Power Transformers

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In its simplest form, a power transformer is an apparatus for converting electrical power in an AC system at one voltage or current into electrical power at some other voltage or current without the use of rotating parts.

A transformer consists of three main parts:

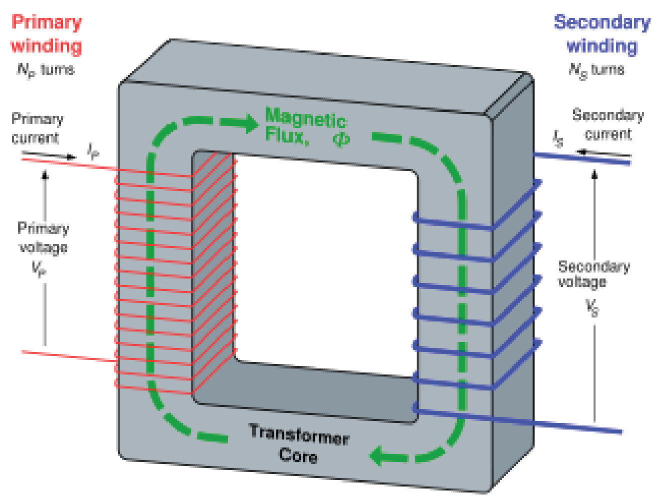
• the primary coil which carries the alternating current from the supply lines;

• the core of magnetic material in which is an alternating magnetic flux is produced; and

• the secondary coil in which an EMF is generated by the change of magnetism in the core which it surrounds.

Sometimes the transformer may have only one winding, which will serve the dual purpose of primary and secondary coils. The high tension winding comprises many turns of relatively fine copper wire, well insulated to withstand the voltage impressed on it. The low tension winding comprises relatively few turns of heavy copper wire capable of carrying considerable current at a low voltage.

Figure 1: An elementary transformer



(Courtesy of statemaster.com)

Winding of transformer

The primary winding is the winding of the transformer which is connected to the source of power. It may be either the high or the low voltage winding, depending upon the application of the transformer. The secondary winding is the winding of the transformer which delivers power to the load. It may be either the high or the low voltage winding, depending upon the application of the transformer. The core is the magnetic circuit upon which the windings are wound. The high tension winding is the one which is rated for the higher voltage. The low tension winding is the one which is rated for the lower voltage. A step up transformer is a constant voltage transformer so connected that the delivered voltage is greater than the supplied voltage. A step down transformer is one so connected that the delivered voltage is less than that supplied; the actual transformer may be the same in one case as in the other, the terms step up and step down relating merely to the application.

Until recently, all transformer cores were made up of stacks of sheet steel punchings firmly clamped together. Sometimes the laminations are coated with a thin varnish to reduce eddy current losses. When the laminations are not coated with varnish, a sheet of insulating paper is inserted between laminations at regular intervals.

A new type of core construction consists of a continuous strip of silicon steel which is wound in a tight spiral around the insulated coils and firmly held by spot welding at the end. This type of construction reduces the cost of manufacture and reduces the power loss in the core due to eddy currents.

Transformers are classified in many ways (named or described). These include:

• the method of cooling;
• the insulation between windings;
• the number of phases;
• the method of mounting;
• their purpose; and
• the service required.

The cooling of transformers is important. A certain amount of the electrical energy delivered to a transformer is transformed into heat energy because of the resistance of its windings and the hysteresis and eddy currents in the iron core. Consequently, a means must be provided for removing this heat energy from the transformer and dissipating it into the surrounding air. If this were not done in a satisfactory manner, the transformer would operate at an excessively high temperature, which would destroy or harm the insulation of the transformer.

There are many ways in which transformer can be cooled and it will depend on their application and the amount of heat generated that need to be dissipated as a result of the performance requirements. Typical cooling methods are: Self-air-cooled (dry type); Air-blast–

cooled (dry type); Liquid-immersed, self-cooled; oil-immersed, combination self-cooled and air-blast; oil-immersed, water-cooled; oil-immersed, forced-oil-cooled; and, oil-immersed, combination self-cooled and water-cooled. These cooling methods are not explained here.

The oil used in transformers performs two important functions. It serves to insulate the various coils from each other and from the core, and it conducts the heat from the coils and core to some cooler surfaces, where it is either dissipated in the surrounding air or transferred to some cooling medium. It is evident that the oil should be free from any conducting material, it should be sufficiently thin to circulate rapidly when subjected to differences of temperatures at different places, and it should not be ignitable until its temperature has been raised to a very high value. Although numerous kinds of oils have been tried in transformers, generally mineral oil is used. A good grade of transformer oil should show very little evaporation at 100°C, and it should not give off gases at such a rate as to produce an explosive mixture with the surrounding air at a temperature below 180°C.

Since the oil is a very important part of the insulation, every effort is made in modern transformers to preserve both its insulating and cooling qualities. Oxidation and moisture are the chief causes of deterioration. Oil takes into solution about 15 percent by volume of whatever gas is in contact with it. In the open-type transformer, oil rapidly darkens, owing to the effects of oxygen in solution in the oil and the oxygen in contact with the top surface of the hot oil.

One of the first devices used to reduce oxidation was the expansion tank (or conservator), which consisted of a small tank mounted above and connected with the main tank by means of a constricted connection; so that the small tank could act as a reservoir to take up the expansion and contraction of the oil due to temperature changes and reduce the oil surface exposed to air. This is the drum/cylinder that can be seen on transformers, generally on the top of them.

A second less common type is the Inertaire transformer. This transformer has the space above the oil in the tank filled with a cushion of inert gas which is mostly nitrogen. The nitrogen atmosphere is initially blown in from a cylinder of compressed nitrogen and is thereafter maintained by passing the inbreathing air through materials which remove the moisture and the oxygen, permitting dry nitrogen to pass into the case.

Figure 2: Typical Transformer

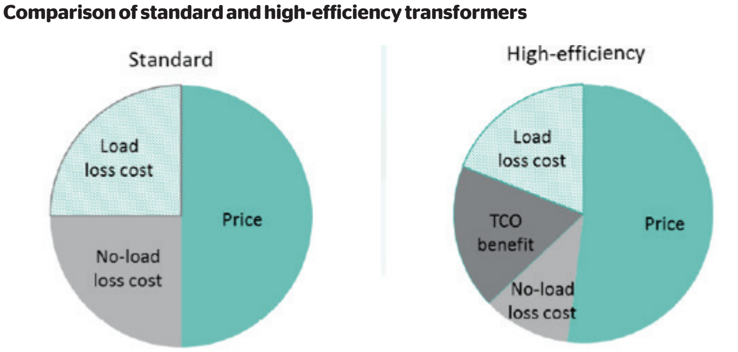
Figure 2 above shows a typical power transformer with expansion tank, this would be fairly typical of a local power distribution transformer.

Two or more windings

The great majority of transformers are constructed with two or more windings which are electrically insulated from each other. In some cases a single winding is employed, parts of the winding functioning as both primary and secondary. These transformers are called autotransformers. They are frequently used when the voltage ratio is small, say voltages in the 220-230-240 V range. Autotransformers should never be used for high voltage ratios, as the low-voltage winding is not insulated from the high-voltage one, so that in case of trouble it would be dangerous to both life and equipment.

The winding has at least three taps where electrical connections are made. Since part of the winding does double duty, autotransformers have the advantages of often being smaller, lighter, and cheaper than typical dual winding transformers, but the disadvantage of not providing electrical isolation between primary and secondary circuits. Other advantages of autotransformers include lower leakage reactance, lower losses, lower excitation current, and increased KVA rating for a given size and mass.

Comparison of standard and high-efficiency transformers



Other aspects that should be understood of transformers are:

• **transformer insulation**;
1) Its bearing on the size and operating temperature
2) There are different classes of insulation with different properties.

• **transformers are built in both single- and polyphase units**;
1) they comprise separate insulated electric windings for the different phases;
2) certain portions are common to the different phases;
3) they generally comprise several one phase transformers with separate electric circuits but having certain magnetic circuits in common;
4) a three-phase transformer requires three times as much copper as the one-phase component transformer but less than 3 times as much iron.

• **methods of mounting or the construction arrangement**;
1) constructed with different types of metal enclosing structures to meet the requirements of different conditions of installation, e.g., designed for mounting on poles; platform type; underground transformers; vault transformers.

• **application of constant voltage transformers**;
1) raising the voltage of an electric transmission circuit so that energy can be transmitted for considerable distances.

• **transformer ratios**;
1) voltage ratio of a constant voltage transformer, i.e., the ratio of primary to secondary voltage, depends primarily upon the ratio of the primary to the secondary turns.

• **regulation of a transformer**;
1) change in secondary voltage from no load to full load;
2) regulation depends upon the design of the transformer and the power factor of the load

• **transformer ratings**;
1) rated at their kilovolt-ampere (kVA) outputs. If the load to be supplied by a transformer is at 100 percent power factor (pf), the kilowatt (kW) output will be the same as the kilovolt-ampere (kVA) output.

The efficiency of a transformer is, as with any other devices, the ratio of the output to input or, in other words, the ratio of the output to the output plus the losses. Specifically for a transformer it is

Copper loss of transformer

The copper loss of a transformer is determined by the resistances of the high tension and low tension windings and

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of the leads. It is equal to the sum of the watts of I2R losses in these components at the load for which it is desired to compute the efficiency.

The iron loss of a transformer is equal to the sum of the losses in the iron core. These losses consist of eddy or Foucault current losses and hysteresis losses. Eddy current losses are due to currents generated by the alternating flux circulating within each lamination composing the core, and they are minimized by using thin laminations and by insulating adjacent laminations with insulating varnish. Hysteresis losses are due to the power required to reverse the magnetism of the iron core at each alternation and are determined by the amount and the grade of iron used for the laminations for the core.

Different metrics may be used to assess the energy performance of a distribution transformer:

- maximum no-load and maximum losses at full load – this metric places two constraints on each design and is closest to that specified in the common test standards;
- maximum combined losses at a specified loading point – this metric, measured in watts, is the sum of the no-load losses and the load losses at the specified loading point and places a single constraint on the design;
- percent efficiency at a defined loading point – this metric is a single unit less value, percentage efficiency, representing the active power in watts delivered by the transformer to the load relative to the active power in watts drawn by it from the source;
- peak efficiency index (PEI) – this is a new index that was developed by a technical working group supporting the European Commission's analysis of regulations for power transformers. The equation for peak efficiency determines the highest efficiency value of any transformer design, irrespective of a specified loading point

It's worth considering just how important the value of the energy losses is to the total cost of ownership (whole life cost). For a typical standard efficiency distribution transformer the value of the losses is very similar to the purchase price whereas for a high efficiency amorphous design it is approximately a third less.

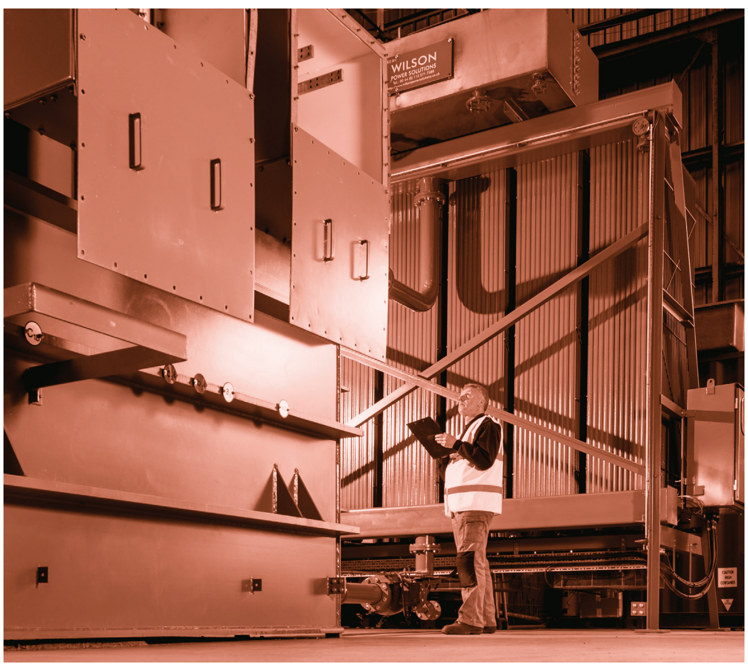
Target transformer efficiency

Many economies have developed policies that target the efficiency of the transformers directly. Minimum energy performance standards (MEPS) are one of the most powerful tools to ensure

Timeline	
Oct 2009	EU adopted revised "Ecodesign Directive" (2009/125/EC) for Energy-related products – establishing a framework to be complemented by "implementing measures" (E.Q. regulations on individual products and systems)
June 2014	EU commission adopted a regulation to apply the defined Ecodesign requirements on transformers and the regulation 548/2014 entered into force
July 2015	Transformers need to be compliant with the efficiency requirements of "Tier 1" – level of the regulation
2017	Mid-term assessment of the regulation by the European Commission
2021	Transformers need to be compliant with the efficiency requirements of "Tier 2" – level of the regulation

that energy efficient transformers are taken-up in the market. These mandatory regulations prohibit the sale of transformers that fail to meet or exceed specified minimum energy performance requirements. MEPS can help to facilitate a shift to higher levels of efficiency, particularly when they are combined with supporting policies including financial incentives and communications programmes, and with monitoring, verification and enforcement activities to ensure regulatory compliance. Some 12 economies have currently adopted MEPS for transformers, another seven have adopted mandatory energy labelling requirements and five have adopted voluntary energy labelling. The minimum standards for transformers in place in the UK came into practice in June 2014 (with transition period to July 2015). A second improvement date (tier 2) is set for 2021.

This MEPS has come from Working document on a Commission Regulation implementing Directive 2009/125/EC with regard to small, medium and large power transformers. This stemmed from supplier feedback from key transformer manufacturers in both Europe and the US who stated that the losses associated with distribution transformers can technically be reduced by between 30



and 40 per cent below current levels (in 2008). This increase in energy efficiency has a big impact on the cost per unit for the transformer (Department for Environment, Food and Rural Affairs report March 2013).

This became the Directive 2009/125/EC which established eco-design requirements related to small, medium and large power transformers with a minimum power rating of 1 kVA used in 50Hz electricity transmission and distribution.

Transformers are seen as one of the energy related product (ERP) priority groups within the EU with considerable energy saving potential. Consequently, the European Commission has set as a legal framework the regulation No. 548/2014 which states the minimum efficiency levels of transformers. The aim of the regulation is to prevent non-efficient products from being placed into the European market.

Savings upwards of 8 per cent

With the new regulations on transformer design and with the potential to match the sizes closer to the requirements in a building or a facility, energy/building managers may see savings of upwards of 8 per cent by replacing older transformers. To consider this, the following should be carried out:

- an evaluation of the energy demand (in most cases this can be done through half hourly data from a supplier);
- a review of the life expectancy of the transformer in situ;
- a review of the size of the transformer to give approximate idea of loading and consequently the efficiency at those loading; and
- proposed options of new transformer sizes.

In some circumstances an integrated unit with voltage optimisation (or two separate units) may be appropriate but this should be reviewed in isolation as well as together to form a more robust understanding of the potential.

Further information

1) ABB: Energy efficient transformer solutions European Minimum Energy Performance Standard (MEPS)
2) DEFRA report: Estimating energy saving potential from transformers and evaluating their impact on the feasibility of renewable energy systems
3) EU Commission Regulation 548/2014 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers.

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ENTRY FORM

TRANSFORMER TECHNOLOGY

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

QUESTIONS

1. A transformer is used to

- ☐ Drop or increase the current in power systems
- ☐ Regulate the current in power systems
- ☐ Transmitted electricity over long distances
- ☐ Drop or increase the voltage in power systems

2. The primary winding in a transformer is

- ☐ Connected to the source of power
- ☐ Delivers power to the load
- ☐ Core of magnetic material
- ☐ Made up of stacks of sheet steel punchings

3. Cooling is important in power transformers as

- ☐ It prevent loss in performance of the insulation materials
- ☐ It prevents failures in the electrical components
- ☐ It ensures the effectiveness of the transformer
- ☐ All of the above

4 Oil is used in most transformers to

- ☐ Cool and insulate
- ☐ Cool and reduce noise
- ☐ Reduce noise and insulate
- ☐ Insulate and lubricate

5. What does MEPS stand for

- ☐ Minimum Energy Performance System
- ☐ Minimum Energy Performance Standard
- ☐ Maximum Energy Performance System
- ☐ Maximum Energy Performance Standard

6. How many different metrics are there for assessing the energy performance of a distribution transformer?

☐ 3 ☐ 4 ☐ 5 ☐ 6

7. A high efficiency amorphous design transformer is approximately

- ☐ 10% less than previous standard transformer
- ☐ 25% less than previous standard transformer
- ☐ 33% less than previous standard transformer
- ☐ 40% less than previous standard transformer

8. When did the Tier 1 of the eco design directive come into place?

☐ 2009 ☐ 2014 ☐ 2015 ☐ 2017

9. When is the Tier 2 of the eco design directive come into place?

☐ 2015 ☐ 2017 ☐ 2018 ☐ 2021

10. It was suggested back in 2008 that transformer performance could be improved by how much through better design?

☐ 10-15% ☐ 15-20%
☐ 20-30% ☐ 30-40 per cent

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