# POWER ENGINEERING
## #11 THREE-PHASE TRANSFORMERS

2018

University of Glasgow

# **Tesla** Quote of the Day

***“Let the future tell the truth, and evaluate each one according to his work and accomplishments. The present is theirs; the future, for which I have really worked, is mine”***

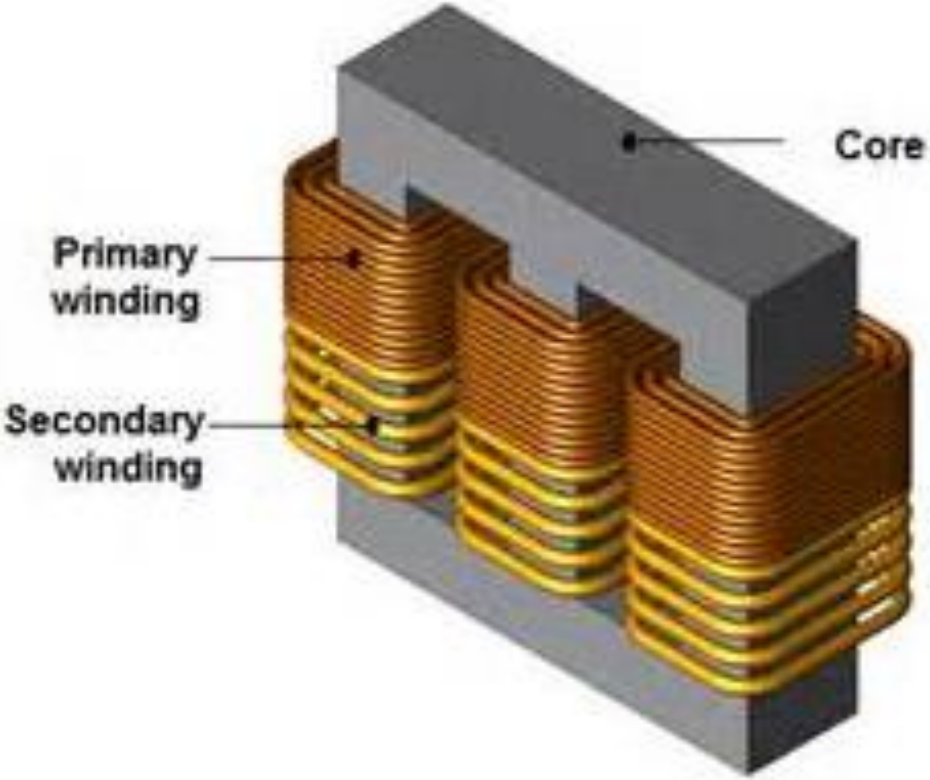
Gulp ☹

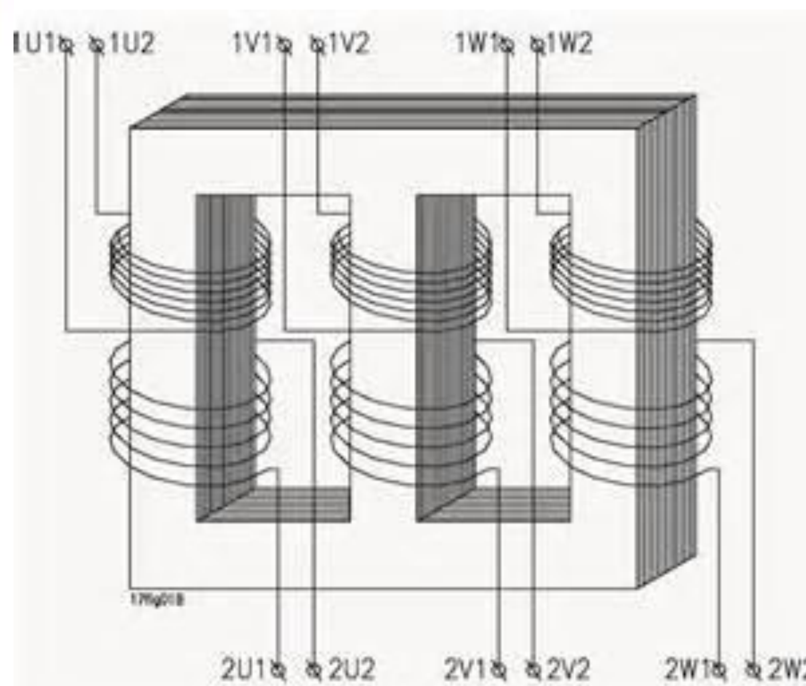
# Transformers

As we saw in lecture 2 the transformer is one of the principal reasons behind the adoption of AC power systems. Its ability to provide a (relatively!) cheap and reliable means of converting AC voltage levels results in high efficiency AC power transmission.

*Over the next 4 lectures we will investigate:*

- Types of Transformers
- The Ideal Transformer
- Basic Electromagnetics
- Transformer Limits
- The Equivalent Circuit for a practical Transformer
- Transformer performance under load: Efficiency & Regulation
- Tests to determine the Equivalent Circuit
- Three Phase Transformers **Today**

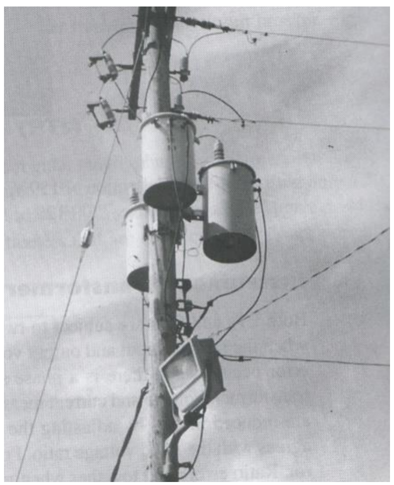

Core
Primary winding
Secondary winding


1U1 1U2
1V1 1V2
1W1 1W2
2U1 2U2
2V1 2V2
2W1 2W2

# 3 Phase Transformers

## Option 1

3 x Single Phase Transformers



Advantages:

- Only need to replace one transformer when faulty

## Option 2

1 x Three Phase Transformers


Advantages:

- Smaller and cheaper option (due to common iron core)

## Connection Options:

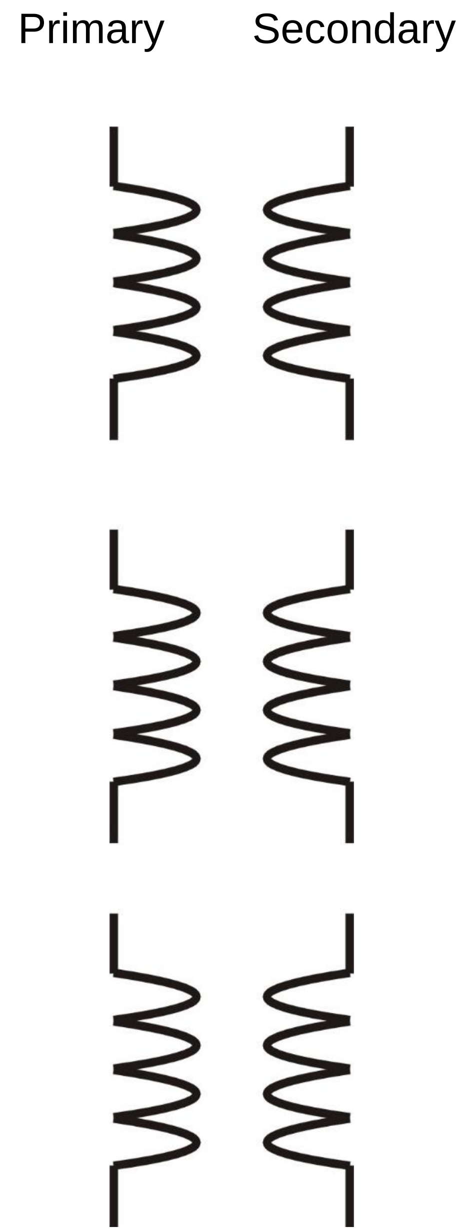
ΔΔ - Delta/Delta

YY - Star/Star

ΔY - Delta/Star

YΔ - Star/Delta

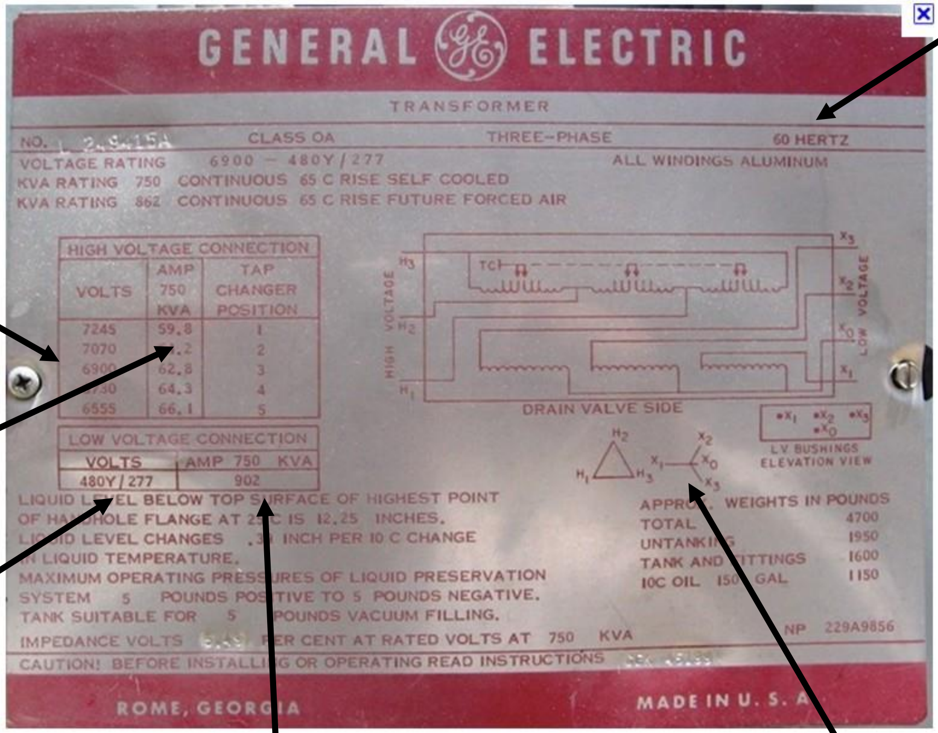
**Primary** **Secondary**



# 3 Phase Transformers: Nameplate Information

Supply frequency

VA Rating




Input Line Voltage Rating

Input Line Current Rating

Output Line Voltage Rating

Output Line Current Rating

Connection type eg ΔY

Note: VA Rating = $\sqrt{3}.V_L.I_L$ for 3 phase transformers

# Definitions:

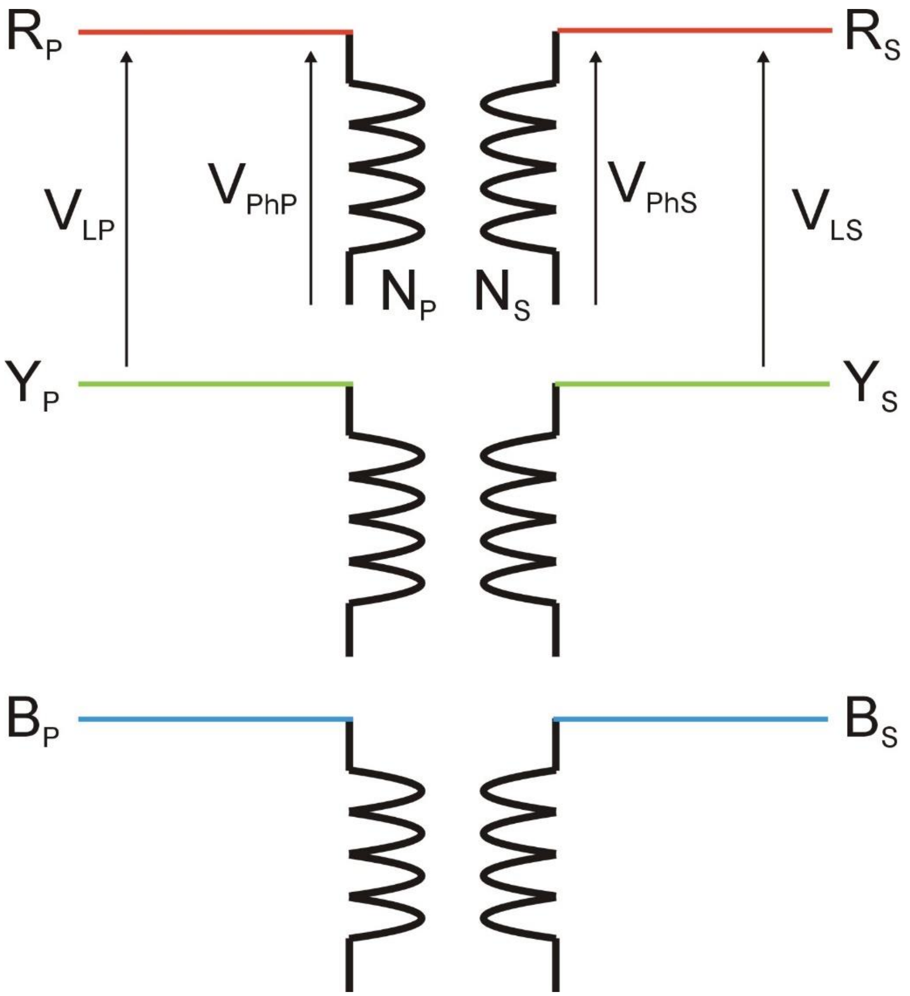
- Bank Ratio:

$$\frac{V_{LP}}{V_{LS}}$$

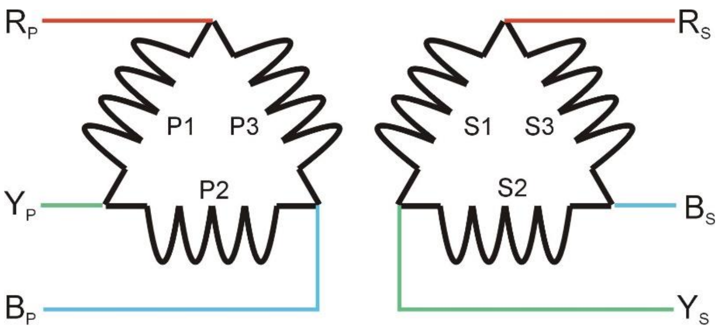
- Phase Ratio:

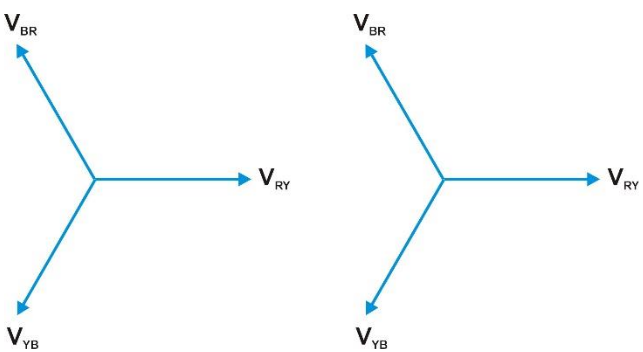
$$\frac{V_{PhP}}{V_{PhS}} = \frac{N_P}{N_S}$$

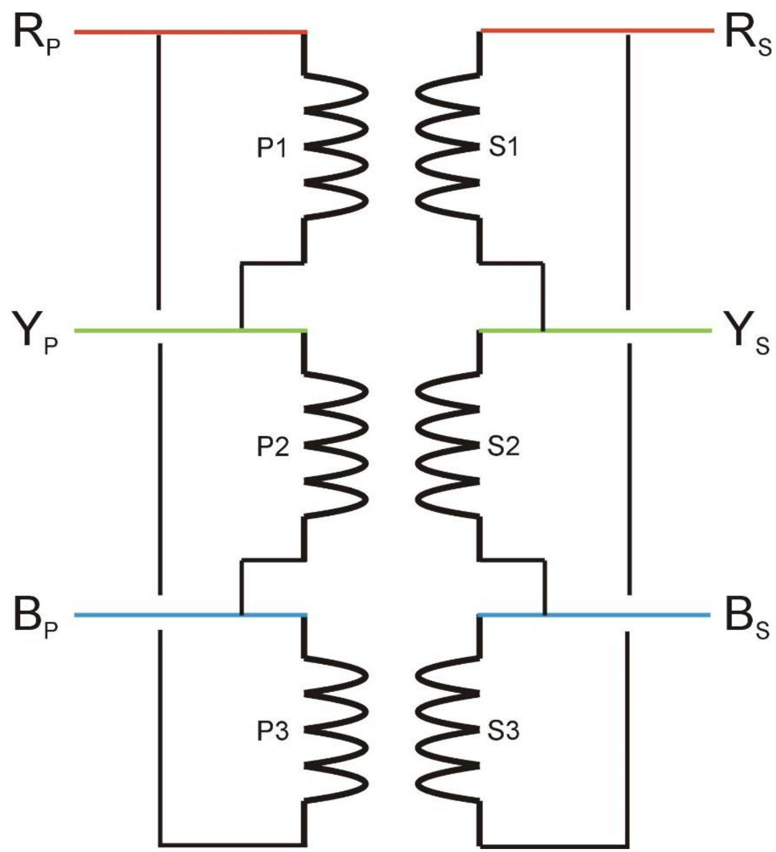
Note: Bank Ratio is only equal to Phase Ratio for ΔΔ or YY connections



## ΔΔ - Delta/Delta

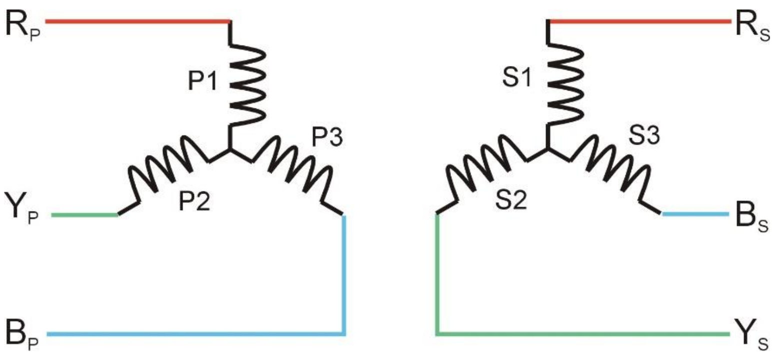


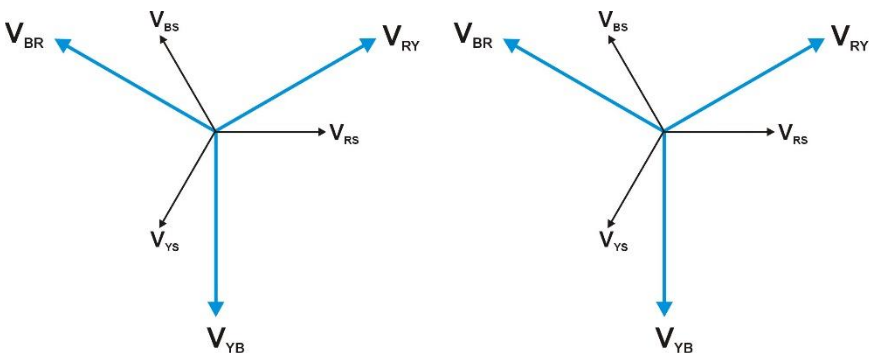



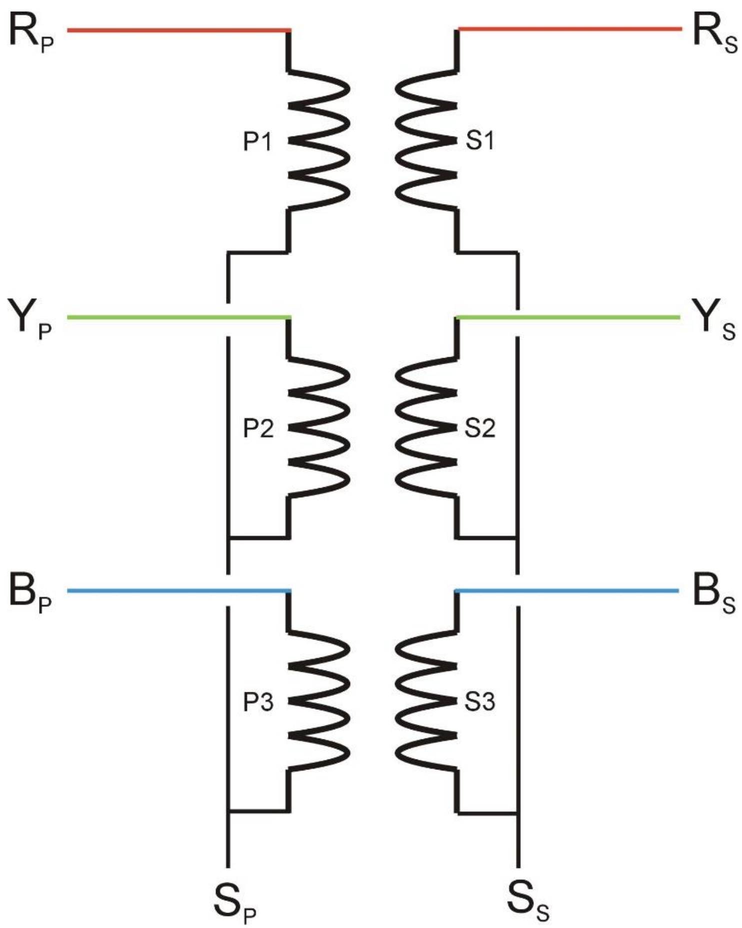




- No Phase Shift between Primary & Secondary Line Voltages
- Bank Ratio = Phase Ratio

# YY - Star/Star

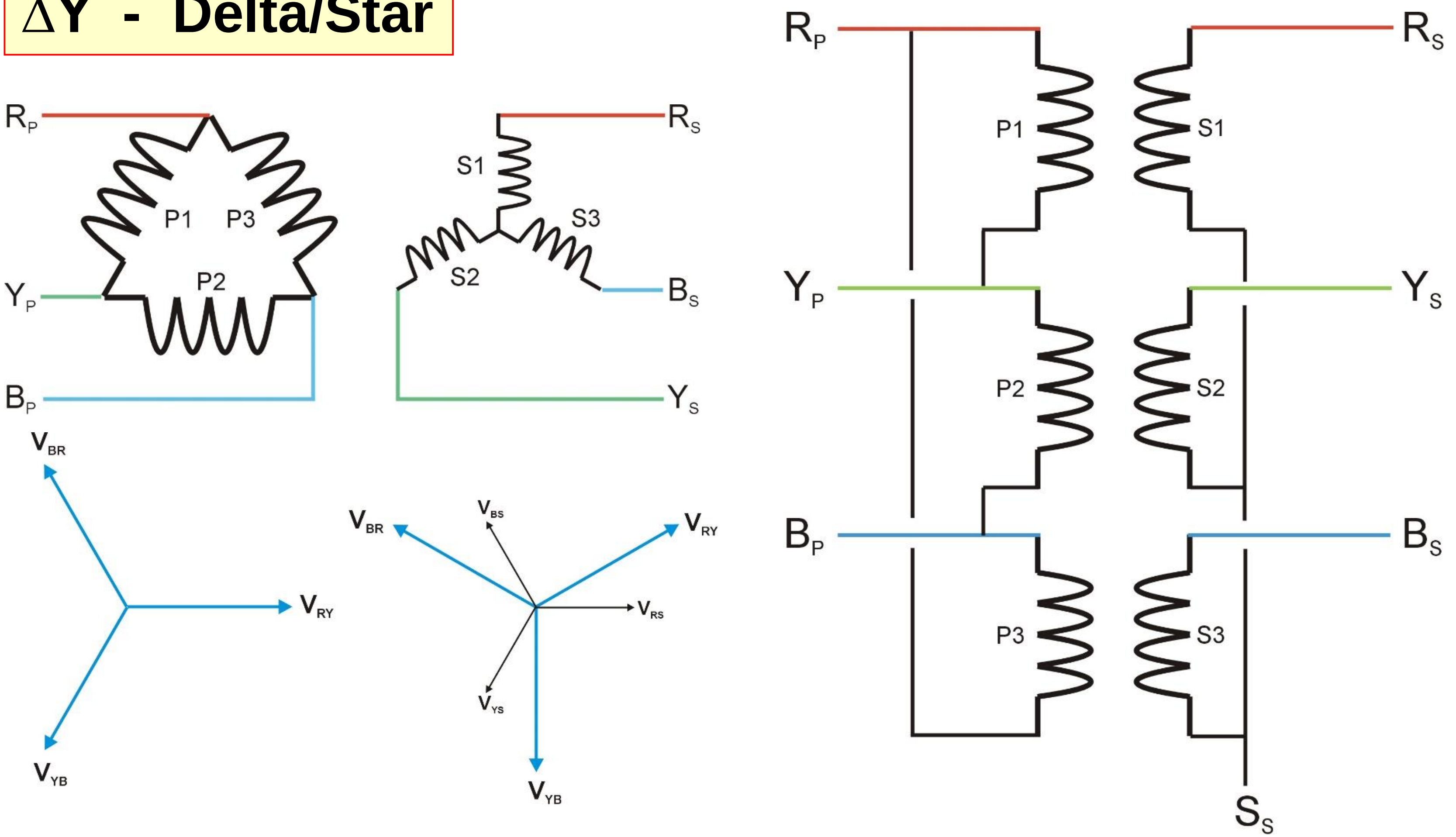


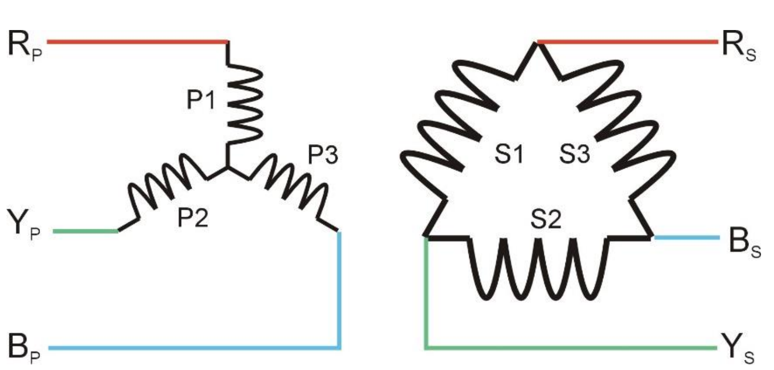

- No Phase Shift between Primary & Secondary Line Voltages
- Bank Ratio = Phase Ratio

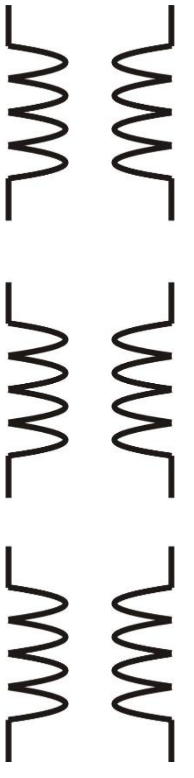
# ΔY - Delta/Star




- Secondary Line Voltages LEAD Primary Line Voltages by 30°
- Bank Ratio = Phase Ratio/√3

## YΔ - Star/Delta

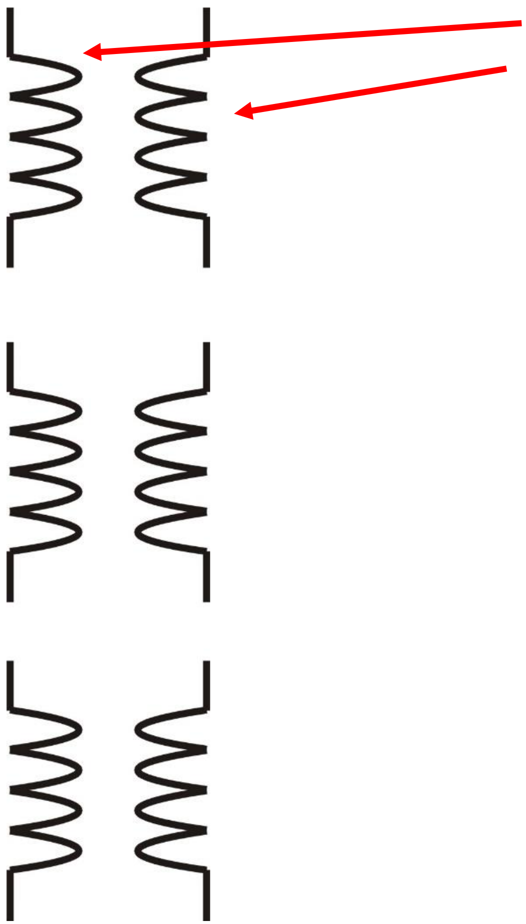


- Secondary Line Voltages Primary Line Voltages by
- Bank Ratio =

# Notes on Application of 3 Phase Transformers #1

## Transformer Insulation Voltage Limit



We generally want to keep the voltage across the primary and secondary windings as low as possible to minimise the insulation requirements

This is a bigger issue on the High Voltage (HT) side of the transformer

Therefore it is advantageous to have only the PHASE voltage ($V_L/\sqrt{3}$) across the windings on the HT side:

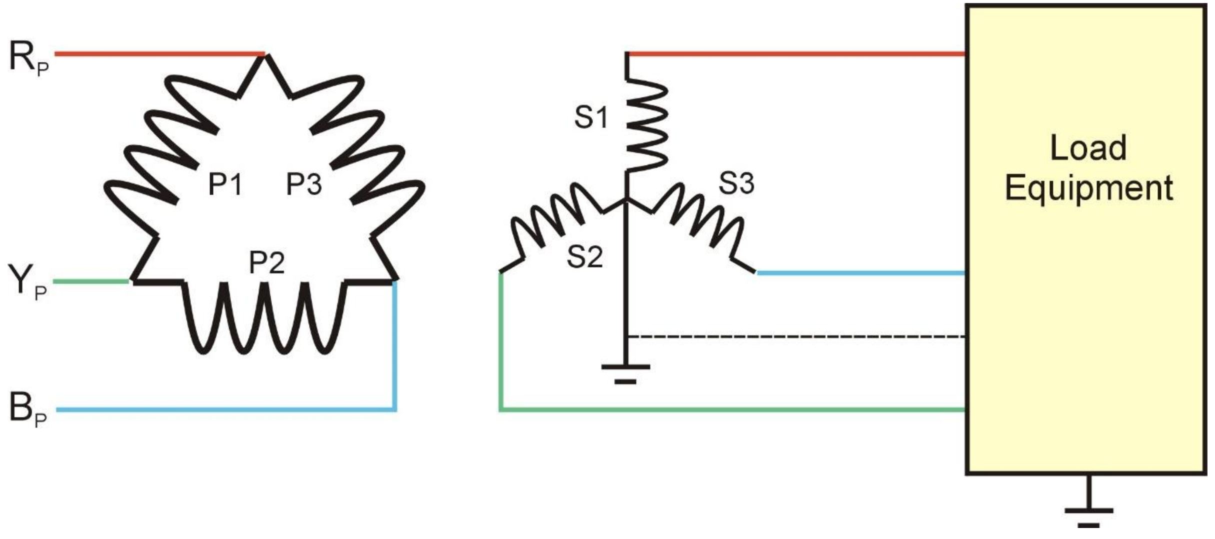
Step Up Application: Use $\Delta$Y connection

Step Down Application: Use Y$\Delta$ connection

# Notes on Application of 3 Phase Transformers #2

## Grounded Secondary

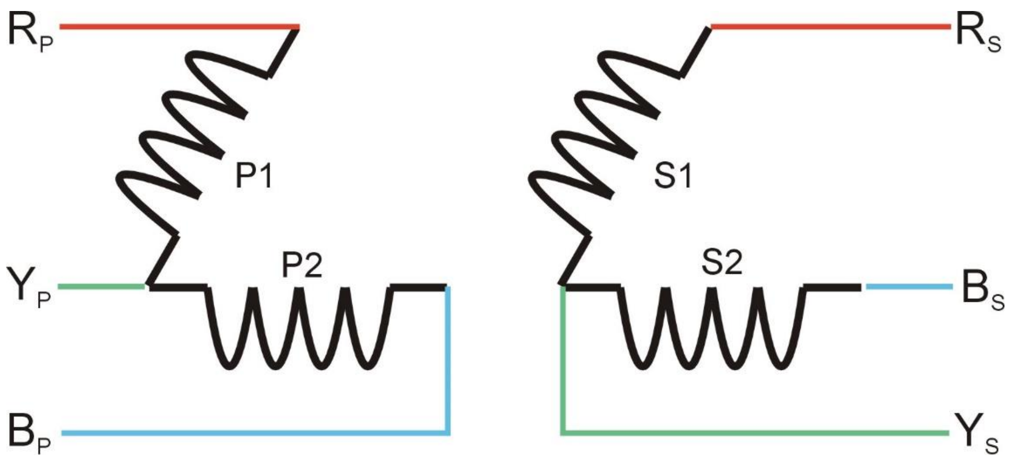
In some situations (safely) it is desirable to have a grounded neutral point connection on the Secondary windings. This therefore requires either the YY or $\Delta$Y connection:



# Notes on Application of 3 Phase Transformers #3

## Open Delta configuration

If 3 single phase transformers are connected as ΔΔ and one of them becomes defective and has to be removed it is possible to feed the 3 phase load on a temporary basis with the two remaining transformers (an advantage of ΔΔ):

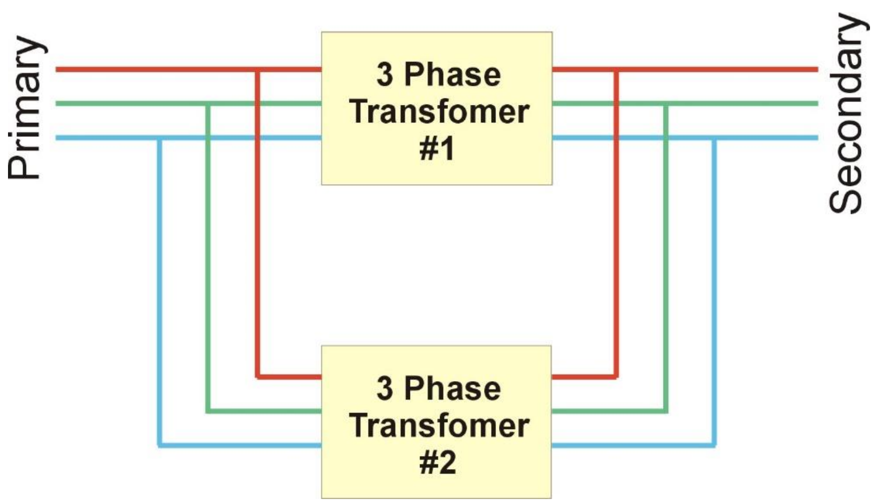



Note that when operating in Open Delta the three-phase transformers have to be *de-rated* to **57.7%** of their nominal rating. For example if each transformer is rated at 50kVA then the maximum 3 phase load must not exceed 86.7kVA

# Notes on Application of 3 Phase Transformers #4

## Parallel connection of transformer secondary windings

Care has to be taken when considering connecting the secondary windings of 3 phase transformers in parallel (sourced from the same 3 phase primary supply) – this being due to the different phase shifts for each of the connection:

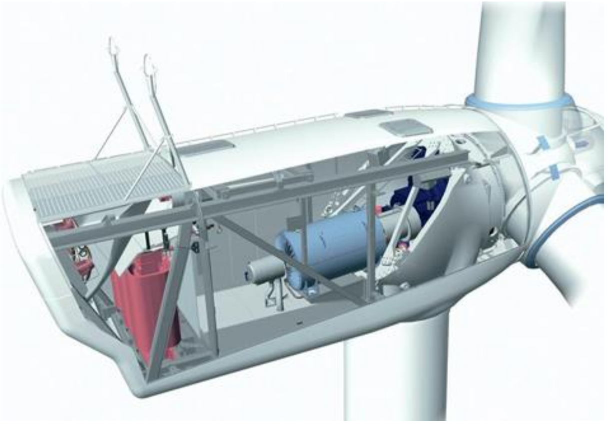



| | ΔΔ | YY | ΔY | YΔ |
|---|---|---|---|---|
| ΔΔ |  |  | | |
| YY |  |  | | |
| ΔY | | |  | |
| YΔ | | | |  |

**Note: Secondary line voltage magnitudes also need to be equal in ALL cases!**

**Example 1**

3 phase transformers are required to convert large (>1MW) wind turbine generator voltages to grid voltages. Calculate the bank ratio and phase ratio for a 690V/33kV $\Delta Y$ connected transformer.



Solution done on whiteboard during lecture

**Example 2**

A three phase $\Delta$Y transformer bank is rated 4160V/208V and delivers 300kVA to a balanced delta connected load at rated voltage. Assuming an ideal transformer calculate the following:

1. The magnitudes of the load phase currents
2. The magnitudes of the secondary line current
3. The magnitudes of the primary line current
4. The magnitudes of the currents in the primary coils of the transformer

Solution done on whiteboard during lecture

**Example 3**

A three phase ΔΔ transformer consists of three single phase units, each rated at 33.33kVA, 4160V/480V. Determine the rated secondary line current and the rated current in each of the secondary windings.

Solution done on whiteboard during lecture

## Example 4

Due to maintenance requirements one of the transformers in Example 3 is removed and the remaining two transformers are connected in Open Delta. Determine the maximum secondary line current and VA rating for the remaining pair of 33.33kVA transformers?

Solution done on whiteboard during lecture