TRANSFORMER

A transformer is an electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. Commonly, transformers are used to increase or decrease the voltages of alternating current in electric power applications.

The windings consist of the current-carrying conductors wound around the sections of the core, and these must be properly insulated, supported and cooled to withstand operational and test conditions.
The terms winding and coil are used interchangeably in this discussion. Copper and aluminium are the primary materials used as conductors in power-transformer windings.

While aluminium is lighter and generally less expensive than copper, a larger cross section of aluminium conductor must be used to carry a current with similar performance as copper. Copper has higher mechanical strength and is used almost exclusively in all but the smaller size ranges, where aluminium conductors may be perfectly acceptable.

The conductors used in power transformers are typically stranded with a rectangular cross section, although some transformers at the lowest ratings may use sheet or foil conductors. Multiple strands can be wound in parallel and joined together at the ends of the winding, in which case it is necessary to transpose the strands at various points throughout the winding to prevent circulating currents around the loop(s) created by joining the strands at the ends.

Individual strands may be subjected to differences in the flux field due to their respective positions within the winding, which create differences in voltages between the strands and drive circulating currents through the conductor loops.

Continuously transposed cable (CTC) - Proper transposition of the strands cancels out these voltage differences and eliminates or greatly reduces the circulating currents. A variation of this technique, involving many rectangular conductor strands combined into a cable, is called continuously transposed cable (CTC).

A varying current in the transformer's primary winding creates a varying magnetic flux in the transformer core and a varying magnetic field impinging on the transformer's secondary winding. This varying magnetic field at the secondary winding induces a varying electromotive force (EMF) or voltage in the secondary winding. Making use of Faraday's Law in conjunction with high magnetic permeability core properties, transformers can thus be designed to efficiently change AC voltages from one voltage level to another within power networks.

Since the invention of the first constant potential transformer in 1885, transformers have become essential for the AC transmission, distribution, and utilization of electrical energy. A wide range of transformer designs is encountered in electronic and electric power applications. Transformers range in size from RF transformers less than a cubic centimetre in volume to units interconnecting the grid weighing hundreds of tons.

Ideal Transformer

For simplification or approximation purposes, it is very common to analyse the transformer as an ideal transformer model. An ideal transformer is a theoretical, linear transformer that is loss less and perfectly coupled; that is, there are no energy losses and flux is completely confined within the magnetic core. Perfect coupling implies infinitely high core magnetic permeability and winding inductances and zero net magneto motive force.

Ideal transformer connected with source VP on primary and load impedance ZL on secondary, where $0 < ZL < \infty$

A varying current in the transformer's primary winding creates a varying magnetic flux in the core and a varying magnetic field impinging on the secondary winding. This varying magnetic field at the secondary induces a varying electromotive force (EMF) or voltage in the secondary winding. The primary and secondary windings are wrapped around a core of infinitely high magnetic permeability so that all of the magnetic flux passes through both the primary and secondary windings. With a voltage source connected to the primary winding and load impedance connected to the secondary winding, the transformer currents flow in the indicated directions.

Ideal transformer and induction law

According to Faraday's law of induction, since the same magnetic flux passes through both the primary and secondary windings in an ideal transformer, a voltage is induced in each winding. The primary EMF is sometimes termed counter EMF. This is in accordance with Lenz's law, which states that induction of EMF always opposes development of any such change in magnetic field.

The transformer winding voltage ratio is thus shown to be directly proportional to the winding turn’s ratio.

According to the law of Conservation of Energy, any load impedance connected to the ideal transformer's secondary winding results in conservation of apparent, real and reactive power.

Polarity

A dot convention is often used in transformer circuit diagrams, nameplates or terminal markings to define the relative polarity of transformer windings. Positively increasing instantaneous current entering the primary winding's dot end induces positive polarity voltage at the secondary winding's dot end.

Real transformer

Deviations from ideal

The ideal transformer model neglects the following basic linear aspects in real transformers.

Core losses, collectively called magnetizing current losses, consist of

- Hysteresis losses due to nonlinear application of the voltage applied in the transformer core, and
- Eddy current losses due to joule heating in the core that are proportional to the square of the transformer's applied voltage.

Whereas windings in the ideal model have no resistances and infinite inductances, the windings in a real transformer have finite non-zero resistances and inductances associated with:

- Joule losses due to resistance in the primary and secondary windings.
- Leakage flux that escapes from the core and passes through one winding only resulting in primary and secondary reactive impedance.