Information Sheet #108

The ultimate solution for maintaining your nationwide generator network

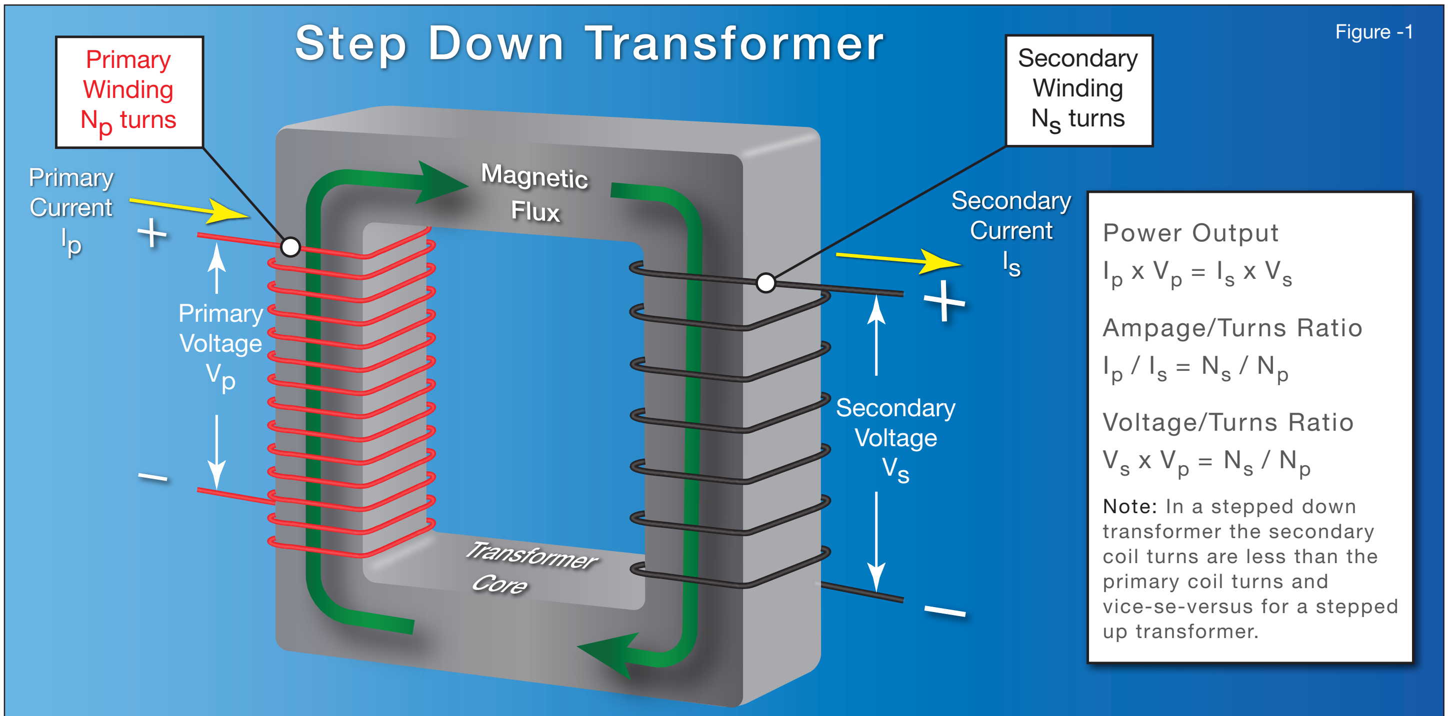
Introduction to Transformers Used In Power Distribution Systems

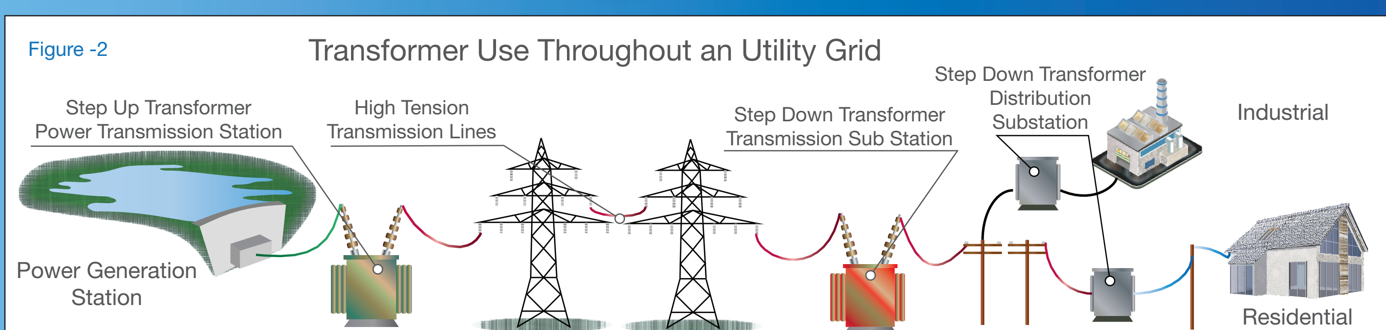
1.0 Introduction:

When the electrification of towns, industry, and commerce began, there were two competing systems: Direct Current (DC) and Alternating Current (AC). Within a relatively short period, the universal system adopted was AC. A fundamental reason for AC was its ability to use electromagnetic principles to convert AC voltages from their original generated source. While DC was acceptable to individual users generating their own power, where converting voltages was not a significant requirement, when it came to mass electrification of whole towns and bringing power to rural areas, there had to be an efficient process to move electricity some distance from its original generated location and offer various voltages. AC power's ability to efficiently step voltage up or down by using a transformer, a device operating on electromagnetic induction principles, resulted in AC being the winner.

This information sheet discusses the workings of a transformer, its use locally, and how it made the efficient transmission of electricity and complete electrification of countries through utility grids (macrogrid) a reality.

The Fundamental Operation of a Transformer and Power Distribution Voltages





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2.0 Operating Principal of a Transformer:

The principal developer of electromagnetic force (EMF) was Faraday. In AC power generation, Faraday's first and second law of induction are being followed, which states:

First law: *Whenever there is a change in magnetic flux associated with a coil, EMF is induced in that coil.*
Second law: *The magnitude of EMF induced in the coil is directly proportional to the rate of change of magnetic flux associated with that coil.*

3.0 How a Transformer Primary Coil Influences the Secondary Coil:

At the heart of a transformer is a ferromagnetic coil, ferro (or iron) is one of the best materials for inducing magnetism. (***See figure 1***) Wound around one side of the magnet is the primary coil, which carries the input current of the electrical power voltage input to be converted. Wound around the other side of the magnet is the secondary coil. This secondary coil carries the output current at the voltage required, either stepped up or down. Following Faraday's law, the EMF in the secondary coil is influenced as follows:

- The AC input cycles in one second from 0° to 360° at 0° zero power, building to maximum positive power at 90°, back to 0 at 180°, through to maximum negative power at 270° and then back to zero at 360°. This is referred to as a time-varying AC current represented by a sine wave.
- Per Faraday's second law, the rate of change of magnetic flux due to the time-varying magnetic field the primary coil induces into the transformer's magnetic core influences the secondary coil.
- The secondary coil on the other side of the magnet uses the time-varying magnetic field generated by the primary coil, with the magnetic flux inducing an into the secondary coil an EMF. Per Faraday's first law, whenever there is a change in magnetic flux associated with a coil, EMF is induced in that coil.

If the primary and secondary coils had the same quantity of turns, the input and output voltages would be the same, with only a marginal loss in power due to transformer efficiency. Coils are usually copper for the best conductivity. In equation terms, this is represented as follows:

Power W = I amps x V volts: $P = I \times V$

Therefore, where "p" is the primary coil and "s" is the secondary coil: $I_p \times V_p = I_s \times V_s$

4.0 How A Transformer Steps Up or Down the AC Voltage:

Having demonstrated this, the input EMF in the primary coil produces a time-varying magnetic force in the transformer's magnet, with the resultant magnetic flux inducing an output EMF in the secondary coil. The voltage ratio is defined as the ratio of the primary voltage of the transformer to the secondary voltage. The resultant voltage change is the ratio of coil turns between the input primary coil and output secondary call. This difference between step-up and step-down transformer being:

- Step-up Transformer - To increase voltage, the turns in the secondary coil have to increase by the same ratio (fraction) as the increase in voltage required. Therefore, the step-up voltage is 240 to 480, and the ratio is 2:1. In this case, the primary coil has 500 turns, and the same ratio is 2:1, with the secondary coil having 1000 turns.

  Using the formula Ip x Vp = Is x Vs, if the Ip= 20A, then Is = (20 x 240)/480 = 10A. So, as the volts increase, the amps will fall by the same ratio.
- Step-Down Transformer - To decrease voltage, the turns in the secondary coil have to decrease by the same ratio (fraction) as the decrease in voltage required. Therefore, the step-down voltage is 480 to 240, and the ratio is 1:2. In this case, the primary coil has 1000 turns, and the same ratio is 1:2, with the secondary coil having 500 turns.

  Using the formula Is x Vs = Ip x Vp, if the Ip= 10A, then Ip =(10 x 480)/240 = 20A. So, as the volts decrease, the amps will rise inversely.

Voltage (V) variation is a factor of the ratio of the coil turn represented as N.

The voltage conversion ratio is expressed as: $V_s / V_p = N_s / N_p$

The amps conversion ratio is expressed as: $I_p / I_s = N_s / N_p$

5.0 Transformer Efficiency:

The formulas above assume an ideal situation where there is no loss of power between the secondary and primary coils. While transformers are very efficient, they are not 100% efficient. Transformers lose power due to magnetic core losses and copper losses. Core losses are the eddy current losses and hysteresis losses of the core. However, power transmission transformers can have efficiencies greater than 95%.

6.0 Transformer Use in Power Distribution

As stated one of the principal reasons AC power was adopted over DC was the ability of AC, using electro-magnetism in the form of transformers, to easily step-up and step-down voltages with minimal loss in power. A high percentage of electrical power is generated in central power stations, remote from high population centers, the primary consumers of power. From power station locations, transmission substations use large transformers to step up the voltages for long-distance transmission as high as 800k volts. Local substations, using step down transformers located near to users, convert the higher voltages to the 480/240/220/110 level most electrical loads require. (***See figure 2***)

7.0 Stepped Up Transformers, a More Efficient Method of Electrical Distribution:

As given above, power (p) is expressed as volts (V) times amps (I). In a high-efficiency substation transformer, the output secondary coils put out nearly as much power as the input primary coils. When the voltage is stepped up to hundreds of thousands of volts, there is still some voltage loss over several hundred miles, but not as much as the amperage that would be lost transmitting lower voltage lines over the same distances.

So, in relative terms, when the power is stepped down to user levels nearer to user locations, the power lost in transmission is considerably less.

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