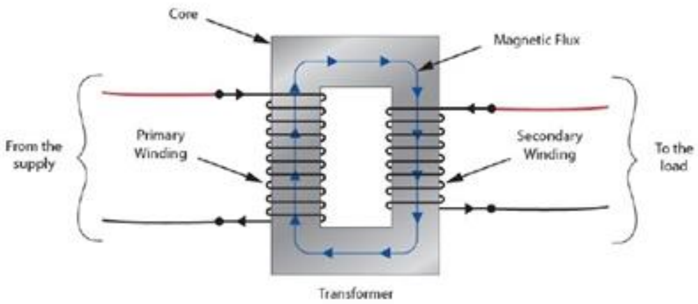
4.Transformer

In order to understand the operation of a transformer, you must first understand how a transformer is constructed. In this topic, you will learn about the different parts of a transformer, how they fit together, and how to perform basic tests to determine serviceability.

Basic Transformer Construction

A basic single phase transformer consists of two insulated coils of wire, wound around a common ferromagnetic core. The coil that is connected to the supply is called the 'primary winding', and the coil that is connected to the load is called the 'secondary winding'.



Transformer Cores

Transformer cores are made from either silicon steel (sometimes called 'transformer steel') for low frequency applications (e.g. 50 Hz), or ferrite for higher operating frequencies (e.g. above 1 kHz).

Transformer cores are typically produced by stacking several thin sheets of laminated steel called 'stampings' or simply 'laminations. This helps to reduce magnetic losses by limiting the magnitude of eddy currents that develop in the core. Common types of laminations are shown in the following table.

Transformer Laminations				
E & I type	**U & I type**	**L type**	**I type**	**C type**
				

The laminations are stacked in an alternating/overlapping pattern to produce the required shape and thickness.

Different types of single phase transformer cores are shown in the following table.

Single Phase Transformer Cores		
Type	**Illustration**	**Description**

N_2 = number of turns on the secondary winding

V_1 = primary voltage

V_2 = secondary voltage

I_1 = primary current

I_2 = secondary current

Worked Example – Calculating Turns

A transformer has 800 turns on the primary winding. Calculate the number of turns on the secondary winding required to step down a 230 V supply to connect to a 12 V luminaire.

$$\frac{N_1}{N_2} = \frac{V_1}{V_2}$$

$$N_2 = \frac{N_1 \times V_2}{V_1}$$

$$N_2 = \frac{800 \times 12}{230}$$

$$N_2 = 41.7\ turns$$

Worked Example – Calculating Voltage

A transformer has 300 turns on the primary winding and 120 turns on the secondary winding. Calculate the secondary voltage if a supply voltage of 230 V is applied to the primary winding.

$$\frac{N_1}{N_2} = \frac{V_1}{V_2}$$

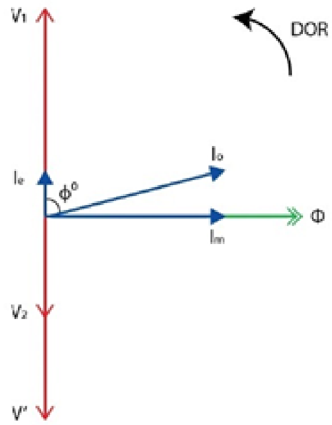
$$V_2 = \frac{V_1 \times N_2}{N_1}$$

$$V_2 = \frac{230 \times 120}{300}$$

$$V_2 = 92\ V$$

Transformer No-Load Relationships

A 'no-load condition' refers to a transformer that has its primary winding connected to the supply, but it's secondary winding open circuited. The following phasor diagram shows the relationships between the primary and secondary parameters of a transformer under no-load conditions.



Where:

V_1 = primary voltage

V_2 = secondary voltage

V' = primary self-induced voltage

I_e = current component of losses

I_o = no-load current (phasor sum of current component of losses and magnetising current)

I_m = magnetising current

ϕ° = phase angle

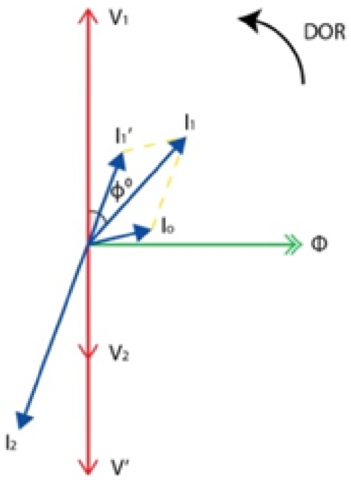
Φ = magnetic flux

Points to note about transformer relationships under no-load conditions:

- The applied voltage causes a small current to flow in the primary winding, equal to the phasor sum of the magnetizing current and the iron loss current.
- This current causes an alternating flux to be established in the core, known as the 'mutual flux', magnetically linking the two windings.
- The alternating flux induces a voltage into the primary winding that opposes the applied voltage.
- The alternating flux induces a voltage into the secondary winding, but no current flows until a load is connected.

Transformer Load Relationships

A 'load condition' refers to a transformer that has its primary winding connected to the supply, and its secondary winding connected to a load. The following phasor diagram shows the relationships between the primary and secondary parameters of a transformer under load conditions.



Where:

V_1 = primary voltage

V_2 = secondary voltage

V' = primary self-induced voltage

I_1 = primary current (phasor sum of primary reflected current and no-load current)

I_1' = primary reflected current

I_2 = secondary current

I_o = no-load current

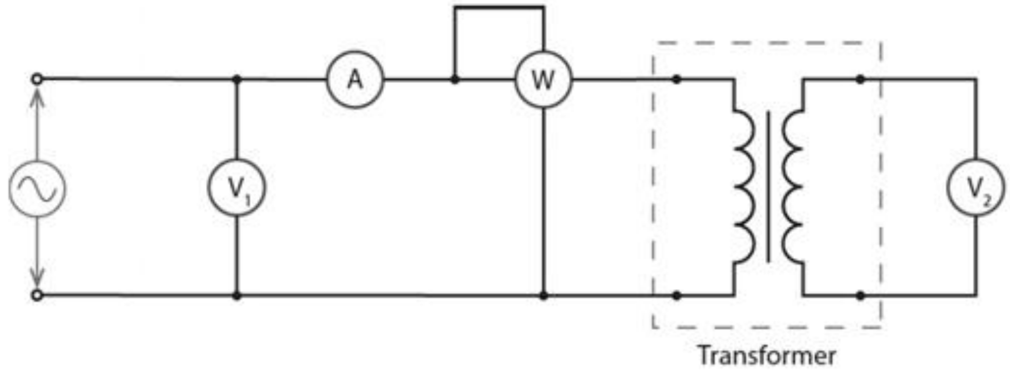
$\phi°$ = phase angle (between V_1 and I_1)

Φ = magnetic flux

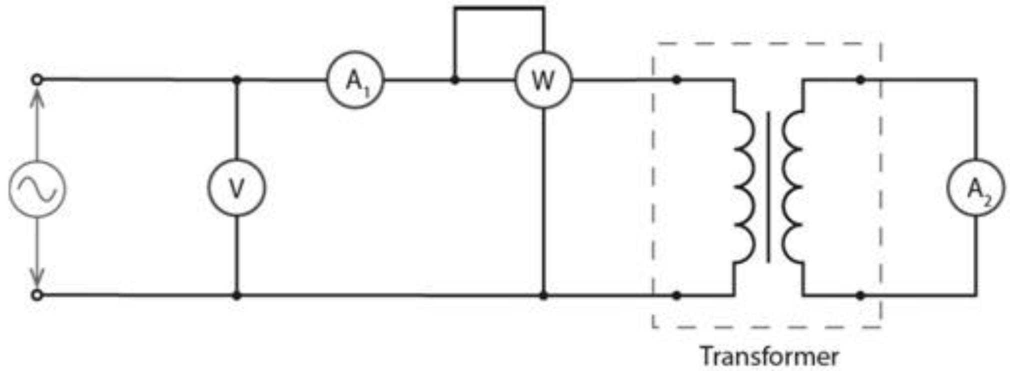
Points to note about transformer relationships under load conditions:

- The applied voltage causes a small current to flow in the primary, setting up the mutual flux which causes an induced voltage in the secondary winding.
- The connected load draws a current (I_2) from the secondary winding which in turn causes an alternating magnetic flux in the core that opposes the mutual flux.
- This 'demagnetizing flux' causes the self-induced voltage in the primary to reduce, which causes the primary current to increase.
- This increase in primary current causes an increase in the primary self-induced voltage.

The effect of the two opposing fluxes gives a transformer a self-regulating property. It also means that an increase in the secondary (load) current will cause an increase in the primary current.



The following diagram shows the connections necessary to carry out a short-circuit test:



Transformer Efficiency

Transformers are inherently efficient electrical machines, generally being more than 90% efficient. The copper loss is the main factor affecting the efficiency of a transformer, which in turn is affected by:

- The winding impedance.
- The loading.
- The power factor of the connected loads.

A transformer is at its most efficient when the copper losses and the iron losses are equal.

The efficiency of a transformer is usually determined from the losses, using the following equation:

$$\eta = \frac{P_{OUT}}{P_{OUT} + P_{Cu} + P_{Fe}} \times 100$$

Where:

n = efficiency as a percentage (%)

P_{OUT} = output power in watts (W)

P_{Cu} = copper losses in watts (W)

P_{Fe} = iron losses in watts (W)

Worked Example – Transformer Efficiency

Calculate the full-load efficiency of a 230/12 V transformer supplying a 50 W, 12 V downlight. At full load, the copper losses are 1.05 W and the iron losses are 0.25 W.

$$n = \frac{50}{50 + 1.05 + 0.25} \times 100$$

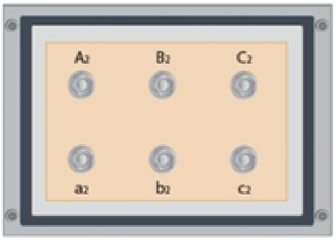
$$n = \frac{50}{51.3} \times 100$$

$$n = 97.47\%$$

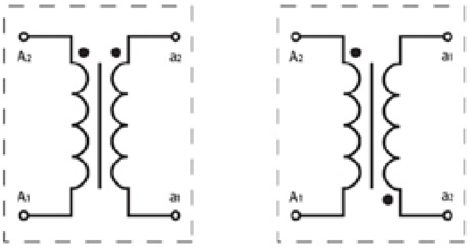
All-Day Efficiency

The all-day efficiency of a transformer is an averaging of its efficiency over 24 hours. All-day efficiency can be determined from the total energy input and output over the course of a 24 hour period, using the following equation:

$$\eta\ (\text{all-day}) = \frac{E_{OUT}\ (\text{over 24 hrs})}{E_{IN}\ (\text{over 24 hrs})} \times 100$$

Three Phase Delta-Delta Transformer		'A_2', 'B_2' and 'C_2' are the 'starts' of the three higher voltage phase windings. 'a_2', 'b_2' and 'c_2' are the 'starts' of the three lower voltage phase windings. The primary and secondary sides are each connected in delta, so there is no need for any neutral terminals.

When represented in a circuit diagram, a dot is used to indicate the polarity of a winding. Note the terminal markings and placement of the dots in the following two examples.



Transformer 1 Transformer 2

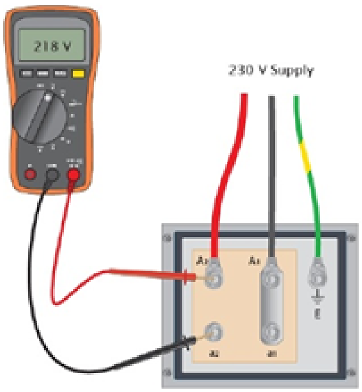
Transformer Polarity Testing

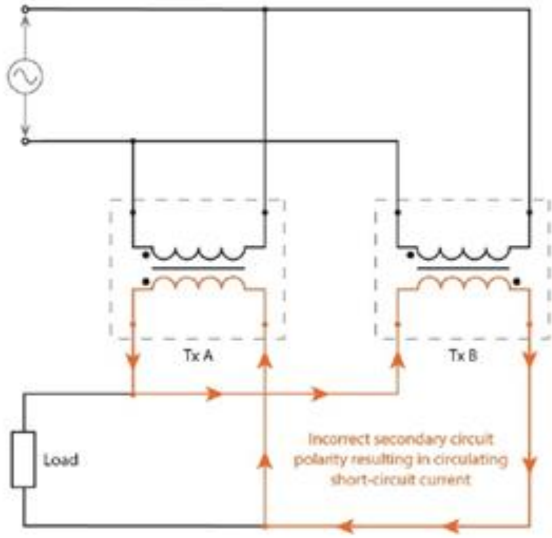
There are three basic methods used to determine the polarity of a transformer, these are:

- The a.c. test method.
- The d.c. test method.
- The trial and error method.

These three tests are illustrated and described in the following three tables.

Warning: these tests are carried out with the supply connected

a.c. Test Method




Determining Load Share

A given load will be shared by parallel transformers in proportion to the impedance of each transformer. This relationship is expressed by the following two equations:

$$\text{Tx A Load Share} = \frac{Z_B}{(Z_A + Z_B)} \times \text{Total Load}$$

$$\text{Tx B Load Share} = \frac{Z_A}{(Z_A + Z_B)} \times \text{Total Load}$$

Where:

Z_A = percent impedance of transformer A

Z_B = percent impedance of transformer B

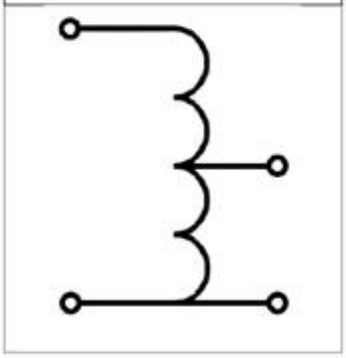
Introduction

There are a number of variations on the basic transformer construction, designed to give specific operation characteristics for specific applications. In this topic you will learn about instrument transformers and autotransformers, including their construction, characteristics, applications and specific safety requirements.

Autotransformers

Unlike a standard transformer, an autotransformer consists of just a single winding to which both the primary and secondary circuits are connected. This means that the two sides of an autotransformer are both magnetically coupled and electrically connected. Due to this arrangement, the Wiring Rules requires that all circuit wiring and equipment connected to an autotransformer must be rated for the highest input or output voltage.

Autotransformer Winding Diagram

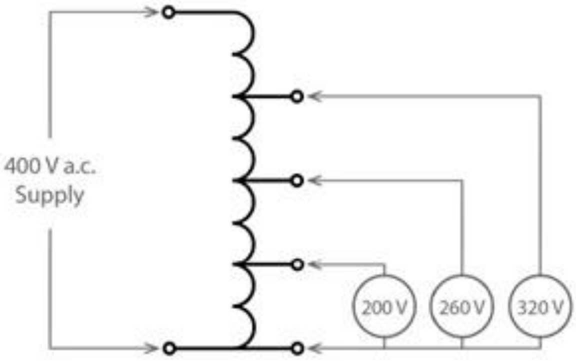


There are two main types of autotransformers, these are:

- Tapped autotransformers.
- Variable autotransformers (Variac).

Tapped Autotransformers

One side of the transformer is connected to each end of the common winding. The secondary side of the transformer consists of several points tapped along the winding. The ratio of total turns to the number of turns between the secondary taps determines the transformation ratio. The advantage of this is that several output voltages can be selected by switching between taps. The following diagram shows an autotransformer with tappings at 50 %, 65 % and 75 % connected across a 400 V supply.



Variable Autotransformers (Variac)

Connecting single phase transformers to a three phase supply

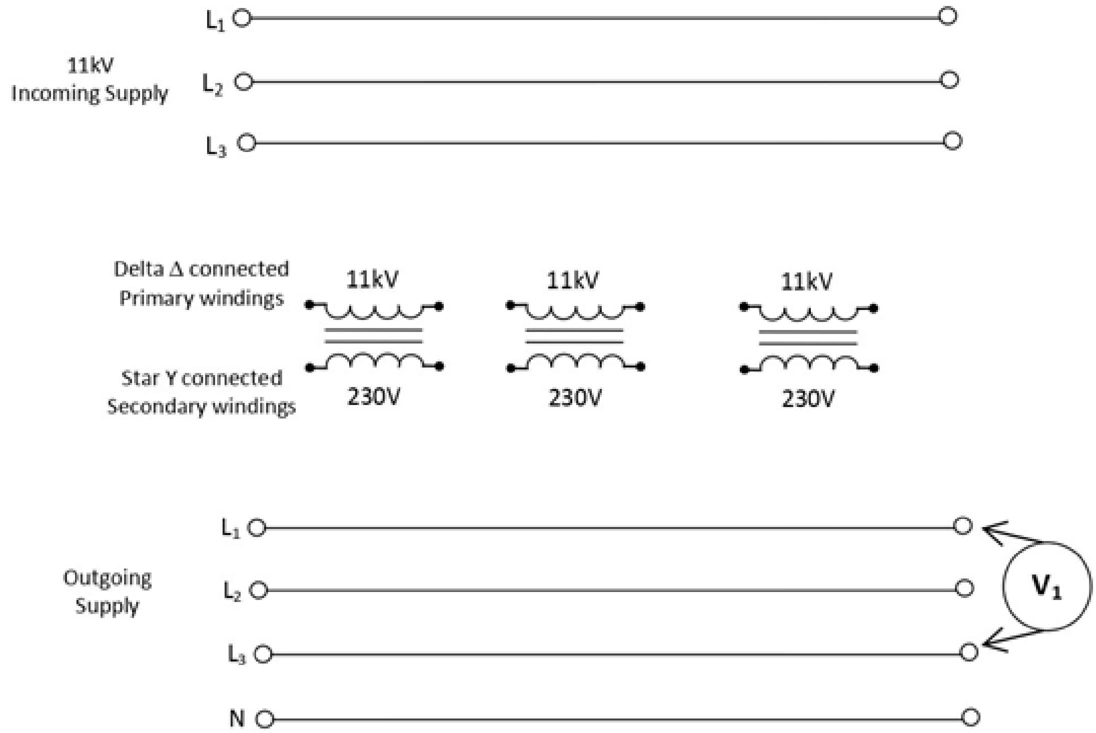
Three single phase 11kV / 230V transformers are to be connected to a three phase supply.

On the schematic diagram below, draw the connections for the three single phase transformers to operate from a three phase supply so that:

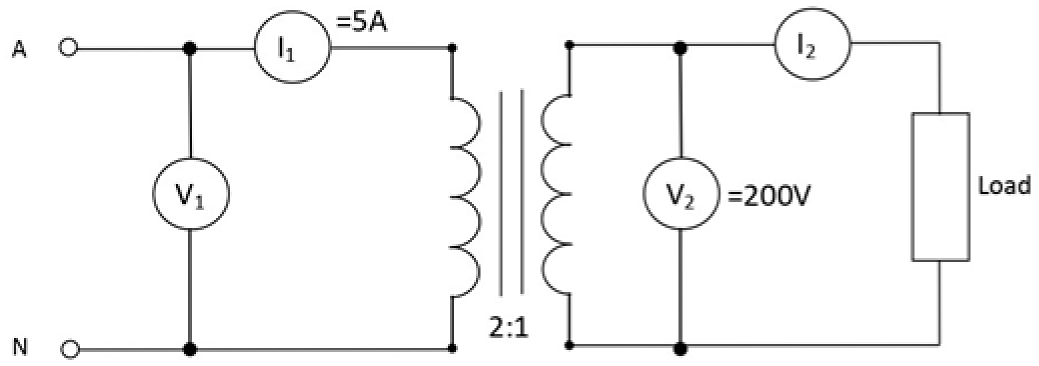
a. The transformer primary windings are connected in delta Δ to the 11kV incoming supply.

b. The transformer secondary windings are connected in star **Y** (WYE) to the outgoing supply

Also:
c. What will the reading be on voltmeter V_1? _____________ Volts



Single phase transformer ratios



For the single phase transformer circuit drawn above, and using the circuit values shown:

a. The reading on voltmeter V_1 will be approximately = _______________

b. The reading on ammeter I_2 will be approximately = _______________

NOTE: The transformer ratio is 2:1

Show your calculations here...

1ϕ transformer – connecting multiple secondary windings

A single phase transformer with multiple secondary windings is to supply 45 Volts to the Load.

a. On the diagram below, draw the necessary connections for the transformer to supply the load with 45 volts at the load terminals.

Correct winding connections ☐

b. The maximum current that could be supplied to the load at 45 volts would be ________ Amps