

Lecture Notes

EEE 360

TOPIC 3b

Transformer (Part 2: Three Phase)

Read Chapter : 4.7

Transformer

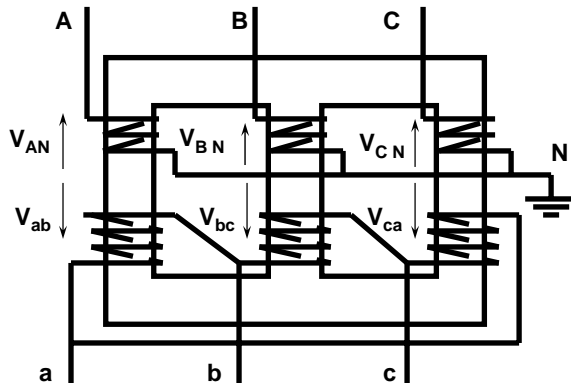
Three phase transformers

- The three-phase transformer can be built by:
 - the interconnection of three single-phase transformers
 - using an iron core with three limbs
- The usual connections for three-phase transformers are:
 - wye / wye seldom used, unbalance and 3th harmonics problem
 - wye / delta frequently used step down.(345 kV/69 kV)
 - delta / delta used medium voltage (15 kV), one of the transformer can be removed (open delta)
 - delta / wye step up transformer in a generation station
- For most cases the neutral point is grounded.

Transformer

Three phase transformers

Analyses of the grounded wye / delta transformer



- Each leg has a primary and a secondary winding.
- The voltages and currents are in phase in the windings located on the same leg.
- The primary phase-to-line voltage generates the secondary line-to-line voltage. These voltages are in phase

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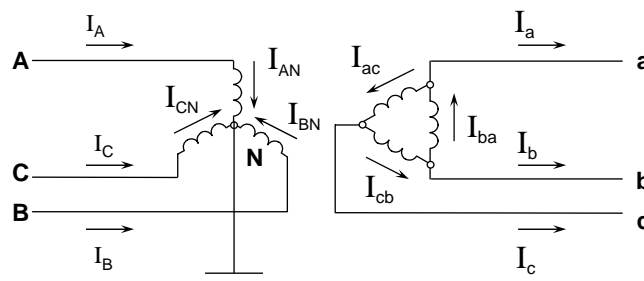
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Transformer

Three phase transformers.

Analysis of the grounded wye/ delta transformer



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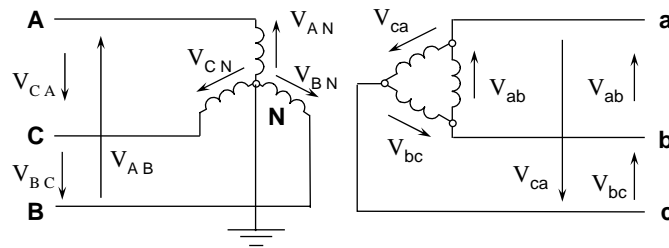
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Transformer

Three phase transformers.

Analyses of the grounded wye / delta transformer



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Transformer

Three phase transformers

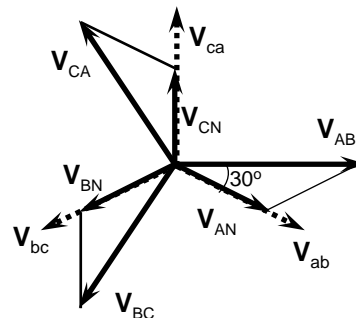
Analyses of the wye / delta transformer operation.

- The operation is demonstrated on an example.
- The vector diagram shows that:

$$\mathbf{V}_{ab} = \sqrt{3} \mathbf{V}_{AN} e^{i30^\circ}$$

Voltage vector diagram

- The primary line-to-line voltage V_{AB} is selected as a reference to draw the vector diagram.



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Three-phase Wye/Delta Transformer Operation Analysis

- Three single phase transformers form a three phase transformer bank. This bank is loaded with an inductive load. Calculate the primary and secondary currents and voltages if the three transformers are connected in:

- wye/wye
- wye/delta
- delta/wye
- delta/delta

Calculate the current and voltages

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Three-phase Wye/Delta Transformer Operation Analysis

$$S_{tr} := 100\text{kV}\cdot\text{A}$$

$$V_p := 7.967\text{kV}$$

$$V_s := 120\text{V}$$

Load data are:

$$P_{load} := 240\text{kW}$$

$$\text{pf}_{load} := 0.8 \quad \text{lagging}$$

Each transformer carries 1/3 of the load.

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Video for Transformer construction

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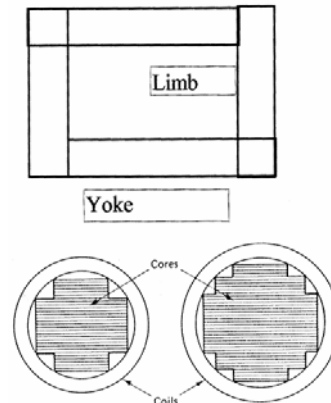
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Transformer

Transformer Construction

Iron Core

- The iron core is made of thin laminated silicon steel (2-3 % silicon)
- Pre-cut insulated sheets are cut or pressed in form and placed on the top of each other .
- The sheets are overlap each others to avoid (reduce) air gaps.
- The core is pressed together by insulated yokes.



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Transformer

Transformer Construction Winding

- The winding is made of copper or aluminum conductor, insulated with paper or synthetic insulating material (kevlar, maylard).
- The windings are manufactured in several layers, and insulation is placed between windings.
- The primary and secondary windings are placed on top of each others but insulated by several layers of insulating sheets.
- The windings are dried in vacuum and impregnated to eliminate moisture.

Small transformer winding

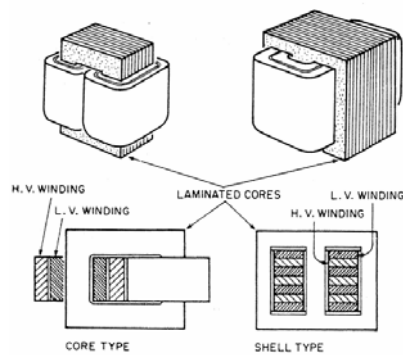


Figure 2-4 Transformer core types.

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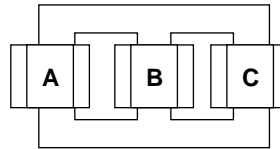
Transformer

Transformer Construction Iron Cores

The three phase transformer iron core has three legs.

- A phase winding is placed in each leg.
- The high voltage and low voltage windings are placed on top of each other and insulated by layers or tubes.
- Larger transformer use layered construction shown in the previous slides.

Three phase transformer iron core



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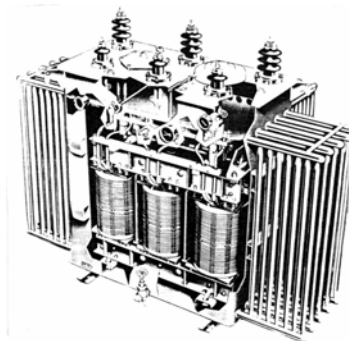
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Transformer

Transformer Construction

- The dried and treated transformer is placed in a steel tank.
- The tank is filled, under vacuum, with heated transformer oil.
- The end of the windings are connected to bushings.
- The oil is circulated by pumps and forced through the radiators.

Three phase oil transformer



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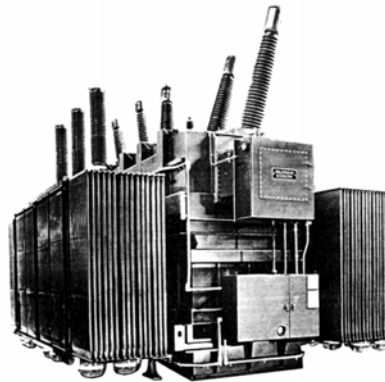
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Transformer

Transformer Construction

- The transformer is equipped with cooling radiators which are cooled by forced ventilation.
- Cooling fans are installed under the radiators.
- Large bushings connect the windings to the electrical system.
- The oil is circulated by pumps and forced through the radiators.
- The oil temperature, pressure are monitored to predict transformer performance.

Large three phase oil transformer



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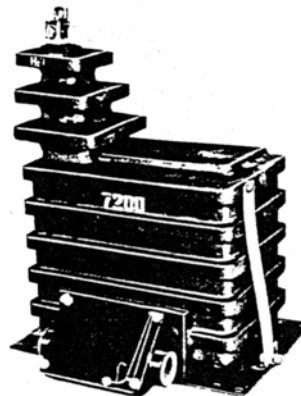
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Transformer

Transformer Construction

- Dry type transformers are used at medium and low voltage.
- The assembled transformer is molded in epoxy resin which surrounds both the windings and iron core.
- The winding is vacuumed and dried before the molding.
- The slide shows a 7.2 kV, dry type voltage transformer.



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Transformer

Dry type transformer

Transformer Construction

- Dry type transformers are used at medium and low voltage.
- The winding is vacuumed and dried before the molding.
- The winding is insulated by epoxy resin
- The slide shows a three phase, dry type transformer.



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Transformer

Transformer Construction

- The slide shows cross section of a pole mounted, single phase distribution transformer.
- The transformer is placed in a steel tank filled with oil.
- The laminated iron core is held together by insulated bolts.
- The windings are separated by insulating tubes.
- Cooling ducts are provided between the low and high voltage windings to assure proper oil circulation.

Small single phase oil transformer

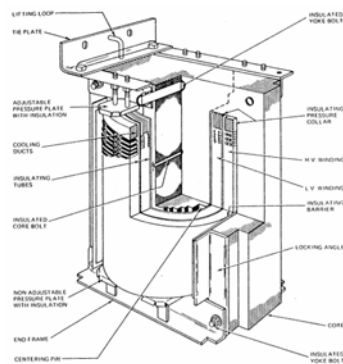


Figure 2-4 Typical construction of shell-type transformer.

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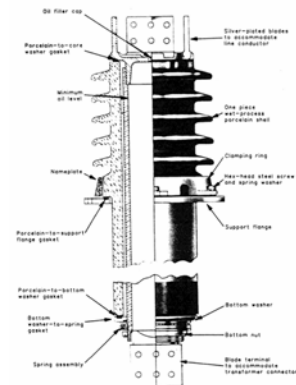
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Transformer

Transformer Construction

- The transformer bushing is a hollow porcelain insulator.
- The insulator has corrugated surface to increase leakage distance and flashover voltage in bad weather.
- An aluminum or copper bar is threaded through the porcelain.
- The insulator is filled with transformer oil, which provides insulation.

Transformer bushing 15 kV class.



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Transformer

Questions to ponder.

- **Why the discovery of transformers has accelerated the development and use of electricity ?**
- **What problem occurs if you connect transformers in parallel to supply large load?**
- **Why the magnetizing or iron losses depend on the frequency ?**
- **What is the reason that the largest number of transformer failures occurs on Christmas time?**

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Three-phase Transformer Parameters and Operation Analysis

A three-phase transformer is supplied by a network through a transmission line. The open and short circuit measurement was performed to permit the calculation of the transformer parameters.

- 1) Calculate the transformer and network parameters and draw the equivalent circuit for the system
- 2) Derive the transformer current, voltage and regulation equations as function of load and load voltage
- 3) Plot the regulation vs. load and determine the load voltage when the load is 75kVA

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Three-phase Transformer Parameters and Operation Analysis

Network data :	$V_{net} := 4600V$	$I_{net_short} := 2000A$	
Transmission line data :	$Z_{line} := (0.1 + i \cdot 0.6) \frac{\Omega}{mi}$	$L_{line} := 15mi$	
Transformer test results:			
Open circuit, measure at low voltage side	$V_o := 230V$	$I_o := 13A$	$P_o := 550W$
Short circuit test, measured at high voltage side	$V_s := 160V$	$I_s := 16A$	$P_s := 1200W$
Transformer ratings	$S_{tr} := 100kV \cdot A$	$V_p := 4600V$	$V_s := 230V$

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