Transformers

Some history

Historically, the first electrical power distribution system developed by Thomas Edison in the 1880s was distributing DC. It was designed for low voltages (*safety and difficulties in voltage conversion*); therefore, high currents were needed to be generated and transmitted to deliver the necessary power. This system suffered significant energy losses!

Some history

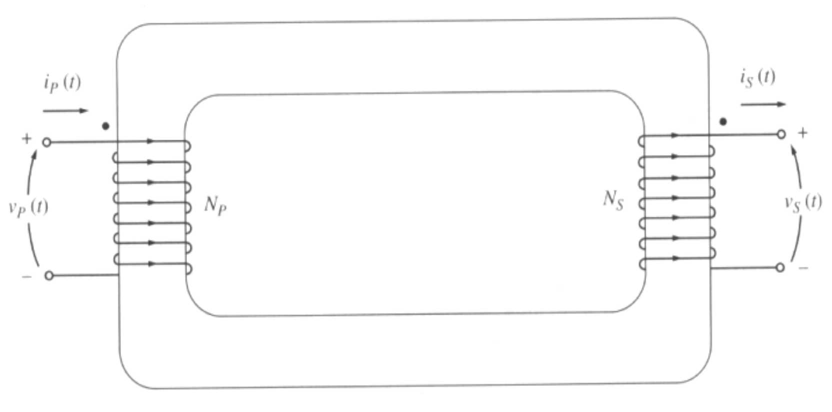
The second generation of power distribution systems was proposed by Nikola Tesla a few years later. His idea was to generate AC power of any convenient voltage, step up the voltage for transmission then step down its voltage for the end user. Since power loss is proportional to the square of the current transmitted, raising the voltage, say, by the factor of 10 would decrease the current by the same factor (to deliver the same amount of energy) and, therefore, reduce losses by factor of 100.

This step up and step-down voltage conversion was based on the use of Transformers.

Preliminary considerations

A Transformer is a device that converts one AC voltage to another AC voltage. It consists of one or more coil(s) of wire wrapped around a common ferromagnetic core. These coils are usually not connected electrically together. However, they are connected through the common magnetic flux confined to the core.

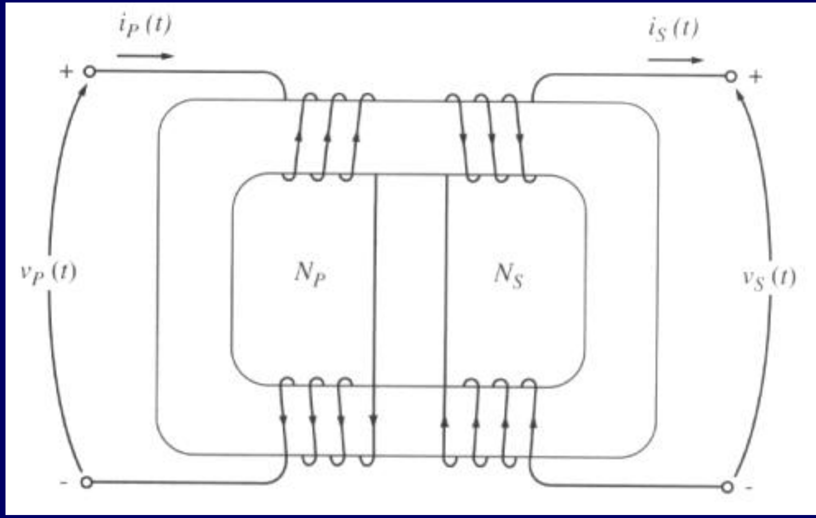
If the Transformer has at least two windings, one of them (primary) is connected to a source of AC power; the other (secondary) is connected to the load.



The invention of the Transformer can be attributed to Michael Faraday, who in 1831 used it to demonstrate electromagnetic induction, foreseen at the time to have no practical application. ☹

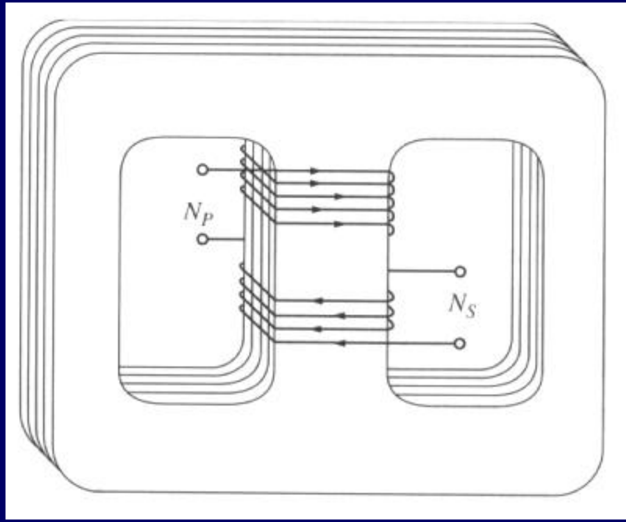
Types and construction

Core form



Windings are wrapped around two sides of a laminated square core.

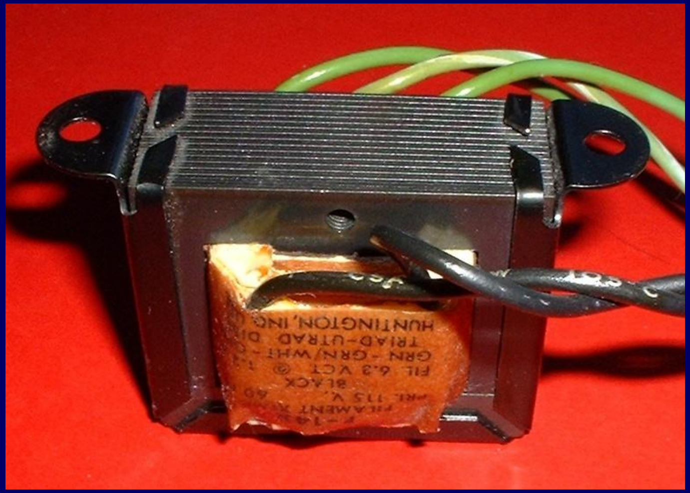
Shell form



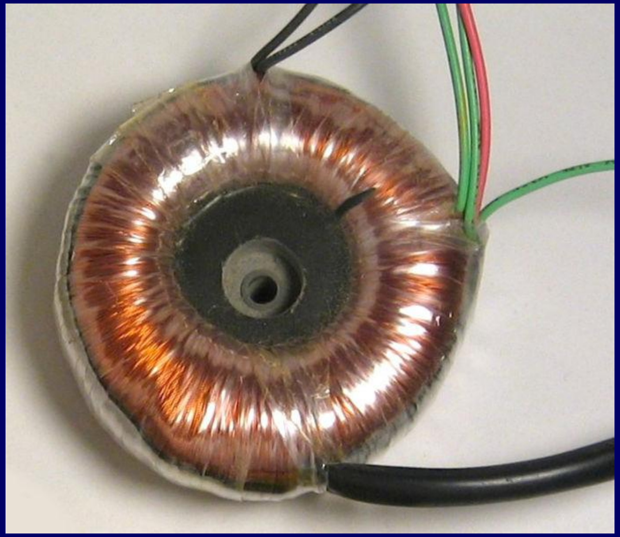
Windings are wrapped around the center leg of a laminated core.

Usually, windings are wrapped on top of each other to decrease flux leakage and, therefore, increase efficiency (Shell Form).

Types and construction



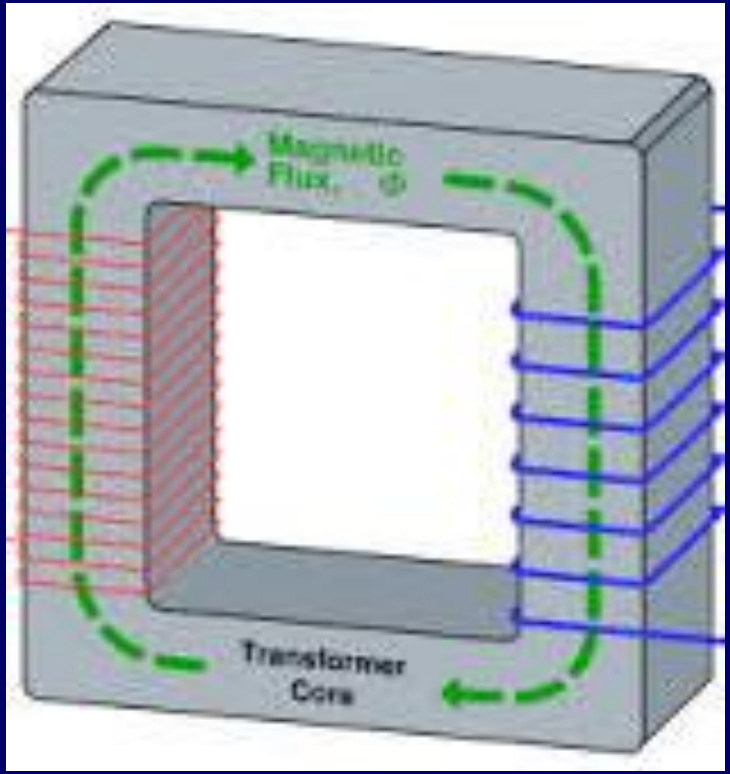
Laminated steel cores



Toroidal ferrite cores

Efficiency of Transformers with toroidal cores is usually higher.

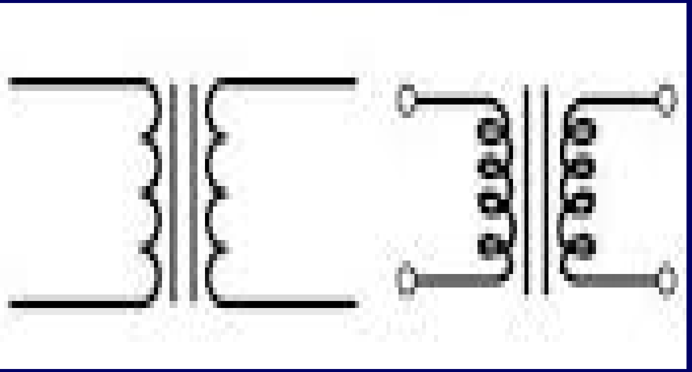
Double Wound/Isolating *(Mutual Induction)*



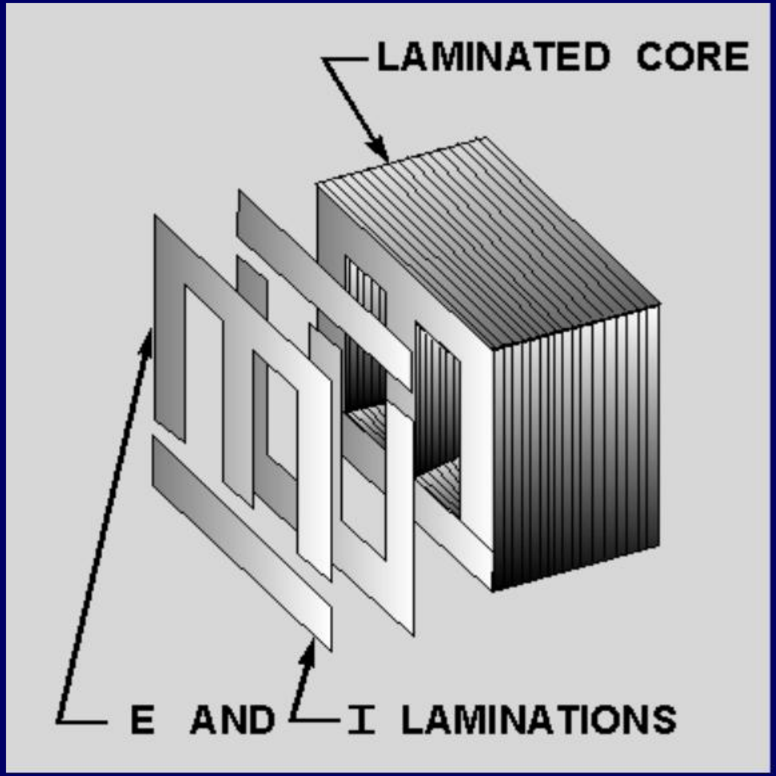
Primary Voltage

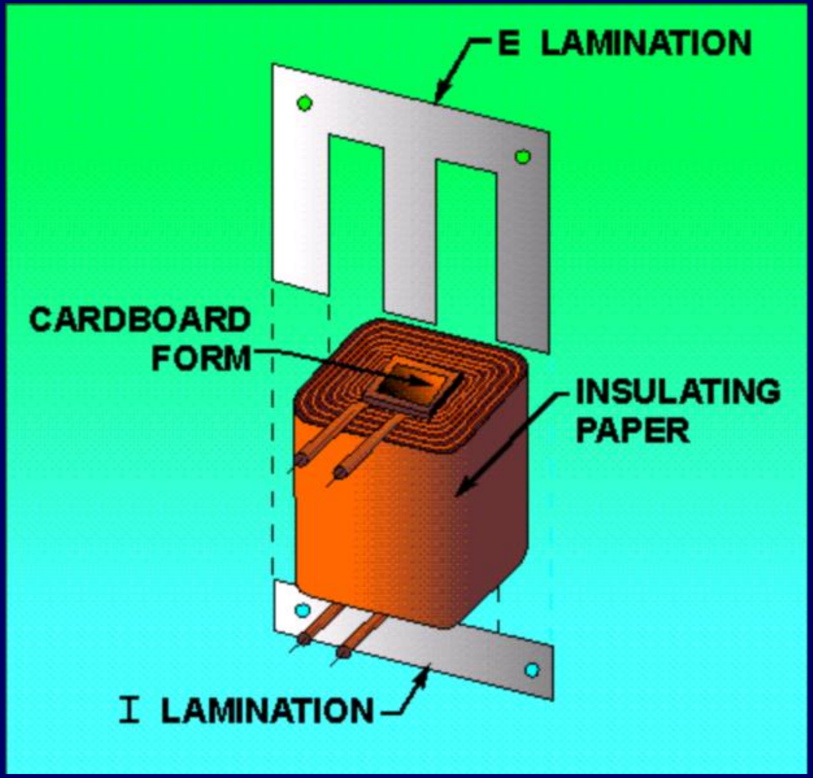
Secondary EMF

Double wound Transformer alternative Circuit Symbols



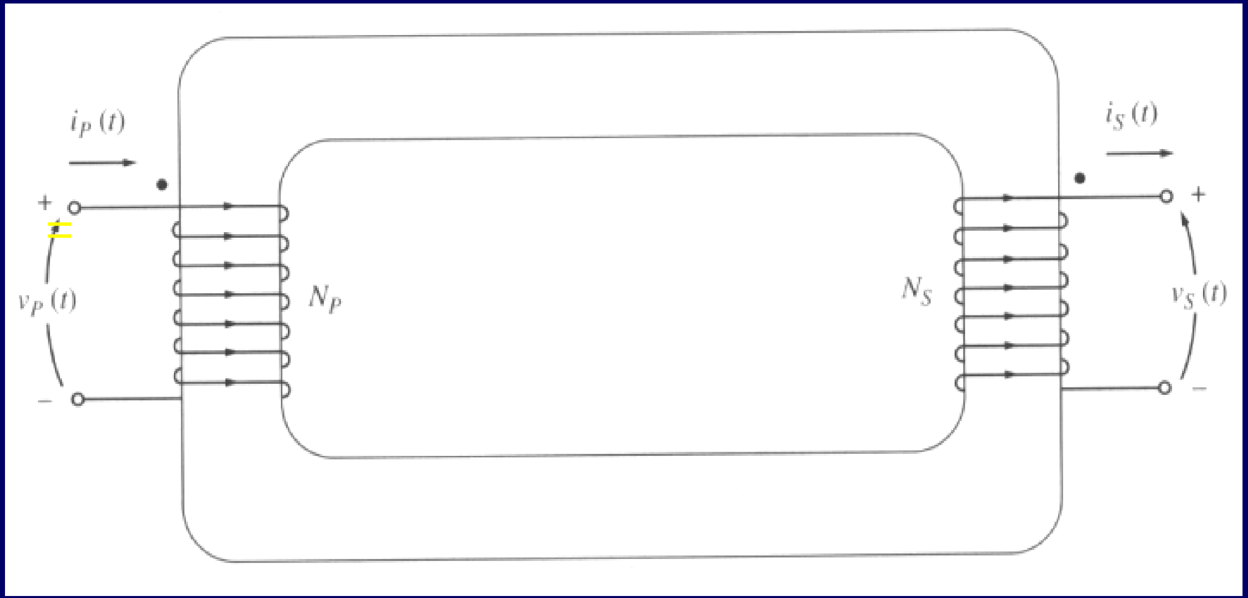
Shell type core construction





Ideal transformer

We consider a lossless Transformer with an input (primary) winding having N_p turns, and a secondary winding of N_s turns.



The relationship between the voltage applied to the primary winding v_p and the voltage produced on the secondary winding v_s is:

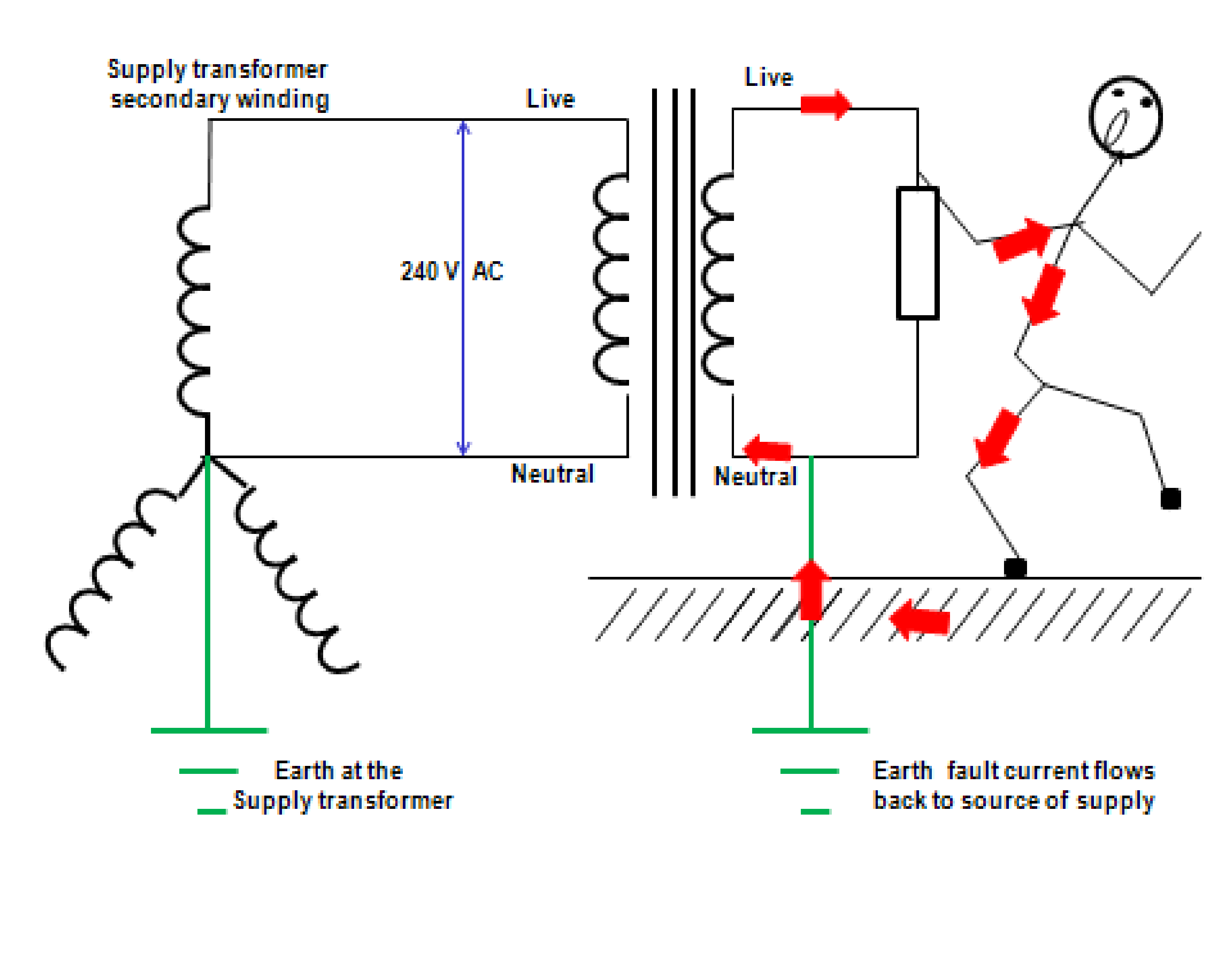
$$\frac{V_p}{V_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p}$$

The Transformer Equivalent circuit

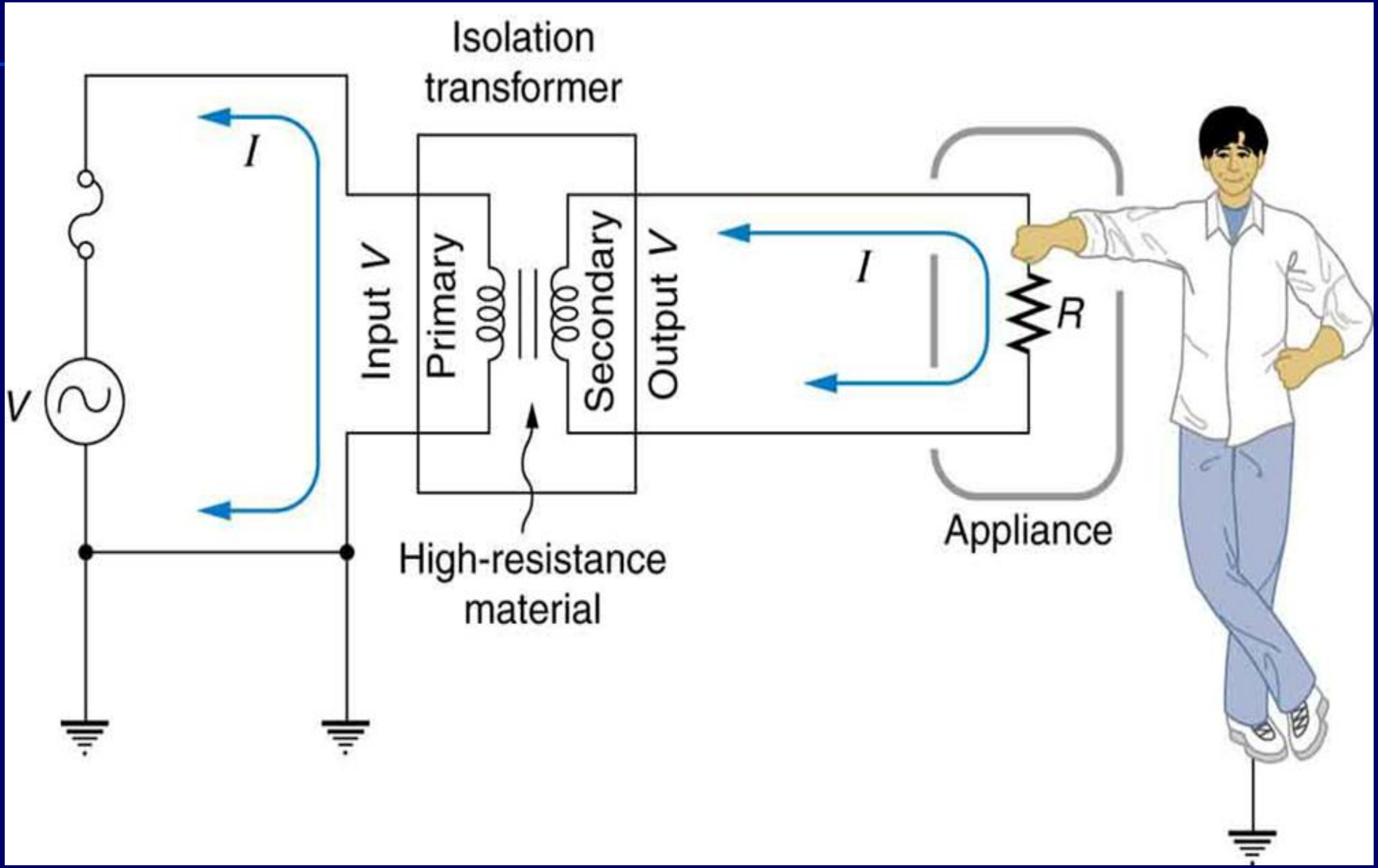
To model a real Transformer accurately, we need to account for the following losses:

1. Copper losses – resistive heating in the windings: I^2R.
2. Eddy current losses – resistive heating in the core: proportional to the square of voltage applied to the transformer.
3. Hysteresis losses – energy needed to rearrange magnetic domains in the core: nonlinear function of the voltage applied to the Transformer.
4. Leakage flux – flux that escapes from the core.

Double Wound

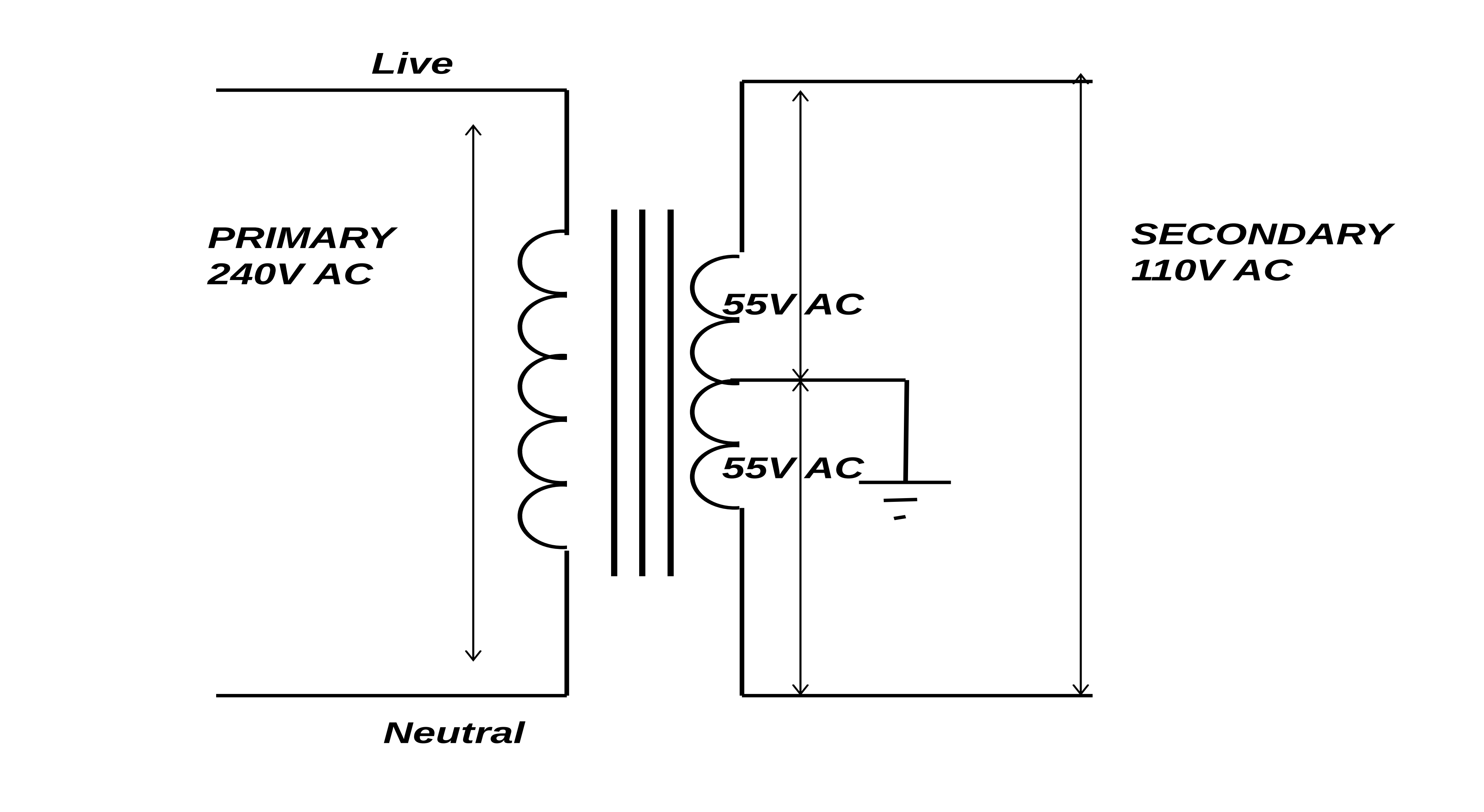


Double Wound/Isolating



Safety Transformer

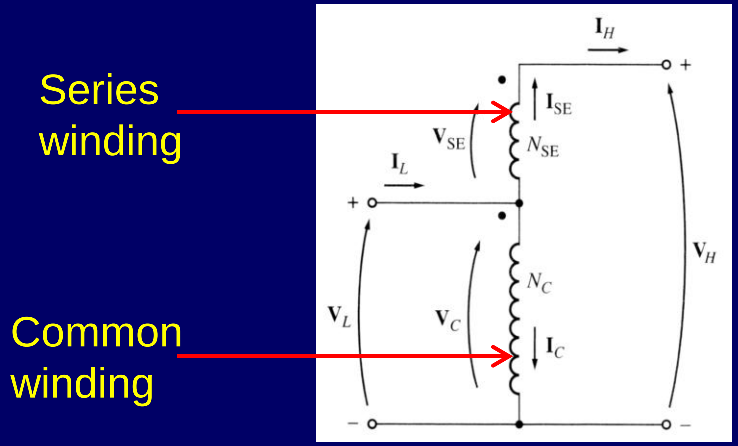
Safety Transformer

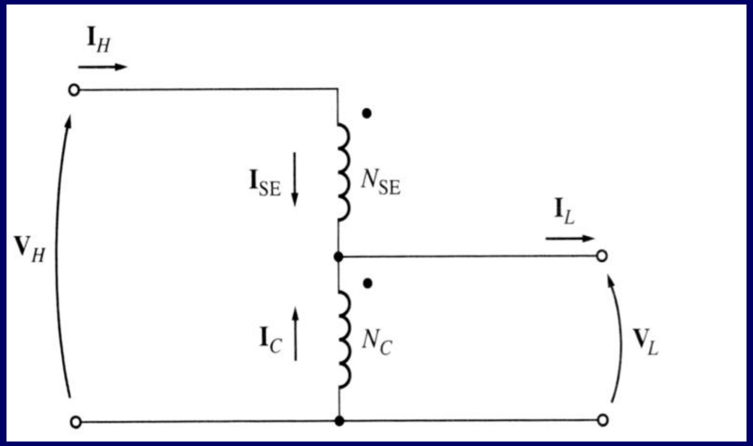


The Autotransformer *(Self Induction)*

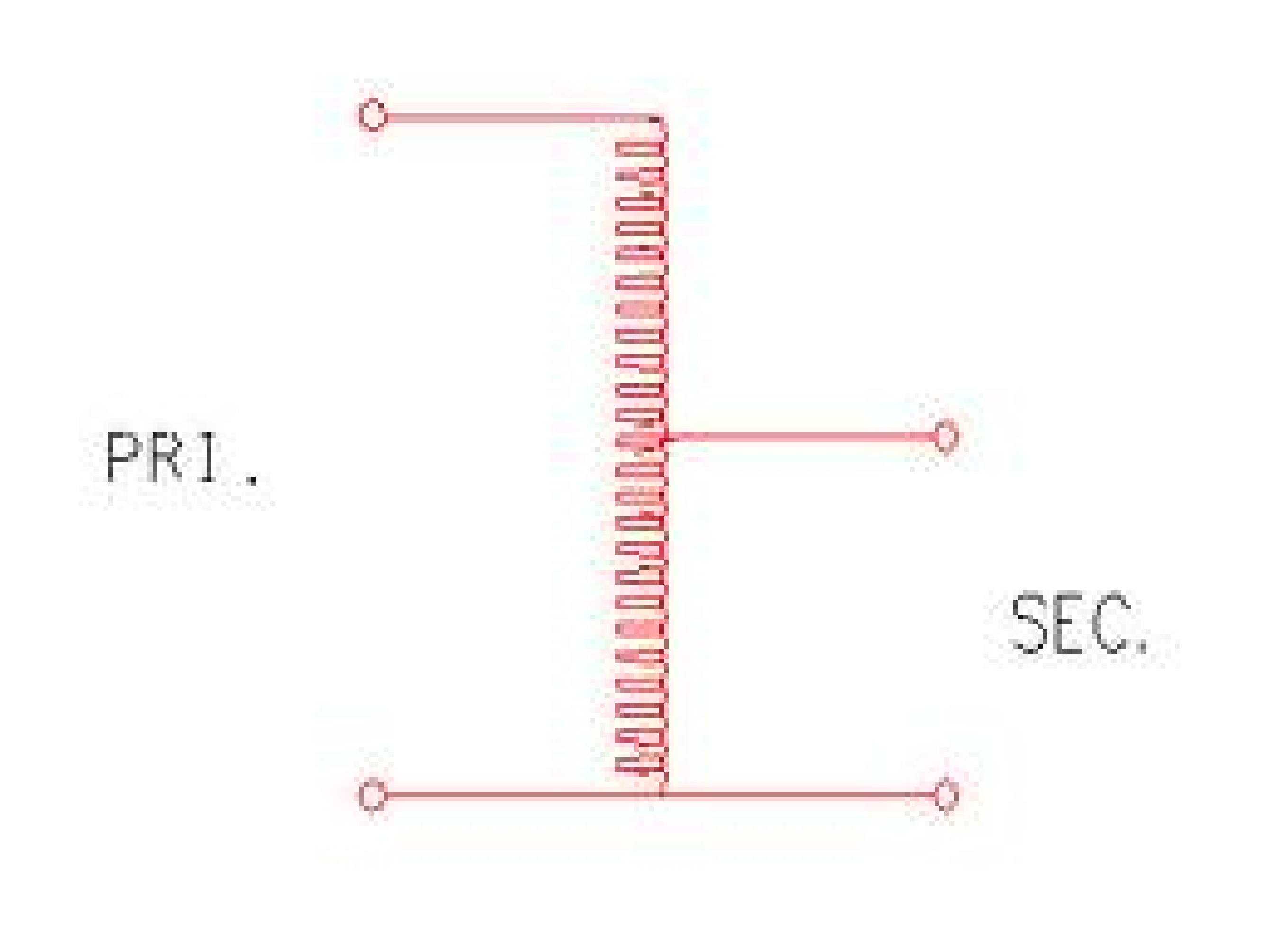
Sometimes, it is desirable to change the voltage by a small amount (for instance, when the consumer is far away from the generator, and it is needed to raise the voltage to compensate for voltage drops).

In such situations, it would be expensive to wind a Transformer with two windings of approximately equal number of turns. An Autotransformer (a transformer with only one winding) is used instead.



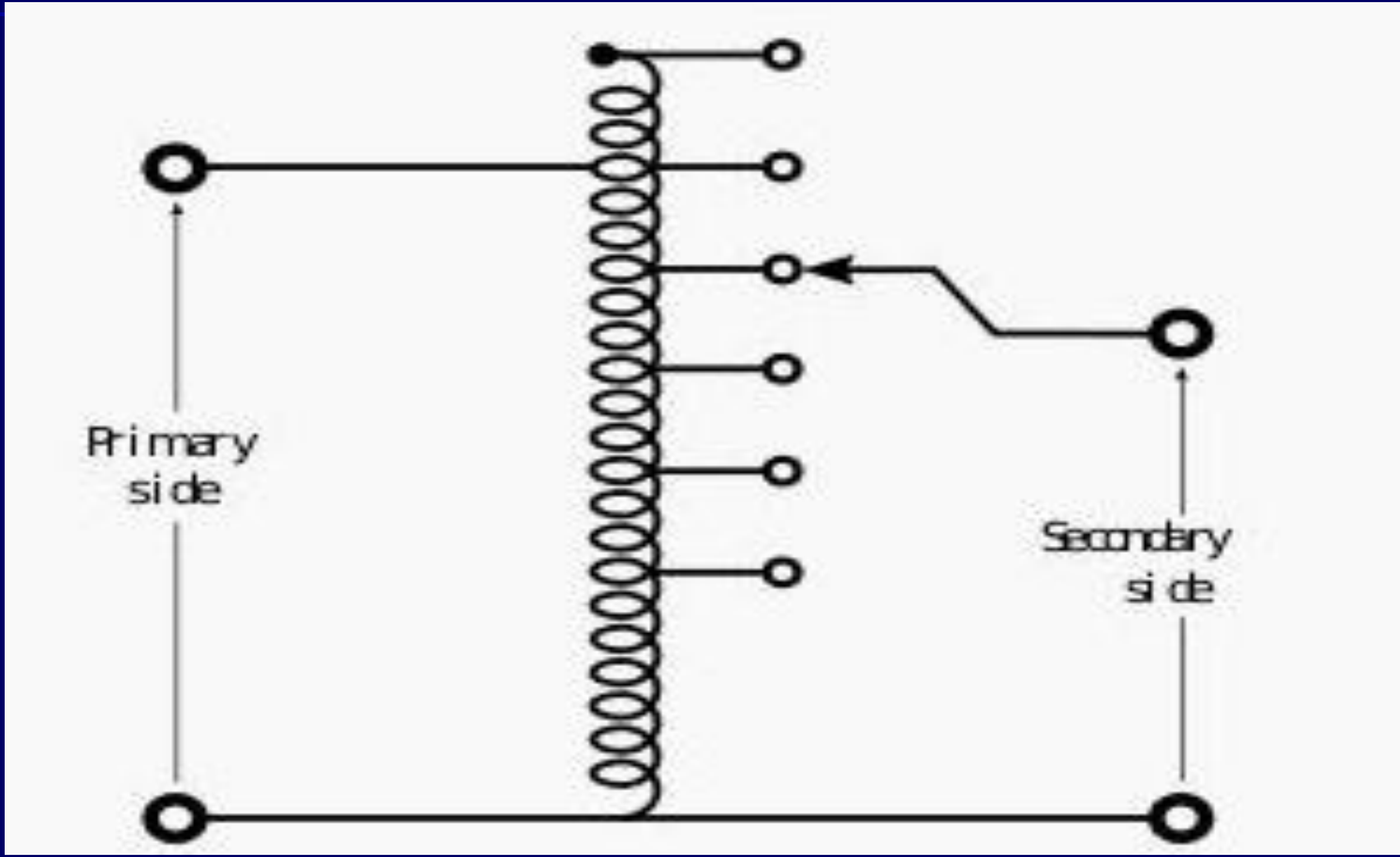


The Autotransformer

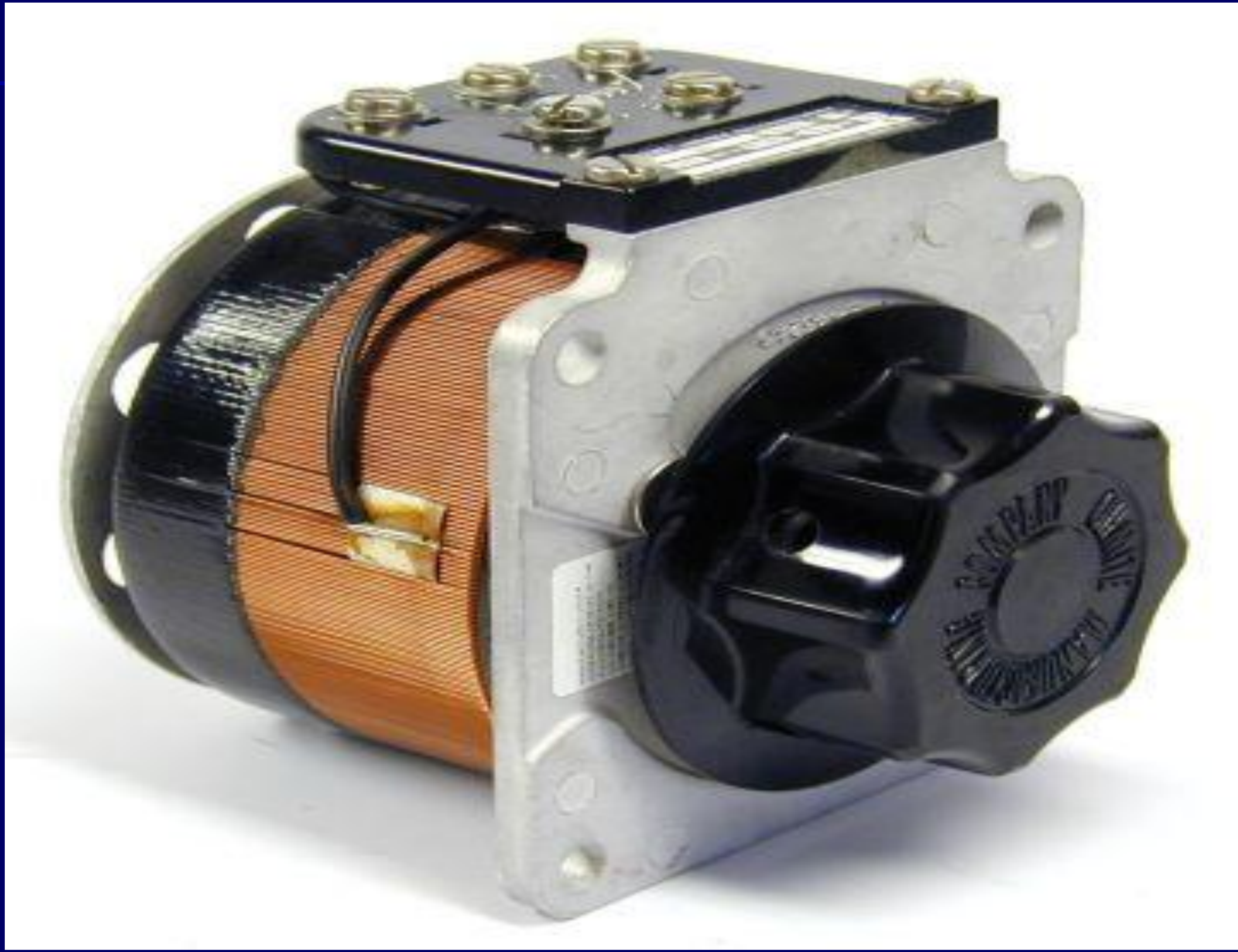


Autotransformer step-down
circuit symbol

Variable-voltage Autotransformers (Tapped)

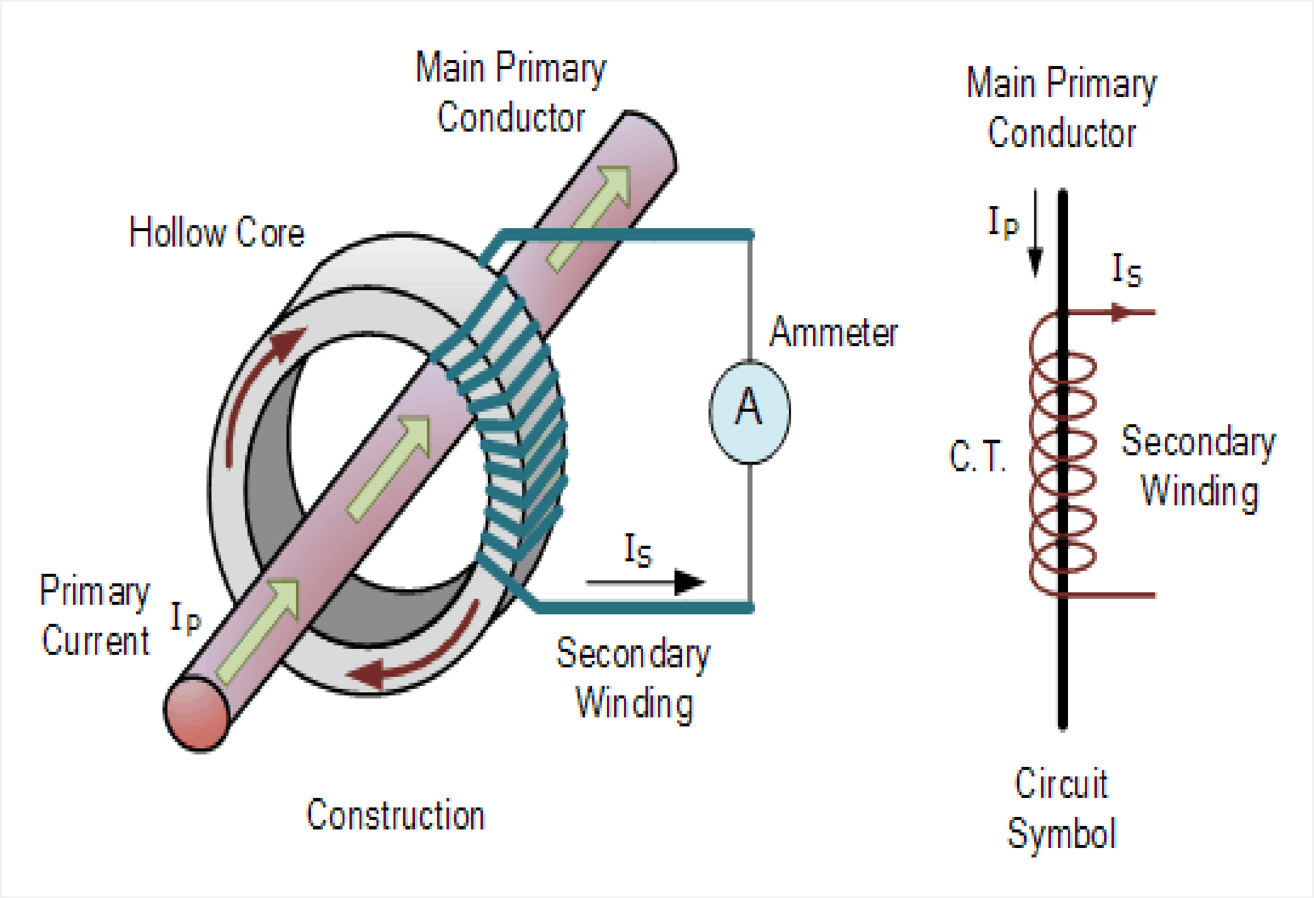


VARIAC



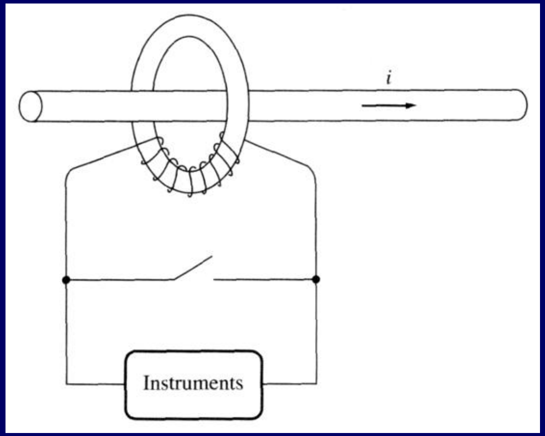
Current Transformers (CT's)

Special-purpose Transformers used to take measurements:



Current Transformers (CT's)

A Current Transformer measures the current flowing in a conductor by sampling the flux surrounding it. The strength of this flux is proportional to the amount of current flowing.

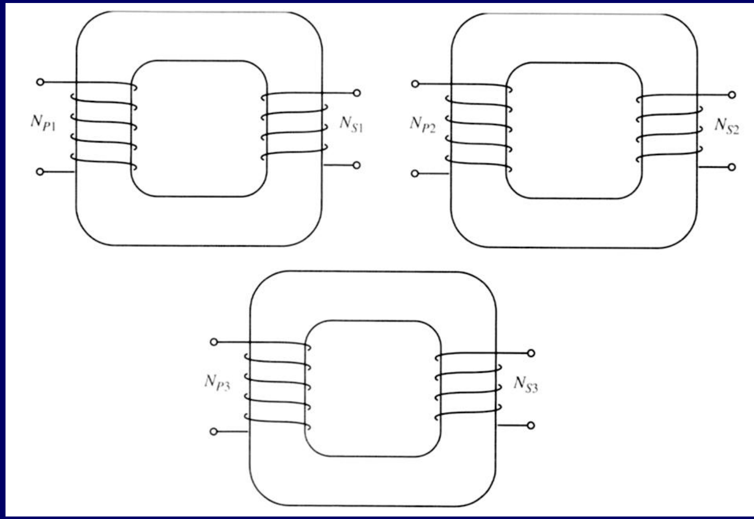


When not in use current Transformers must be always short-circuited since very high voltages can appear across their terminals.

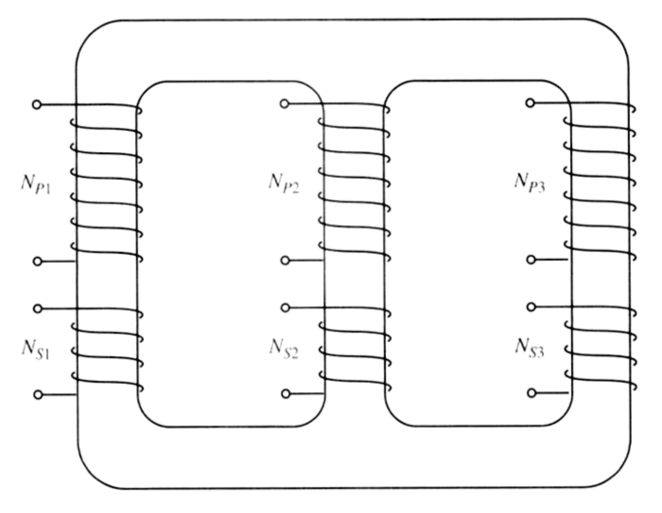
3-Phase Transformers

Many of the generation/distribution systems in the world are 3-phase systems.

The Transformers for such systems can be constructed either as a 3-phase bank of identical Transformers (which can be replaced independently)



Or as a single Transformer wound on a single 3-legged core (lighter, cheaper, more efficient).



3 Phase Step Down