SINGLE AND THREE PHASE TRANSFORMERS

REFERENCES

- Electrical Principles for Electrical Trades, Jenneson 5th Edition, Chapter 14, Pages 335 – 355.

- Electrical Trade Principles – " A Practical Approach", Jeffrey Hampson & Steven Hanssen 2nd Edition, Section 3, Pages 325 – 377.

TRANSFORMER APPLICATIONS INCLUDE

- Power generation and distribution
- Power supplies for a wide range of equipment
- Isolation from the mains
- Gas ignition
- Arc welding
- Discharge lighting
- Induction heating

TRANSFORMERS

The Basics –

- A transformer is a device for changing AC voltage from one level to another.
- They are very efficient device and run at between 92% and 99% efficiency.
- Transformers will not operate on DC.

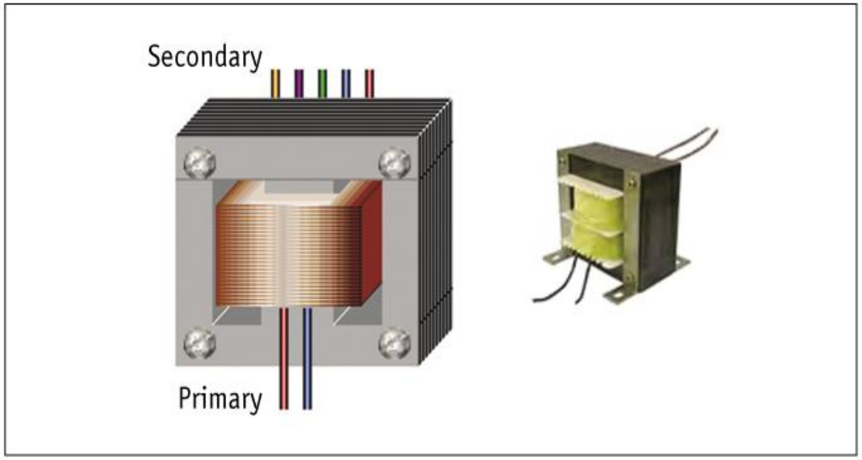
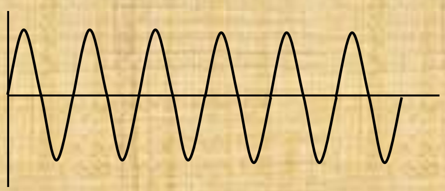


Figure 9.2 Shell-type contruction

OPERATION OF A TRANSFORMER

The basic transformer as shown consists of two coils in close proximity to each other wound on a ferromagnetic substance and sharing a common electromagnetic circuit. A transformer is a device for transferring electrical energy from one sinusoidal circuit to another.



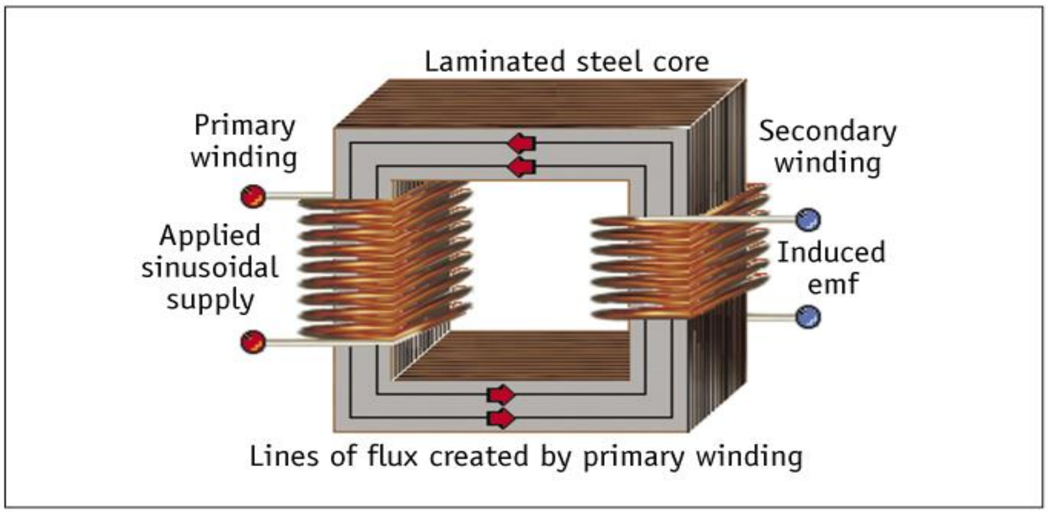
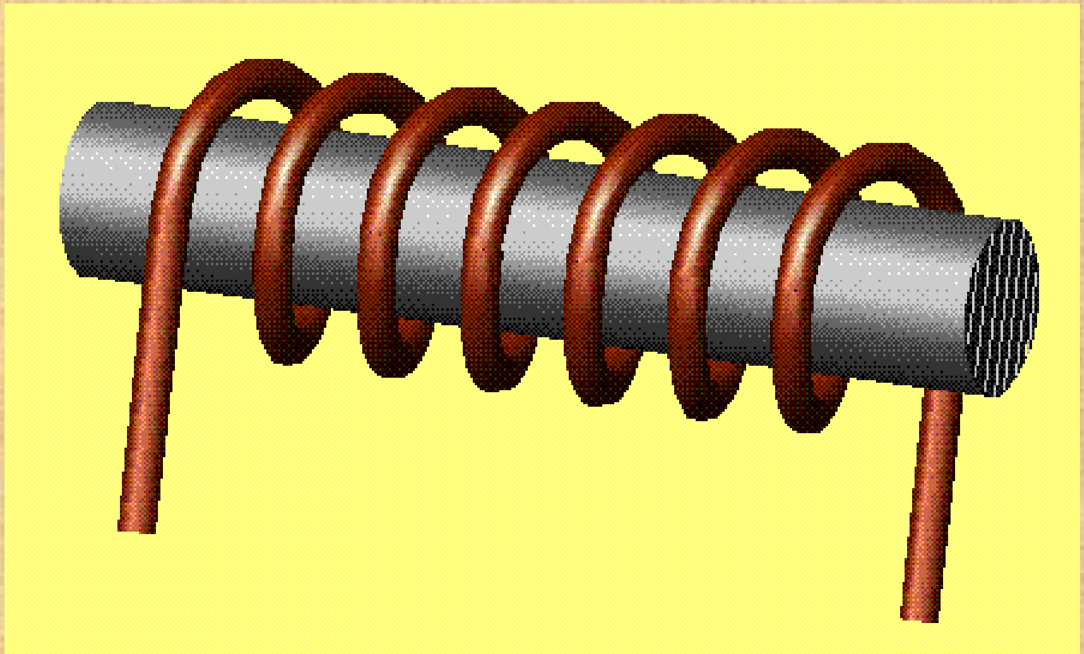


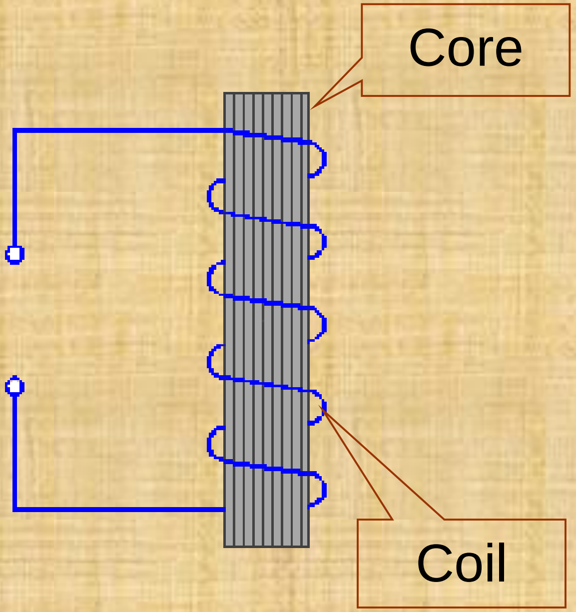
Figure A.1 Basic transformer

When AC is applied to the primary winding. Electrical energy is transferred from the primary winding to the secondary winding by means of mutual induction.

TYPICAL COIL

A typical electrical coil is a number of turns of insulated copper winding wire wound on a magnetic core made from a stack of steel (Stalloy) laminations.





Suitable insulation is provided so that the coil winding can not come in electrical contact with the Stalloy core.

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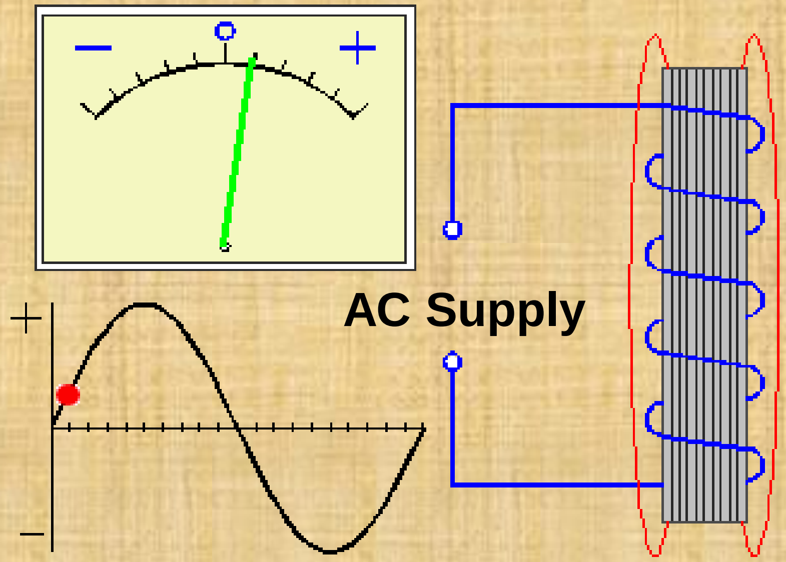
ALTERNATING MAGNETIC FIELD

When an a.c. voltage source is connected to the coil an electric current flows in the coil and produces an alternating magnetic field.



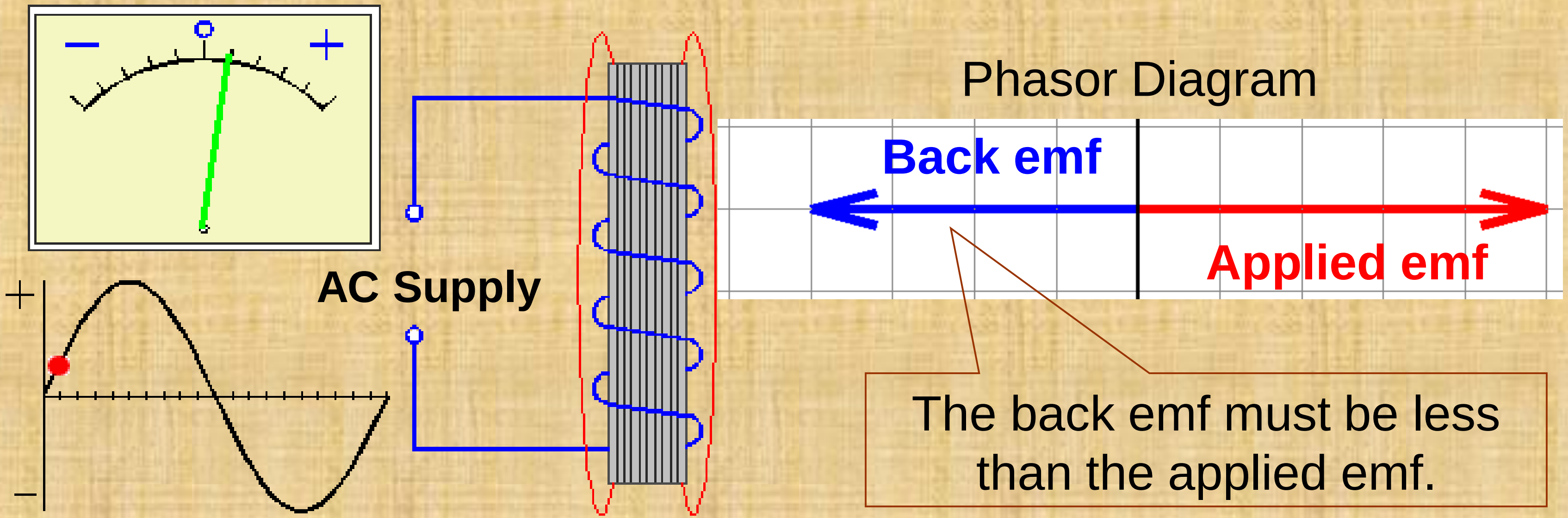
If a magnetic field cuts across a conductor a current is always induced in the conductor.

The strength of the magnetic field is directly proportional to the number of turns and the current flowing in the coil at any instant.

Continue

BACK EMF

As the magnetic field rises and falls it also cuts the turns of the coil that is creating it, and induces in it a voltage of opposite polarity to the applied voltage.

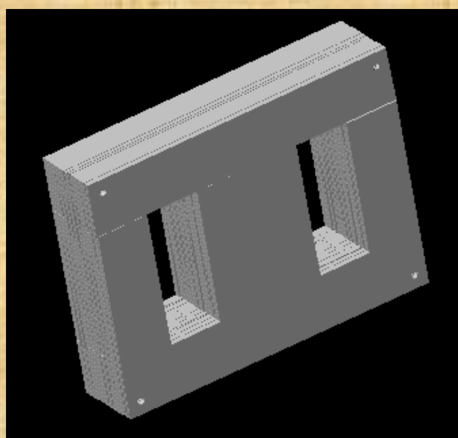


The voltage induced in the coil by the changing flux is called the 'back emf'.

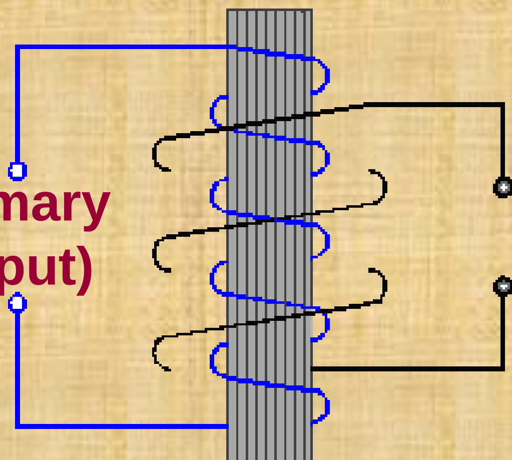
Continue

ELECTROMAGNETIC INDUCTION

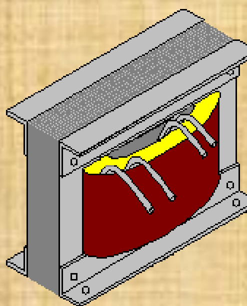
If a second insulated coil is wound over the primary coil, a voltage is induced in the secondary coil by electromagnetic induction.



Primary (Input)



Secondary (Output)



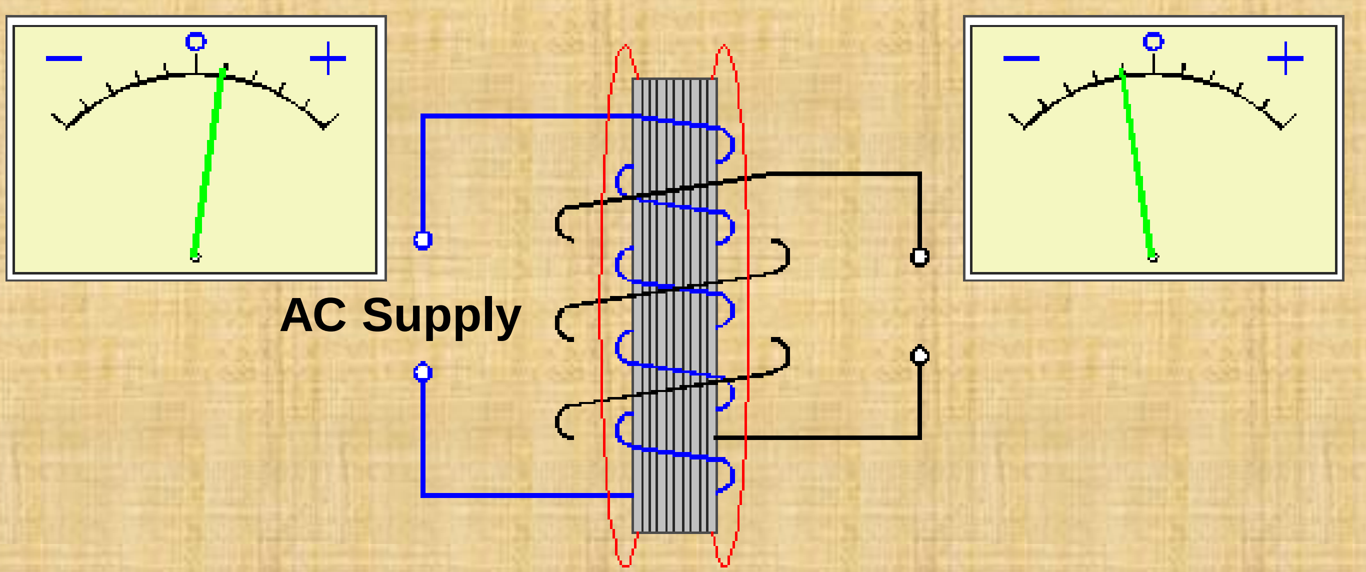
This type of device is known as a double-wound transformer

The voltage in the secondary coil is governed by the number of turns on the primary compared to the turns on the secondary.

Continue

INDUCED VOLTAGE

The voltage induced in the secondary coil is the opposite polarity to the voltage applied to the primary coil at any instant.

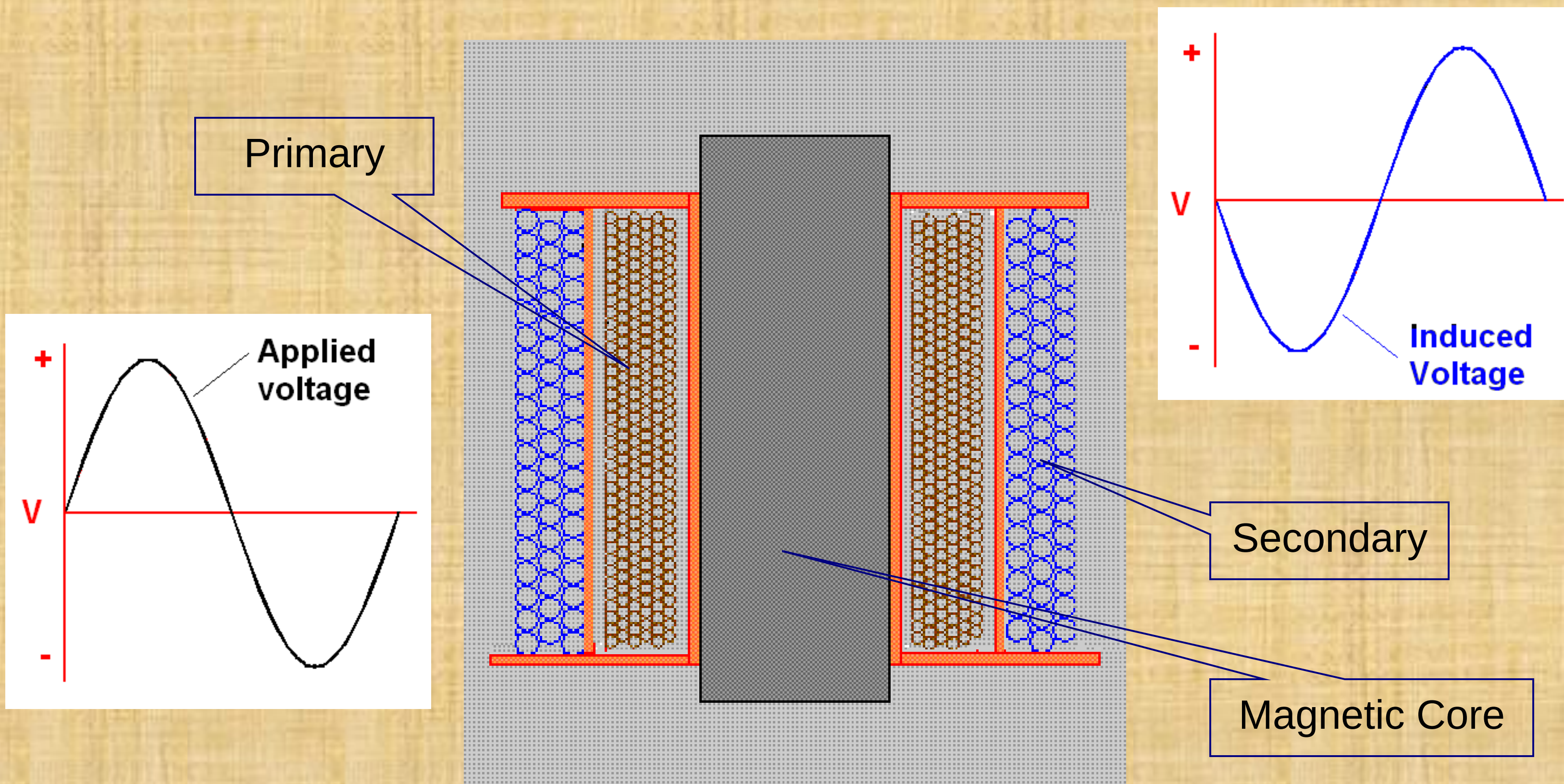


The voltage induced in the secondary coil is said to be 180 degrees out of phase with the primary voltage.

Continue

VOLTAGE IN THE SECONDARY

The alternating current flowing in the primary causes a changing magnetic field which induces a voltage in the secondary winding.



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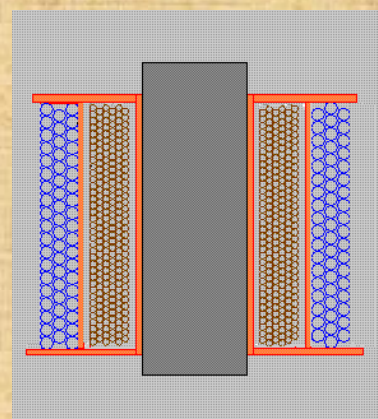
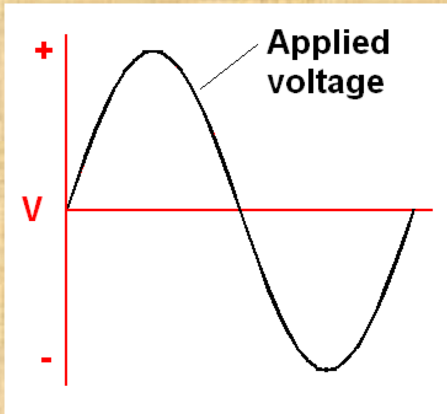
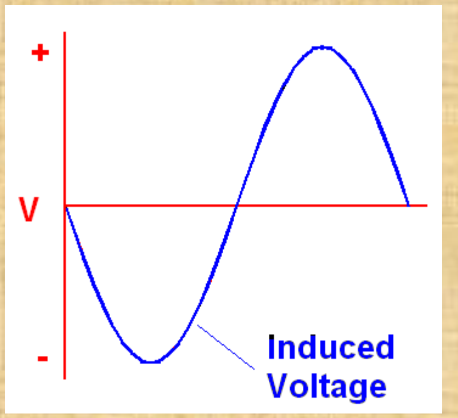
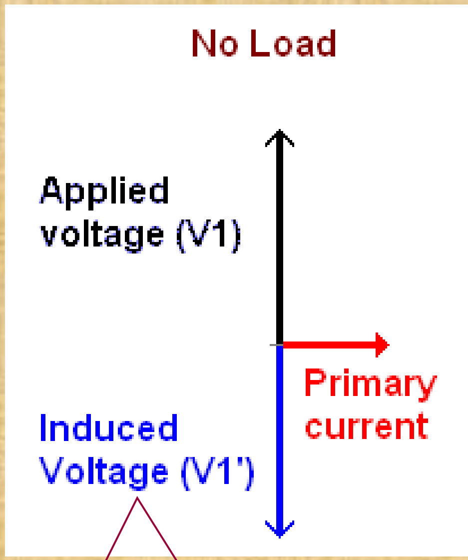
TRANSFORMER OPERATION

No-Load Condition. When a supply voltage V1 is applied to the primary winding a self-induced voltage V1' is produced (Lenz's Law) in the primary winding and opposes the applied voltage V1.









Also known as the ‘back emf’

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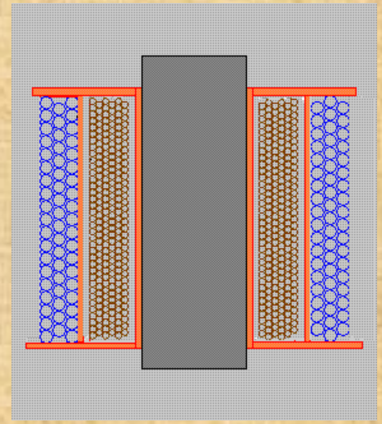
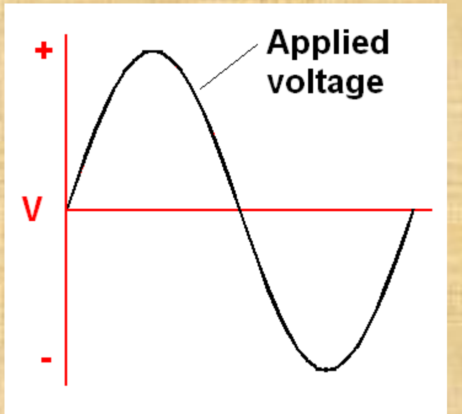
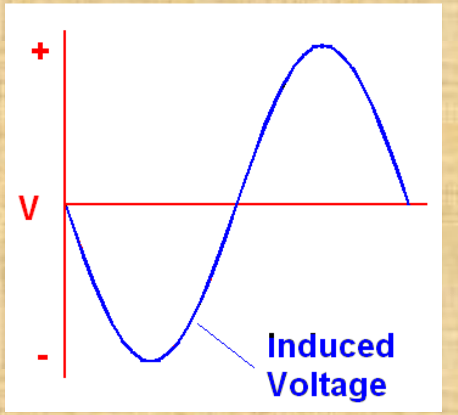
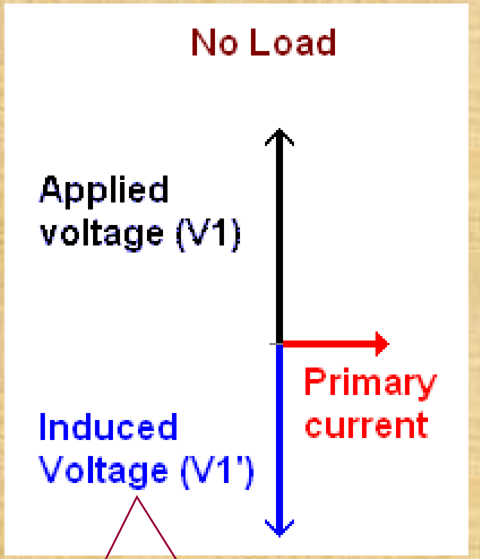
NO LOAD PRIMARY CURRENT

On no-load, voltage V1 practically equals voltage V1' and the no-load primary current or excitation current is usually about 1% to 3% of the rated full-load current.









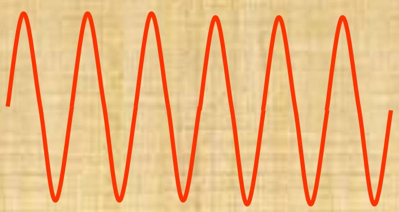
Also known as the 'back emf'

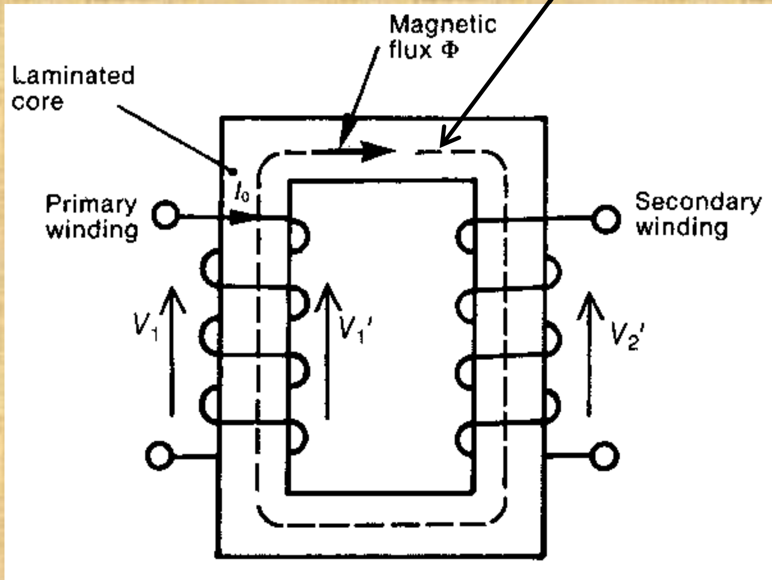
Contiue

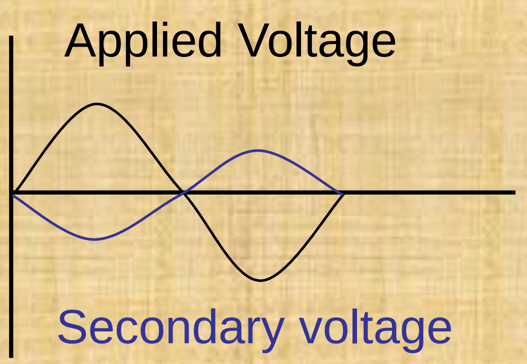
OPERATION OF A TRANSFORMER

- A alternating AC waveform causes an alternating magnetic flux to be transferred to the iron core. This is called the primary flux.

- This primary flux cuts the secondary conductors and induces an emf into the secondary conductor at 180^0 from the primary.







- The value of induced voltage depends **on three factors, frequency, number of turns and the maximum instantaneous flux**.

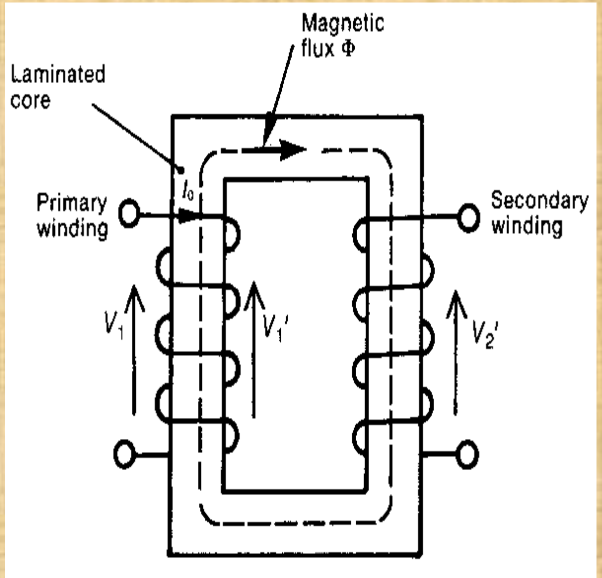
OPERATION OF A TRANSFORMER – ON NO LOAD

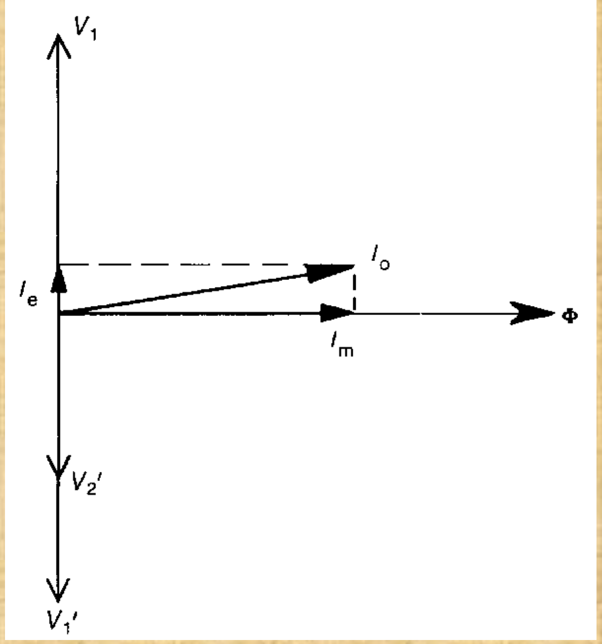
- On no load, applying Lenz's law we can see that a back emf is set up that will be almost equal to the applied voltage. V2 is the secondary voltage but no current can flow until a load is connected.

- Very little current is used typically 1 to 3% of FLI (Full Load Current). This is just enough to keep the flux to a point where the back emf is just below the applied voltage. This current is called magnetising current and the flux it produces is called magnetising flux.

- The energy component of current I_e that represents the losses in the iron cct and the small copper losses is resistive and will be represented by a component in phase with the voltage.

- It can be seen that there is a large angle between V_1 & I_0 which indicates a very poor power factor.



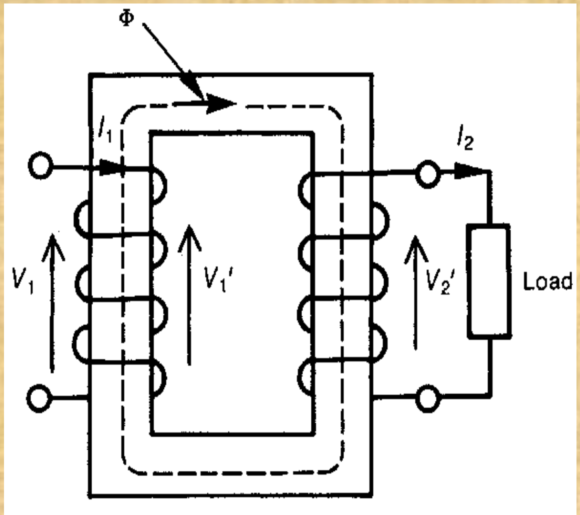


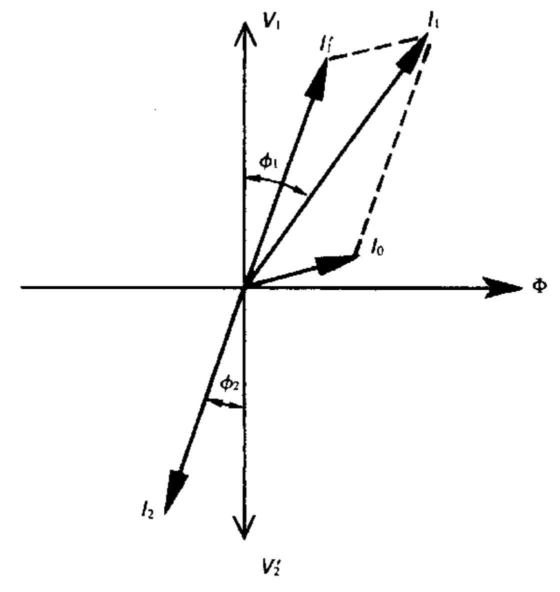
OPERATION OF A TRANSFORMER – WITH LOAD

- The secondary voltage is 180^0 out of phase with the primary. So it can be assumed that the secondary voltage is in phase with the back emf.

- We already know that the flux caused by the primary is causing the back emf and when a load is applied to the secondary I_2 produces a secondary flux, sometimes called a demagnetising flux, which opposes the mutual flux.

- The load causes a demagnetising flux; the mutual flux decreases; the self induced voltage decreases; the primary current increases; the mutual flux rises to its original value.

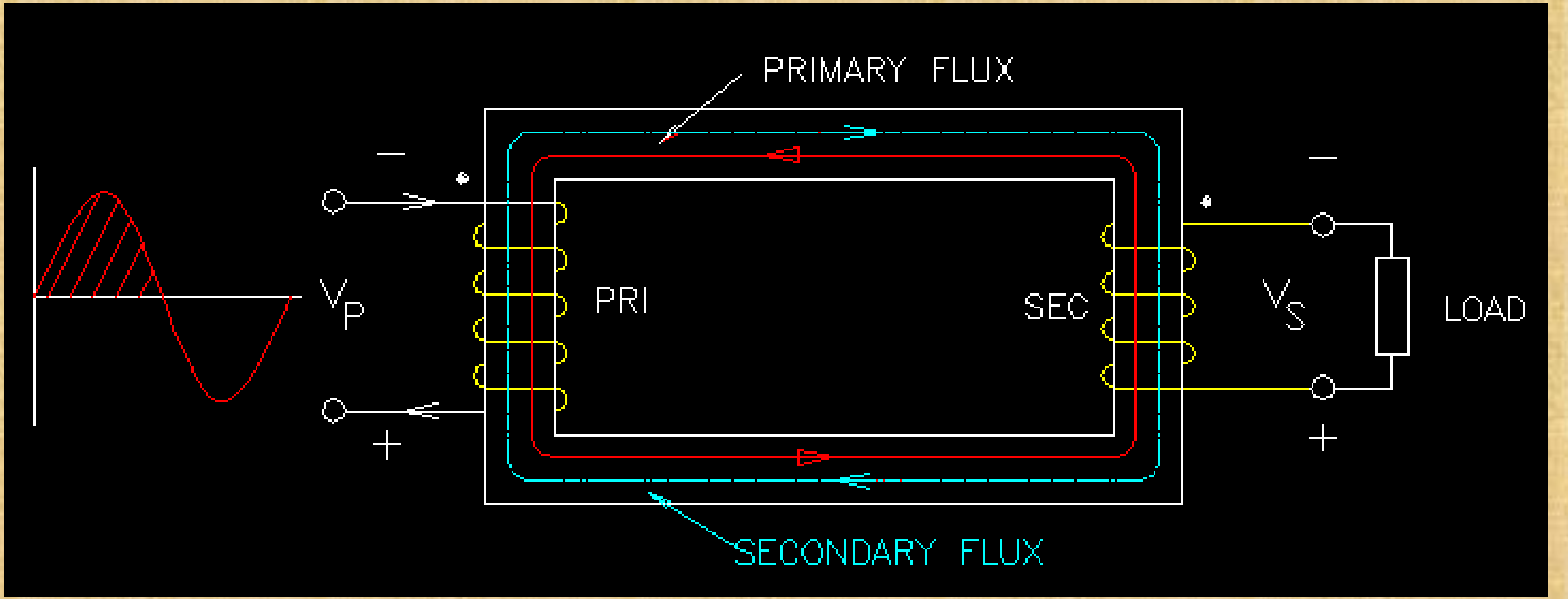




Overall an increase in secondary current output means an increase in primary current input.

EFFECT ON LOAD

When the load is switched on the secondary current produces a demagnetising force. Consequently, the flux is reduced, thus reducing the self induced voltage (or back emf) in the primary. The difference between the back emf in the primary and the supply voltage is increased and more current flows in the primary.



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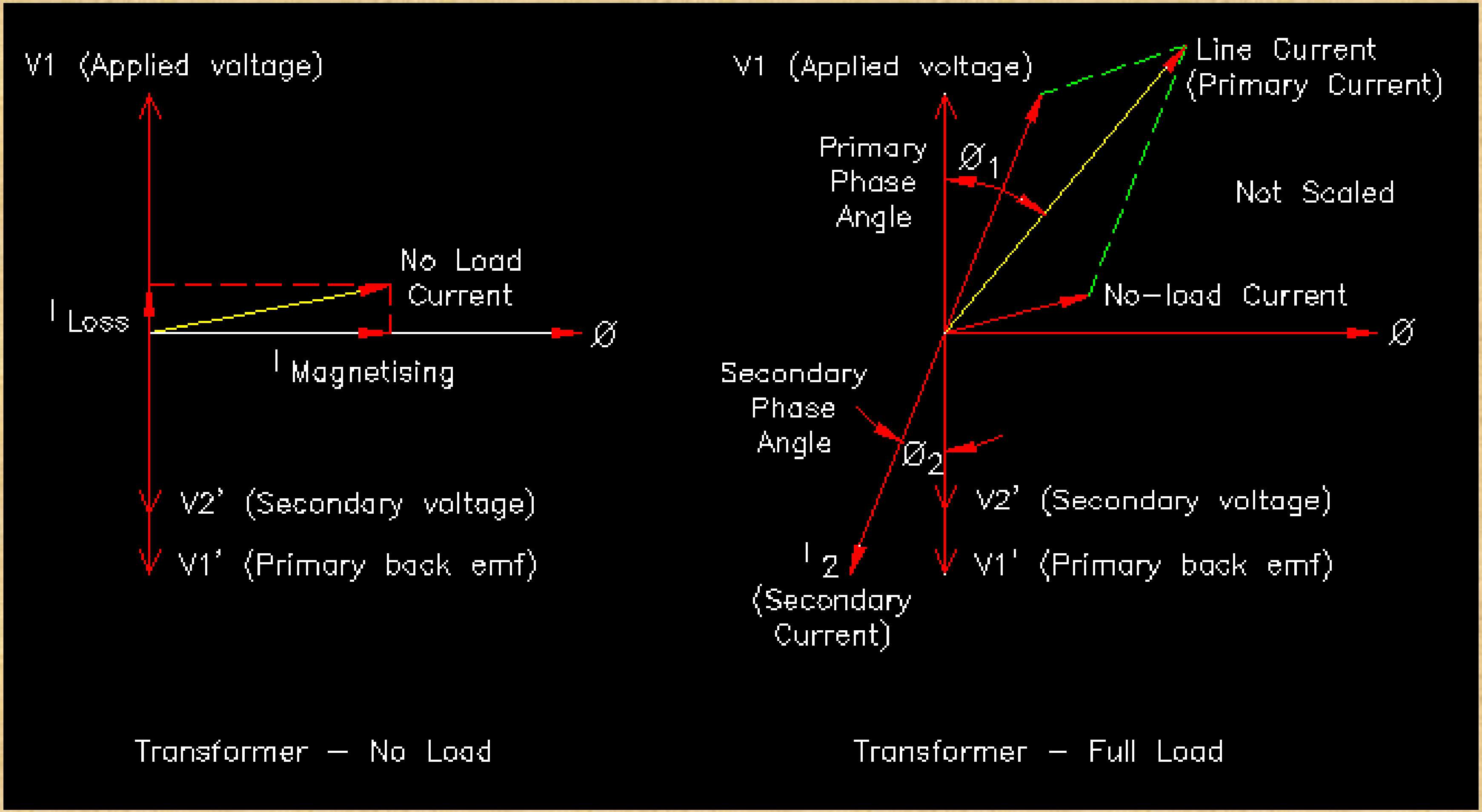
PHASOR DIAGRAMS

Phasor diagrams - no load and full load



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TRANSFORMER PRINCIPLES AND CONSTRUCTION

TRANSFORMER CONSTRUCTION

Toroidal Type – This type of core provides an almost perfect magnetic circuit having its primary and secondary windings uniformly distributed around the core. The ring core minimises losses, fringing, leakage and distortion, and provides good magnetic shielding.

TRANSFORMER CONSTRUCTION

Shell Type construction – The name Shell results from the fact that the coil windings are completely surrounded by a shell of steel. In general this transformer design is more economical for low voltage transformers.

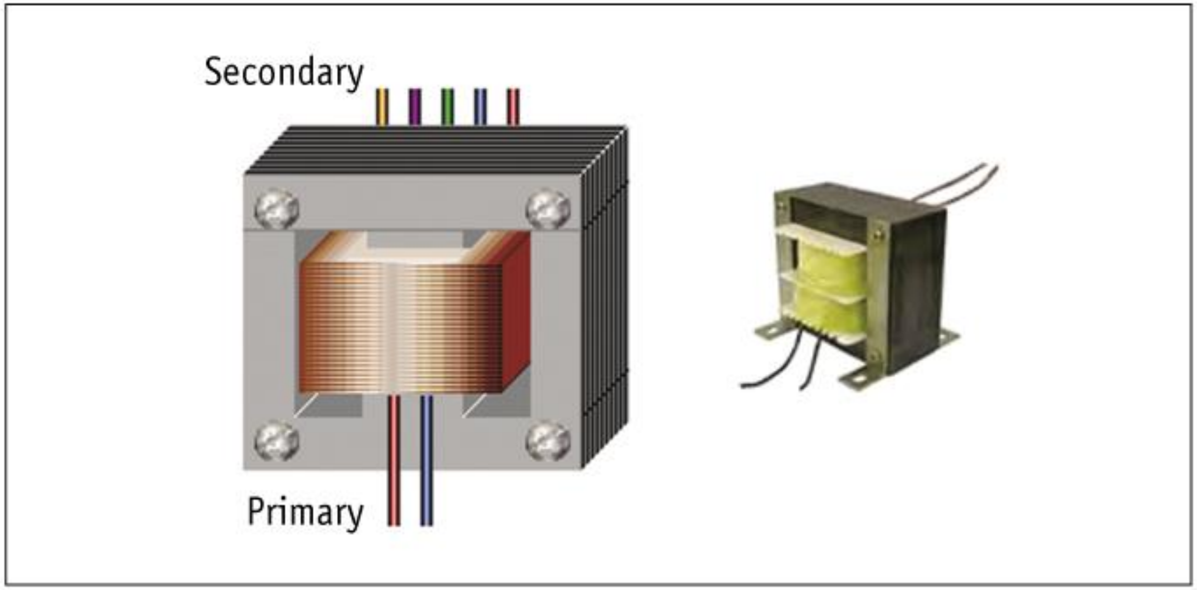


Figure 9.2 Shell-type contruction

TRANSFORMER CONSTRUCTION

Core Type construction – The core type of transformer is more economical for high voltage transformers. The characteristics of a core type transformer are a long electromagnetic circuit and a shorter length mean turn for the winding.

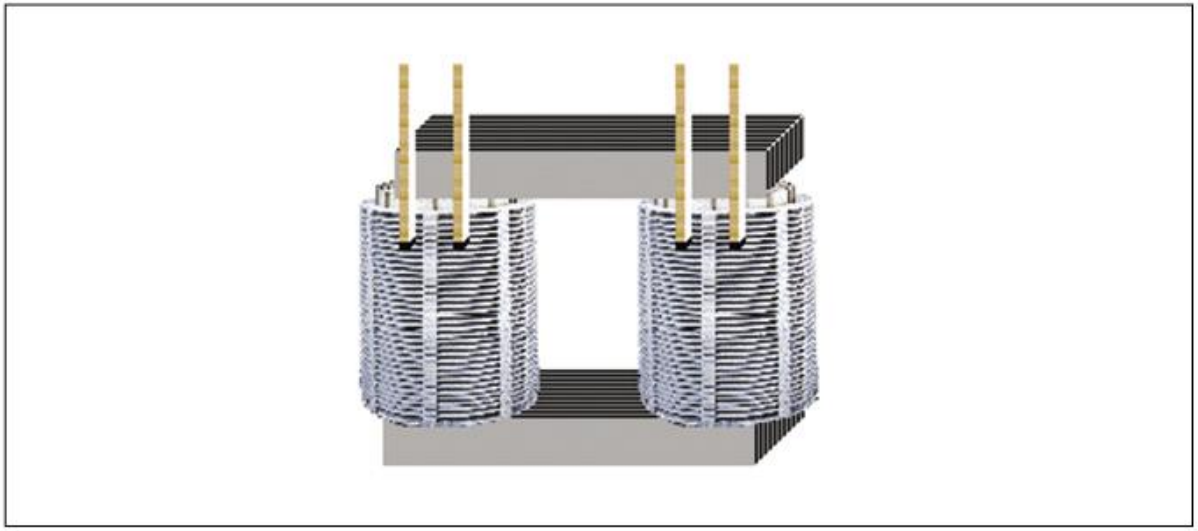


Figure 9.5 Core-type showing the yoke, legs

TRANSFORMER CONSTRUCTION

WINDING TYPES

Transformer windings are designed to get the required number of conductor turns into a minimum space. At the same time the cross section of the conductor must be able to carry the rated current without overheating.

The winding types used depending on the transformer design are:

- Layer
- Pancake
- Bobbin
- Toroidal

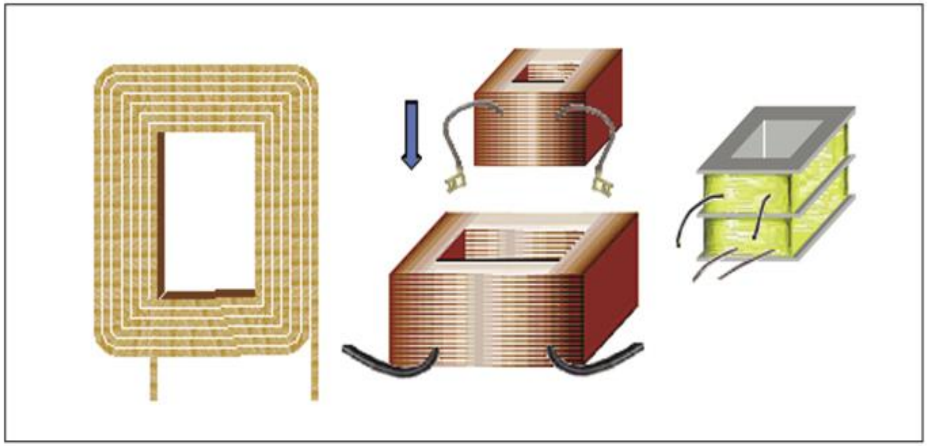
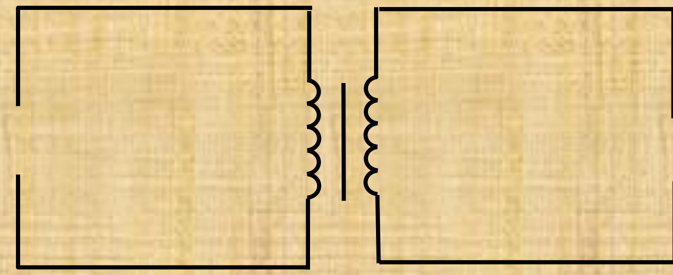


Figure 9.3 Shell coils—Pancake, layer and bobbin

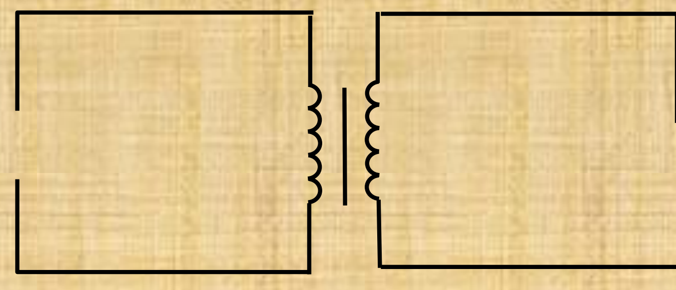
Lower input voltage



Higher output voltage

Step up transformer

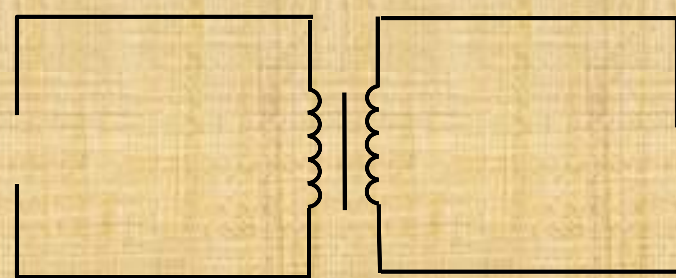
Higher input voltage



Lower output voltage

Step down transformer

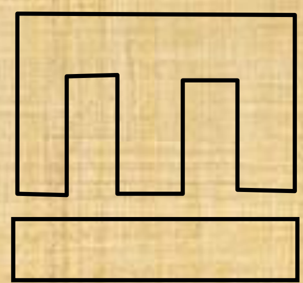
Input voltage equals



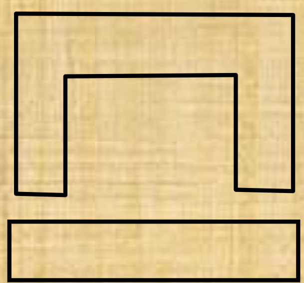
Output voltage

Isolation transformer

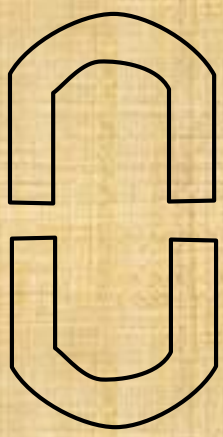
Types of Cores used in single phase transformers.



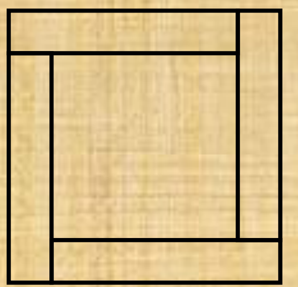
E-I Shell
type



U-I core type



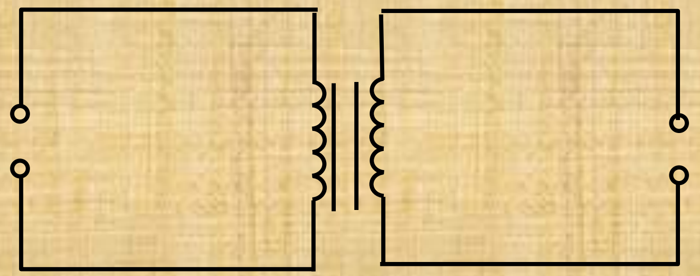
C core
type



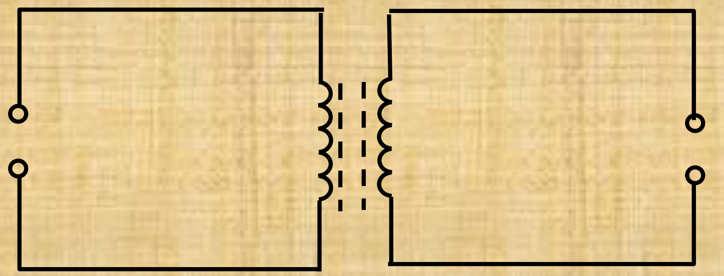
I-I core type

CIRCUIT SYMBOLS FOR THE DIFFERENT TYPES OF TRANSFOMER CORES

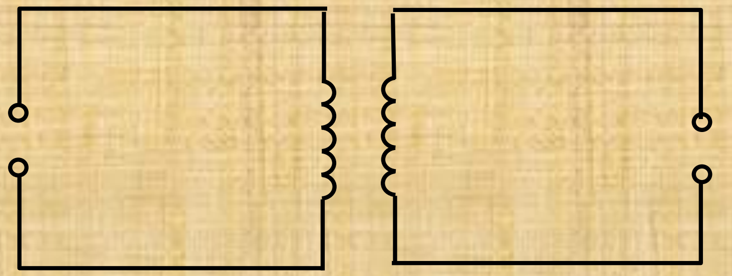
Iron core



Ferrite core

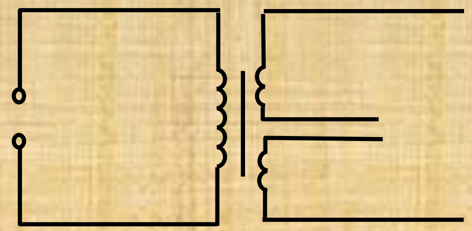


Air core

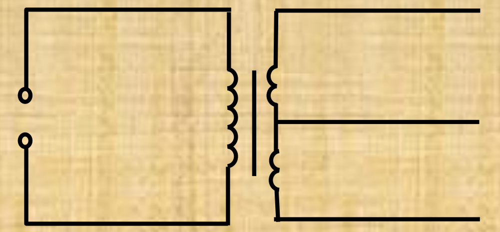


Transformers can have multiple outputs and can be

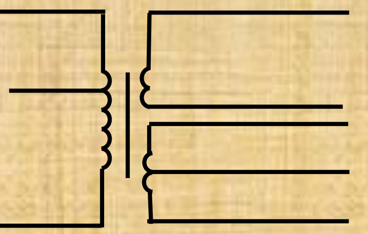
- Independent windings



- Tapped windings



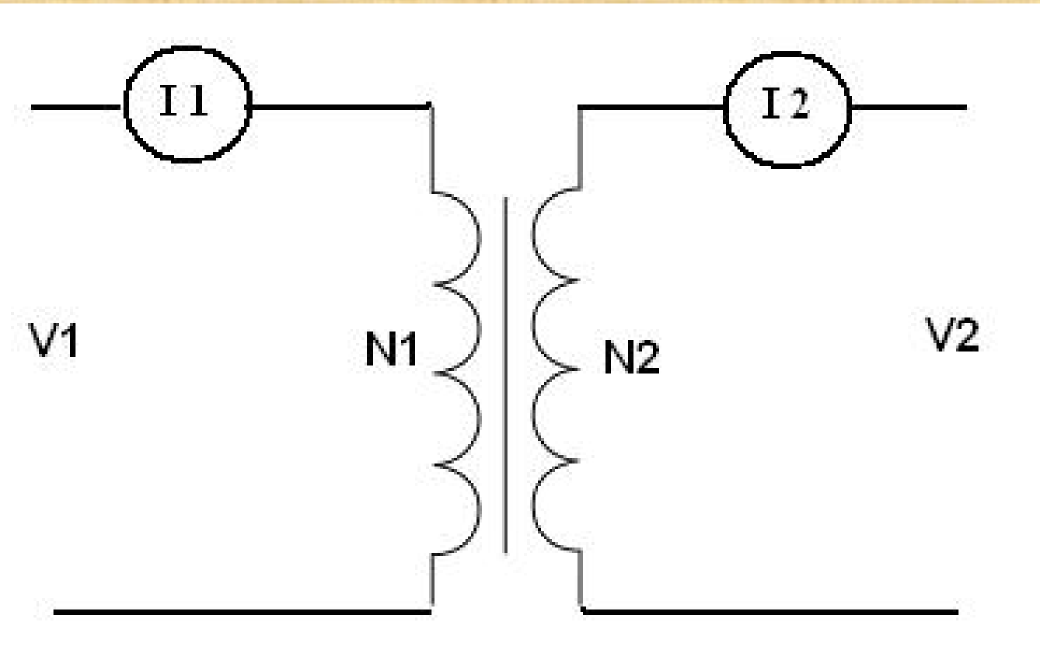
- Or a combination of both



TRANSFORMATION RATIOS

All the ratios for a transformer can be obtained from this formula

$$\frac{V1}{V2} = \frac{N1}{N2} = \frac{I2}{I1}$$



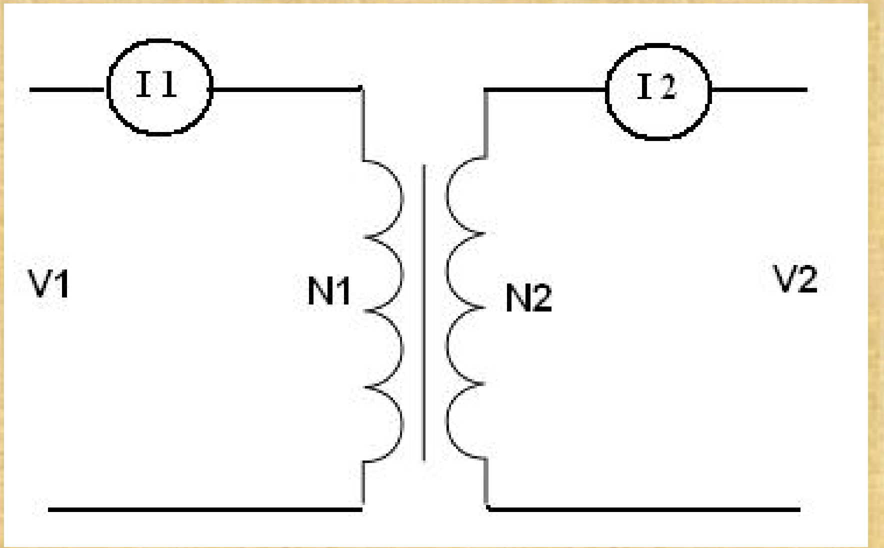
TRANSFORMATION RATIO'S - VOLTAGE

Because the mutual flux is common to each winding it must induce the same voltage per turn in each winding ie

$$\frac{V1}{V2} = \frac{N1}{N2}$$

$$V1 = \frac{N1 \; V2}{N2}$$

$$\frac{N1 \; V2}{V1} = N2$$



PROBLEM 1

A transformer has 1000 turns on the primary winding and 200 on the secondary. If the applied voltage is 250 V, calculate the output voltage of the transformer.

$$\frac{V1}{V2} = \frac{N1}{N2}$$

$$V2 = V1 . \frac{N2}{N1}$$

$$= 250 \times \frac{200}{1000}$$

$$= 50 \text{ v}$$

CURRENT RATIO

The current ratio is the ratio between the primary current and the secondary current.

The current ratio is the inverse of voltage ratio in a transformer. If the voltage ratio is 10:1 the current ratio must be 1:10 (losses are neglected).

Current Ratio = Ip:Is.

Therefore:

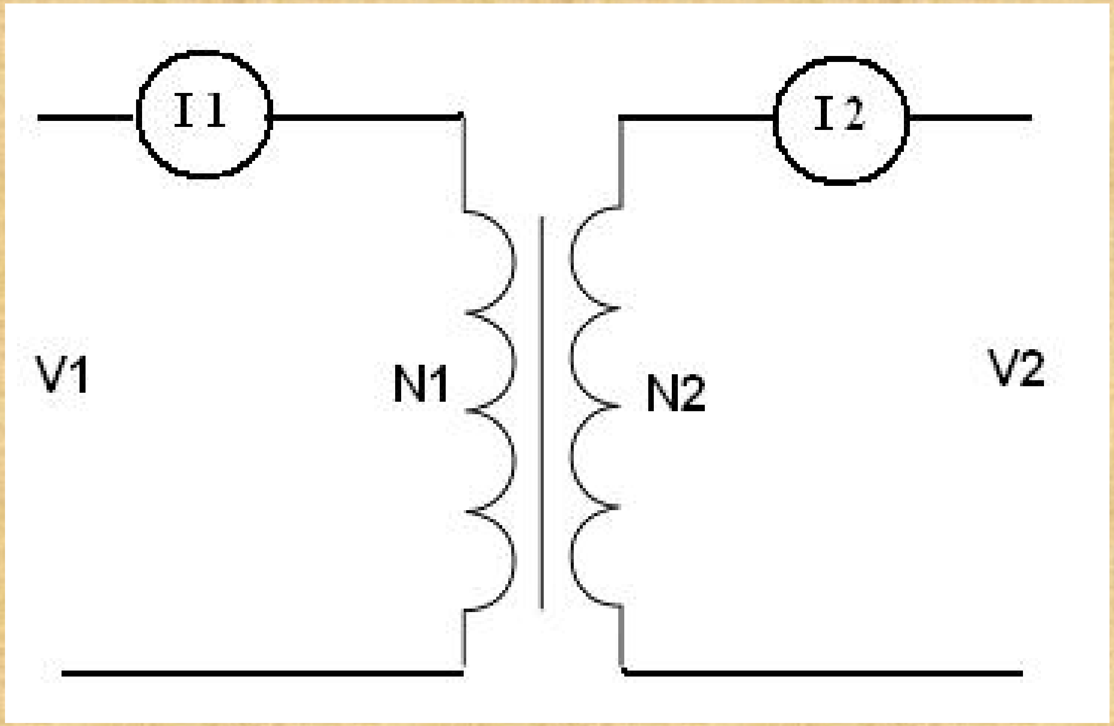
$$\frac{V_p}{V_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p}$$

Continue

TRANSFORMER RATIOS - CURRENT

When the transformer is connected to the load, the secondary current I 2 produces a demagnetising flux proportional to the the secondary ampere turns I2N2. The primary current increases providing an increase in the primary ampere turns I1N1 to balance the effect of the secondary ampere turns

$$\frac{I_1}{I_2} = \frac{N_2}{N_1}$$

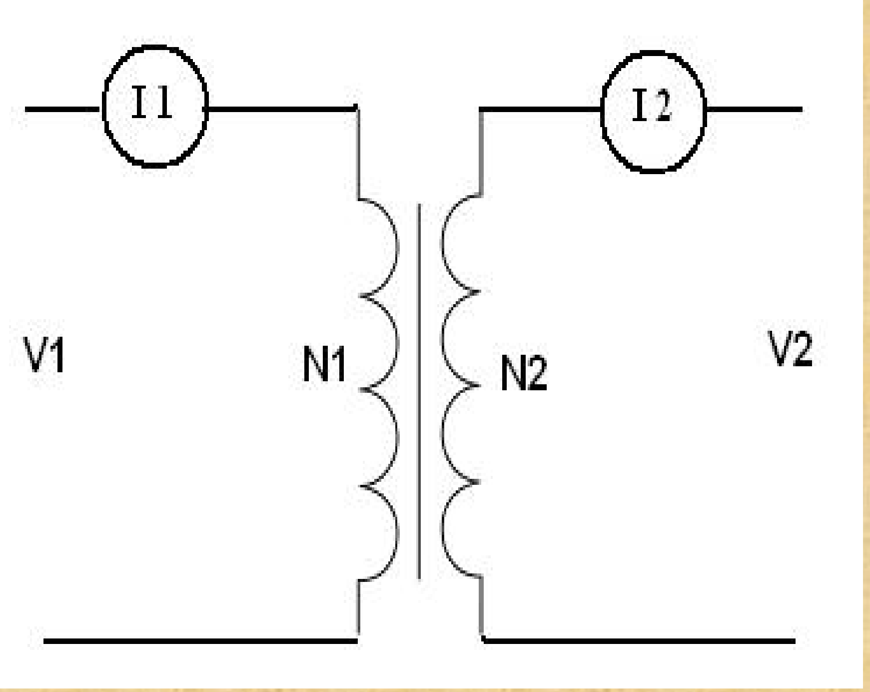


TRANSFORMER RATIOS

$$\frac{V1}{V2} = \frac{I2}{I1}$$

$$V1 = \frac{I2 \quad V2}{I1}$$

$$\frac{I2 \quad V2}{V1} = I1$$

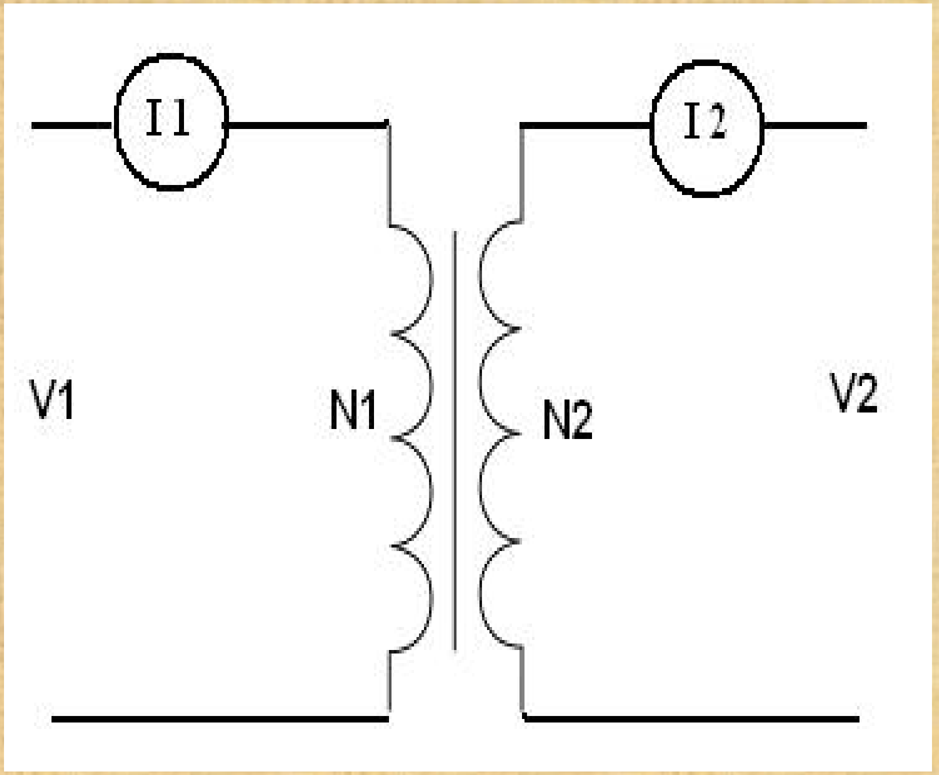


TRANSFORMER RATIOS

$$\frac{N1}{N2} = \frac{I2}{I1}$$

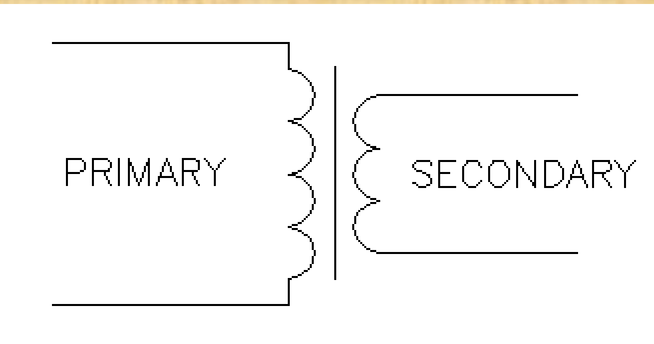
$$N1 = \frac{I2 \; N2}{I1}$$

$$\frac{I2 \; N2}{N1} = I1$$



CALCULATING PRIMARY CURRENT

Example A single phase 240:50 V step down transformer supplies 150 amps from the secondary winding. Calculate the primary current.



$$\frac{Vp}{Vs} = \frac{Is}{Ip}$$

$$\frac{240}{50} = \frac{150}{Ip}$$

$$Ip = \frac{150 \times 50}{240}$$

$$= 31.25 \text{ Amps}$$

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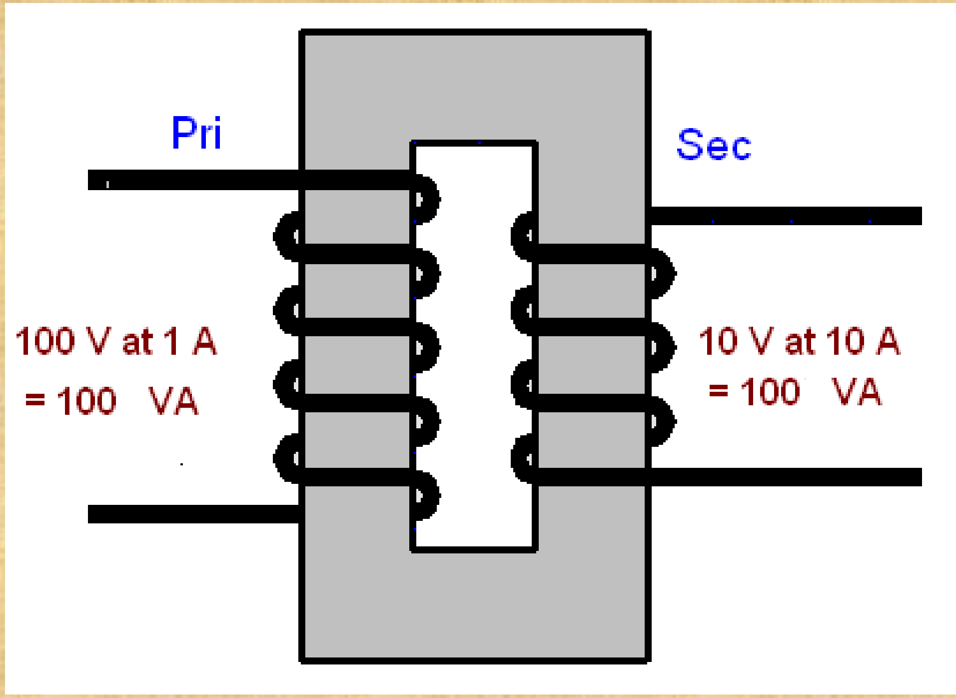
VA (VOLT-AMP) RATING

Since the primary current is proportional to the secondary current and the primary voltage is proportional to the secondary voltage:

Primary VA = Secondary VA (neglecting losses)



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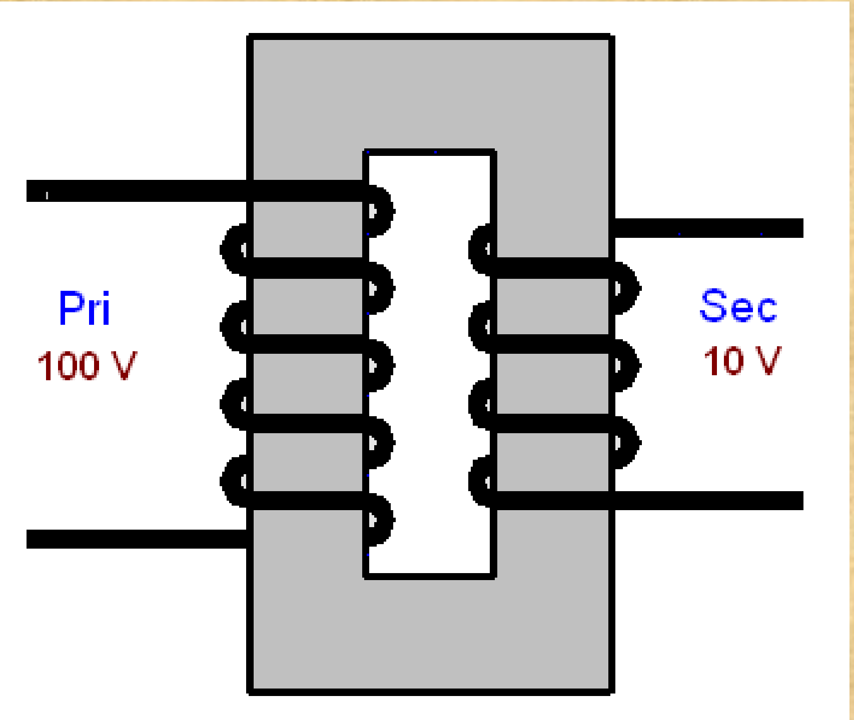
VOLTAGE RATIO

The voltage ratio is the ratio between the primary voltage and the secondary voltage:

Voltage Ratio = Vp:Vs



$$\text{Voltage Ratio} = \frac{V_p}{V_s} = \frac{100}{10} = 10:1$$

The voltage ratio is always given with the primary value first, so 10:1 means it is a step-down transformer.

Continue

SUMMARY OF RELATIONSHIPS

Any variation of secondary current is accompanied by a proportional variation of the primary current. Therefore:

$$\frac{Vp}{Vs} = \frac{Np}{Ns} = \frac{Is}{Ip}$$

Where: Is = secondary current

Ip = primary current

Vs = secondary voltage

Vp = primary voltage

Ns = secondary turns

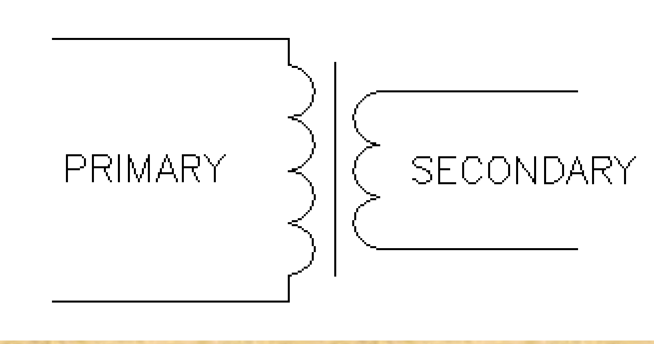
Np = primary turns

Continue

CALCULATIONS

The fixed relationship between voltages, turns and currents enable various calculations to be made.

Example: A 240:24 volt transformer has 1200 turns on the primary. How many turns are there on the secondary (neglecting losses)?



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

So $N_s = \frac{V_s \times N_p}{V_p}$

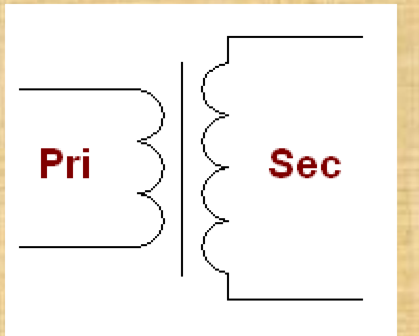
$= \frac{24 \times 1200}{240}$

$= 120$ turns

Continue

VOLTAGE CALCULATION

Example: **A transformer has 200 turns in the primary winding and 600 turns in the secondary winding. Calculate the turns ratio and the secondary voltage if the primary voltage is 50 V.**



$$\text{Turns ratio} = \frac{N_p}{N_s} = \frac{200}{600} = 1 \text{ to } 3 \text{ (step up)}$$

$$\text{Secondary Volts} = 3 \times 50 = 150\ \text{V}$$

Continue

TRANSFORMER RATINGS

Transformers and alternators are not rated in kilowatts (kW) because the load drawn from a transformer may have a variable power factor, so they are rated in voltamperes (VA) or kilo voltamperes (kVA) which are derived from the line voltage and the line current.

In all transformers, the output kVA from the secondary is equal to the input kVA less any losses in the transformer.

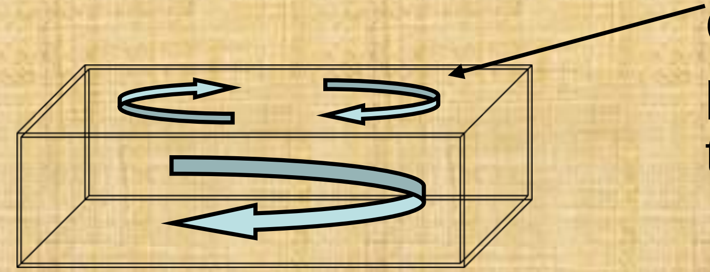
Continue

TRANSFORMER LOSSES

IRON LOSSES

EDDY CURRENTS - are caused by the steel core (which is a conductor) being cut by magnetic lines of force.

The current produced by the change in field will circulate within the core. If the core is solid the resistance is low and large currents would flow.

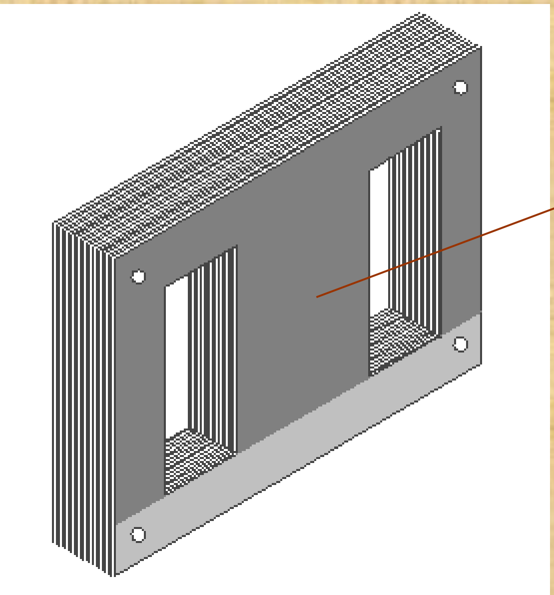


Circulating currents producing heat and therefore losses.

To reduce this the steel core is laminated and electrically insulated from each other and this reduces the actual current that circulates.

REDUCING EDDY CURRENTS

Eddy currents are reduced by using a laminated or ferrite powder iron core instead of a solid block of magnetic iron.



The laminations are stacked in alternate layers of ‘Es’ and ‘Is’.

All transformers have laminated or ferrite cores because both have a.c. currents flowing in them when operating.

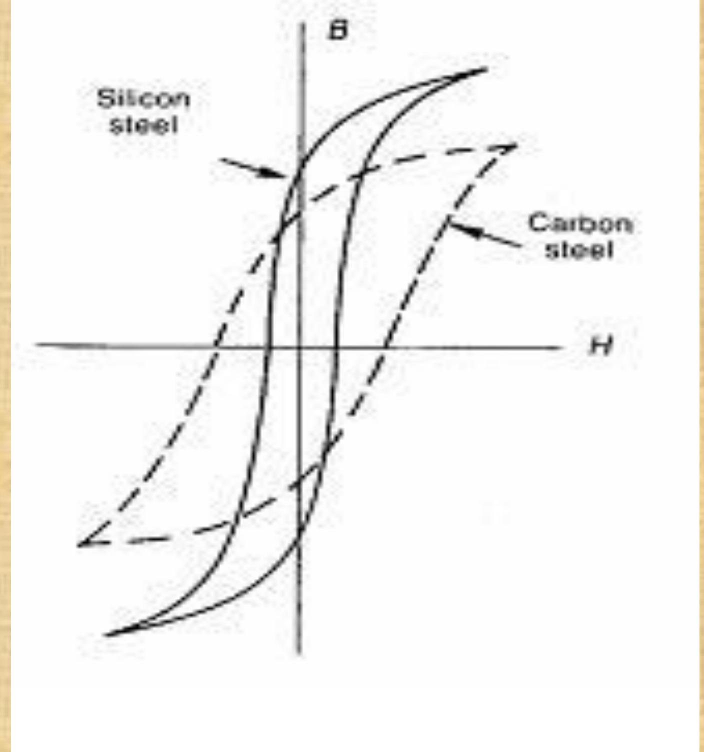
Continue

TRANSFORMER LOSSES

IRON LOSSES

HYSTERESIS LOSSES - are caused by the fluctuating magnetic field.

- The fluctuations do not allow the magnetic field to reach zero on each part of the cycle . This is called residual magnetism or Remanance.



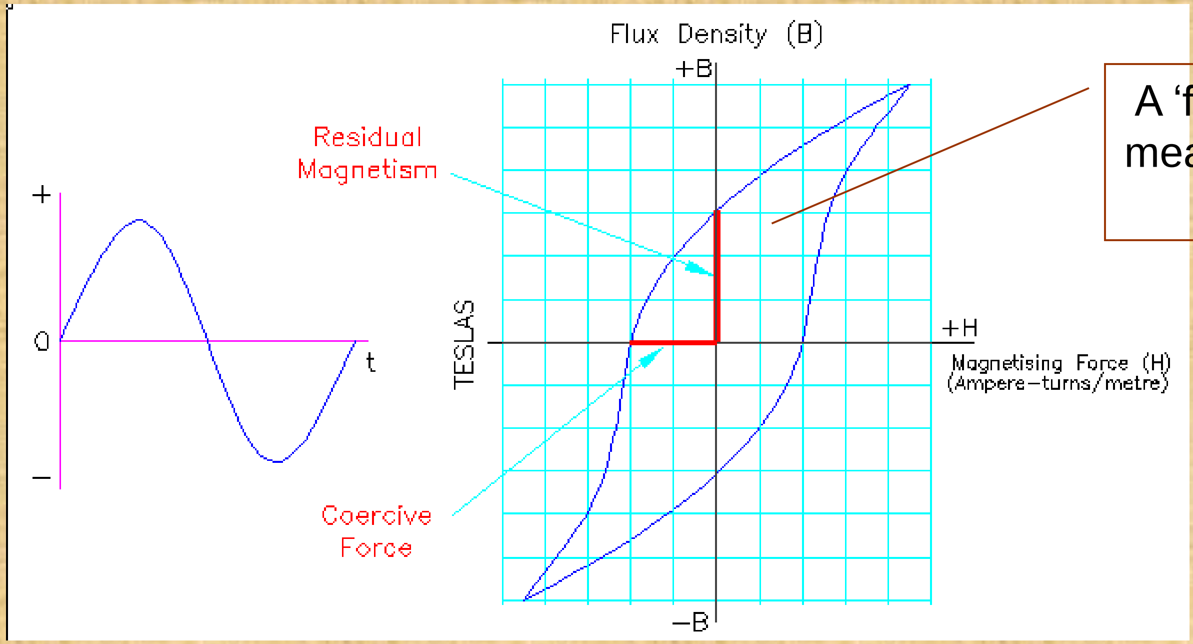
The power required to overcome this is a loss.

B – FLUX DENSITY

H – MAGNETISING FORCE

HYSTERESIS LOOP

A small amount of power has to be used after each half cycle to overcome this residual magnetism (or remanence), before the core can be re-magnetised with the opposite polarity. A typical hysteresis loop is shown below.



A ‘fat’ hysteresis loop means that it is a poor material.

The value of the loss is directly proportional to the area of the hysteresis loop

Continue

REDUCING HYSTERESIS LOSS

Hysteresis losses can be reduced by using a better quality iron, which has less residual magnetism or remanence, but higher quality irons are expensive, so most manufacturers use a lower quality iron and allow for losses in the design of the device.

Continue

TRANSFORMER LOSSES

COPPER LOSSES

This is the energy loss in the windings when the transformer is loaded.

The resistance of each winding is relatively low, but since the power dissipated in each winding is proportional to the square of the current flowing through that winding, it follows that the copper loss is significant when the load current is high.

$$P_{CU} = I_1^2 R_1 + I_2^2 R_2$$

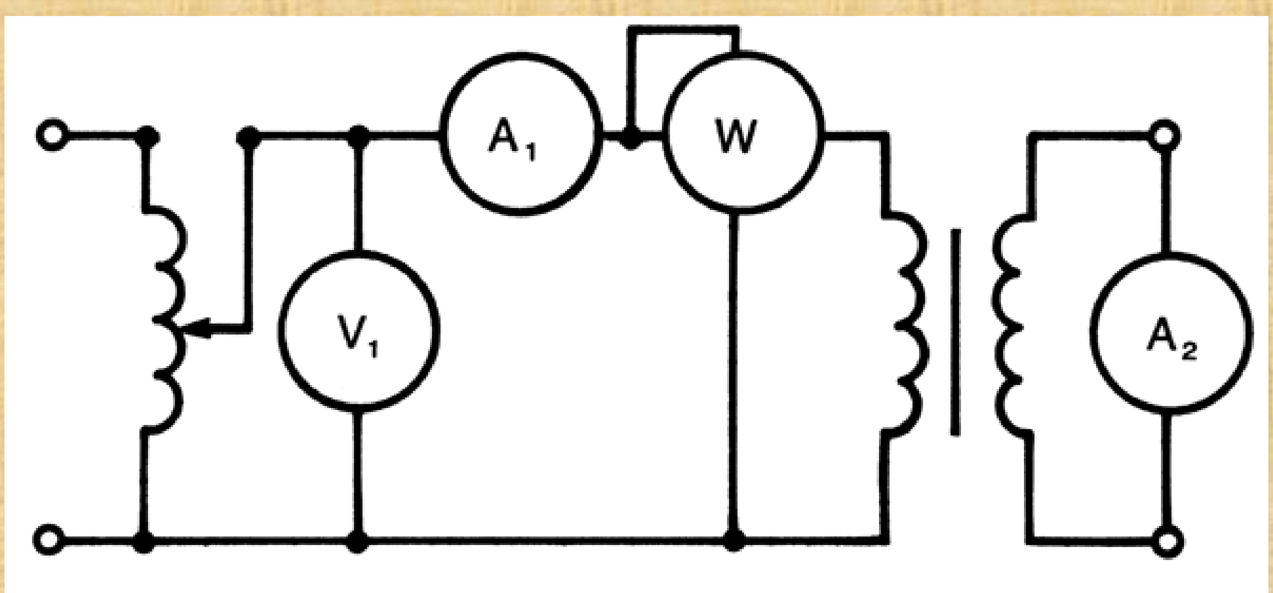
Where R1 and R2 are the resistance values of the primary and secondary windings

The copper losses are not constant, but vary according to the square of the load current.

TESTING FOR TRANSFORMER LOSSES

COPPER LOSS TEST – Is used to measure the energy loss in the windings when the transformer is loaded.

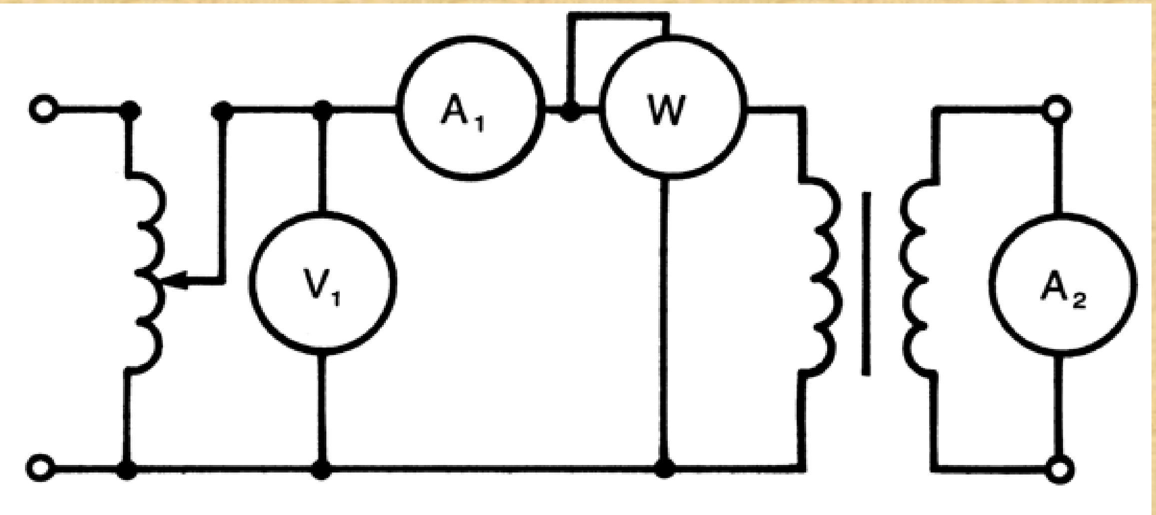
- The output from the autotransformer is adjusted to circulate full rated currents in the primary and secondary circuits. Because the supply voltage to the transformer is low, the flux in the iron core is also low, and so the iron core losses are negligible. The power registered on the wattmeter can then be taken as the total **I^2 R (copper losses)** in the transformer on full load.



TESTING FOR TRANSFORMER LOSSES

THE % IMPEDENCE OF THE TRANSFORMER CAN BE OBTAINED FROM THE SHORT CIRCUIT TEST AS WELL.

- The percentage impedance of a transformer is the volt drop on full load due to the winding resistance and leakage reactance expressed as a percentage of the rated voltage. **It is also the percentage of the normal terminal voltage required to circulate full-load current under short circuit conditions.**

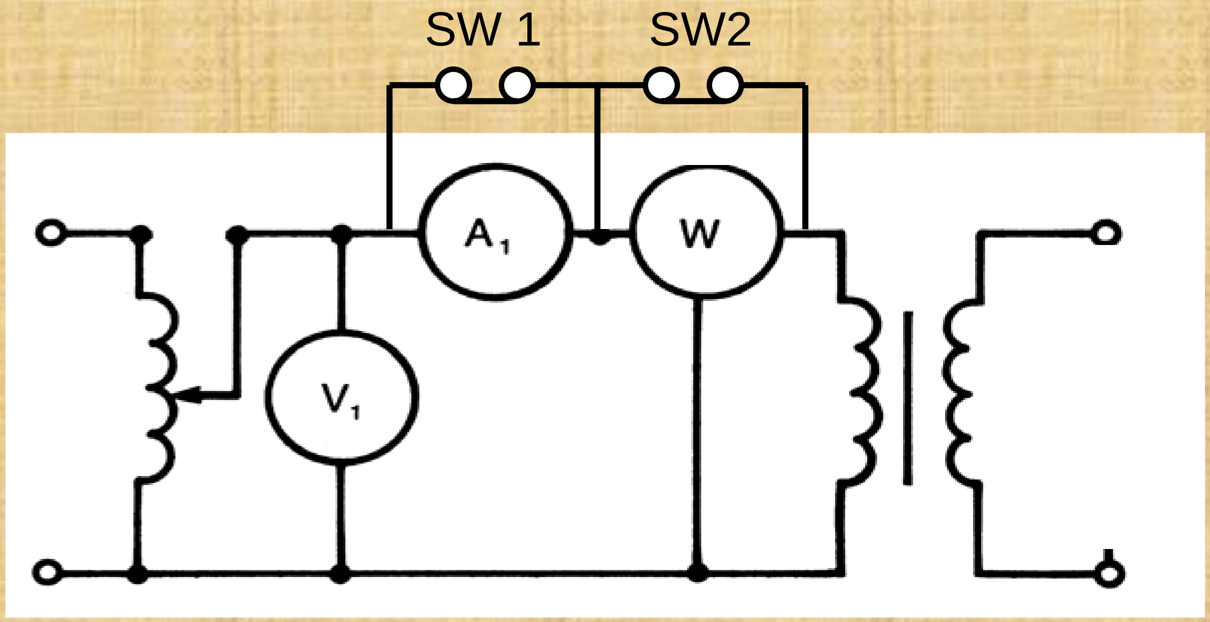


$$Z\% = \frac{\text{IMPEDENCE VOLTAGE}}{\text{RATED VOLTAGE}} \times 100$$

TESTING FOR TRANSFORMER LOSSES

OPEN CIRCUIT TEST – The OPEN CCT test is to measure the iron losses of a transformer.

With the connections shown with A and W shunted out adjust the regulating transformer to the rated voltage. Switch off and disconnect the voltmeter. Open SW1 & energise, record the current flowing. Shunt out SW1 across the ammeter and open SW2 across the Wattmeter and record the wattmeter reading. **The ammeter measures the no load current while the wattmeter measures the total iron losses within the transformer.**



TRANSFORMER EFFICIENCY

The efficiency of a transformer can be calculated using the equation:

$$\text{Efficiency\%} = \frac{\text{Output Power}}{\text{Input Power}} \times 100 \quad \text{or} \quad \frac{\text{Output Power}}{\text{Output Power + Losses}} \times 100$$

Continue

CALCULATING EFFICIENCY

A single phase transformer is delivering 120 volts at 9.6 amps at a power factor of 0.8 lagging, with an input of 240 volts at 5 amps at a power factor of 0.8 lagging.

If the total copper loss is 24 watts and the total iron loss is 15 watts, the efficiency of the transformer is:

$$\text{Efficiency\%} = \frac{\text{Output Power}}{\text{Output Power + Losses}} \times 100$$

$$= \frac{V_{Out} \times I_{Out} \times \text{Cos } \text{Ø}}{(V_{Out} \times I_{Out} \times \text{Cos } \text{Ø}) + \text{Losses}} \times 100$$

$$= \frac{120 \times 9.6 \times 0.8}{(120 \times 9.6 \times 0.8) + (24 + 15)} \times 100$$

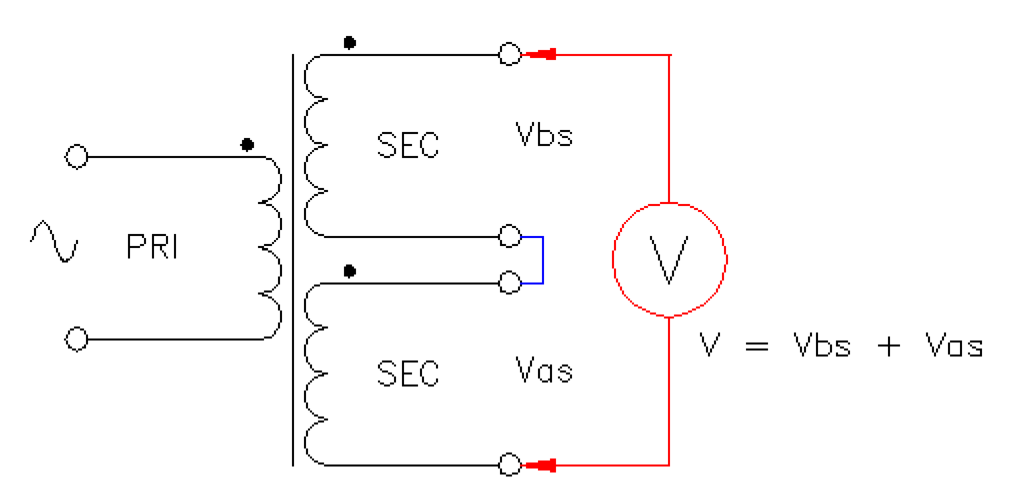
Efficiency% = 96%

Continue

SERIES-AIDING CONNECTION

Transformer secondaries can be connected Series Aiding and Series Opposing.

The diagram shows the effect of terminals of unlike and like polarity being connected together - this is known as a 'series aiding' connection.



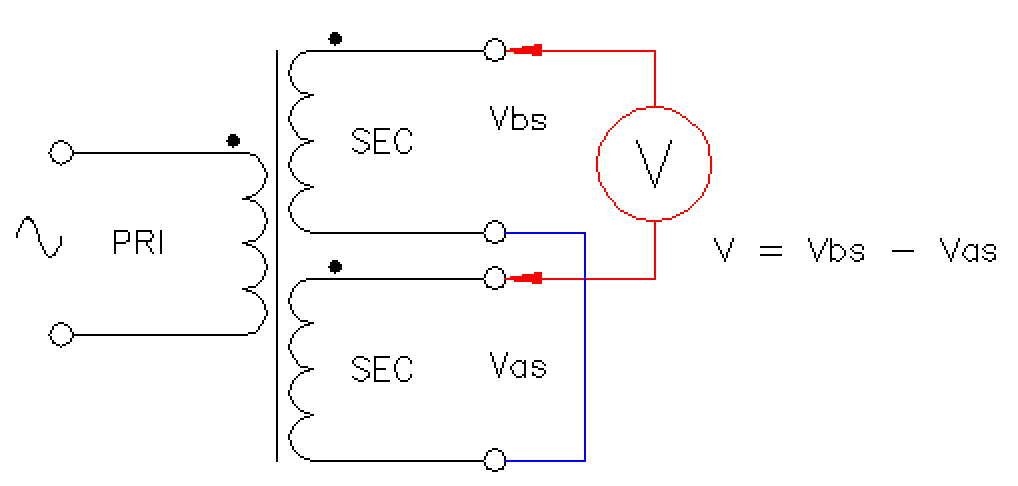
With the two secondary windings connected as SERIES AIDING the output secondary voltage will be: V = Vbs + Vas

Continue

SERIES OPPOSING CONNECTION

With the two secondary windings connected as SERIES OPPOSING the output secondary voltage will be:

V = Vbs - Vas



Continue

PARALLELING SINGLE PHASE TRANSFORMERS

It is possible to connect single phase transformers in parallel provided that the output voltages are the same and the regulation is the same in each.

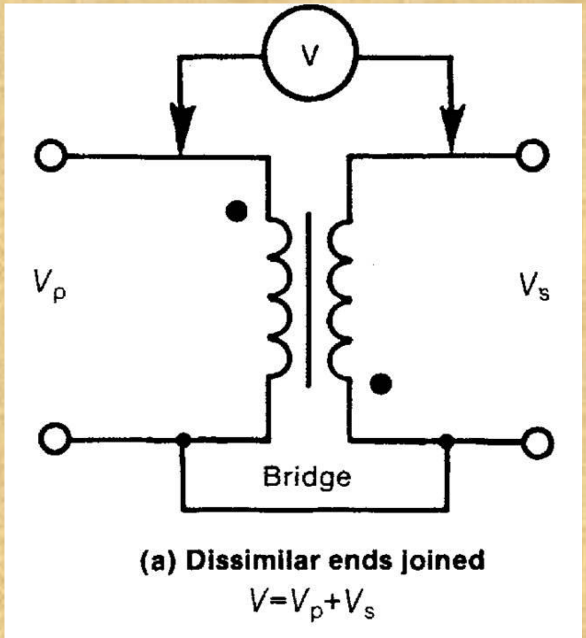
However, since the secondary voltage of a transformer is 180 degrees out of phase with the primary voltage, the two transformers must be connected so that the instantaneous voltage is the same polarity in each.

Continue

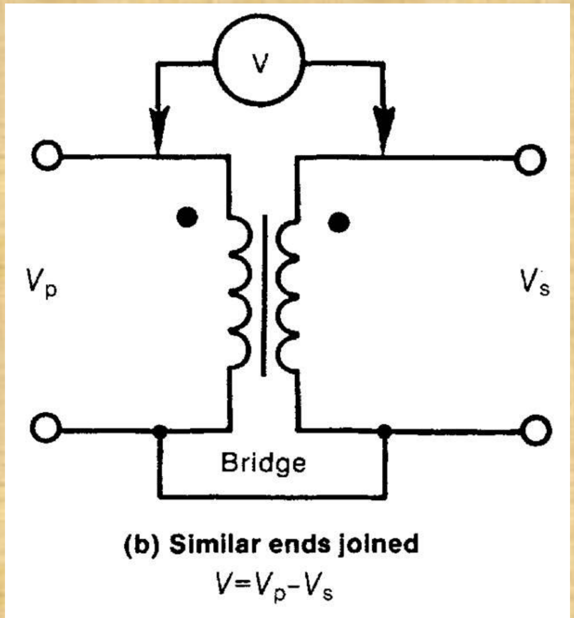
To connect Single Phase transformers in parallel the connecting secondary must be in phase with each other.

Most transformers have dots on the primary and secondary that indicates the instantaneous positive of the of both the primary and secondary windings.

Polarity refers to the instantaneous voltage direction obtained from the primary in relation to the secondary winding.

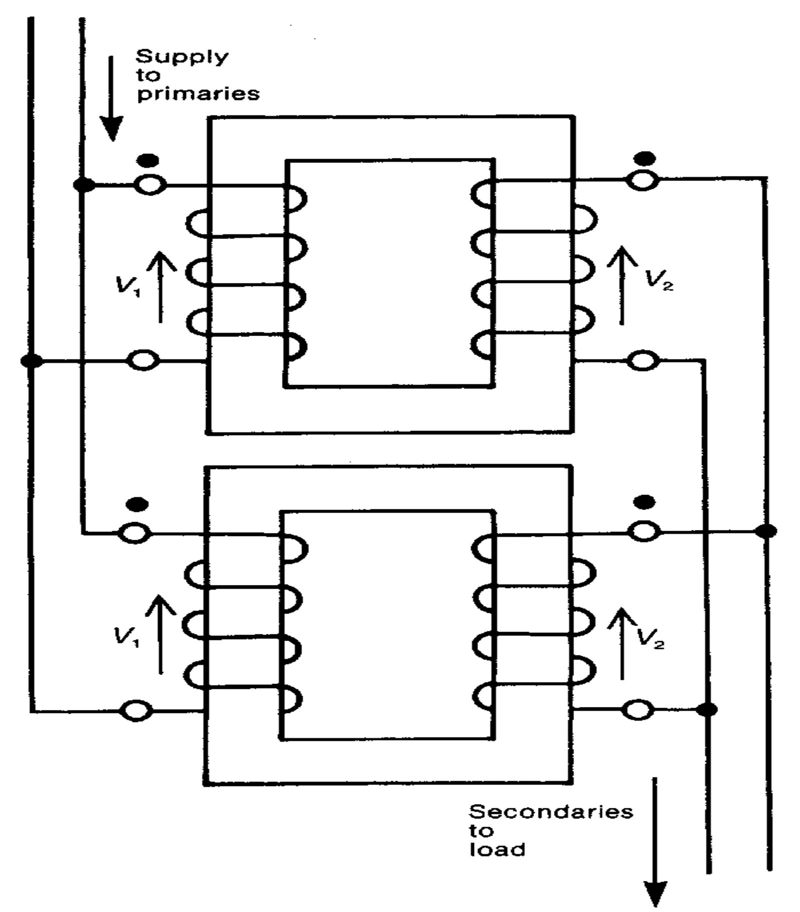


ADDITIVE CONNECTION

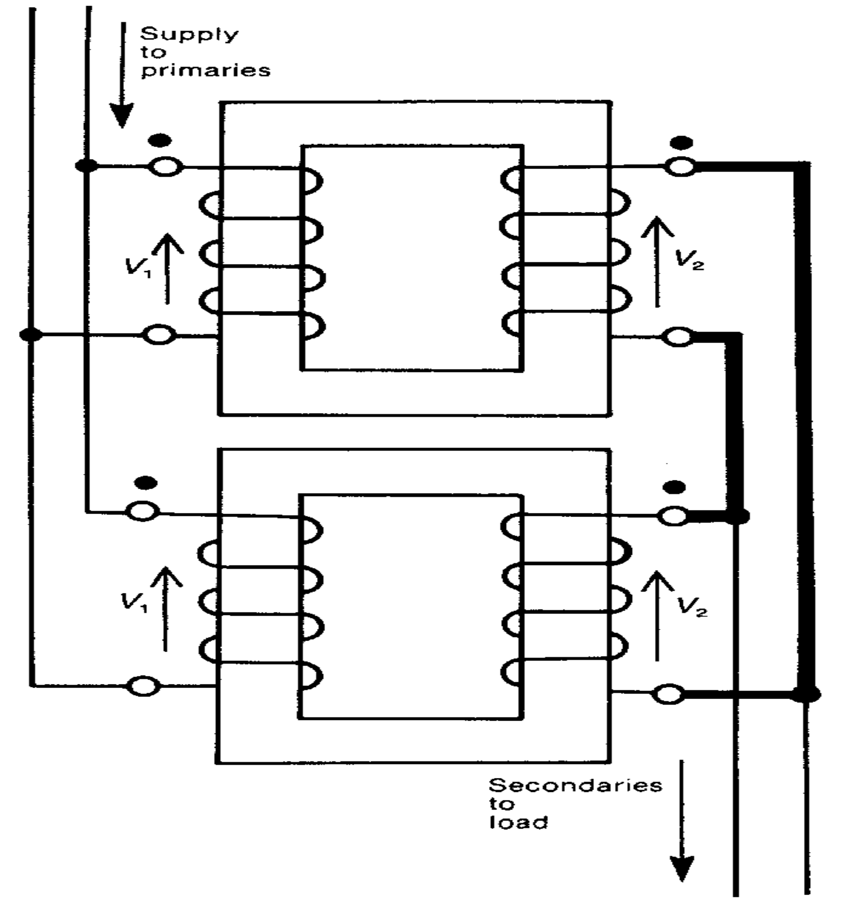


SUBTRACTIVE CONNECTION

PARALLELLING TWO SINGLE PHASE TRANSFORMERS



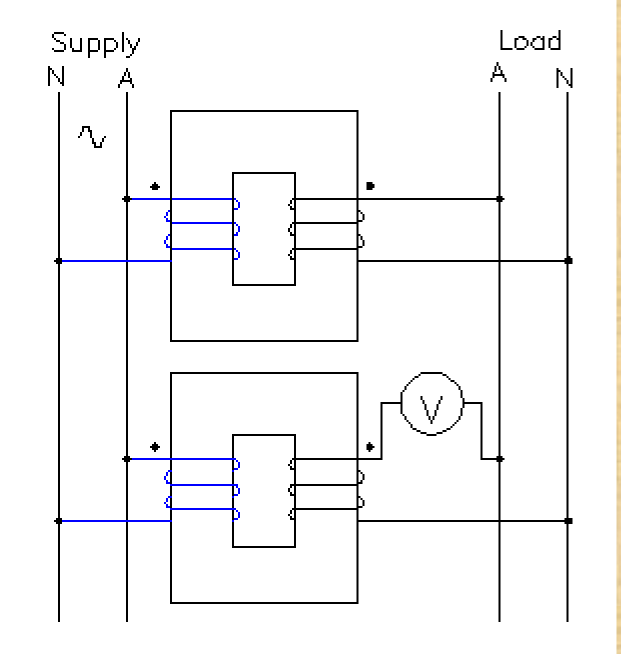
Correct connection



In Correct connection

CHECK BEFORE PARALLELING

Before two small transformers are connected in parallel a voltmeter should be connected as shown below. If the reading is zero the connection is correct. If the reading is double the normal secondary voltage the connection is incorrect. To connect it correctly reverse the output terminals from the secondary of one of the transformers.



Continue

OTHER TYPES OF SINGLE PHASE TRANSFORMERS

- High – reactance (leakage) transformers
- Constant voltage/ ferroresonant transformers
- Autotransformers
- Step up transformers
- Step down transformers

OTHER TYPES OF TRANSFORMER ACTION

- In line induction water heaters.
- Induction furnaces.
- Induction cooking.
- Induction bearing heaters.
- Saturable core reactors.

REVISION

- The core of the transformer serves as a path for the magnetic lines of force between the windings. Providing the mutual induction for the transformer to operate.

- The percentage impedance of a transformer is the voltage drop on full load due to the winding resistance and the leakage reactance expressed as a percentage of the rated voltage**.**

$$Z\% = \frac{\text{IMPEDENCE VOLTAGE}}{\text{RATED VOLTAGE}} \times 100$$

- The Voltage regulation is the term used to give a measure of the performance of the transformer when it is operating between No Load and Full Load conditions.

$$\text{Voltage Regulation\%} = \frac{\text{No load voltage} - \text{Full load voltage}}{\text{Full load voltage}} \times 100$$

REVISION

-Transformers have losses: these are found from a Open Circuit Test for **Iron Losses** and Short Circuit Test for **Copper Losses.**

Iron Losses remain constant for all loads on the transformer, being dependent on the voltage and frequency only.

Copper Losses varies as the square of the load current. This means that if the load drops by a half the copper losses decreases to a quarter.

- The all day efficiency is defined as the ratio of the total energy output of the transformer during a 24 hour period to the total energy input for the same time interval.

REVISION

- **Frequency** has a very important place in the selection of the core materials

- 50 Hz to 1000 Hz have a iron core made of high grade silicon Steel.

- Up to 100kHz Ferrite cores are used.

- Up to 1MHz Powdered iron cores are used.

- Over 1MHz air cores are used.

THREE PHASE TRANSFORMERS

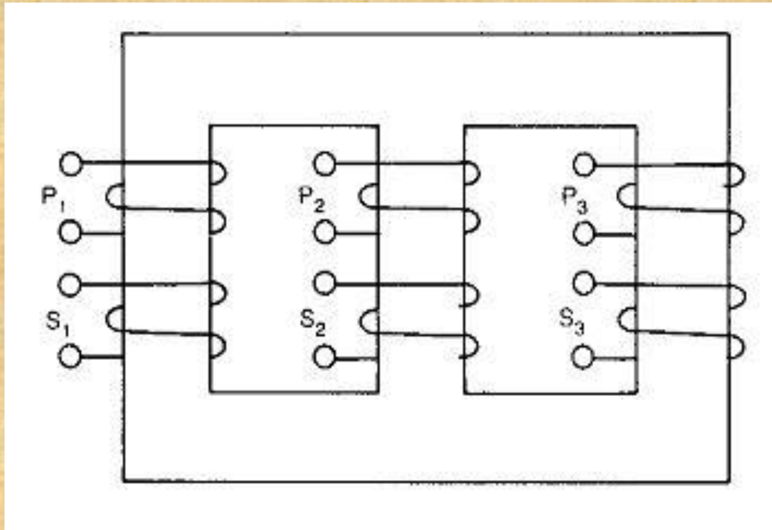
THREE PHASE TRANSFORMERS

- A transformer can be used on a three phase supply by using a three legged core with primary and secondary windings on each leg. The fluxes established will be 120° apart and their instantaneous sum will always be zero. Because the windings are on a common core, the three phase transformer is smaller and lighter than three separate transformers for the same VA rating.

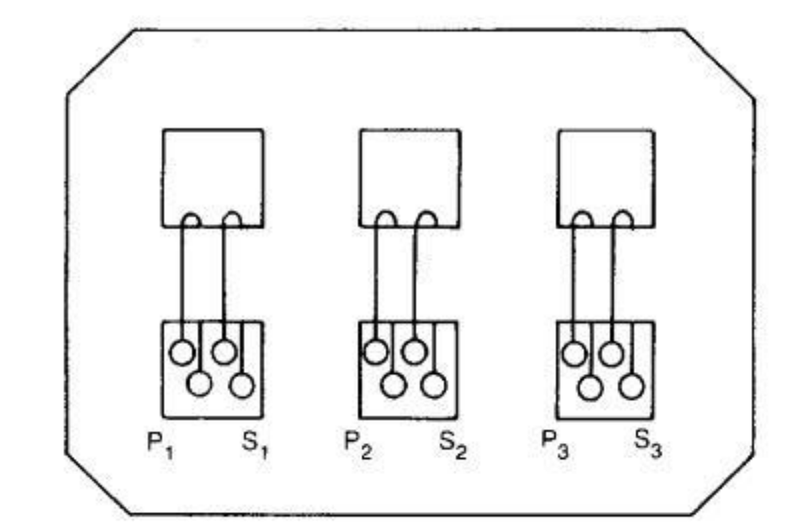
THREE PHASE TRANSFORMERS

- The same variations in single phase cores apply to three phase cores. For single phase, the majority of transformer cores use the shell - type construction, while for **three phase, the majority are of core – type construction.**

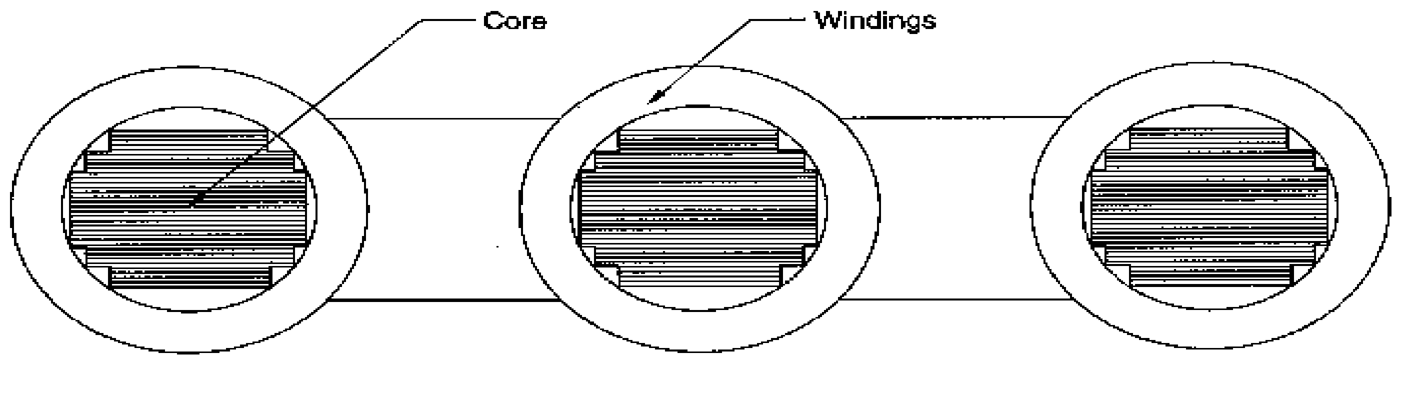
THREE PHASE TRANSFORMER CORES



Core type



Shell type

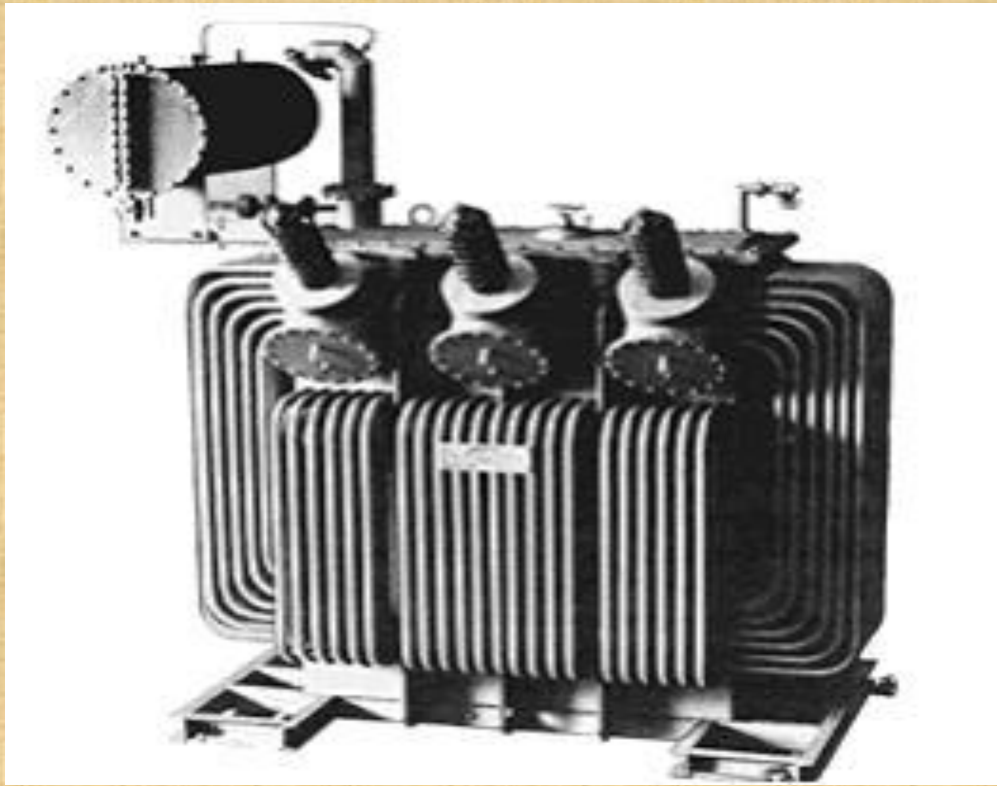


(c) Cross-section of a cruciform or stepped core

Parts of a Three PhaseTransformer

Continue

LARGE DISTRIBUTION TRANSFORMERS



Three phase 1000kVA oil cooled transformer. The rated input voltage is 33kV and output voltage is 11kV

DISTRIBUTION TRANSFORMERS

What are they?

- Distribution transformers are generally three phase and are used in electrical power distribution and transmission systems. This class of transformer has the highest power, or VA ratings, and the highest continuous voltage rating. The current rating is increased in a distribution transformer, by increasing the size of the primary and secondary windings.

125 MVA Three Phase Transformer

Continue

167 MVA Three Phase Transformer

Continue

448 Three Phase Transformer

Continue

Transformer Cooling

Continue

TRANSFORMER COOLING
TYPES OF

- ONAN – OIL NATURAL AIR NATURAL
- OFAN – OIL FORCED AIR NATURAL
- OFAF – OIL FORCED AIR FORCED
- ONAF – OIL NATURAL AIR FORCED

Distribution Transformer

Continue

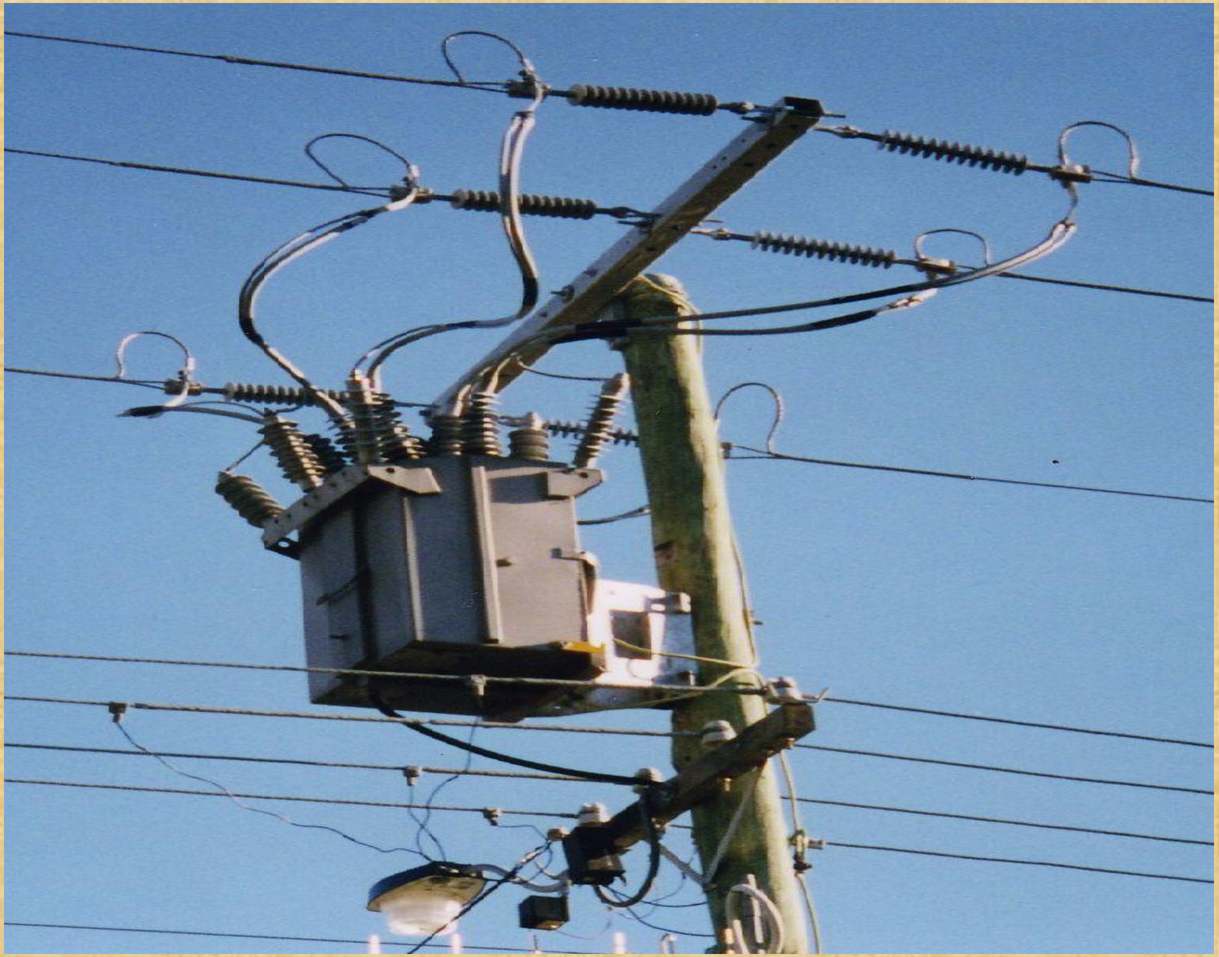
Distribution Transformer

Continue

Distribution Transformer

Continue

Pole Top Transformer



Continue

Pole Top Transformer

Continue

Pole Top Transformer

Continue

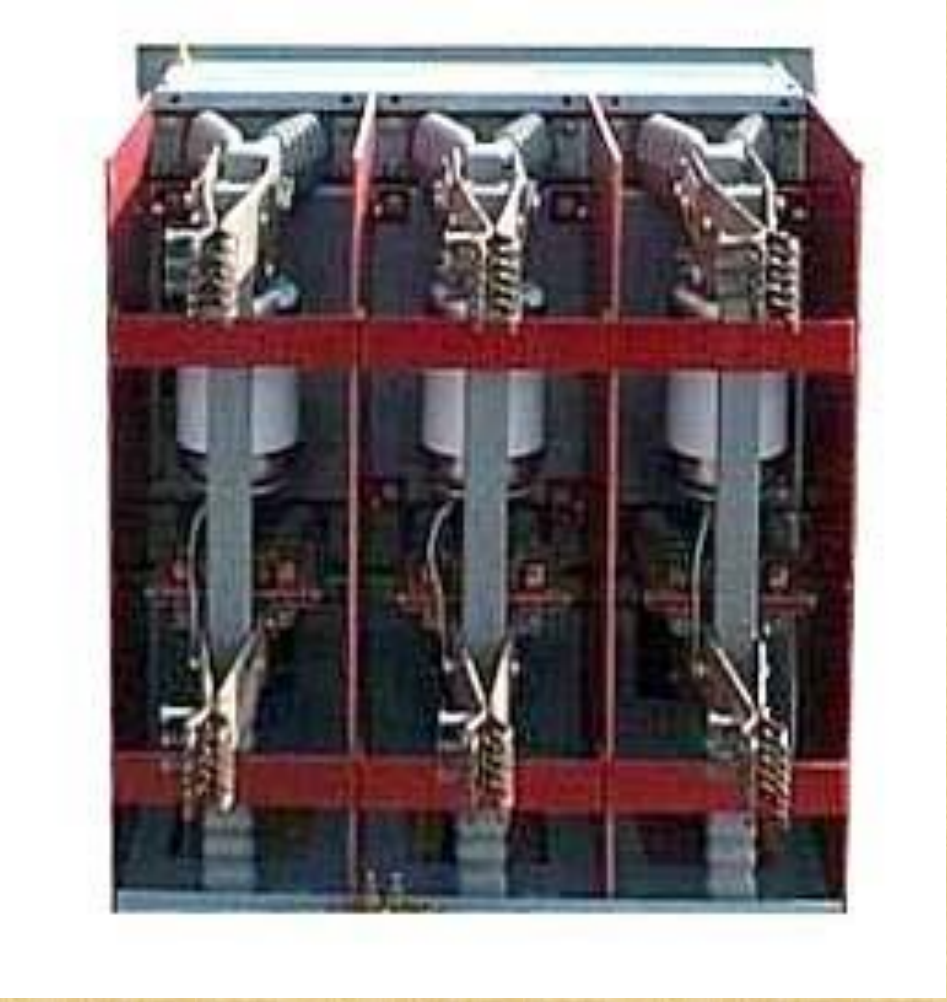
Underground Transformer

Continue

Vacuum Circuit Breaker

Continue

Vacuum Circuit Breaker



Continue

Vacuum Circuit Breaker

Continue

Full Load Current

Given: 1000 kVA Transformer

Z% = 5.7 %

$$I_{FL} = \frac{KVA \times 1000}{\sqrt{3} \times 415}$$

$$I_{FL} = \frac{1000 \times 1000}{\sqrt{3} \times 415}$$

$$I_{FL} = 1\,391.21 \text{ A}$$

Prospective Short Circuit Current

$$I_{SC} = \frac{I_{FL} \times 100}{Z\ \%}$$

$$I_{SC} = \frac{1391.21 \times 100}{5.7}$$

$$I_{SC} = 24\ 407.11\ A$$

Continue

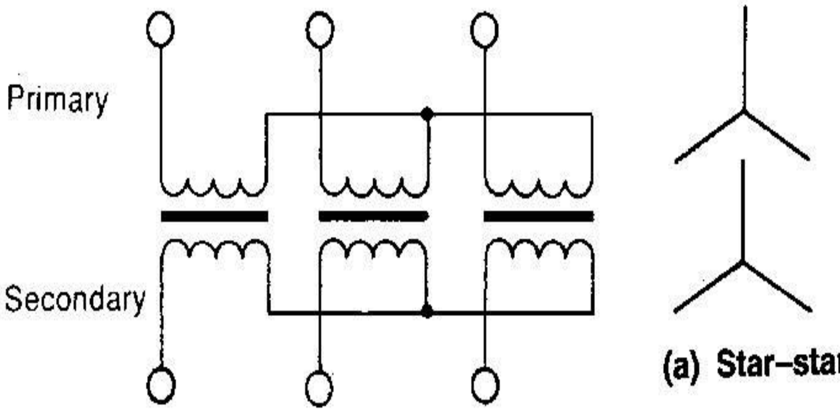
Single Wire Earth Return

Continue

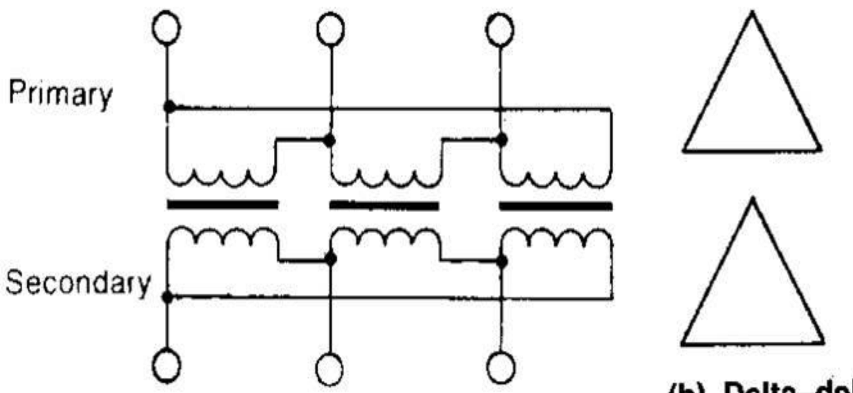
Transformer Windings

Continue

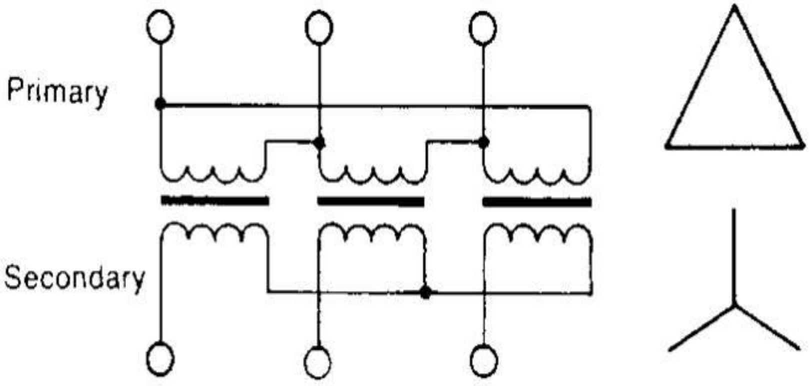
THREE PHASE TRANSFORMERS CONNECTIONS



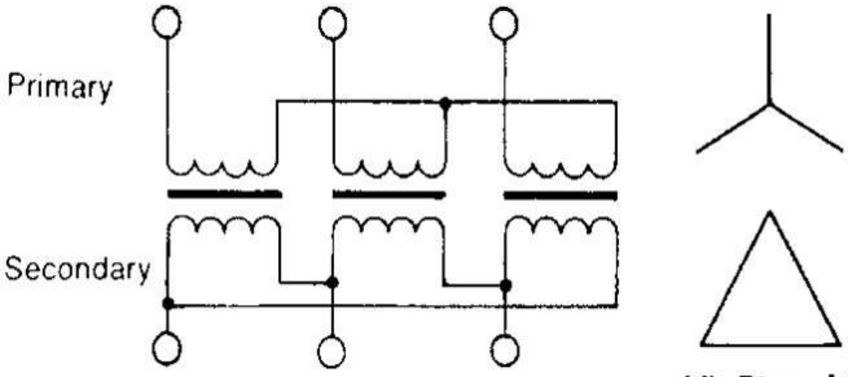
(a) Star–star



(b) Delta–delta



(c) Delta–star



(d) Star–delta

THREE PHASE TRANSFORMERS CONNECTIONS

PHASE SHIFTS

- **STAR – STAR** – No phase shift between primary and secondary.
- **DELTA – DELTA** – No phase shift between primary and secondary.
- **DELTA – STAR** – Phase shift between line voltages. V2 lags V1 by 30°.
- **STAR – DELTA** – Phase shift between line voltages. V2 leads V1 by 30°.

THREE PHASE TRANSFORMERS CONNECTIONS

PARALLELING

When paralleling three phase transformers you must take care to have;

- **EQUAL VOLTAGES –** If not circulating currents is set up between the two sources and each transformer becomes a burden on the other and they are unable to supply power to an external load.
- **SAME PHASE SEQUENCE (VECTOR GROUPING) –** If different phase sequences are connected in parallel the least that can occur is a short circuit between the lines.
- **PHASE VOLTAGES IN STEP –** Satisfactory parallel operation can only occur when the two transformers belong to the same group and have the same phase shift.
- **PERCENTAGE IMPEDENCE** – If transformers of different impedences were connected the lower percentage impedence will take more than its proper share of the load.

THREE PHASE TRANSFORMERS - PARALLELING

REVERSE COIL CHECKS

STAR CONNECTION

Primary coils:

- Connect the primary coils in ***star*** and to the supply, but leave the secondary coils unconnected.
- Switch on and measure the individual secondary coil voltages; if one is higher than the other two its associated primary coil is reversed.

Secondary Coils:

- Having tested (and corrected) the primary side, connect the secondary coils in ***star*****,** switch on and measure the ***line - to - line*** voltages.
- If one is higher than the other two, determine which coil gives a low reading with respect to the other two – this one is the **reversed** coil.

THREE PHASE TRANSFORMERS - PARALLELING
REVERSE COIL CHECKS

DELTA CONNECTION –

Primary and Secondary sides are treated the same

- Connect the coils in ***delta***, but leave the final connection point open.
- Connect to the supply and switch on, then using a voltmeter set it to twice the expected line voltage, and measure the voltage appearing across the open point.
- If the reading obtained is **zero volts** – all is well.
- If the reading obtained is approximately **twice** the expected line voltage one of the coils is reversed.
- To correct the reversed coil, simply reverse any one of the coils and test again. Repeat this until you get zero volts is found across the connection point – the open point may now be closed to complete the delta connection.– all is well.
- This is sometimes called the **"Closing Delta Connection Test"**

THE FOUR MAIN ELECTRICAL FAULTS EFFECTING TRANSFORMERS ARE

- EARTH FAULTS
- INTERWINDING FAULTS
- SHORTED TURNS
- OPEN CIRCUITS

TRANSFORMER TESTING

- INSULATION TESTING
- CONTINUITY TESTING
- WINDING IDENTIFICATION TEST

Transformer Testing

Part: ____________________

Part Number: ____________________

Insulation Resistance (Meggar 500 V):

	Actual Reading	*Expected Reading*
A1 – E		> 1 M Ω
A2 – E		> 1 M Ω
a1 – E		> 1 M Ω
a2 – E		> 1 M Ω
A1 - a1		> 1 M Ω
A1 – a2		> 1 M Ω
A2 – a1		> 1 M Ω
A2 – a2		> 1 M Ω

Earth continuity (Multimeter):

	Actual Reading	*Expected Reading*
E – E frame		Low Ω

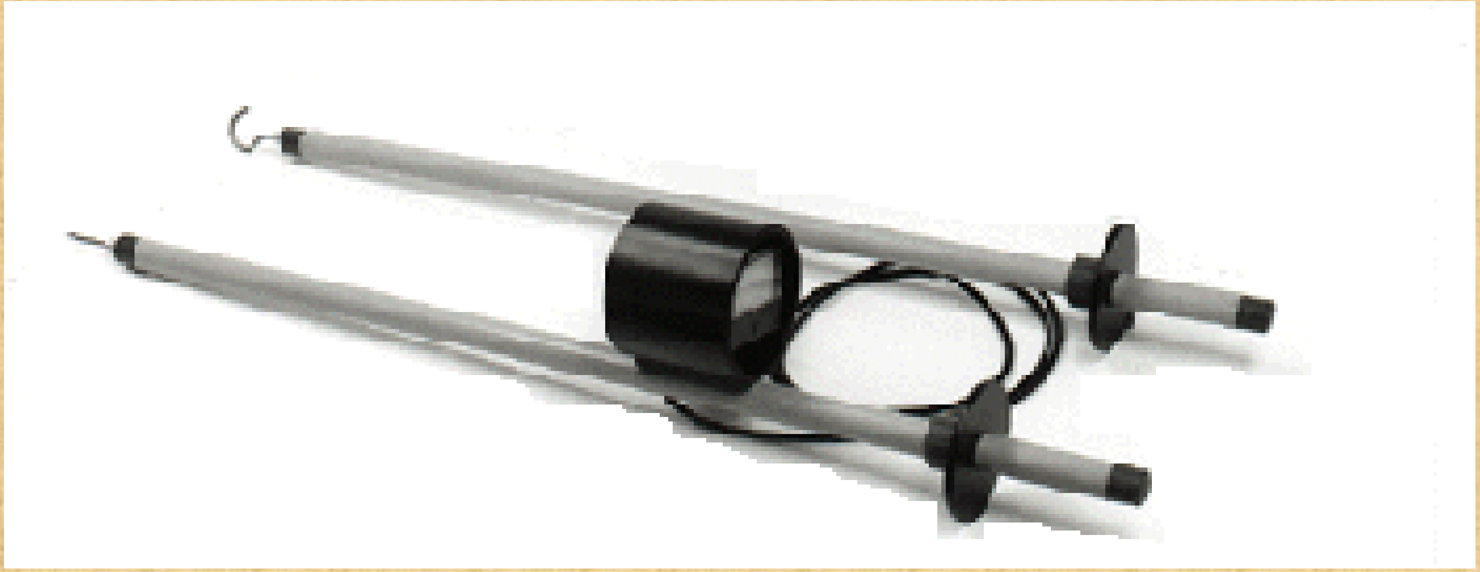
Continuity of Windings (Multimeter):

	Actual Reading	*Expected Reading*
A1 – A2		Ω
a1 – a2		Ω

Visual Check: *Pass?* Yes No **Serviceable?** Yes No **Reason:**

Continue

Phasing Stick



Continue

TRANSFORMER FAULTS AND CAUSE OF FAILURE

- Lightning
- Light Surges
- Poor Workmanship/Manufacturer
- Deterioration of insulation
- Overloading
- Moisture
- Inadequate Maintenance
- Sabotage and Malicious Mischief
- Loose Connections

Note Rewinding or Rebuilding a large power transformer can take six to 12 Months.

INSTALLATION AND OPERATION

MAIN Considerations

- Keep the electrical loading within the design of the transformer.
- Install transformers in places it is designed for.
- Protect transformers from surges and other external hazards.
- **TEST THE OIL One part water in 10,000 parts oil decreases the dielectric strength 50 percent.**

ADDITIONAL Considerations

- Keep porcelain bushings and insulators clean.
- Check cooling fins, for leaks, rust, accumulation of dirt and any other accumulation.
- Keep electrical connections tight.
- Inspect tap changes.
- The transformer windings , bushings, and arrestors should be tested on a regular basis.
- CHECK THE GROUND CONNECTION on the surge arrestor annually.

Transformer Protection

Buchholz Relay

Buchultz Relay

Continue

Buchholz Relays

A Buchholz relay is a gas and oil operated device installed in the pipe work between the top of the transformer main tank and the conservator.

A second relay is sometimes used for the tap changer selector chamber. The function of the relay is to detect an abnormal condition within the tank and send an alarm or trip signal.

Under normal conditions the relay is completely full of oil. Operation occurs when floats are displaced by an accumulation of gas, or a flap is moved by a surge of oil.

Almost all large oil-filled transformers are equipped with a Buchholz relay, first developed by Max Buchholz in 1921.

Front view

Fault conditions within a transformer produce gases such as carbon monoxide, hydrogen and a range of hydrocarbons.

A small fault produces a small volume of gas that is deliberately trapped in the gas collection chamber (A) built into the relay.

A – Gas collection chamber

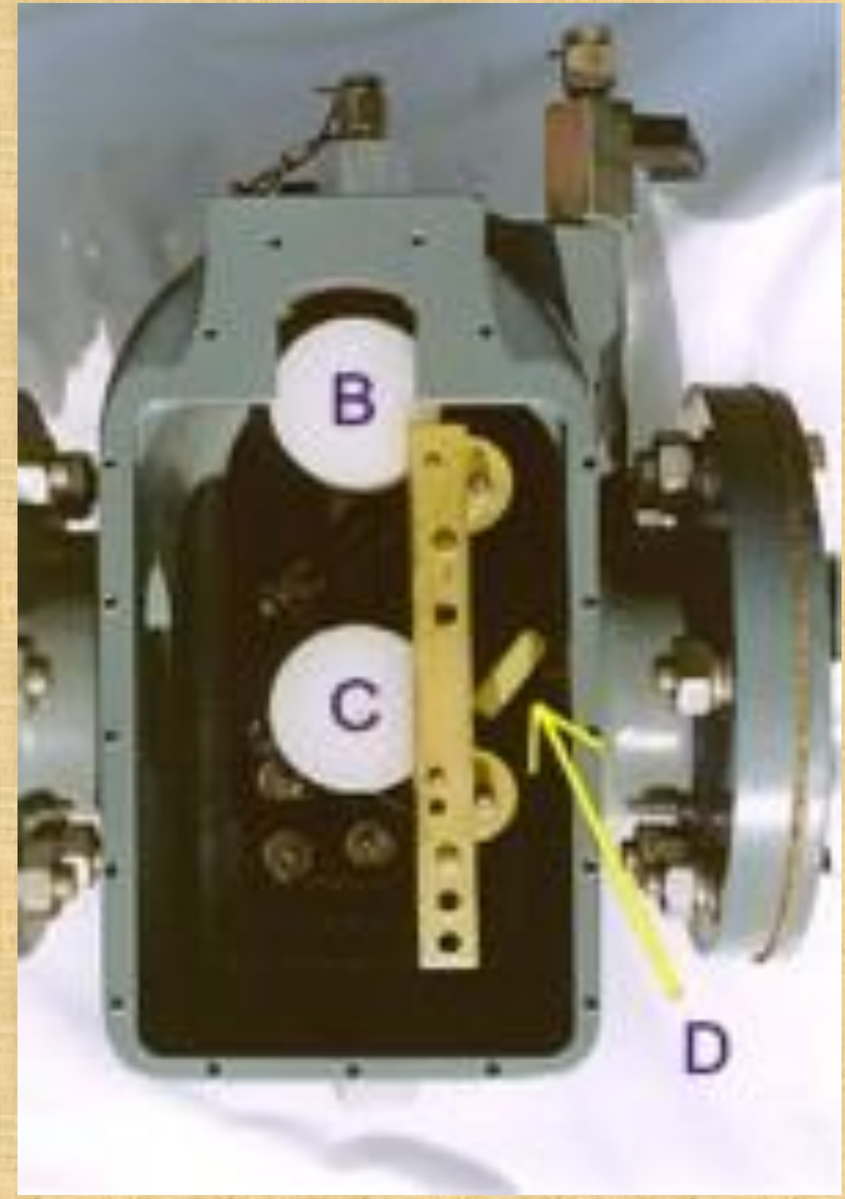
Rear view

Covered removed

Typically, as the oil is displaced a float (B) falls and a switch operates - normally to send an alarm. A large fault produces a large volume of gas which drives a surge of oil towards the conservator.

This surge moves a flap (D) in the relay to operate a switch and send a trip signal. A severe reduction in the oil level will also result in a float falling.

Where two floats are available these are normally arranged in two stages, alarm (B) followed by trip (C).



B – Upper float

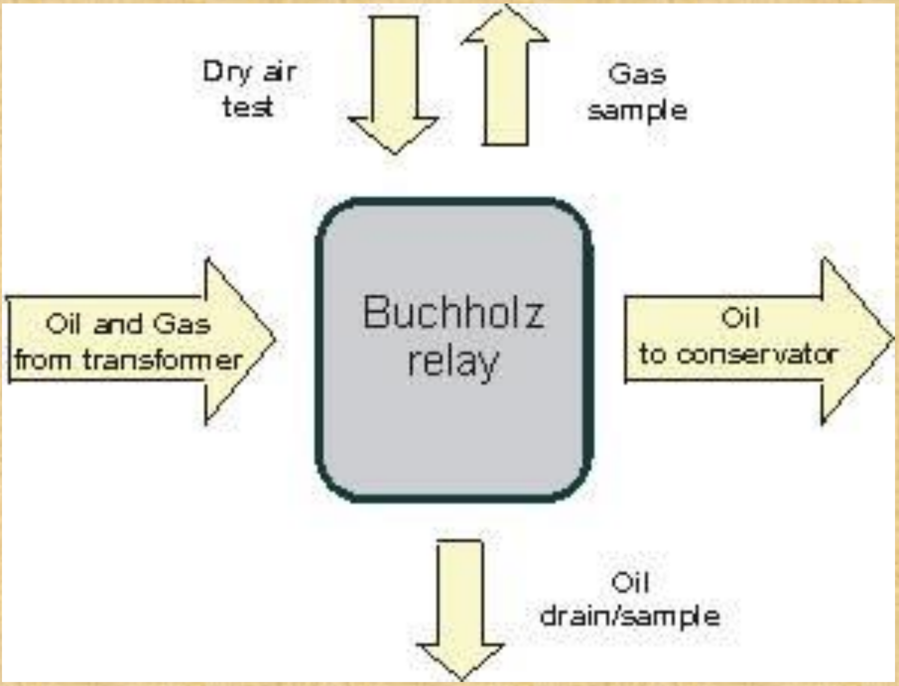
C – Lower float

D – Oil surge detector

A Buchholz relay will detect:

- Gas produced within the transformer
- An oil surge from the tank to the conservator
- A complete loss of oil from the conservator (very low oil level)

Buchholz relays are equipped with a number of gas and oil inputs and outputs, including test and sampling facilities



Gas sampling - a graduated sight glass provides an indication of the volume of gas that has accumulated, typically 100-400cm3. After an alarm or trip signal has been received this must be collected and analysed before the transformer is returned to service. Gas collection can be done at the relay, or at ground level if suitable arrangements exist. Clearly the latter is a safer and more convenient option.

Functional Tests - a test petcock enables dry air to be admitted into the relay to check correct operation. A trickle of air is equivalent to a gradual accumulation of gas. A blast simulates an oil surge. These tests are sometimes referred to as 'blowing the Buchholz'. On completion it is important that the relay is bled to remove the air that has been introduced.

Draining - a valve in the bottom of the relay enables an oil sample to be taken or the relay to be drained. As with gas sampling, this facility can be brought down to ground level for enhanced operator safety and convenience.

THE END