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Shri Vishweshwar Shikshan Prasarak Mandal's

Vishweshwarayya Abhiyantriki Padvika Mahavidhyalaya, Almala

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This is to certify that students of our institute from **First** year **Computer Engineering (CO2I)** have successfully completed the micro project report on "TRANSFORMER" of course **"ELEMENT OF ELECTRICAL ENGINEERING (22215)"** as part of curriculum by the Maharashtra State Board of Technical Education, Mumbai.

For partial fulfillment of "Diploma in Computer Engineering" during the academic year 2022-2023.

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Micro-Project Report On

TRANSFORMER

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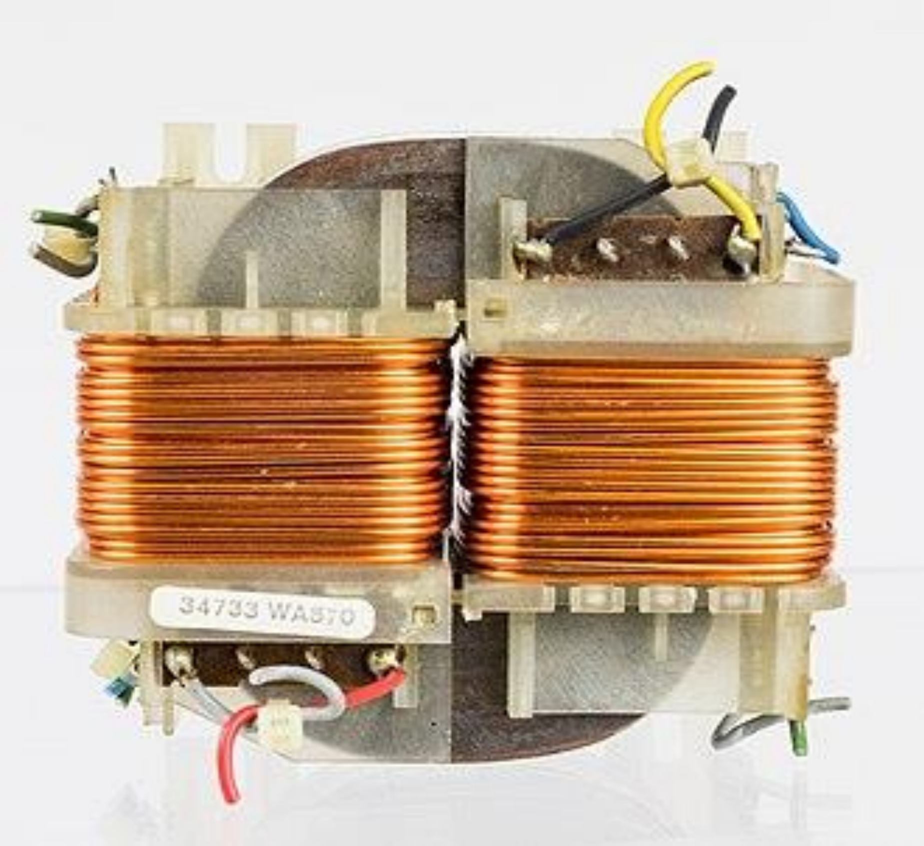
Academic Year 2022-23

Transformer

A **transformer** is a passive component that transfers electrical energy from one electrical circuit to another circuit, or multiple circuits. A varying current in any coil of the transformer produces a varying magnetic flux in the transformer's core, which induces a varying electromotive force (EMF) across any other coils wound around the same core. Electrical energy can be transferred between separate coils without a metallic (conductive) connection between the two circuits. Faraday's law of induction, discovered in 1831, describes the induced voltage effect in any coil due to a changing magnetic flux encircled by the coil.

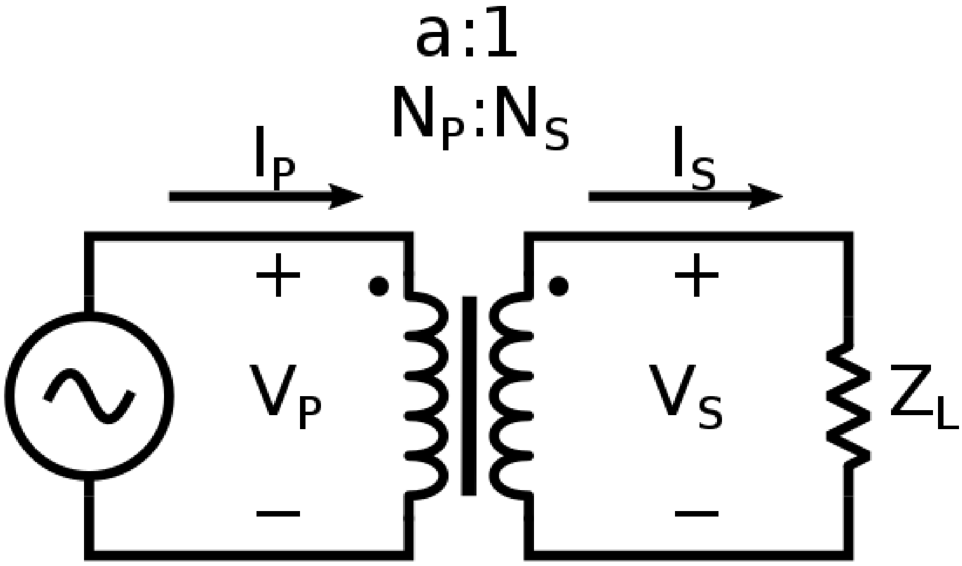
Transformers are used to change AC voltage levels, such transformers being termed step-up or step-down type to increase or decrease voltage level, respectively. Transformers can also be used to provide galvanic isolation between circuits as well as to couple stages of signal-processing circuits. Since the invention of the first constant-potential transformer in 1885, transformers have become essential for the transmission, distribution, and utilization of alternating current electric power. 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 centimeter in volume, to units weighing hundreds of tons used to interconnect the power grid.



Principles

Ideal transformer

An ideal transformer is linear, lossless and perfectly coupled Perfect coupling implies infinitely high core magnetic permability and winding inductance and zero net megnometive force (i.e. $i_p n_p - i_s n_s = 0$).

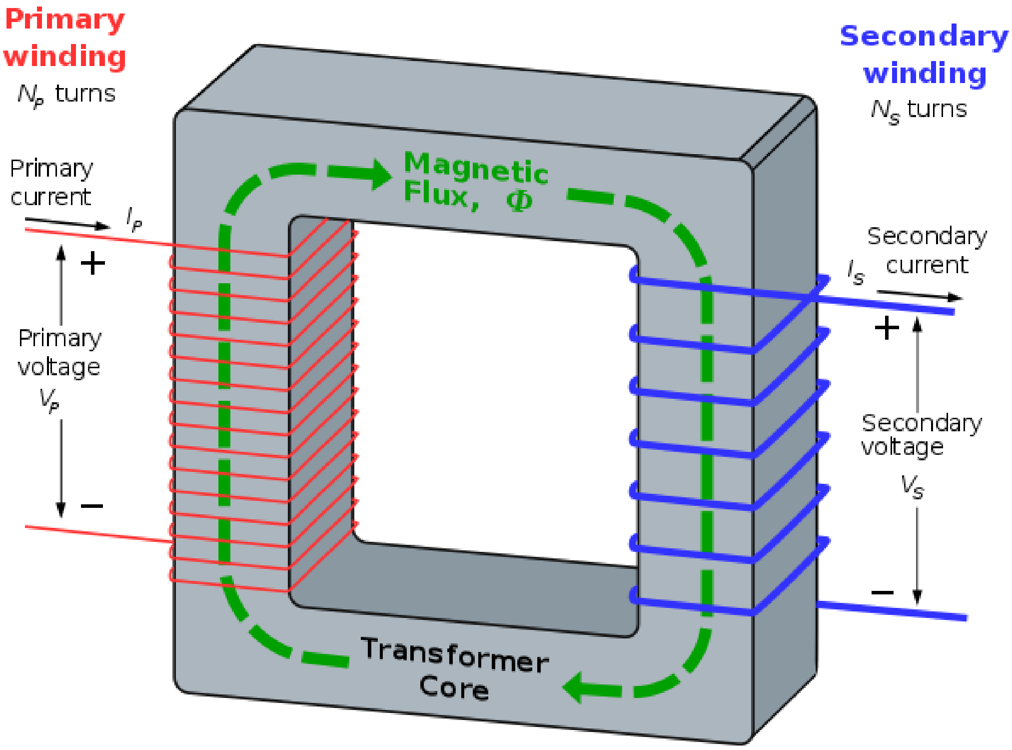


A varying current in the transformer's primary winding creates a varying magnetic flux in the transformer core, which is also encircled by the secondary winding. This varying flux at the secondary winding induces a varying electromotive force or voltage in the secondary winding. This electromagnetic induction phenomenon is the basis of transformer action and, in accordance with Lenz's law, the secondary current so produced creates a flux equal and opposite to that produced by the primary winding.

The windings are wound 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 a load connected to the secondary winding, the transformer currents flow in the indicated directions and the core magnetomotive force cancels to zero.

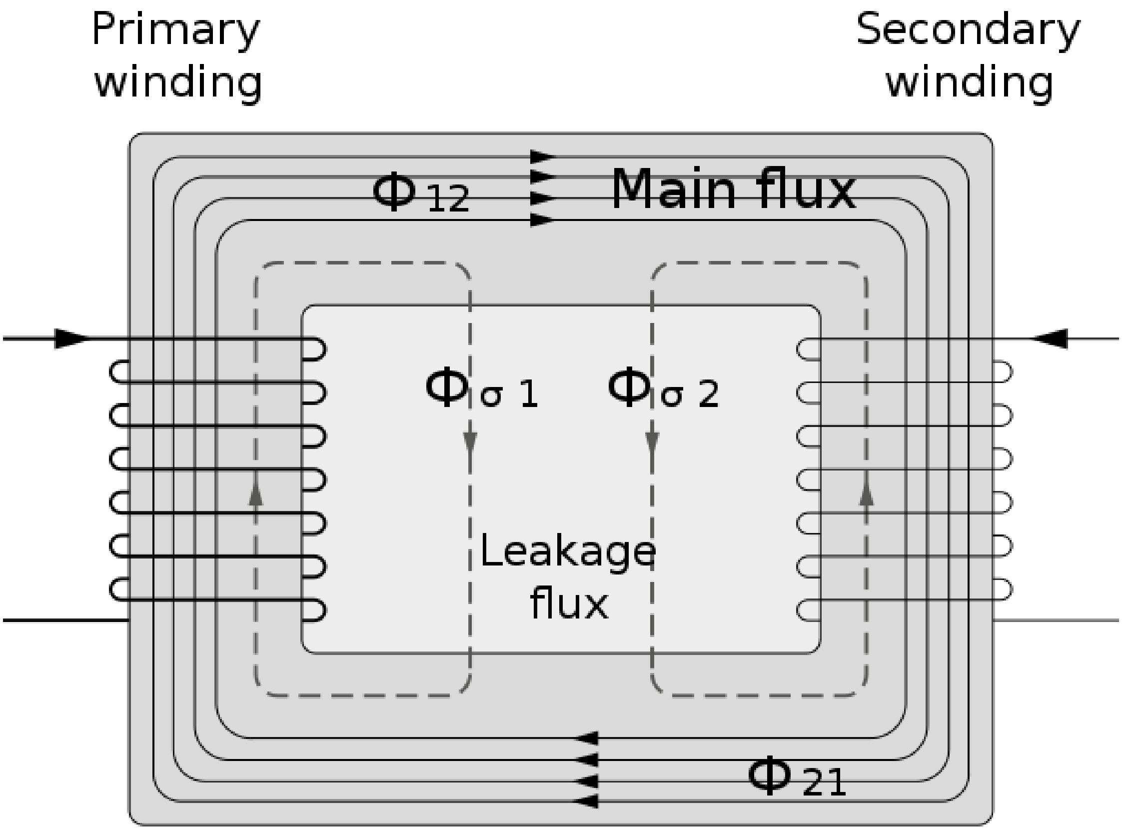
According to Faraday's law, since the same magnetic flux passes through both the primary and secondary windings in an ideal transformer, a voltage is induced in each winding proportional to its number of windings. The transformer winding voltage ratio is equal to the winding turns ratio.

An ideal transformer is a reasonable approximation for a typical commercial transformer, with voltage ratio and winding turns ratio both being inversely proportional to the corresponding current ratio.



The load impedance *referred* to the primary circuit is equal to the turns ratio squared times the secondary circuit load impedance.

Real transformer



Leakage flux of a transformer

Deviations from ideal transformer

The ideal transformer model neglects the following basic linear aspects of real transformers:

(a) Core losses, collectively called magnetizing current losses, consisting of Hysteresis losses due to nonlinear magnetic effects 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.

(b) Unlike the ideal model, the windings in a real transformer have 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.

(c) similar to an inductor, parasitic capacitance and self-resonance phenomenon due to the electric field distribution. Three kinds of parasitic capacitance are usually considered and the closed-loop equations are providedCapacitance between adjacent turns in any one layer;

- Capacitance between adjacent layers;
- Capacitance between the core and the layer(s) adjacent to the core;

Inclusion of capacitance into the transformer model is complicated, and is rarely attempted; the ‘real’ transformer model’s equivalent circuit shown below does not include parasitic capacitance. However, the capacitance effect can be measured by comparing open-circuit inductance, i.e. the inductance of a primary winding when the secondary circuit is open, to a short-circuit inductance when the secondary winding is shorted.

Leakage flux

The ideal transformer model assumes that all flux generated by the primary winding links all the turns of every winding, including itself. In practice, some flux traverses paths that take it outside the windings. Such flux is termed *leakage flux*, and results in leakage inductance in series with the mutually coupled transformer windings. Leakage flux results in energy being alternately stored in and discharged from the magnetic fields with each cycle of the power supply. It is not directly a power loss, but results in inferior voltage regulation, causing the secondary voltage not to be directly proportional to the primary voltage, particularly under heavy load. Transformers are therefore normally designed to have very low leakage inductance.

In some applications increased leakage is desired, and long magnetic paths, air gaps, or magnetic bypass shunts may deliberately be introduced in a transformer design to limit the short-circuit current it will supply. Leaky transformers may be used to supply loads that exhibit negative resistance , such as electric arcs,mercury and sodium por lamps and neon signs or for safely handling loads that become periodically short-circuited such as electric arc welders .:485

Air gaps are also used to keep a transformer from saturating, especially audio-frequency transformers in circuits that have a DC component flowing in the windings. A saturable rector exploits saturation of the core to control alternating current.

Knowledge of leakage inductance is also useful when transformers are operated in parallel. It can be shown that if the percent impedance and associated winding leakage reactance-to-resistance (*X*/*R*) ratio of two transformers were the same, the transformers would share the load power in proportion to their respective ratings. However, the impedance tolerances of commercial transformers are significant. Also, the impedance and X/R ratio of different capacity transformers tends to vary.

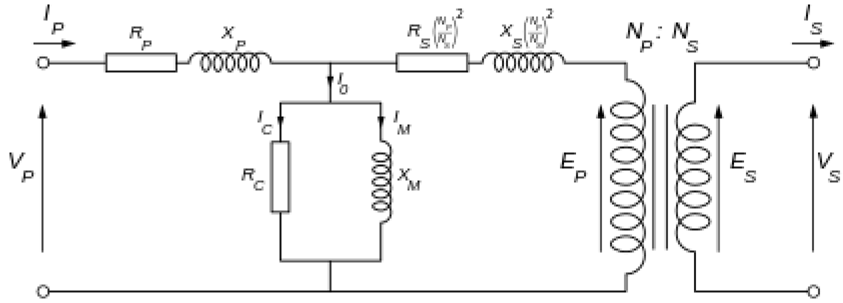
Equivalent circuit

Referring to the diagram, a practical transformer's physical behavior may be represented by an equivalent circuit model, which can incorporate an ideal transformer.

Winding joule losses and leakage reactances are represented by the following series loop impedances of the model:

- Primary winding: R_P, X_P
- Secondary winding: R_S, X_S.

In normal course of circuit equivalence transformation, R_S and X_S are in practice usually referred to the primary side by multiplying these impedances by the turns ratio squared, $(N_P/N_S)^2 = a^2$.



Real transformer equivalent circuit

Core loss and reactance is represented by the following shunt leg impedances of the model:

- Core or iron losses: R_C
- Magnetizing reactance: X_M.

R_C and X_M are collectively termed the *magnetizing branch* of the model. Core losses are caused mostly by hysteresis and eddy current effects in the core and are proportional to the square of the core flux for operation at a given frequency. :142–143 The finite permeability core requires a magnetizing current I_M to maintain mutual flux in the core. Magnetizing current is in phase with the flux, the relationship between the two being non-linear due to saturation effects. However, all impedances of the equivalent circuit shown are by definition linear and such non-linearity effects are not typically reflected in transformer equivalent circuits. 142 With sinusoidal supply, core flux lags the induced EMF by 90°. With open-circuited secondary winding, magnetizing branch current I_0 equals

Transformer no-load current.

Instrument transformer, with polarity dot and X1 markings on low-voltage ("LV") side terminal

The resulting model, though sometimes termed 'exact' equivalent circuit based on linearity assumptions, retains a number of approximations. Analysis may be simplified by assuming that magnetizing branch impedance is relatively high and relocating the branch to the left of the primary impedances. This introduces error but allows combination of primary and referred secondary resistances and reactances by simple summation as two series impedances.
Transformer equivalent circuit impedance and transformer ratio parameters can be derived from the following tests: open-circuit test, short-circuit test, , winding resistance test, and transformer ratio test.

Transformer EMF equation

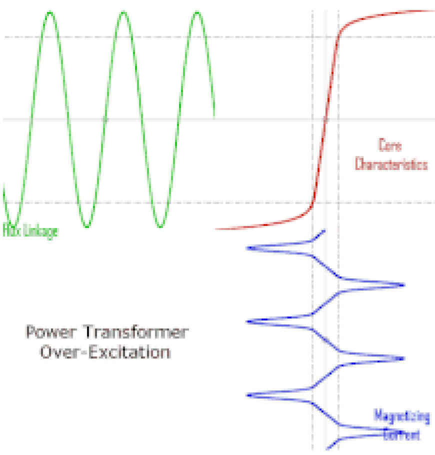
If the flux in the core is purely sinusoidal, the relationship for either winding between its rms **voltage** E_{rms} of the winding, and the supply frequency f, number of turns N, core cross-sectional area A in m^2 and peak magnetic flux density B_{peak} in Wb/m^2 or T (tesla) is given by the universal EMF equation:

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 exiting the secondary winding's ‘dot’ end. Three-phase transformers used in electric power systems will have a nameplate that indicate the phase relationships between their terminals. This may be in the form of a phasor diagram, or using an alpha-numeric code to show the type of internal connection (wye or delta) for each winding.

Effect of frequency

The EMF of a transformer at a given flux increases with frequency. By operating at higher frequencies, transformers can be physically more compact because a given core is able to transfer more power without reaching saturation and fewer turns are needed to achieve the same impedance. However, properties such as core loss and conductor skin effect also increase with frequency. Aircraft and military equipment employ 400 Hz power supplies which reduce core and winding weight. Conversely, frequencies used for some railway electrification systems were much lower (e.g. 16.7 Hz and 25 Hz) than normal utility frequencies (50–60 Hz) for historical reasons concerned mainly with the limitations of early electric traction motors . Consequently, the transformers used to step-down the high overhead line voltages were much larger and heavier for the same power rating than those required for the higher frequencies.



Power transformer overexcitation condition caused by decreased frequency; flux (green), iron core's magnetic characteristics (red) and magnetizing current (blue).

Operation of a transformer at its designed voltage but at a higher frequency than intended will lead to reduced magnetizing current. At a lower frequency, the magnetizing current will increase. Operation of a large transformer at other than its design frequency may require assessment of voltages, losses, and cooling to establish if safe operation is practical. Transformers may require protective relays to protect the transformer from overvoltage at higher than rated frequency.

One example is in traction transformers used for electric multiple unit and high speed train service operating across regions with different electrical standards. The converter equipment and traction transformers have to accommodate different input frequencies and voltage (ranging from as high as 50 Hz down to 16.7 Hz and rated up to 25 kV).
At much higher frequencies the transformer core size required drops dramatically: a physically small transformer can handle power levels that would require a massive iron core at mains frequency. The development of switching power semiconductor devices made switch-mode power supplies viable, to generate a high frequency, then change the voltage level with a small transformer.
Transformers for higher frequency applications such as SMPS typically use core materials with much lower hysteresis and eddy-current losses than those for 50/60 Hz. Primary examples are iron-powder and ferrite cores. The lower frequency-dependant losses of these cores often is at the expense of flux density at saturation. For instance, ferrite saturation occurs at a substantially lower flux density than laminated iron.

Large power transformers are vulnerable to insulation failure due to transient voltages with high-frequency components, such as caused in switching or by lightning.

Energy losses

Transformer energy losses are dominated by winding and core losses. Transformers' efficiency tends to improve with increasing transformer capacity. The efficiency of typical distribution transformers is between about 98 and 99 percent
As transformer losses vary with load, it is often useful to tabulate no-load loss , full-load loss, half-load loss, and so on. Hysteresis and eddy current losses are constant at all load levels and dominate at no load, while winding loss increases as load increases. The no-load loss can be significant, so that even an idle transformer constitutes a drain on the electrical supply. Designing energy efficiencient transformers for lower loss requires a larger core, good-quality silicon steel, or even amorphous steel for the core and thicker wire, increasing initial cost. The choice of construction represents a trade-off between initial cost and operating cost.

Transformer losses arise from:

Winding joule losses

Current flowing through a winding's conductor causes joule heating due to the resistance of the wire. As frequency increases, skin effect and proximity effect causes the winding's resistance and, hence, losses to increase.**Core losses**,**Hysteresis losses** Each time the magnetic field is

reversed, a small amount of energy is lost due to hysteresis within the core, caused by motion of the magnetic domains within the steel. According to Steinmetz's formula, the heat energy due to hysteresis is given by and, hysteresis loss is thus given by
where, *f* is the frequency, η is the hysteresis coefficient and β_{max} is the maximum flux density, the empirical exponent of which varies from about 1.4 to 1.8 but is often given as 1.6 for iron. For more detailed analysis, see Magnetic core and Steinmetz's equation.

Eddy current losses

Eddy current are induced in the conductive metal transformer core by the changing magnetic field, and this current flowing through the resistance of the iron dissipates energy as heat in the core. The eddy current loss is a complex function of the square of supply frequency and inverse square of the material thickness. Eddy current losses can be reduced by making the core of a stack of laminations (thin plates) electrically insulated from each other, rather than a solid block; all transformers operating at low frequencies use laminated or similar cores.

Magnetostriction related transformer hum

Magnetic flux in a ferromagnetic material, such as the core, causes it to physically expand and contract slightly with each cycle of the magnetic field, an effect known as magnetostriction, the frictional energy of which produces an audible noise known as mains hum or "transformer hum". This transformer hum is especially objectionable in transformers supplied at power frequencies and in high-frequency flyback transformers associated with television CRTS.

Stray losses

Leakage inductance is by itself largely lossless, since energy supplied to its magnetic fields is returned to the supply with the next half-cycle. However, any leakage flux that intercepts nearby conductive materials such as the transformer's support structure will give rise to eddy currents and be converted to heat.

Radiative

There are also radiative losses due to the oscillating magnetic field but these are usually small.

Mechanical vibration and audible noise transmission

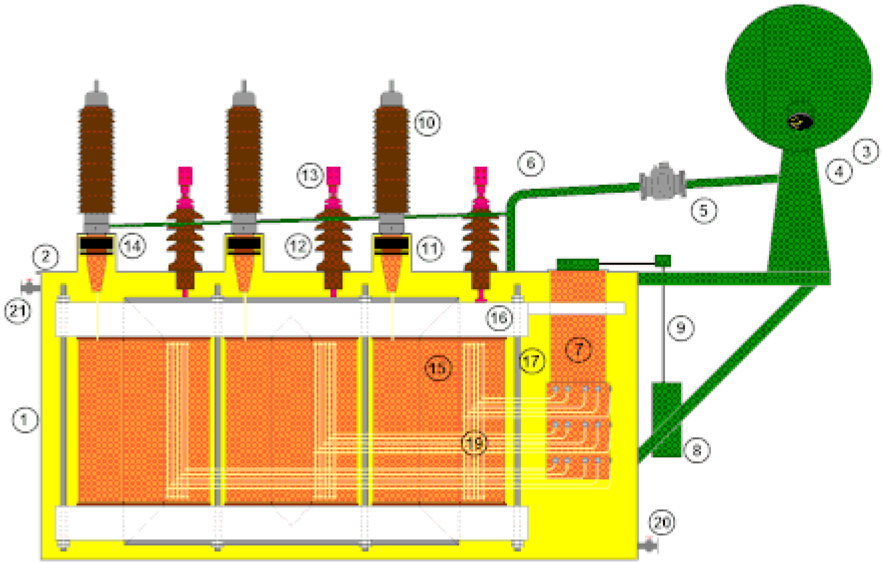
In addition to magnetostriction, the alternating magnetic field causes fluctuating forces between the primary and secondary windings. This energy incites vibration transmission in interconnected metalwork, thus amplifying audible transformer hum.

Applications

Various specific electrical application designs require a variety of transformer types.. Although they all share the basic characteristic transformer principles, they are customized in construction or electrical properties for certain installation requirements or circuit conditions.

In electric power transmission, transformers allow transmission of electric power at high voltages, which reduces the loss due to heating of the wires. This allows generating plants to be located economically at a distance from electrical consumers. All but a tiny fraction of the world's electrical power has passed through a series of transformers by the time it reaches the consumer. In many electronic devices, a transformer is used to convert voltage from the distribution wiring to convenient values for the circuit requirements, either directly at the power line frequency or through a switch mode power supply.

Signal and audio transformers are used to couple stages of amplifiers and to match devices such as microphones and record players to the input of amplifiers. Audio transformers allowed telephone circuits to carry on a two-way conversation over a single pair of wires. A balun transformer converts a signal that is referenced to ground to a signal that has balanced voltage to ground , such as between external cables and internal circuits. Isolation transformers prevent leakage of current into the secondary circuit and are used in medical equipment and at construction sites. Resonant transformers are used for coupling between stages of radio receivers, or in high-voltage Tesla coils.



Schematic of a large oil-filled power transformer 1. Tank 2. Lid 3. Conservator tank 4. Oil level indicator 5. Buchholz relay for detecting gas bubbles after an internal fault 6. Piping 7. Tap changer 8. Drive motor for tap changer 9. Drive shaft for tap changer 10. High voltage (HV) bushing 11. High voltage bushing current transformers 12. Low voltage (LV) bushing 13. Low voltage current transformers 14. Bushing voltage-transformer for metering 15. Core 16. Yoke of the core 17. Limbs connect the yokes and hold them up 18. Coils 19. Internal wiring between coils and tapchanger 20. Oil release valve 21. Vacuum valve