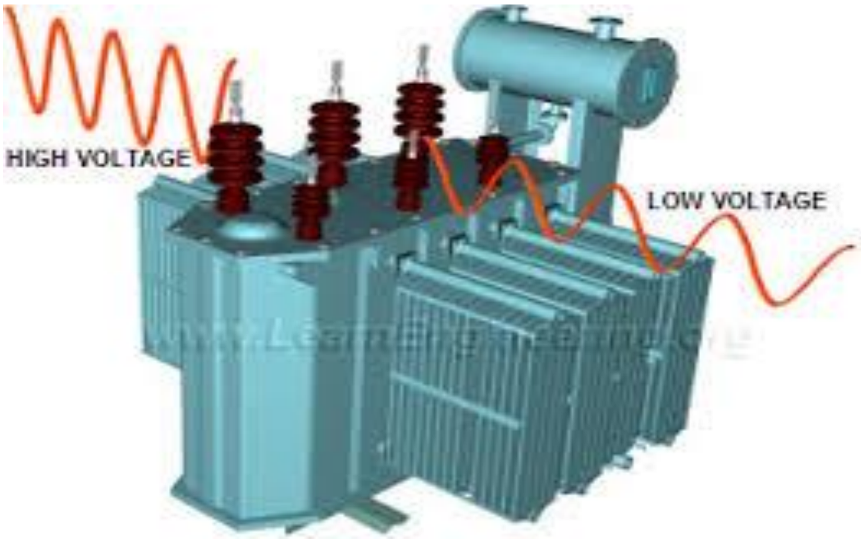
TTE Training Ltd.

Phase 2

Electrical Course Notes

E2-CN-004

Transformers



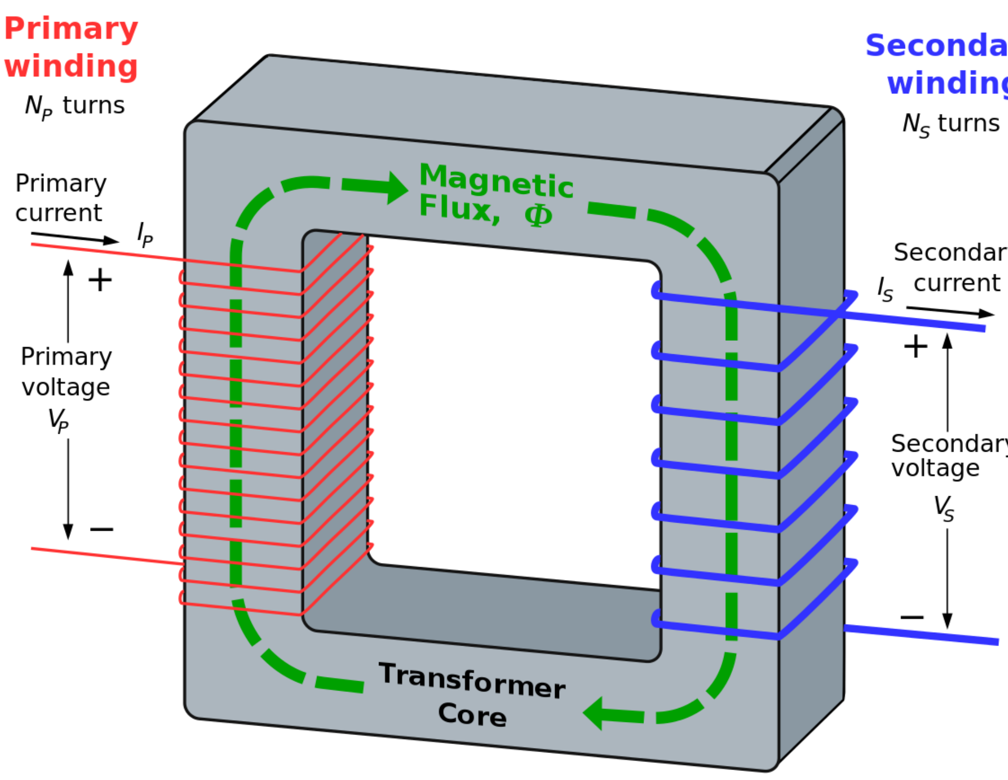
Operation of Transformers

A transformer is an electro-magnetic induction machine.

When an alternating current is applied to a coil of wire it produces an alternating magnetic flux.

If this coil of wire – the primary winding - is fitted onto a laminated 'iron" core the strength of the flux will be increased considerably.

If we also fit a second coil – the secondary winding - to the same "iron" core, then the flux will link with both coils.



The voltage from the secondary winding is dependent on the ratio of the number of turns on the primary winding compared to the number of turns on the secondary winding.

As an example, if there are 500 turns on the primary and 250 turns on the secondary the secondary voltage will be half of the primary voltage. If you swap the primary voltage with the secondary voltage you will double the voltage on the secondary.

If you were to measure the resistance of the primary winding you will find it is very low – only a few ohms. Referring to the primary voltage and applying Ohms Law would indicate that the primary current would be very high. In your transformer assignment the primary winding resistance is about 2 ohms. If the primary voltage is 110 volts this means that the primary current should be 110 volts / 2 ohms = 55 amps. If this were true, the transformer would probably burst into flames as it could as it could not possibly handle that current. This will be proven practically in the transformer assignment.

What actually happens is the magnetic flux because it is constantly changing induces a voltage back into the primary coil – this is known as the electromotive force or emf. As it is induced back into the primary winding it is therefore referred to as the back emf.

The value of the back emf will be less than the primary voltage due to energy being lost in producing the magnetic flux and the resistance of the copper windings. Because there is now a small difference between the Primary Voltage and Primary Back emf the Primary Current is kept very low possibly less than one amp.

A good analogy is to think of the Primary voltage as pressure and the Primary Back emf as a slightly lower pressure.

Transformer Turns Ratios

$$\frac{\text{Primary Volts}}{\text{Secondary Volts}} = \frac{\text{Secondary Current}}{\text{Primary Current}} = \frac{\text{Primary Turns}}{\text{Secondary Turns}}$$

$$\frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{T_p}{T_s}$$

Therefore, depending upon how many turns we put in each coil we can either raise or lower the value of output voltage relative to the supply voltage.

This might suggest that we can get something for nothing, however, the power given out by the transformer cannot be greater than the power put in, therefore if the voltage increases then something must decrease to compensate for it, the other component of power is the current, therefore, this must be the factor that decreases. The most common type of transformer is called a “double-wound” transformer because it has two completely independent windings, however, there are, for special applications some transformers which have only one winding part of which is common to both primary and secondary windings, these are called

“AUTOTRANSFORMERS”.

Although their construction is different the principle of operation is the same.

AUTOTRANSFORMERS (Primary Winding Only)

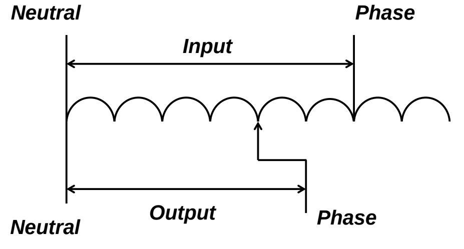
The advantage of the autotransformer is the saving in copper.

The disadvantage is the fact that, with there being no separation between the windings, there is a danger in the case of step-down transformers that either the supply polarity will reverse giving the low voltage system a high potential to earth, or in the event of insulation failure the turns will short out and the voltage on the secondary will increase leading to excessive current in the transformer.

This puts considerable limitation on the permitted use of autotransformers.

An alternative version of an autotransformer is known as a **“Variac”**, this is a continuously variable transformer.

The supply is connected to a fixed pair of terminals and the output has its neutral to the common terminal and its high voltage is connected to a wiper arm to allow the variation of the output voltage to be achieved, generally it has a facility to vary from 0 volts to slightly higher than the supply voltage.



IT IS IMPERATIVE THAT ONLY THE NEUTRAL OF THE SUPPLY IS CONNECTED TO THE COMMON TERMINAL.

Transformer losses

There two main causes of loss in a transformer, these are:

Iron loss and Copper Loss.

Iron Loss
This is also referred to as the core loss and has two components hysteresis loss and eddy current loss.

Hysteresis loss is that associated with the magnetizing and demagnetizing of the transformer core when an ac voltage is applied to the primary winding. To reduce the hysteresis loss, we select a core material which has B/H characteristic with a small loop area (low energy loss) such as MuMetal which is a Nickel Iron alloy.

Eddy current loss is that which occurs when circulating currents are induced into the core, these are reduced by forming the core from thin laminations.

Copper loss this is the loss associate with the voltage drop in the two windings ($I^2 R$ loss) and is proportional to the load current.

Construction

Transformer cores are constructed from thin laminated sheet steel coated with a high resistance to limit the eddy currents. The windings, primary and secondary are produced from enameled or lacquered copper wire, the enameling or lacquering being the means of insulation. Air cooled transformers will be housed in a steel tank which will be weather proof if it is to be sited outdoors.

Transformer cooling
On power transformers which handle large currents some means of cooling is required to reduce the heating effect of the $I^2 R$ losses generated in the windings. This will normally be by means of air cooling or oil cooling.

Air cooling
This is where transformer is cooled by natural or forced convection air currents, the transformer container will be finned to increase the surface area to assist in the cooling process, and these are known as dry transformers.

Oil Cooling
For multi-kilowatt high power work, oil cooled transformers are usually used. These have metal pipes running though the core carrying a thin oil. This method is the most efficient as the oil also acts as the winding insulation, as well as the cooling medium, the windings are immersed n the oil, which will circulate by convection currents or by pumping, carrying heat to tubes external to the transformer core for dissipation. These are common in power station & substations. Often on larger systems there will be a radiator and a storage tank for the oil.

Isolating Transformers

Used in areas where there is a high risk of electric shock in particular areas where working live or areas where there is a lot of moisture / water.

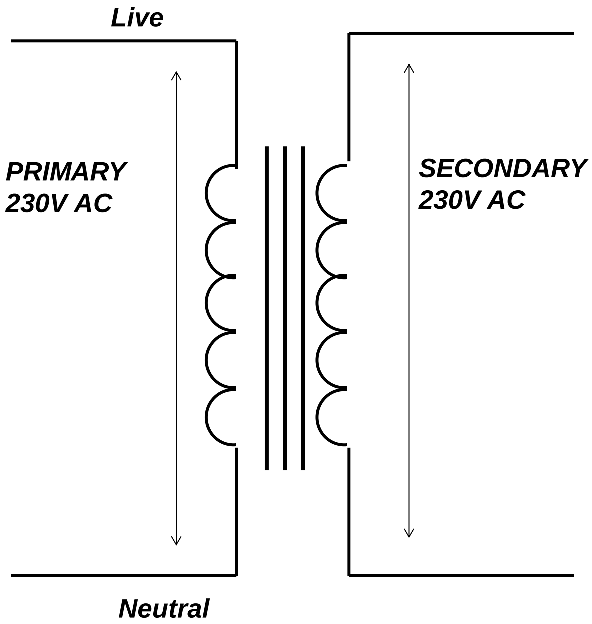
Medical Locations – Operating Theatres - IET Reg. 710.512.1.1 refers

Electronic Repair Workshops - IET Reg. 418.3 refers

Bathrooms for Shaver Sockets - IET Reg. 414.3 refers

(NB above quotes from IET Regs. will not be kept up to date)

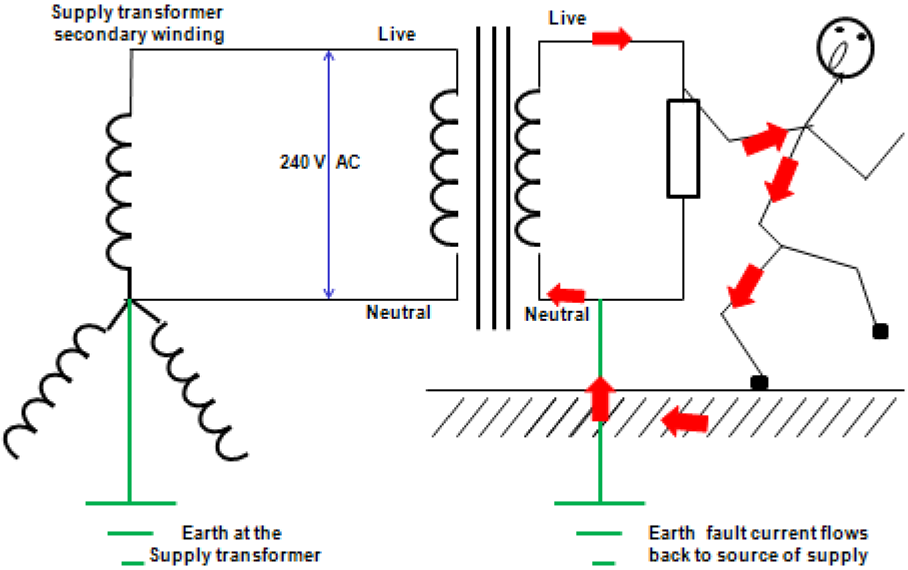
Isolating transformers have a turn's ratio of 1:1



On the Primary winding the Neutral is held a zero volts due to the Neutral being connected to Earth at the Star Point of the secondary in the supply transformer.

On the secondary there is no neutral designated neutral or live or no earth connection.

To fully understand the operation of an isolating transformer the easiest way is to see what the problem is that makes the isolating transformer the solution.



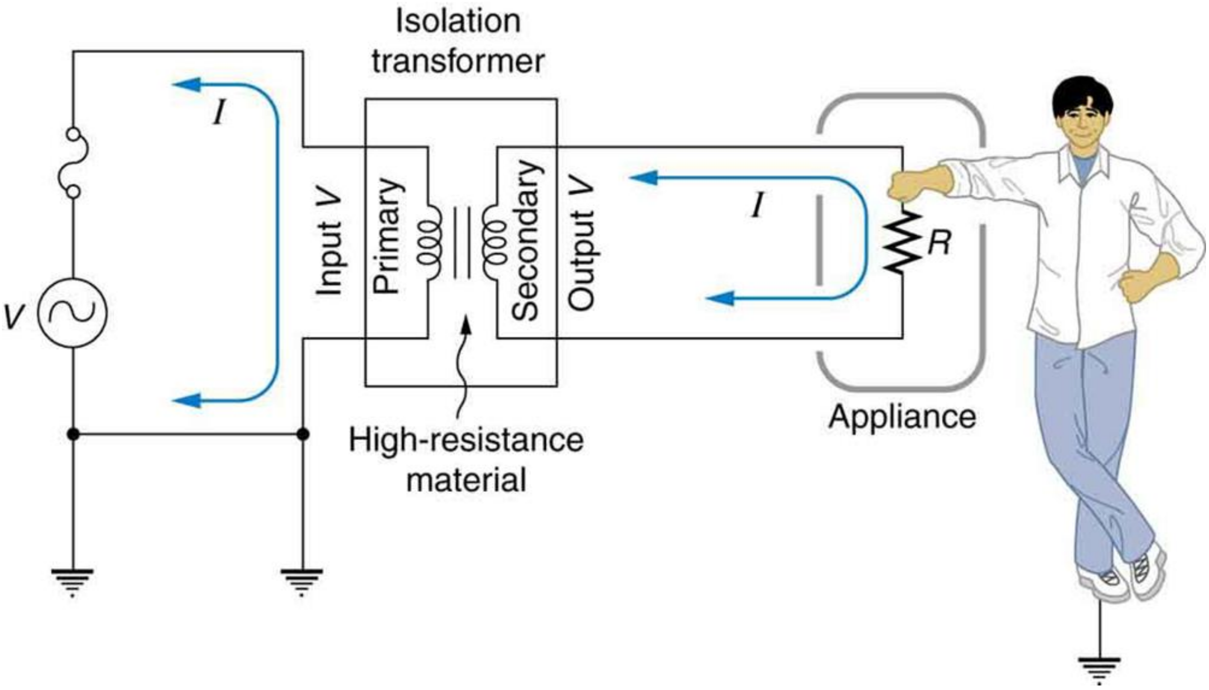
Operator touches Live and current flows through the operator, through the earth (in this case via his or her feet) and returns to the transformer secondary winding via the earth on the transformer neutral.

So, the fault current is flowing back to its source – it cannot flow back to the earth on the supply side i.e. the Earth on the transformer star point / Neutral as it is not part of the circuit.

In a hospital operating theatre there is a danger of liquid from medical drips or body fluids contacting medical equipment.

In an electronic repair workshop when working live i.e. measuring voltage or current there is a danger of touching a live conductor.

Shaver sockets in bathrooms risk of shock from wet hands or shaver being dropped into a sink full of water.

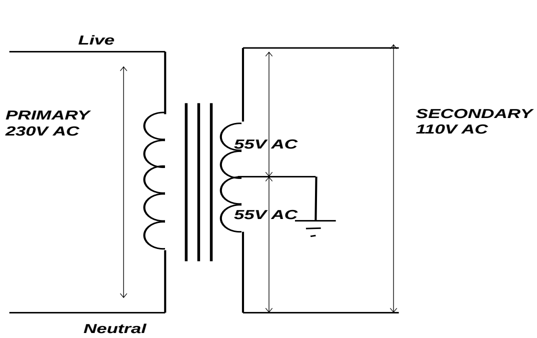


Operator touches Live but current will not flow through his / her body (no electric shock) as there is no return path to the source of the supply on the secondary.

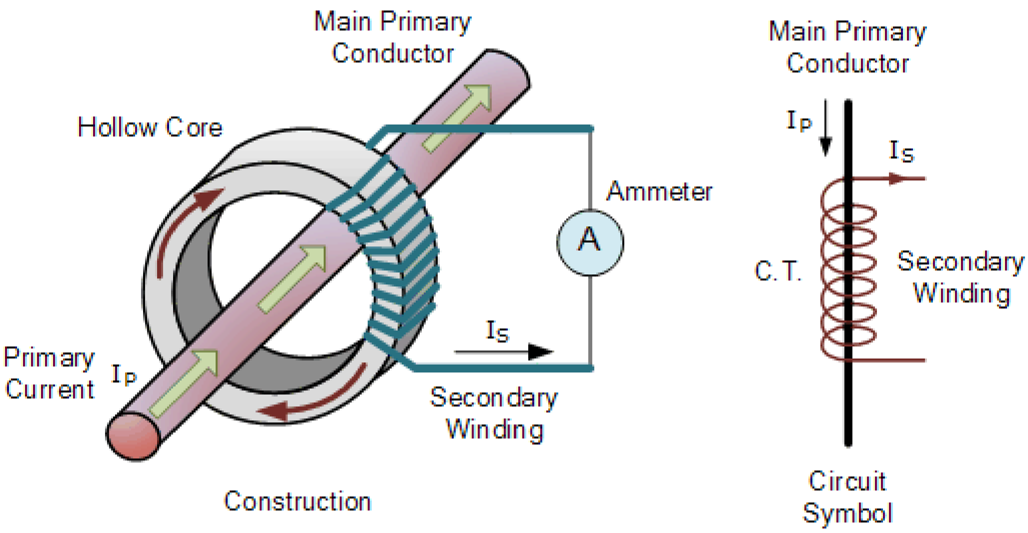
Single phase transformer

Portable Safety Transformers for Hand Tools

In factories and on site, hand tools used by operatives will for safety reasons be on a reduced low voltage AC supply. The standard voltage will be 110volts, less than half that of the normal single-phase supply voltage. To enhance safety, a centre tapped secondary is used, with the centre tap earthed. The purpose of this earthing is to limit the voltage that a person may be subjected to in the event of a failure to a max of 55volts with respect to earth. On site a portable transformer is used. This will be a self-contained device having one or more outlet, which can be used to plug in the hand tools.



CURRENT TRANSFORMERS (Secondary Winding Only)



CURRENT TRANSFORMERS (Secondary Winding Only)

Although a conventional voltage transformer changes the value of current in the windings, the current in the primary winding is dependent upon the load current in the secondary winding.

In a current transformer the process is the opposite way around, the current in the primary winding is the controlling influence and the current in the secondary winding adjusts itself to suit the primary current.

Current transformers are used to reduce the value of very high currents, which it would not be convenient to pass through devices such as ammeters or overload protective devices, to a convenient value such as amperes.

Alternatively, the transformer may be used to isolate the measuring device from a dangerously high voltage circuit.

In many cases the primary winding consists only of the current carrying conductor over which is a toroidally wound coil with an “iron” core has been places. This coil is the secondary winding.

The load current to be measured passes though the primary “winding” and cannot vary, this produced a magnetic flux in the “iron” core and induce a corresponding current in the secondary winding. This current, flows though the ammeter and registers a value corresponding to the primary current.

Since the primary current cannot be increased, the secondary load “reverse flux” limits the voltage that will be induce in the secondary winding to a safe value.

However, if the load is removed from the secondary winding, there will be no current in this winding and the induced emf will rise to an unsafe value which will damage the coil.

IT IS, THEREFORE, ESSENTIAL THAT THE LOAD DEVICE ON THE SECONDARY WINDING MUST NEVER BE DISCONNECTED WHILE THE PRIMARY WINDING IS CARRYING CURRENT.

IF NECESSARY THE ENDS OF THE SECONDARY COIL MUST BE “SHORT-CIRCUITED” BEFORE THE LOAD IS REMOVED.

THREE-PHASE TRANSFORMERS

We can transform a three-phase supply by using three separate single-phase transformers.

However, this is not economical since a much simpler construction using a single magnetic core for all three phases can be used.

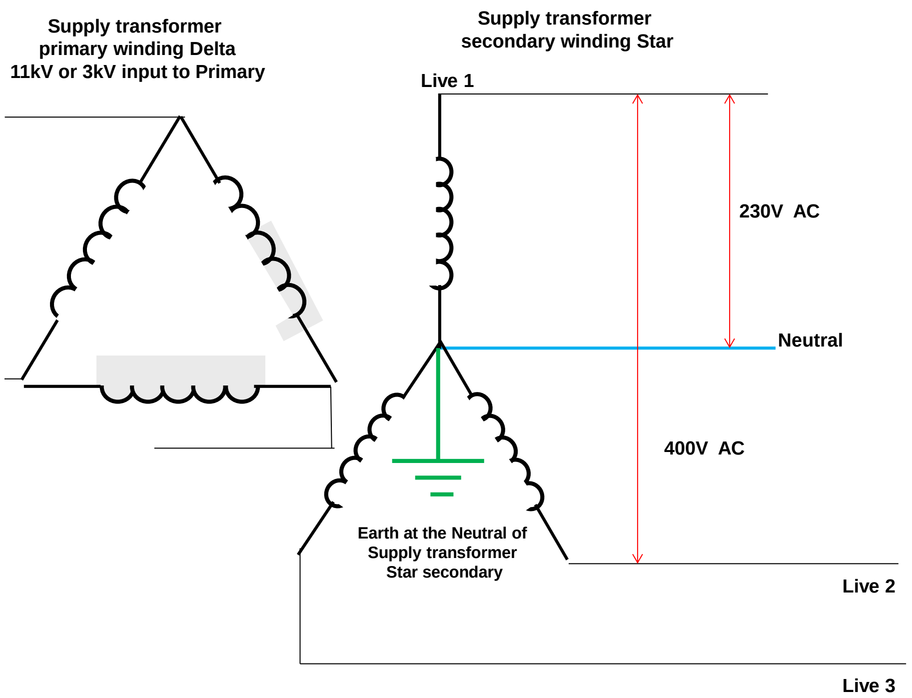
The three fluxes produced by the three-phase supply will balance at all instants as long as the supply and loads are balanced.

For use with unbalanced loads a modified construction of the core has two extra limbs to compensate for the out-of-balance flux.

THREE-PHASE TRANSFORMER CONNECTIONS

Depending upon the requirements the three-phase windings can be connected in either star or delta, giving four possible combinations.

STAR-STAR
STAR-DELTA
DELTA-DELTA
DELTA-STAR



Example of THREE-PHASE TRANSFORMER using Delta/ Star, primary to secondary CONNECTION used for supply transformer.