and end-of-the-life material disposal issues in case of mineral oil and in dry type transformers.

(v) Another excuse usually expressed by the manufacturers is the paucity of resources and infrastructure, inadequate or accredited testing facilities for promoting energy efficient and environment friendly transformers.

Roadblocks faced by Project Promoters and Builders



(i) Not all project promoters and builders possess requisite knowledge on availability of energy efficient transformers and mandatory requirements for maintaining energy efficiency in compliance to the statutory regulations and standards.

(ii) Most of project teams consider only the lowest first cost of transformers while selecting / procuring and would not consider total cost of ownership, by applying the life-cycle cost analysis techniques.

(iii) Many a times the reason of shortage of capital for marginally higher investment is pushed for not buying the most energy efficient transformers. Usually, the estimated cost of electrical system is included on thumb rule percentage basis in the total estimated cost of the project, which results into allocating shortage of capital for electrical systems.

(iv) In many cases, it has been observed that, the life-cycle cost analysis, if carried out, is without proper consideration of various contributing factors, which may result into indeterminate or too long payback periods to offer overall cost benefits.

Energy efficient transformers offer other benefits as well. The efficient transformers are designed for lower maximum temperature rise, consume less operating energy, and hence are cooler during continuous operations. They are more reliable (due to lesser stress on the insulation) and these transformers will have higher overload capacity and longer life.

5 Smart selection of Distribution Transformers and its impact on Life-cycle Cost

As a purchaser and user, we need to depend on Transformer manufacturers for getting vital technical specifications, such as merits and demerits, losses, etc.

This chapter discusses the criteria to be applied when selecting a type of distribution transformer (250 kVA and above capacities) for a specific application to get life-cycle cost benefit by efficient performance and lesser installation cost coupled with lesser impact on the environment.

General Criteria for Selection of Distribution Transformer:

(i) Compliance to the CEA Safety Regulations:

In accordance with the prevailing CEA Safety Regulations 2010, Rule 44(2)(viii)(e), installation of only dry-type transformer is permitted in indoor applications in residential and commercial complexes. Prior to implementation of CEA regulations, this provision was included in the IE Rules, 1956. Though IE Rules have been withdrawn post enactment of CEA Safety Regulations, the legacy remains.

(ii) Compliance to Fire Safety Regulations and adherence to prescribed test protocol:

Provisions for fire safety as follows must be complied.

(a) Provisions in IS:1646-2015 installation of transformers:

As provided in Cl.7.1, in case an oil-filled transformer is installed indoor, the room should be lockable, properly ventilated and separated by minimum 6 m distance from all surrounding buildings. In case of less than 6 m clearance, no door or window shall be provided in the walls of transformer room and building facing each other

As provided in Cl.7.11, if installed outdoor, the area should be suitably fenced and separated by 6 m from all surrounding buildings.

(b) Provisions for oil-immersed transformers in IS:1646-2015:

Oil spill containment area is to be created to prevent a fire risk due to oil leaks for all the liquid-immersed transformers whether installed indoors or outdoors.

Additionally, in case of transformer containing 2000 litres oil (individual or aggregate) or more, drain pipe and soak pit are to be provided for draining the oil, during unforeseen event of fire. These provisions result into cost escalations.

(c) Provisions in CEA Safety Regulations for indoor installation of transformer:

At present, only the dry-type transformers are permitted for installation in the basement of residential and commercial buildings. As per Rule (44)(2)(x), the room should be in the first basement at the periphery of the basement with direct access from outside. The entrance doors should be lockable and provided with 2 (two) hour fire rating. The surrounding walls should be lined with fire bricks. These provisions result into significant additional cost of installation.

As mentioned in Chapter 1, Govt. of Maharashtra has already permitted the installation of ester oil-filled units in the basement of residential and commercial facilities by issuing suitable amendment to the referred regulation. If this approach is adopted by other states as well, it will immensely boost the efforts for acceptance of energy efficient ester oil-filled units and thereby reducing the carbon footprint.

(iii) Review of the State Utility requirements for the transformers:

In many states of India, the location for the transformer installation in the consumer's premises is decided by the Utility Company, which is required to be complied with. Selection of type of transformer to be installed is also decided based on the applicable regulations in the respective state.

(iv) Understanding distribution transformer types, comparison of characteristics vis-a-vis applications requirements:

Details of different types of distribution transformers have already been described in Chapter 3 of this guidebook. The characteristics of each type of transformer have been compared along with impact on the performance, preventive maintenance requirements, life cycle cost, etc... Type of transformer may be decided considering the characteristics most suitable for that specific application.

(v) Location and clear access:

When located either indoor or outdoor, type of environment/building material where the transformer is located and the surrounding occupancies or rooms adjacent to the transformer should be considered. The location should have clear and direct access, adequate space for maintenance, escape routes, etc... The fire-fighting team should be able to reach the area quickly in the event of fire to take remedial action. Minimum clearances as specified in the applicable Indian Standard should be maintained on all four sides for the transformer installed either indoor, or outdoor, or in semi-covered areas.

If there is a presence of corrosive atmosphere in the manufacturing process area, it is better to keep the location at a suitable distance away from corrosive surroundings.

(vi) Environmental conditions and site conditions:

The site climate also matters in the selection process. Generally, transformers require less maintenance than most other electrical equipment. However, harsh weather conditions can adversely affect performance of transformers. Each type of winding insulation is specifically suited for a particular environment. If the transformer is exposed to the outside environment, it is necessary to understand how the climate can affect the integrity of the transformer, and need to select the type of transformer accordingly.

As the mineral oil, being hygroscopic material, it absorbs atmospheric moisture and deteriorates quickly, the mineral oil-immersed transformers require additional maintenance like oil testing and filtration at shorter intervals.

The cast resin transformer is suitable for areas with high humidity; provided they meet efficiency criteria. However, the dry-type units are not suitable for dusty areas, as the dust, carried via ventilation louvres provided in the enclosure for cooling, gets deposited on the winding insulation, which reduces cooling effectiveness, causing more temperature rise and rapid deterioration of insulation properties.

Ester oil-filled units are found better choice for installation in various weather conditions.

(vii) Transformer installation footprint:

As the ambient air is cooling medium, the dry-type transformers are larger than liquid-immersed units for the same voltage and capacity (kV/kVA) rating for controlling temperature rise. Therefore, dry-type transformers require larger floor area to maintain optimum performance parameters. Total space requirement should also include clearances to be maintained on all four sides of the transformer in compliance to the standards. The clearances are recommended based on the area of installation, viz., whether the transformer has been installed in the area, opened on all four sides, or opened on three sides, two sides, or installed in a covered room. The footprint can be reduced by installing the liquid-immersed transformers and cost can be optimized.

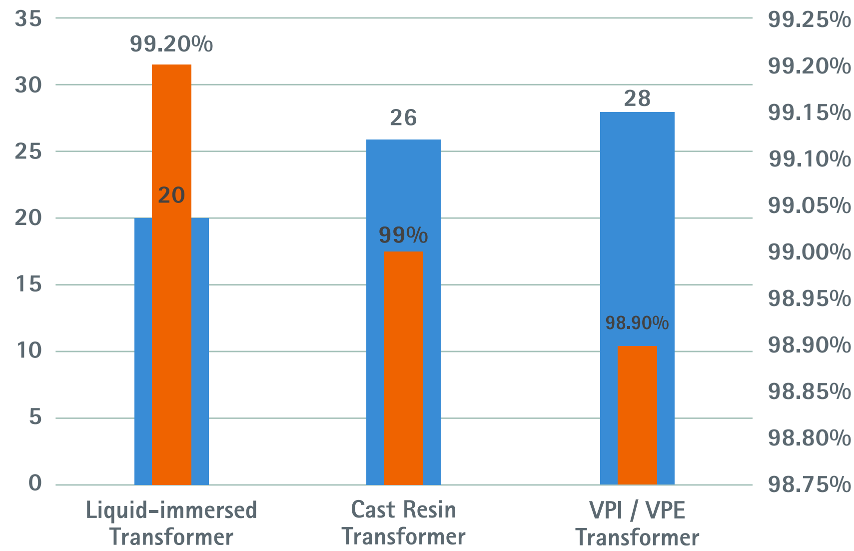
(viii) Consideration of energy efficiency at different loads - Loading profile and load factor and losses:

Important step for the selection is to determine the rating based on estimated peak load, minimum load and normal load and their time duration. The load profile v/s time duration is analysed and then the appropriate rating is selected.

Loading pattern is probably the most influential factor for the selection of proper distribution transformers, based on the losses at different loads. Generally, the load losses should be considered for the transformers expected to be loaded to 60-70% and above, and the no-load losses should be considered for the transformers expected to be loaded to 50% and below.

Usually, the transformers installed in residential and commercial sectors are not loaded beyond 50% of their rated capacity. Hence no-load losses of the transformer should be compared and the transformer offering optimum efficiency below 50% load should be selected for these applications.

Liquid-immersed transformers are more efficient than dry-types, as the insulating liquid is an efficient cooling medium than air, and thereby reducing the winding losses. In addition, liquid-filled units have a better overload capability. The graphic given in Fig. 5.1 shows combined losses at 100% loading for the different types of distribution transformers under consideration.



	Liquid-immersed Transformer	Cast Resin Transformer	VPI / VPE Transformer
Losses in kW	20	26	28
Efficiency in %	99.20%	99%	98.90%

Fig. 5.1 Total losses at 100% loading and efficiency (2500 kVA)

It must be noted that, a liquid-immersed transformer, with its maximum permissible winding temperature rise of 55C above ambient temperature, will always produce lower losses and less heat than a dry-type transformer with its maximum permissible winding temperature rises of 80C, 115C, or 150C above ambient temperature.

(ix) Insulation properties and failure:

In liquid-immersed transformers, the solid and liquid insulation form an inseparable insulation system; while the solid insulation system is used in dry-type transformers.

Analysis of causes of failure of distribution transformers has revealed that maximum failures are attributed to insulation breakdown followed by other causes as shown in Fig. 5.2.

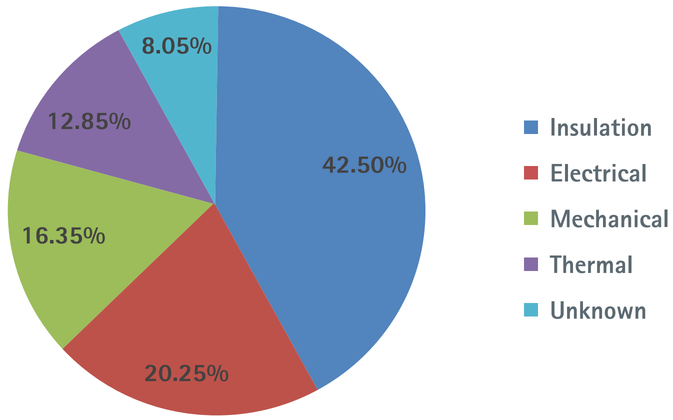


Fig. 5.2 Main causes of failure of transformers

All insulating materials undergo degradation either due to natural ageing, or one or a combination of several external factors that include thermal, electrical, mechanical, chemical and environmental stresses during its service period, causing an irreversible change in its properties. Degradation is more pronounced due to external factors, and presence of imperfections and contaminants in most of the insulation systems.

Factors adversely affecting the insulation and direct interactions between the stresses caused by these factors are provided in Fig. 5.3, in which the mechanism of degradation has been summarised. Some of the important factors are discussed as under:

Fig. 5.3 Factors influencing performance of transformer oil–paper insulation and resulting breakdown mechanisms

Thermal stresses are caused due to excessive temperature rise of the insulation, which depends on the loading pattern of the transformer and ambient conditions. An increase of 8–10C rise in temperature, approximately doubles the rate of oil degradation. The temperature ranges over which these liquid insulations can operate are shown in Fig. 5.4

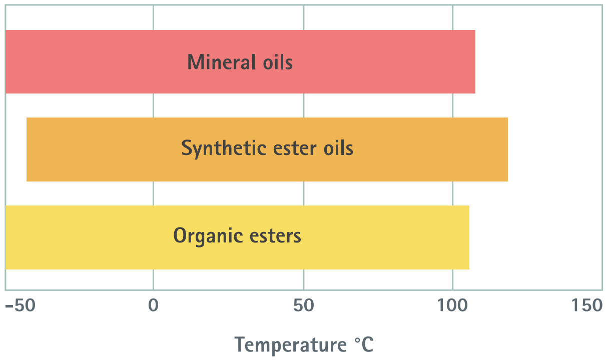


Fig.5.4 Temperature range of normal usability of various classes of liquid insulations

Water content or moisture is another factor causing degradation of oil and solid paper insulation. The rate of thermal degradation of paper is usually directly proportional to its water content. An increase in water content comes partly from the degradation of cellulose in paper due to high temperature and oxidation, and partly from the ingress of water from the atmosphere.

Ageing of insulation due to electrical and mechanical stresses occurs due to electromagnetic forces experienced during flow of heavy short-circuit currents in the winding.

In addition, other external environmental factors such as dust and other contamination on electrical behaviour of the equipment.

(x) Comparison of preventive maintenance and breakdown maintenance procedures:

Preventive maintenance:

Liquid-immersed transformers:

All oil-immersed type transformers, (both mineral oil type and ester oil type), require more preventive maintenance. Major maintenance is periodic testing of oil followed by filtration process based on the analysis of test results. The oil analysis provides a very accurate assessment of the transformer condition – something not possible with dry-type transformers.

Ester oils can absorb significant amounts of moisture in comparison to mineral oil, allowing the insulation paper over windings in the transformer, to remain dry for longer duration. Hence, ester oil filtration arises after long interval. It has been proven that, this property has a positive impact on the transformer loss-of-life curve, and hence on the maximum permissible hot-spot temperature. This is specifically true for the sealed units being installed by the utilities.

Other periodic maintenance activities include cleaning, tightening of joints or replacement of gaskets to prevent oil leakage, topping-up of oil, tightening of cable connections, thermal imaging of the Transformer for checking its heat losses, etc...

Dry-type transformers:

Recommended annual maintenance for a typical dry-type transformer consists of inspection, thermal imaging of bolted connections, cleaning of core and winding assembly and ventilation grills provided on enclosure to maintain adequate cooling and prevent build-up of contaminants over core and winding assembly. Lack of cleaning decreases the transformer efficiency due to decreased airflow and can create a fire hazard. This phenomenon is prominent on open dry-type transformers.

The dry-type transformers are highly resistant to chemical contaminants.

Moreover, if the dust deposited on the winding insulation surface is not cleaned periodically, the dust particles get ionized due to magnetic field and cause rapid deterioration of dielectric properties. This phenomenon is called "trapping" and has severe adverse impact on performance of dry type transformers.
The maintenance cost is more for oil-immersed transformer due to frequent oil testing, filtration and oil topping up. However, the dry-type transformers have higher operating cost due to more losses, as compared with oil-immersed type transformers.

Breakdown maintenance:

Liquid-immersed transformers:

The winding and core in both types of liquid-immersed transformers are easier to repair economically within reasonable time duration. Hence, most of the breakdowns in the liquid-immersed units will not require total replacement, which will save significant life-cycle cost.

Dry-type transformers:

The cost of repairing of core and winding is more and time consuming in open wound, VPI and VPE dry-type transformers, whereas repairing cost of cast resin units is prohibitive due to total encapsulation of core and winding. Many times, the dry-type transformers are found non-serviceable depending on extent of damage and will require total replacement.

The decision for type of transformer should therefore be based on comparison of operation and maintenance costs and breakdown costs.

(xi) Impact on environment: Bio-degradation, disposal and circularity of transformers at end-of-life:

How different types of distribution transformers perform for environmental sustainability in terms of biodegradation, circularity (recyclability) and disposal has been furnished in Fig. 5.5.

Circularity, Biodegradation and Disposal upon completion of useful life

Mineral oil-immersed	Dry type	Ester oil-immersed
Circularity of steel core and copper-aluminum winding materials easily possible due to recyclability	Overall poor circularity performance	Circularity of steel core and copper-aluminum winding materials easily possible due to recyclability
Mineral oil to be disposed after some cycles of filtration Highly toxic in soil and water and not readily biodegradable	Recycling of core and winding material is possible in open type units to some extent	Readily biodegradable with simple natural process Non-toxic in soil and water.
End of life disposal expensive process for prevention of harmful effects on environment	Scope of circularity very limited in VPI, VPE and resin cast units due to construction	Easily recyclable natural process
	Extremely difficult to biodegrade resin insulating materials due to their characteristics, toxicity	
	Disposal causing harmful effects on environment	

Fig.5.5 Transformer performance for environment impact

The performance with regard to ability to biodegrade of different types of insulating materials used in the transformers is compared in the graph given in Fig. 5.6.

As seen from the graph below, at the end of 28 days, bio-degradation of ester oil is faster than mineral oil.

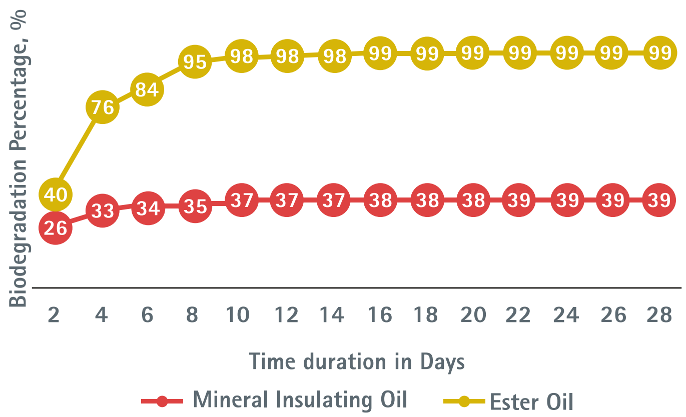


Fig.5.6 Bio-degradation performance of insulating materials

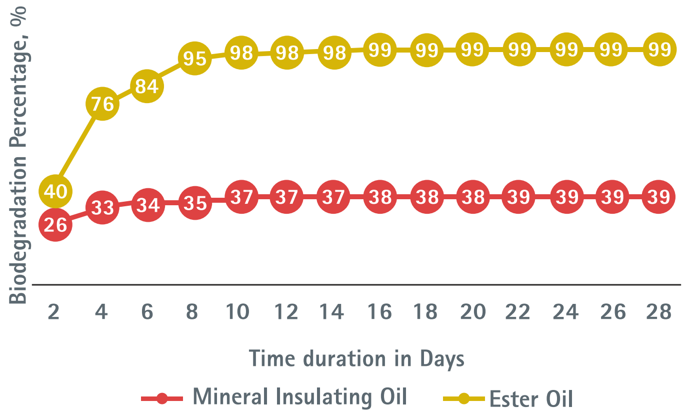


Fig.5.7 Bio-degradation process duration of liquid insulating oils

Thus, the ester oils are easier to biodegrade and hence are classified as eco-friendly insulating materials.

Environmental performance of dry-type transformers:

The dry-type transformers cause the maximum impact on the environment due to overall poor performance for recycling. At the end of their service life, recycling of core and winding materials is possible to an extent in open type units, and very limited in VPI and VPE type units. In cast resin transformers, the winding is encased in tough, synthetic epoxy resin, which is extremely difficult to remove. While proper recycling is technically possible, it is often prohibitively expensive and time consuming process. Many of such dry type transformers are sent from developed world to India and other Asian countries for recycling, as removal of cast resin insulation becomes too labour oriented and costly. The non-recycled solid insulating materials are also not bio-degradable, and if disposed at the landfill sites, they are harmful to people as well as to environment; as extremely hazardous and toxic substances are contained by them.

Environmental impact of liquid-immersed transformers:

The steel core and copper/aluminium winding materials can be readily reclaimed in both liquid-immersed type transformers and can be recycled.

The mineral oil can be cleaned by filtration process at regular intervals, however, it is not possible to regain vital properties, such as dielectric strength, acidity level, etc...,after some cycles of filtration and it needs to be disposed sustainably. As the mineral oil is by-product of crude refining process, it is toxic to soil and water and is not readily bio-degradable. Its contaminants cause significant environmental damage. Even the leaks should be contained from percolating into ground or water. End of life disposal requires expensive process to prevent harmful effects on the environment.

Environmental impact of Ester-oil transformers:

On the other hand, natural and synthetic ester oils are easily recyclable and are bio-degradable. They are non-toxic to soil and water, and contains no hazardous substances, and hence significantly minimises environmental risk. The leak containment systems are simple and cost a meagre amount, when compared to the mineral oil-immersed transformer installations. The treatment for bio-degradation is a simple natural process, such as use of microbes that live in soil and groundwater, to clean up environmental spills.

The ester oil-immersed transformers are the most environment friendly units, followed by the mineral oil-immersed. The energy efficient ester oil-immersed transformers are ideal for achieving important objective of reducing the environmental impact and carbon footprint.

(xii) Operating Sound Level and Noise Pollution:

Operating sound level should be considered, depending on the type of building occupancy. The liquid-immersed transformers have a lower sound level in comparison to the dry-type transformers, as shown in Fig. 5.8.

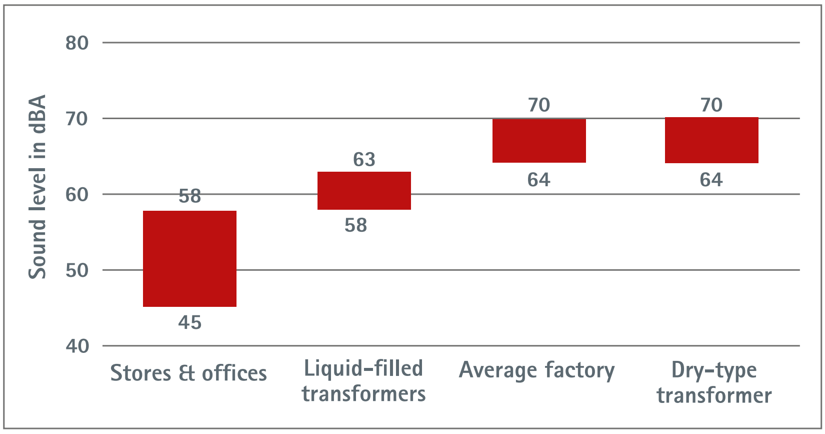


Fig. 5.8 Operating sound level of transformers

Lower sound level provides indoor environmental quality benefit due to less noise pollution. The constant vibrations from the transformer may cause an undesirable audible hum for the occupants. Decibel is a logarithmic function, and sound pressure doubles for every three decibels increase. Research shows that a person's productivity increases, when the workspaces were less noisy.

(xiii) Safety of human beings and installation as a whole:

Safety of human beings and installation as a whole is relevant to the location of installation. Whatever type of transformer is being installed, it is mandatory to pay due attention to safety of people and installation. The distance between transformer location and building with human occupancy should be maintained as provided in the safety regulations and standards. Any unauthorised person's entry in the substation should be prohibited by all means. Minimising safety threats from the outside environment is a key concern that needs attention.

(xiv) Plan for replacement and future development possibilities based on lifespan of transformers

(xv) The lifespan of transformers taken out from service ranges from 25 to 35 years, typical lifespan of liquid-immersed is 25 to 35 years and that of the dry-type is 15 to 20 years; if maintained properly.

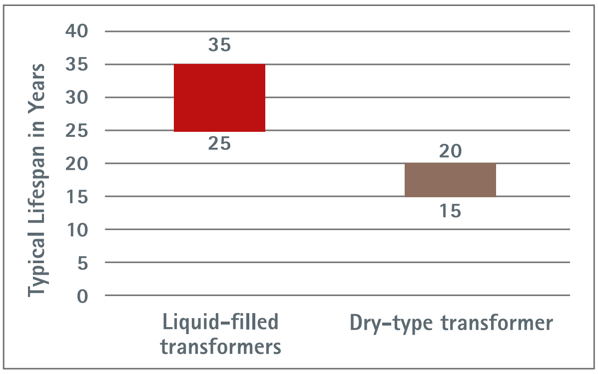


Fig. 5.8 Typical life span of transformers

As the lifespan of liquid-immersed transformers is longer than the dry-type, they save on material, and labour to replace, and operational impact due to outage to be taken for the replacement. Lifespan is a crucial component of the total ownership cost calculation, as the transformers are durable and have long useful lives.

Obviously, it is advisable to install liquid-immersed transformers as a first choice to avoid the replacement costs within shorter duration overcoming other constraints discussed in this chapter as far as possible. And by preferring ester oil-filled transformer, the life-cycle cost can also be optimised.

(xvi) Life cycle cost analysis – Total ownership cost:

Energy efficiency is not the sole criteria for selecting a transformer, whereas, it is essential to consider long-term economics.

The distribution transformers are often procured based on the lowest first cost, when transformer evaluation and purchase decisions are not made by the end-users. The life-time cost of energy losses (operating cost), maintenance costs and cost of de-commissioning after providing for residual value are also significant considerations in determining the most suitable transformer for the intended application.

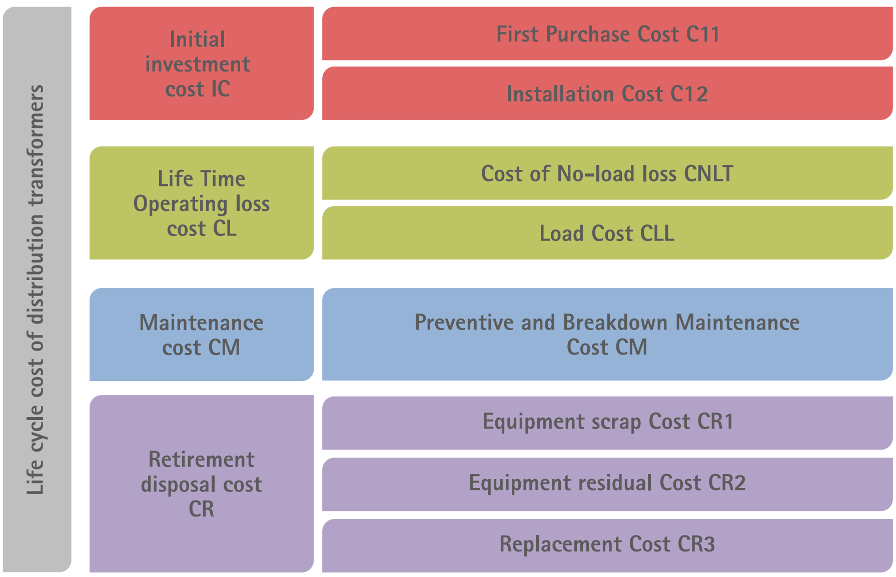


Fig. 5.9 Total Life Cycle Cost (TCO) model for distribution transformers

Total cost of ownership or life-cycle cost is determined using basic formulae as follows:

TCO = IC+ (A x Wi) +(B x Wc)

Where,

IC = Initial cost (including taxes, transportation, etc.) of transformer as quoted by the vendor

Wi = No Load losses quoted by the vendor in Watt

Wc = Full load losses at 75 °C quoted by the vendor in Watt

A Factor = Cost of no-load losses in Rs./Watt

B Factor = Cost of full load losses at 75°C in Rs./Watt

Cost of losses = Per unit cost of power from the utility company

The total capital and estimated lifetime operating and maintenance costs are also significant considerations in determining the most suitable transformer for the intended application. The analysis provides more economical solutions for the optimised selection.

Capitalisation cost of losses – standard transformer				
1.0	Data assumed for loss capitalisation			
1.1	Rate of interest	r	=	8%
1.2	Price of electric energy	EC	=	5.50 Rs./kWh
1.3	Life of liquid-filled transformer	n	=	25 Years
1.4	Nos. of days for which transformer in service	d	=	365 days
1.5	Nos. of hours for which transformer in service in year	h	=	365 x 24
		h	=	8760 Hrs
1.6	Annual load factor for transformer	LF	=	50%
1.7	Annual loss load factor	LLF	=	$0.2LF + 0.8(LF)^2$
			=	0.3
1.8	**Transformer data**			
1.8.1	Capacity of transformer		=	1600 kVA
	Purchase cost of transformer	IC	=	2110000 Rs. Lakhs
	No-load losses	P_{NL}	=	1.61 kW
	Load losses at 50% load	P_{LL50}	=	4.84 kW
	Load losses at 100% load	P_{LL100}	=	12.90 kW
2.0	**Calculation of Loss Capitalisation**			
2.1	Capitalised cost of no-load losses per kW per year of service	C_{NL}	=	$h \times EC \times \left[\frac{(1+r)^n - 1}{r(1+r)^n}\right]$
			=	514311 Rs./kW
2.2	Total capitalised cost of no-load losses for 25 years	C_{NLT}	=	$P_{NL} \times C_{NL}$
		Rs.	=	828040
2.3	Capitalised cost of load losses per kW	C_{LL100}	=	$h \times EC \times \frac{(1+r)^n-1}{r(1+r)^n}$? x LLF
			=	154293
2.4	Total capitalised cost of load losses for 25 years	C_{LLT}	=	$P_{LL100} \times C_{LL100}$
		Rs.	=	1990382
2.5	Total capitalised cost	Rs.	=	$C_{NLT} + C_{LLT}$
			=	2818423

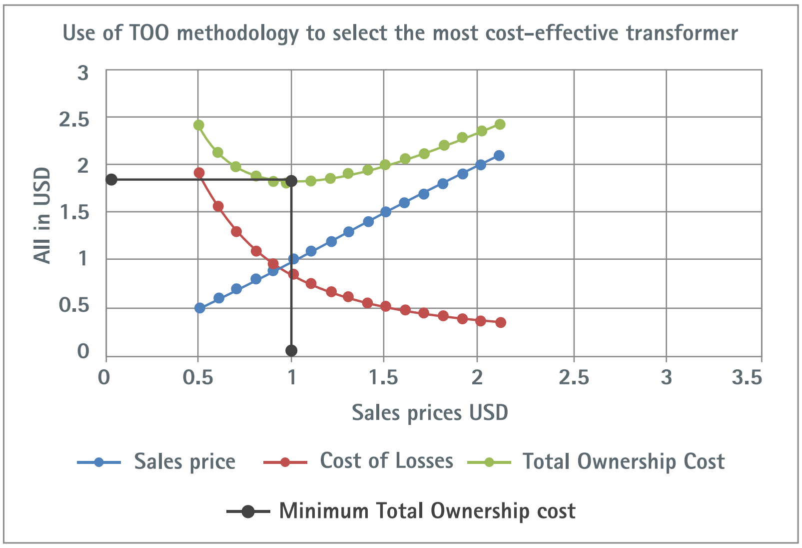


Fig. 5.10 Optimised selection of distribution transformers

Life-cycle cost of a transformer is determined by first purchase cost (comprising of basic cost, cost of finance, etc....), cost of energy losses, O&M cost, and de-commissioning cost after providing for residual value.

The use of a minimum value of Performance Efficiency Index sets a floor for transformer energy performance, but the use of TCO evaluation for purchasing transformers is essential to select a transformer with the optimal economically justified efficiency level.

Therefore, it is important to understand where best to use each type. For example, it costs approximately 50% more to specify a cast resin transformer over a VPE or VPI type unit. Therefore, the final selection can have a significant impact on the overall cost of a project.

The environmental performance of transformers may have an additional bearing on the selection of a more efficient unit. Usually, the cost of CO2 emission certificates is included in the calculation of the energy price for electricity losses. Furthermore, purchasing an energy-efficient distribution transformer demonstrates the company's willingness to contribute towards social goals of reducing greenhouse gas emissions and increasing energy security. The eco-design picture of typical distribution transformer depends in 90% or more on energy losses which result from transformer operations.

The initial purchase price of "green transformers" can be up to 20% higher than conventional mineral oil transformers. Therefore, both tangible (increased asset lifetime) and non-tangible (environment friendly and inherent safety) factors need to be taken into consideration while performing cost benefit analysis of any type of distribution transformer. As per a conservative estimate by a distribution utility in United States, ester oil extends lifespan of a distribution transformer by almost 33%, compensating for increased initial capital cost compared to mineral oil transformers. As the cellulose insulation degrades at elevated temperature, moisture content of insulation increases leading to decrease in dielectric strength. Ester oil can extend insulation lifetime almost 6-8 times by continuously drying out the moisture content from cellulose paper at 10 times faster rate than mineral oil. Cellulose insulation failure is one of the top three reasons for a transformer failure.

Conclusion:

Use of liquid-filled transformers for the industrial facilities is an established design practice. A dry-type transformer is the standard solution for providing power in indoor environment for majority of buildings.

A total ownership cost evaluation of both dry-type and liquid-immersed transformers will show the lowest total owning cost choice is the installation of less-flammable liquid filled transformers.

Considering these factors, mineral oil-immersed transformers seem, on all accounts, to be the better alternative with higher energy efficiency, recyclability, low noise pollution, lower operational costs and a small environmental foot print. In any case, mineral oil filled transformers essentially can't be utilized in any circumstance. Dry type and Ester Oil filled units are the best suited and many times, preferred choice for business and indoor operations, since they are more secure units to work around individuals and areas where fire risks may exist.

6 Applicable Indian and International Standards

As discussed in preceding chapters, Bureau of Indian Standards has published separate standards prescribing the loss and efficiency levels for the distribution transformers which all the manufacturers are required to follow. This chapter discusses about the details of provisions made and labelling programme in the Indian Standards as well as in the International standards IEC and IEEE.

Standards published by Bureau of Indian Standards (BIS):

Number of countries have been focusing on the impact of ever rising level of greenhouse gas, contributed by different sources, in our environment, one of the major contributors being the power generation. Contribution from the power plants can be brought down by bringing down energy utilisation in various sectors and rigorous efforts being made in this direction. It is felt to focus more on residential, commercial, healthcare, etc... sectors for using the electrical equipments.

BIS has initiated numerous steps to improve the efficiency of electrical system. Accordingly, the distribution transformers have been added in mandatory equipment list from 1st February 2016.

(i) BIS published IS:1180 (Part 1)'Outdoor Type Three-phase Distribution Transformers up to and Including 100 kVA - 11 kV - Non-sealed Type' in 1958 and revised in 1981 and 1989.

(ii) BIS published IS:1180 (Part 2)'Outdoor Type Three-phase Distribution Transformers up to and Including 100 kVA - 11 kV - Sealed Type' in 1979 and revised in 1989.

(iii) IS:1180 was revised in 2014 by combining the scope of Part 1 and 2 to make one standard applicable to the mineral oil-immersed distribution transformers, IS:1180-2014, 'Outdoor Type Oil Immersed Distribution Transformers up to and including 2500 kVA, 33kV – Specification, Part 1 Mineral Oil Immersed'. The standard prescribes the technical specification for the mineral-oil immersed three-phase transformers up to and including 2500 kVA, 33 kV voltage rating, and single-phase transformers up to 100 kVA, 3.3 kV to 33 kV voltage rating.IS:1180 was amended in August, 2016, January 2017, January 2019 and March 2021.

(iv) Salient provisions in IS:1180 inclusive of amendments issued from time to time are as follows:

a) The manufacturer must obtain the license from BIS for manufacture distribution transformers conforming to the specification provided in the standard.

b) Transformers of voltage rating from 3.3 kV up to 33 kV are divided in three categories as follows.
- Three phase distribution transformers up to and including 200 kVA
- Three phase distribution transformers higher than 200 kVA up to and including 2500 kVA
- Single phase distribution transformers up to and including 100 kVA

c) As per March 2021 amendment, five energy efficiency levels: level 1, level 2, level 3, level 4 and level 5 have been specified corresponding to1 star, 2star, 3 star, 4 star and 5 star labels issued by BEE.

d) Maximum losses (No Load Loss + Load Loss at 75°C) at 50% load and 100% load are defined for each rating in each level in all categories. The losses are revised to bring India's efficiency levels at par with the international standards. The tables (reference to Table No. as per IS code) have been furnished as Annexures.

(v) Subsequently, BIS published IS:1180 (Part 3) 'Outdoor/Indoor type Liquid Immersed Distribution Transformers up to and including 2500 kVA -33 kV – Specification – Natural/Synthetic Organic Ester Liquid Immersed' in 2021. The standard specified five energy efficiency levels. Maximum total losses for each level are same as specified in IS:1180 (Part 1).The standard paves the way for acceptance of ester-oil as liquid insulation in the transformers in India.

(vi) Principle concern is in area of dry-type distribution transformers, as Indian standard IS:11171-1985 (Reaffirmed 1996), 'Specification for Dry-Type Power Transformers', does not define the efficiency levels like IS:1180 applicable to liquid-immersed distribution transformers.

Bureau Of Energy Efficiency:

Energy Conservation Building Code (ECBC): The code is published by BEE which also provides guidelines for energy efficiency and refers to Indian Standards. It has been observed from some of the tender specifications, issued by public Utilities, Indian transformer manufacturing industry is very much capable of supplying dry type transformer with much better efficiency than those included in the revised draft of ECBC. It would be highly retrograde steps deeply impacting energy footprint of buildings. Therefore, one needs to look carefully at these values and take up on priority to revise the proposed ECBC draft so that national objective is achieved.

Notifications Issued by The Ministry of Power in Consultation With BEE:

The Ministry of Power, in consultation with BEE, has published Notification No. S.O. 185(E) during January, 2009, providing criteria for the maximum losses for "Star Rating" system for the distribution transformer rating from 16 kVA to 200 kVA. Criteria for the maximum losses have been revised downward vide the Notification No. S.O. 4062(E) published during December, 2016 for "Star Rating", effective from 1 January, 2017.

Additionally, the criteria for the maximum losses have been provided for the distribution transformer rating from 250 kVA to 2500 kVA.

As per Notification No S.O.1665(E), dated 27th May, 2020, the validity of criteria for maximum losses for 'Star Rating" system have been extended up to 31 December, 2022.

Bureau of Energy Efficiency's (BEE's) 'Star Rating' System shall also be applicable to the ester oil-immersed transformers.

ECBC-R (Eco Niwas Samhita-2021):

Eco-Niwas Samhita 2021 (Code Compliance and Part-II: Electro-Mechanical and Renewable Energy Systems): This Code has been published by BEE for rating residential buildings. The permissible limits for losses in the dry-type transformers have been specified by dividing the transformers into two classes, i.e., up to 22kV Class and 33 kV Class. No star labelling has been mentioned for the transformers. The tables have been placed as Annexures, for ready reference.

In absence of directly applicable BIS standards for Dry type Transformers, it is advisable to follow international standard such as: IEC TS 60076-20, 2017, 'Power Transformers, Part 20 Energy Efficiency' (Table C).

Applicable International Standards:

IEC Standards:

Minimum energy efficiency level 1 and level 2 have been provided in Table 10 in IEC standard IEC TS 60076-20, 2017, 'Power Transformers, Part 20 Energy Efficiency'. In fact, IEC standard may further become stringent in next couple of years (as every five years IEC standards undergo revision). Hence, as pragmatic view, Level 1 efficiency, as prescribed in Table 10 of IEC may at least be adopted for dry-type transformers in India. Base of ISO: 14064-1 for Carbon Footprint mapping can also be considered for calculating life-cycle cost analysis.

Benefits of adopting Level 1 efficiency specified in Table 10 of IEC TS 60076-20 are as follows:
(i) It will ensure a balanced energy footprint by proper design in respect of dry-type transformers installed for all types of applications and avoid significant energy wastage.

(ii) In absence of Indian Standard, CEA may facilitate BEE with recommendation on MEPS for dry-type distribution transformers, in line with referred IEC standard, which will avoid debate and litigation at later date.

(iii) It will be mandatory for all the States by statute to follow uniform norms to procure the dry-type distribution transformers conforming to Level 1 efficiency specified in the referred IEC.

Statutory Regulations and Compliance for Distribution Transformers:

Over and above, there is need to accommodate a clause in the statutory regulations and standards permitting installation of ester-oil immersed distribution transformers in the basement of the residential and commercial buildings considering excellent characteristics of ester oil relevant to the fire safety need of installation.

There is also an urgent need, as a part of our climate response, to enhance the efficiency of distribution transformers and adopt more "earth-friendly" options of insulations used in the transformers.

Continuous efforts are being made to use eco-friendly materials and reduce the energy losses with Star-labelling of distribution transformers by Bureau of Energy Efficiency (BEE). Energy Conservation and reduction of CO_2 emissions are in the spotlight for environmental sustainability.

7 Future Trends

It is expected that the stakeholders and the consumers would follow the criteria provided in the guidebook for the selection of distribution transformers, most appropriate to its application based on thorough evaluation.

Based on various relevant issues addressed in foregoing chapters, it is expected that increasing acceptance of the ester-oil immersed distribution transformers by the stakeholders besides mineral oil-immersed and dry-type transformers and their contribution to ongoing large-scale efforts for saving substantial amount of energy. This will not only save the cost in long run, but will also help in saving environment and reduce impact of climate change and shall fast track promotion of circular economy and adopting to international standards and trends.

Recommendations for Policymakers:

Policymakers may follow Energy Efficiency's Integrated Policy Approach for transforming market for distribution transformers. A national strategy for Efficient Transformers may be evolved to show how such a transformation is required in the years ahead. Policymakers should collaborate with other experts in the region to bring the prevailing standards at par with the international standards and best practices, and to exchange the resources and lessons learned.

An Integrated Policy Approach includes:

Minimum Energy Performance Standards and Regulations: Minimum energy levels may be defined for all types of transformers and bring them at par with the best international standards. Various codes and standards should provide the same values of minimum energy performance standards. Regulations may be further amended for location of installation of transformers for all applications. Final objective should be to adopt Minimum Energy Performance Standards (MEPS) in accordance with the test method IEC: 60076.

Labelling and Star Rating:

A separate standard may be published defining the Energy Efficiency Levels for the dry-type transformers, in line with the levels defined for mineral oil-immersed and ester oil-immersed transformers respectively in IS:1180-Part 1 and IS:1180-Part 3. The separate standard for specification of dry-type transformers has already been published, but it does not specify MEPS. Labels indicating the performance of the equipment and allow for easy comparison between competing products should be adopted.

Monitoring, Verification and Enforcement:

A track may be kept for the type of transformers sold in the market. Testing may be enforced to ensure that guaranteed values of performance are accurate and to make corrections by those that fail to comply. Otherwise, incentives intended for efficient transformer may reward sub-standard alternatives, which will result into entry of non-compliant equipment in the market.

Premium on Cost:

Roadblock to higher upfront cost of efficient transformer may be suitably overcome through incentives such as grants, rebates and tax-relief, or by extending credit lines, partial risk guarantees, loans, bulk procurement opportunities, etc... The stakeholders should be encouraged to procure the transformers based on the total cost of ownership over a transformer's lifetime, rather than on the first procurement cost.

Environmental and Health:

These considerations are crucial given that mineral oil and resin based solid insulating materials are environmentally hazardous and toxic substances that must be substituted by other suitable alternatives in the transformers. Spread of contaminants from such materials must be prevented by development of a legal framework for recycling and recovery, concept of circularity. In fact, the European Union (EU) in its Green Deal and the new Circular Economy Action Plan is strongly recommending achievement of energy transition with maximum resource efficiency by the systematic assessment of material efficiency and recyclability in product design.

This guidebook aims to encourage the policymakers for promoting energy efficient distribution transformers in the market by using integrated policy approach, which has been used around the world to bring about sustainable market transformations.

8 Conclusion

This guidebook is aimed at becoming Decision Maker's Guide for understanding larger issues, beyond cost factor alone, involved parameters encompass other facets such as, Safety without compromise, Total Cost of Ownership, Capital Utilisation, End of life disposal issues, Sustainability, Carbon-footprint calculations and Corporate Responsibility towards Climate Change etc. in a wholistic manner.

Policy measures are urgently needed to accelerate adoption of energy-efficient transformers. The fact that 13 of the largest economies in the world already regulate these products is a sign that transformers present a compelling opportunity for saving energy and money.

On a life-cycle cost basis, an energy-efficient transformer is very appealing given its on-top operation and 25+ years of service life. These savings translate into reductions in peak loading, lower electricity bills and greater reliable of supply. Payback periods vary with the equipment and electricity costs and can be as short as one year or as long as six years or more, depending on how ambitious the government wishes to be with the regulation.

For transformers, a six-year payback on a product that typically lasts for more than 25 years is still very attractive.

References

(1) Central Electricity Authority (Measures relating to Safety and Electric Supply) Regulations – 2010.

(2) National Building Code, 2016, Bureau of Indian Standards

(3) Eco-Niwas Samhita 2021 (Code Compliance and Part-II: Electro-Mechanical and Renewable Energy Systems)

(4) IS:1646-2015 (Reaffirmed 2020) - Code of Practice for Fire Safety of Buildings – General: Electrical Installations).

(5) IS:1180-2014, Outdoor Type Oil Immersed Distribution Transformers up to and including 2500 kVA, 33kV – Specification, Part 1 Mineral Oil Immersed (previous Part 1 and Part 2 combined in one standard).

(6) IS:1180 (Part 3) Outdoor/Indoor Type Liquid Immersed Distribution Transformers up to and including 2500 kVA, 33kV Specification – Natural/Synthetic Organic Ester Liquid Immersed.

(7) IS:11171-1985 (Reaffirmed 1996), Specification for Dry-Type Power Transformers.

(8) IS 13503-2013 IEC 61039-2008 Classification of Insulating Liquids.

(9) IS 16081-2013 IEC 61099-2010 Insulating Liquids - Specifications for Unused Synthetic Organic Esters for Electrical Purposes.

(10) IS 16659-2017 IEC 62770-2013 Fluids for Electrotechnical Applications - Unused Natural Esters for Transformers and Similar Electrical Equipment

(11) IEC TS 60076-20, 2017, 'Power Transformers, Part 20 Energy Efficiency'

(12) Energy Conservation Building Code – 2017 (Amended 2020) – ministry of Power, Bureau of Energy Efficiency

(13) Transforming the Transformer – How Your Key Asset Can Be Your Best Asset Through Active Repair? – IACI 2017

(14) Medium Power Transformer Recyclability – Fact Sheet – European Copper Institute

(15) A Guide to using TCO when Purchasing Distribution Transformers – 2022, United for Energy, UN Environment Programme

(16) Transformer Ageing: Monitoring and Estimation Techniques (IEEE Press), Tapan Kumar Saha, Prithwiraj Purkait

Annexure - I

Table 3 Maximum Total Losses up to Three-phase 11kV Class Transformers (Clauses 6.8.1.1, 6.8.1.2, 6.8.1.3 and 6.8.2)

Rating (kVA)	Impedance (Percent)	Maximum Total Loss (W)									
		Energy Efficiency Level 1		Energy Efficiency Level 2		Energy Efficiency Level 3		Energy Efficiency Level 4		Energy Efficiency Level 5	
		50% Load	100% Load	50% Load	100% Load	50% Load	100% Load	50% Load	100% Load	50% Load	100% Load
16	4.5	135	440	120	400	108	364	97	331	87	301
25	4.5	190	635	175	595	158	541	142	493	128	448
63	4.5	340	1140	300	1050	270	956	243	870	219	791
100	4.5	475	1650	435	1500	392	1365	352	1242	317	1130
160	4.5	670	1950	570	1700	513	1547	462	1408	416	1281
200	4.5	780	2300	670	2100	603	1911	543	1739	488	1582

Table Maximum Total Losses up to Three-phase 11kV Class Transformers (Clauses 7.8.1.1)

Rating (kVA)	Impedance (Percent)	Maximum Total Loss (W)									
		Energy Efficiency Level 1		Energy Efficiency Level 2		Energy Efficiency Level 3		Energy Efficiency Level 4		Energy Efficiency Level 5	
		50% Load	100% Load	50% Load	100% Load	50% Load	100% Load	50% Load	100% Load	50% Load	100% Load
250	4.50	980	2930	920	2700	864	2488	811	2293	761	2113
315	4.50	1025	3100	955	2750	890	2440	829	2164	772	1920
400	4.50	1225	3450	1150	3330	1080	3214	1013	3102	951	2994
500	4.50	1510	4300	1430	4100	1354	3909	1282	3727	1215	3554
630	4.50	1860	5300	1745	4850	1 637	4438	1536	4061	1441	3717
800	5.00	2287	6403	2147	5838	2015	5323	1892	4853	1776	4425
1000	5.00	2790	7700	2620	7000	2460	6364	2 310	5785	2170	5259
1250	5.00	3300	9200	3220	8400	3142	7670	3066	7003	2991	6394
1600	6.25	4200	11800	3970	11300	3753	10821	3547	10363	3353	9924
2000	6.25	5050	15000	4790	14100	4543	13254	4309	12459	4088	11711
2500	6.25	6150	18500	5900	17500	5660	16554	5430	15659	5209	14813

Annexure – II

Table 9 Maximum Total Losses up to Single-phase 11kV Class Transformers (Clauses 8.8.1.1, 8.8.1.2 and 8.8.1.3)

Rating (kVA)	Impedance (Percent)	Maximum Total Loss (W)									
		Energy Efficiency Level 1		Energy Efficiency Level 2		Energy Efficiency Level 3		Energy Efficiency Level 4		Energy Efficiency Level 5	
		50% Load	100% Load	50% Load	100% Load	50% Load	100% Load	50% Load	100% Load	50% Load	100% Load
5	2.50	35	95	30	75	27	68	24	62	21	57
10	4.00	60	170	55	150	50	135	45	122	40	112
16	4.00	82	224	63	190	58	175	54	164	50	145
25	4.00	110	300	95	260	88	240	80	225	74	210
50	4.00	210	590	190	520	177	480	160	451	148	420
75	4.00	310	880	285	780	265	720	242	670	223	625
100	4.00	410	1140	375	1030	350	964	320	900	299	842

Eco Niwas Samhita by BEE (Code Compliance and Part-II: Electro-Mechanical and Renewable Energy Systems)

Table 6: Permissible Limit for Dry Type Transformers

Rating kVA	Max. Losses at 50%loading W*	Max. Losses at 100% loading W*	Max. Losses at 50% loading W*	Max. Losses at 100% loading W*
	Up to 22 kV class		33 kV class	
100	940	2400	1120	2400
160	1290	3300	1420	3300
200	1500	3800	1750	4000
250	1700	4320	1970	4600
315	2000	5040	2400	5400
400	2380	6040	2900	6800
500	2800	7250	3300	7800
630	3340	8820	3950	9200
800	3880	10240	4650	11400
1000	4500	12000	5300	12800
1250	5190	13870	6250	14500
1600	6320	16800	7500	18000
2000	7500	20000	8880	21400
2500	9250	24750	10750	26500

*The values as per Indian Standard/BEE Standard & Labelling notification for dry type transformer corresponding to values in this table will supersede as and when the Indian standards/ BEE Standard & Labelling notification are published.

Annexure – VI

Total Cost of Ownership of 1250 kVA Transformer Using Losses and Present Value of Money						
1.0	Common factors considered in cost analysis					
1.1	"Discount" factor for relating future costs to present day dollars	I	=	8%	(assumed)	
1.2	Per unit cost of power	C_{kWh}	=	6.00	Rs./kWh	
1.3	No. of hours of year		=	8760	(365 days x 24 hrs)	
1.4	No. of hours in service during year		=	8000	hrs.	
1.5	Transformer technical data					
	Type of transformer considered			Mineral oil-immersed	Dry type	Ester oil-immersed
	Transformer capacity considered		=	1250	kVA (for all types)	
	Dimensions					
	Length	M	=	1.8	2.2	1.8
	Width	M	=	1.1	1.25	1.1
	Useful life of transformer	M	=	30	20	30
	Purchase Price of transformer	Rs.	=	2475000	2970000	2890000
1.6	Combined losses at 50% loading Level 1 (IS:1180-1-2014)			Mineral oil-immersed	Dry type	Ester oil-immersed
	Load Losses in kW	P_{LL50}	=	1.8	2.79	1.8
	No Load Losses in kW	P_{NL50}	=	1.5	2.4	1.5
	Total Losses in kW	P_{TNL50}	=	3.3	5.19	3.3
2.0	Costs of Transformer Losses - Transformer Energy Consumption (@ 50% load)					
				Mineral oil-immersed	Dry type	Ester oil-immersed
	Annual cost of transformer losses Rs,	C_{TL50}	=	158400	249120	158400
	Present Value (P.V.) of total losses for life time of transformer	PW_{TL50}	=	$C_{TL50} \times \frac{(1+i)^n - 1}{i(1+i)^n}$		
		Rs.	=	1783233	2445897	1783233
3.0	Additional cost of losses due to provision of cooling fans					
				Mineral oil-immersed	Dry type	Ester oil-immersed
	Nos. of cooling fan provided			NA	2	NA
	Rating of cooling fan	kW		NA	0.5	NA
	Annual hours of operation	Hrs		NA	8000	NA
	Annual energy consumption	kWh		NA	8000	NA
	Annual cost of losses due to cooling	C_{TLC50}	=	0.00	48000	0.00
	Total life time cost of losses due to forced cooling	Rs.	=	0	960000	0
4.0	Additional cost of footprint					
	Typical cost per square foot in Rs.	C_{FP}	=	1000	Rs. per m^2	
				Mineral oil-immersed	Dry type	Ester oil-immersed

	Space requirement for transformer	Length, m		1.8	2.2	1.8
		Width, m		1.1	1.25	1.1
	Clearances to be maintained on all sides	M		1	for all type of transformers	
	Space requirement for transformer footprint with clearances	Length, m		2.8	3.2	2.8
		Width, m		2.1	2.25	2.1
	Footprint area required	m^2		5.88	7.2	5.88
	Cost of area in Rs.			5880	7200	5880
5.0	Maintenance cost					
				Mineral oil-immersed	Dry type	Ester oil-immersed
	Percentage of purchase cost assumed for maintenance cost			3.0%	2.0%	2.0%
	Annual maintenance cost		=	74250	59400	57800
	Total life time cost of transformer losses		=	2227500	1188000	1734000
6.0	Circularity of materials and resources cost benefit					
				Mineral oil-immersed	Dry type	Ester oil-immersed
	Recoverable value of dielectric fluid					
	Insulating oil quantity considered	Liter	=	850	(Mfr. Leaflet)	
	Mineral oil quantity recovered @ Rs.25 per Liter	Rs.	=	21250	0	
	Ester oil quantity recovered @ Rs.50 per Liter	Rs.	=		0	42500
	Recoverable value of core and winding	Rs.	=	1020900	801900	1020900
	Recoverable value of tank and fittings	Rs.	=	594000	485000	594000
	Total cost of savings	Rs.	=	1636150	1286900	1657400
7.0	Total Life-cycle Cost or Total Ownership Cost					
				Liquid-immersed	Dry type	Ester oil-immersed
	Transformer purchase cost	Rs.		2475000	2970000	2890000
	Present Value (P.V.) of total losses for life time of transformer	Rs.		1783233	2445897	1783233
	Additional cost for forced cooling	Rs.		0	960000	0
	Cost of transformer footprint	Rs.		5880	7200	5880
	Maintenance cost	Rs.		2227500	1188000	1734000
	Cost of disposal of non-recoverable materials	Rs.		61875	297000	43350
	Total life time expenses			6553488	7868097	6456463
	Materials and resources benefit cost (Less)	Rs.		1636150	1286900	1657400
	Net total ownership cost	Rs.		4917338	6581197	4799063
8.0	Cost benefit	Rs.		1663859	Base	1782134

Check-list for Smart Selection of Transformers for Builders/Promoters

Sr. No.	Selection criterion	Verified
(i)	Compliance to the Statutory Regulations	
(ii)	Ensuring compliance to fire safety regulations and adherence to prescribed test protocol	
	(a) Provisions for all transformers installed indoor	
	(b) Provisions for liquid-immersed transformers in IS:1646-2015	
	(c) Provisions in CEA Safety Regulations for all transformer installations	
(iii)	Review of the State Utility requirements for the transformer/s	
(iv)	Location and provision for clear access	
(v)	Transformer installation footprint	
(vi)	Safety of human beings and installation as a whole	
(vii)	Plan for replacement and future development possibilities based on lifespan of transformers	
(viii)	Life cycle cost analysis – Total ownership cost analysed for all options	

Check-list for Smart Selection of Transformers for Electrical Consultants

Sr. No.	Selection criterion	Verified
(i)	Compliance to the Statutory Regulations	
(ii)	Ensuring compliance to fire safety regulations and adherence to prescribed test protocol	
	(a) Provisions for all transformers installed indoor	
	(b) Provisions for liquid-immersed transformers in IS:1646-2015	
	(c) Provisions in CEA Safety Regulations for all transformer installations	
(iii)	Review of the State Utility requirements for the transformers	
(iv)	Understanding distribution transformer types, comparison of characteristics vis-a-vis applications requirements	
(v)	Location and clear access provided	
(vi)	Environmental conditions and site conditions	
(vii)	Transformer installation footprint	
(viii)	Consideration of energy efficiency at different loads - Loading profile and load factor and losses	
(ix)	Insulation properties and failure	
(x)	Comparison of preventive maintenance and breakdown maintenance procedures	
	(a) Preventive maintenance	
	(b) Breakdown maintenance:	
(xi)	Impact on environment: Bio-degradation, disposal and circularity of transformer/s at end-of-life	
(xii)	Operating Sound Level and Noise Pollution and preventive measures	
(xiii)	Safety of human beings and installation as a whole	
(xiv)	Plan for replacement and future development possibilities based on lifespan of transformers	
(xv)	Life cycle cost analysis – Total ownership cost analysed for all options	

International Copper Association India
Copper Alliance

About Us

A member of Copper Alliance®, International Copper Association India (ICA India) works as the Indian arm of the International Copper Association Limited (ICA), the leading not-for-profit organization for the promotion of copper worldwide. ICA was set up in 1959 and has been working with the objective to grow the markets for copper based on its superior technical properties.

ICA India Programs are committed to improving the quality of life through better Electrical Safety, Energy Efficiency, Clean Energy and Sustainability. ICA India's efforts have been pivotal to advancing better standards, across various products, applications and industries, by leveraging upon the superior technical performance of Copper.

Our current initiatives aim to:

- Ensure safe and sustainable Buildings
- Drive awareness for good Power Quality
- Promote 5 mm Microgroove Copper Tube heat exchangers technology
- Promote greater adoption of Energy Efficient Motors and Pumps
- Improve reliability of distribution sector infrastructure and reduce distribution losses in Transformers
- Encourage Renewable Energy Technologies
- Promote safety & reliability in Electric Vehicles & Charging station

ICA India serves as a knowledge hub and drives its initiatives through various publications, seminars, workshops, and capacity building programs across India. The know-how and insights created through ICA India initiatives are shared freely and resources made available on its website and social channels. Digital campaigns by ICA India through its social channels also focus on consumer outreach to help them make informed choices for safer and sustainable solutions.

With a strong partner ecosystem, ICA India drives various advocacy initiatives to engage with Regulatory bodies, policy makers, and industry professionals across levels – decision makers to those working directly on the field.

ICA India is recognized as an expert knowledge partner and valuable collaborator by a variety of organizations including Regulatory bodies, Academic and Professional Institutions, Trade bodies, industries, and individuals as the end-users or domain experts. Research commissioned by ICA India and insights provided by its Program Managers and Associates is regularly sought by the country's leading policy building and standards development agencies.

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International Copper Association India

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The initiative is a joint effort of the International Copper Association (member of Copper Alliance), the Electrical and Electronics Institute (Thailand), the University of Bergamo (Italy) and other prominent organisations from Indonesia, Malaysia, Philippines and Vietnam. The initiative was established in 2008 with financial support from the European Union's Asia-Invest programme.

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Notes

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