THREE PHASE TRANSFORMERS

THREE PHASE SYSTEM

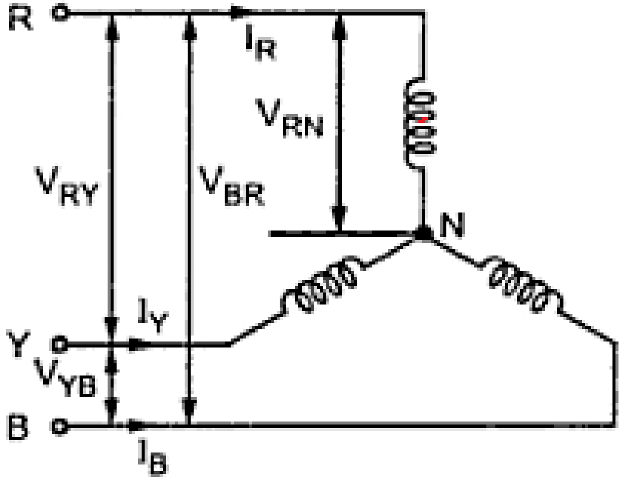
BASICS

Line voltage V_L= voltage between lines

Phase voltage Vph= voltage between a line and neutral

THREE PHASE SYSTEM

BALANCED STAR



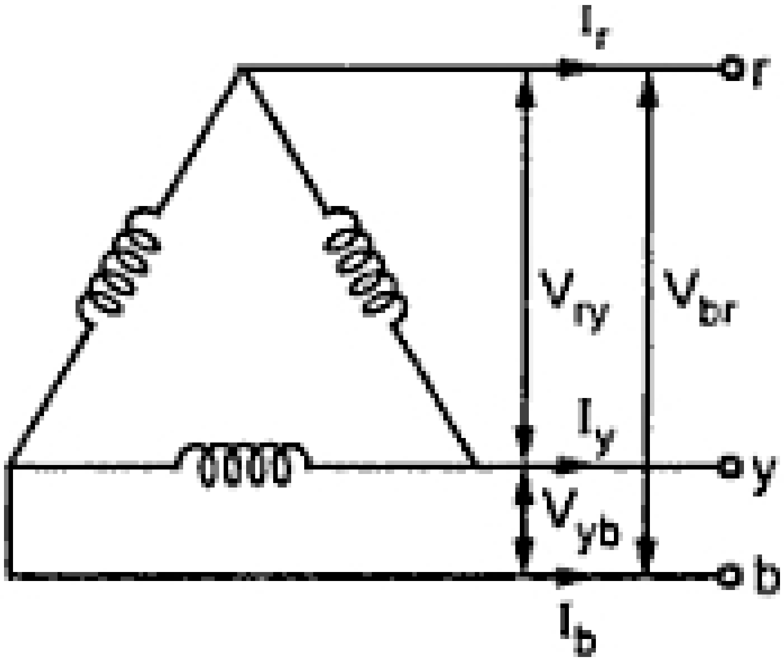
Line Voltage,

$$V_L = \sqrt{3} V_{ph}$$

Line current, $I_L = I_{ph}$

THREE PHASE SYSTEM

BALANCED DELTA



Line Voltage $V_L = V_{ph}$

Line current $I_L = \sqrt{3}\ I_{ph}$

THREE PHASE TRANSFORMERS

Almost all major generation & Distribution Systems in the world are three phase ac systems

Three phase transformers play an important role in these systems

3 phase transformers can be constructed from

(a) 3 single phase transformers

(b) 2 single phase transformers

(c) using a common core for three phase windings

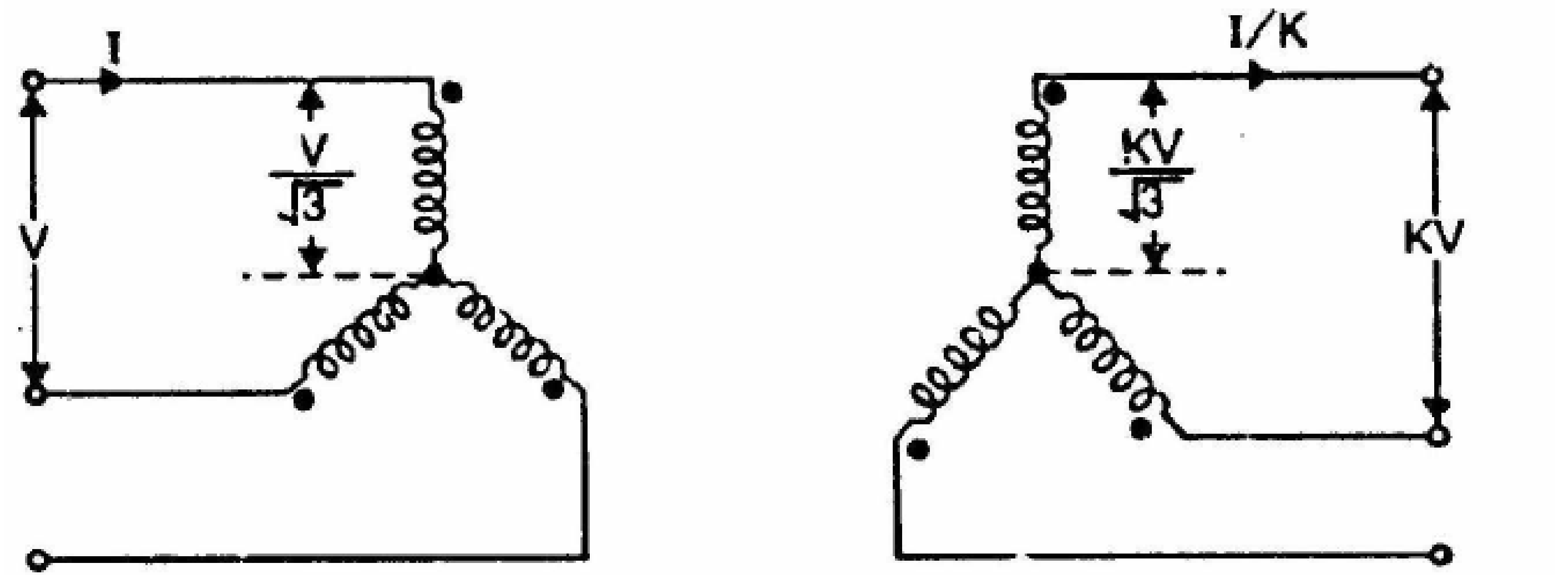
3 phase Transformer connections

By connecting three single phase transformers

1. **Star- Star connection**
2. **Delta- Delta connection**
3. **Star – Delta connection**
4. **Delta – Star connection**

$$\text{Phase transformation ratio, } K = \frac{\text{Secondary phase voltage}}{\text{Primary phase voltage}} = \frac{N_2}{N_1}$$

Star- Star connection



Y – Y Connection

- **This connection satisfactory only in balanced load otherwise neutral point will be shifted.**

Star- Star connection

Advantages

1. **Requires less turns per winding i.e. cheaper**

   Phase voltage is $1/\sqrt{3}$ times of line voltage

2. **Cross section of winding is large i.e. stronger to bear stress during short circuit**

   Line current is equal to phase current

3. **Less dielectric strength in insulating materials**

   phase voltage is less

Star- Star connection

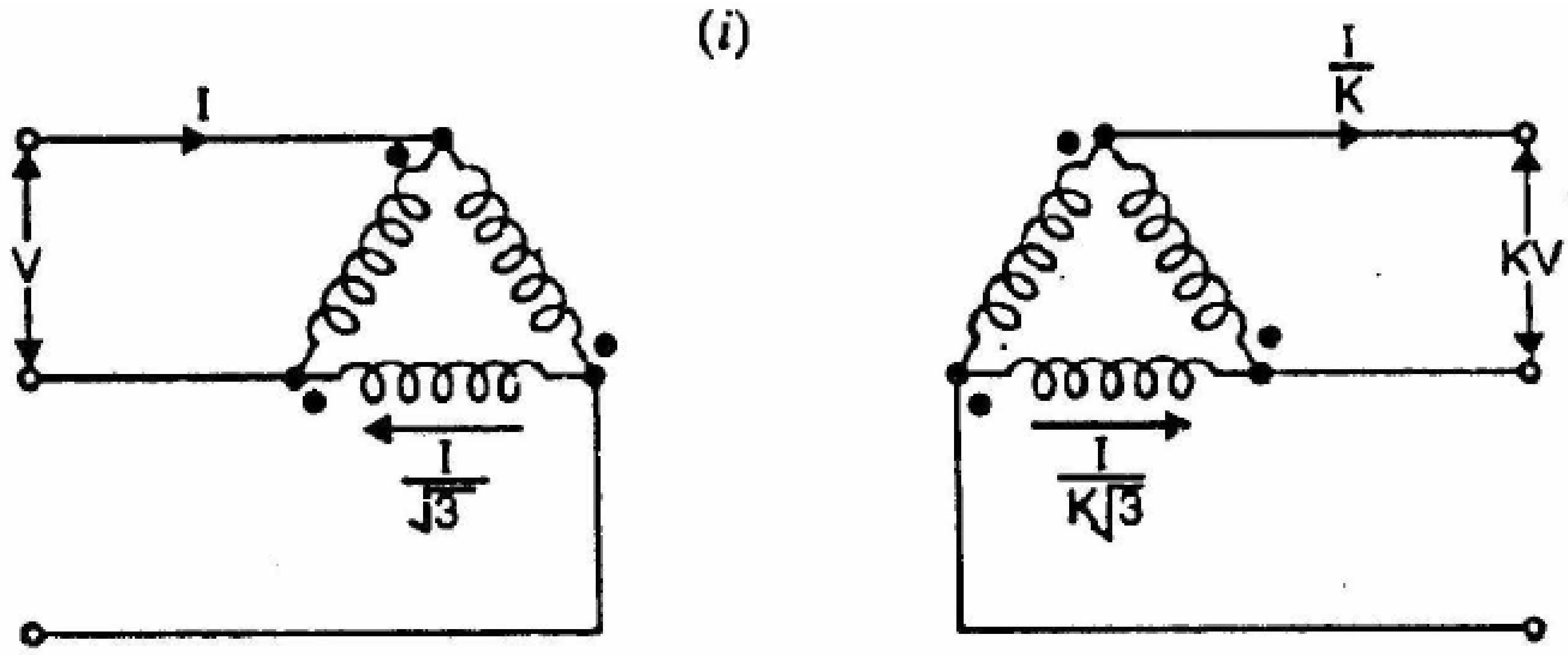
Disadvantages

1. If the load on the secondary side unbalanced then the shifting of neutral point is possible

2. The third harmonic present in the alternator voltage may appear on the secondary side. This causes distortion in the secondary phase voltages

3. Magnetizing current of transformer has 3rd harmonic component

Delta - Delta connection



Δ – Δ Connection

- **This connection is used for moderate voltages**

Delta - Delta connection

Advantages

1. System voltages are more stable in relation to unbalanced load
2. If one t/f is failed it may be used for low power level i.e. V-V connection
3. No distortion of flux i.e. 3rd harmonic current not flowing to the line wire

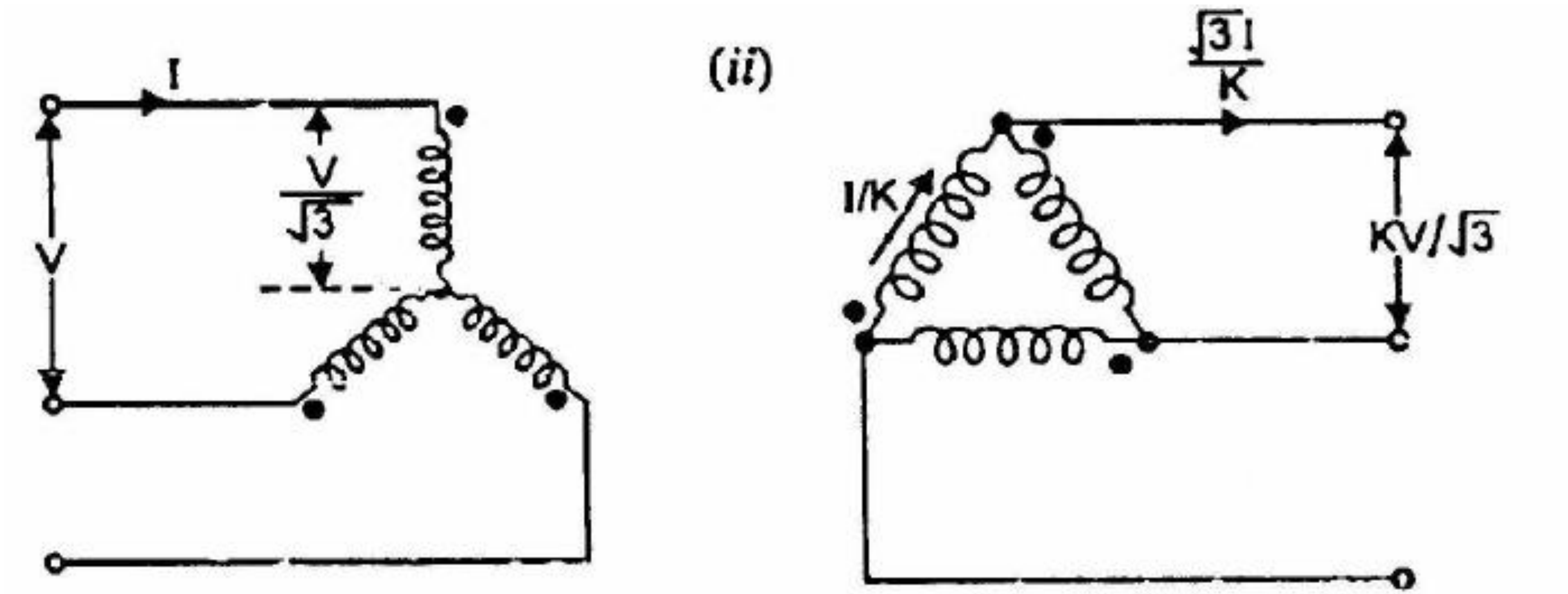
Delta - Delta connection

Disadvantages

1. **Compare to Y-Y require more insulation.**

2. **Absence of star point i.e. fault may severe.**

Star- Delta connection



Y – Δ Connection

- **Used to step down voltage i.e. end of transmission line**

Star- Delta connection

Advantages

1. The primary side is star connected. Hence fewer number of turns are required. This makes the connection economical

2. The neutral available on the primary can be earthed to avoid distortion.

3. Large unbalanced loads can be handled satisfactory.

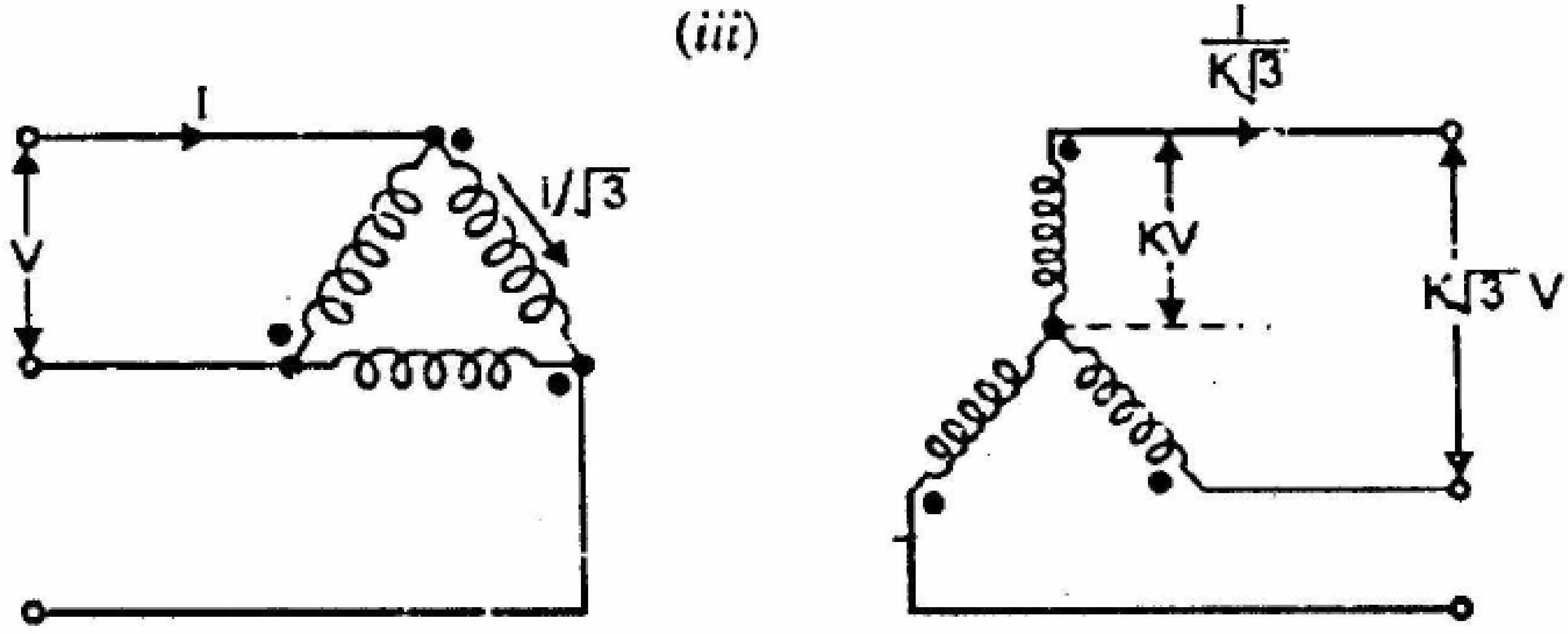
Star- Delta connection

Disadvantages

The secondary voltage **is not in phase** with the primary. (30 ^{0} phase difference)

Hence it is not possible to operate this connection in **parallel** with star-star or delta-delta connected transformer.

Delta - Star connection



Δ – Y Connection

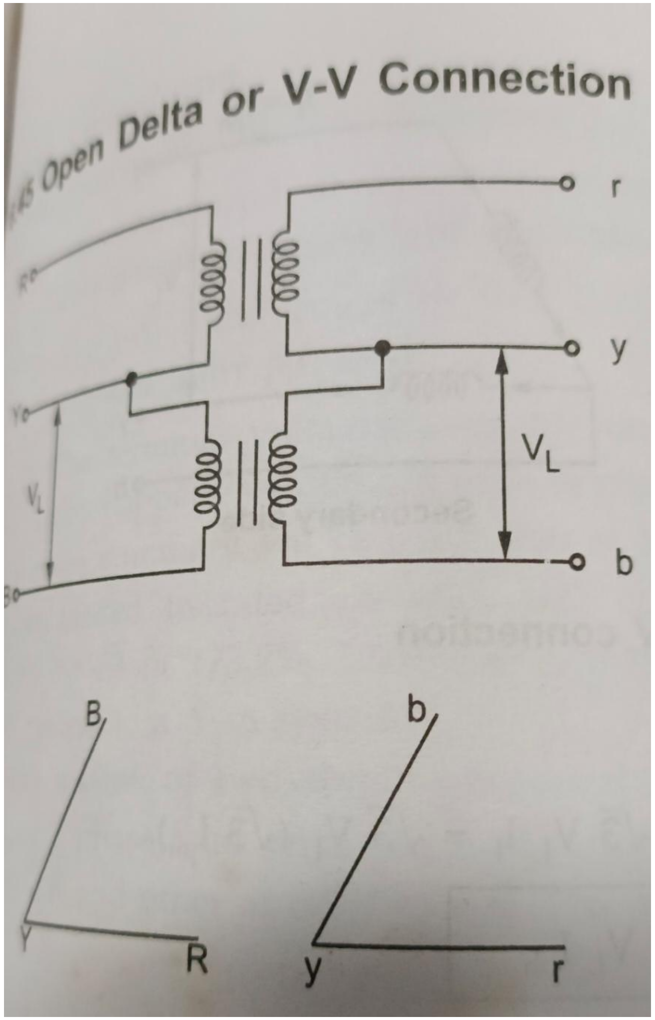
- **This connection is used to step up voltage ie. Beginning of high tension line**

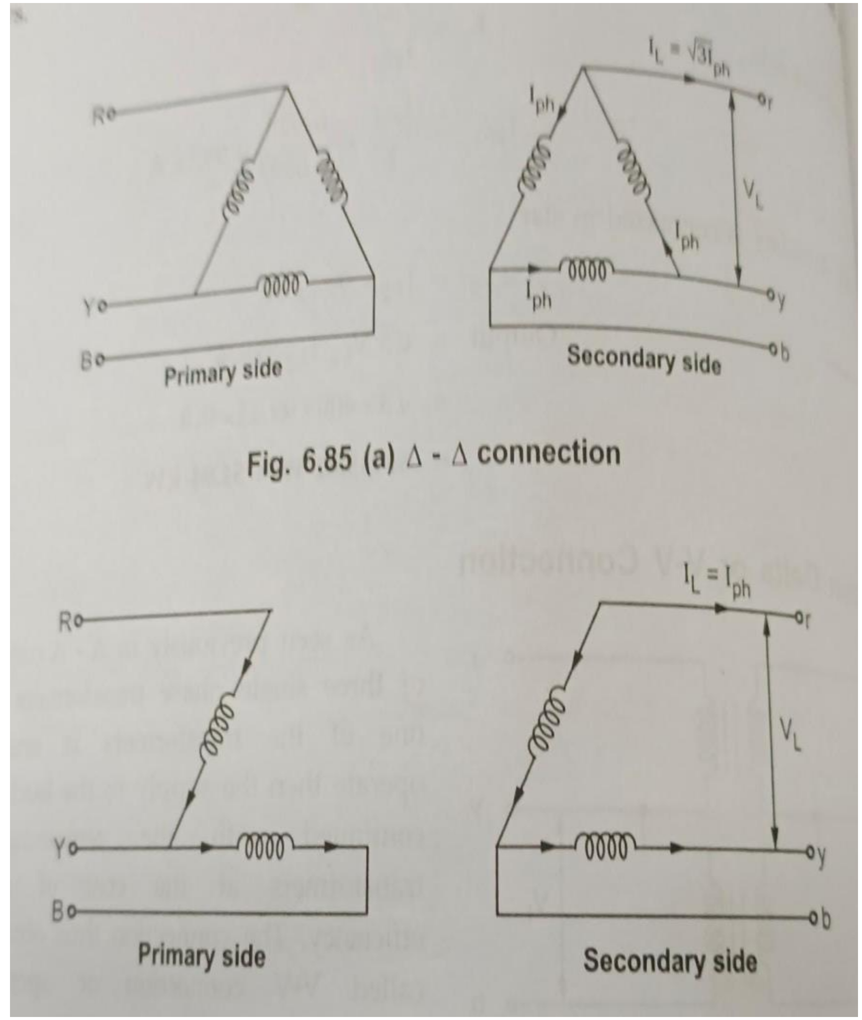
Delta - Star connection

Features

- secondary Phase voltage is $1/\sqrt{3}$ times of line voltage.
- neutral in secondary can be grounded for 3 phase 4 wire system.
- Neutral shifting and 3^{rd} harmonics are there.
- Phase shift of 30^{0} between secondary and primary currents and voltages.

Open Delta or V-V Connection





Open Delta or V-V Connection

$$\Delta - \Delta \text{ capacity} = \sqrt{3}\, V_L\, I_L = \sqrt{3}\, V_L\, (\sqrt{3}\, I_{ph})$$

$$\boxed{\Delta - \Delta \text{ capacity} = 3\, V_L\, I_{ph}}$$

Open Delta or V-V Connection

It can also be noted from the Fig. 6.85 (b) that the secondary line current I_L equal to the phase current I_{ph}.

$$\boxed{\text{V - V capacity} = \sqrt{3}\, V_L\, I_L = \sqrt{3}\, V_L\, I_{ph}} \qquad \text{... (2)}$$

Dividing equation (2) by equation (1)

$$\boxed{\frac{\text{V} - \text{V capacity}}{\Delta - \Delta \text{ capacity}} = \frac{\sqrt{3}\, V_L I_{ph}}{3\, V_L I_{ph}} = \frac{1}{\sqrt{3}} = 0.557 \approx 58\ \%} \qquad \text{... (3)}$$

Thus the three phase load that can be carried without exceeding the ratings of the transformers is 57.7 % of the original load. Hence it is not 66.7 % which was expected otherwise.

The reduction in the rating can be calculated as $\frac{66.67 - 57.735}{57.735} \times 100 = \mathbf{15.476}$

Suppose that we consider three transformers connected in Δ - Δ fashion and supplying their rated load. Now one transformer is removed then each of the remaining two transformers will be overloaded. The overload on each transformer will be given as

$$\frac{\text{Total load in V} - \text{V}}{\text{V A / transformer}} = \frac{\sqrt{3}\, V_L\, I_{ph}}{V_L\, I_{ph}} = \sqrt{3} = 1.732$$

Key Point: *This overload can be carried temporarily if provision is made to reduce the load if overheating and breakdown of the remaining two transformers is to be avoided.*

Open Delta or V-V Connection

if overheating

6.45.1 Limitations

The limitations with V-V connection are given below :

1. The average p.f. at which V-V bank is operating is less than that with the load. This power p.f is 86.6% of the balanced load p.f.
2. The two transformers in V-V bank operate at different power factor except for balanced unity p.f. load.
3. The terminal voltages available on the secondary side become unbalanced. This may happen eventhough load is perfectly balanced.

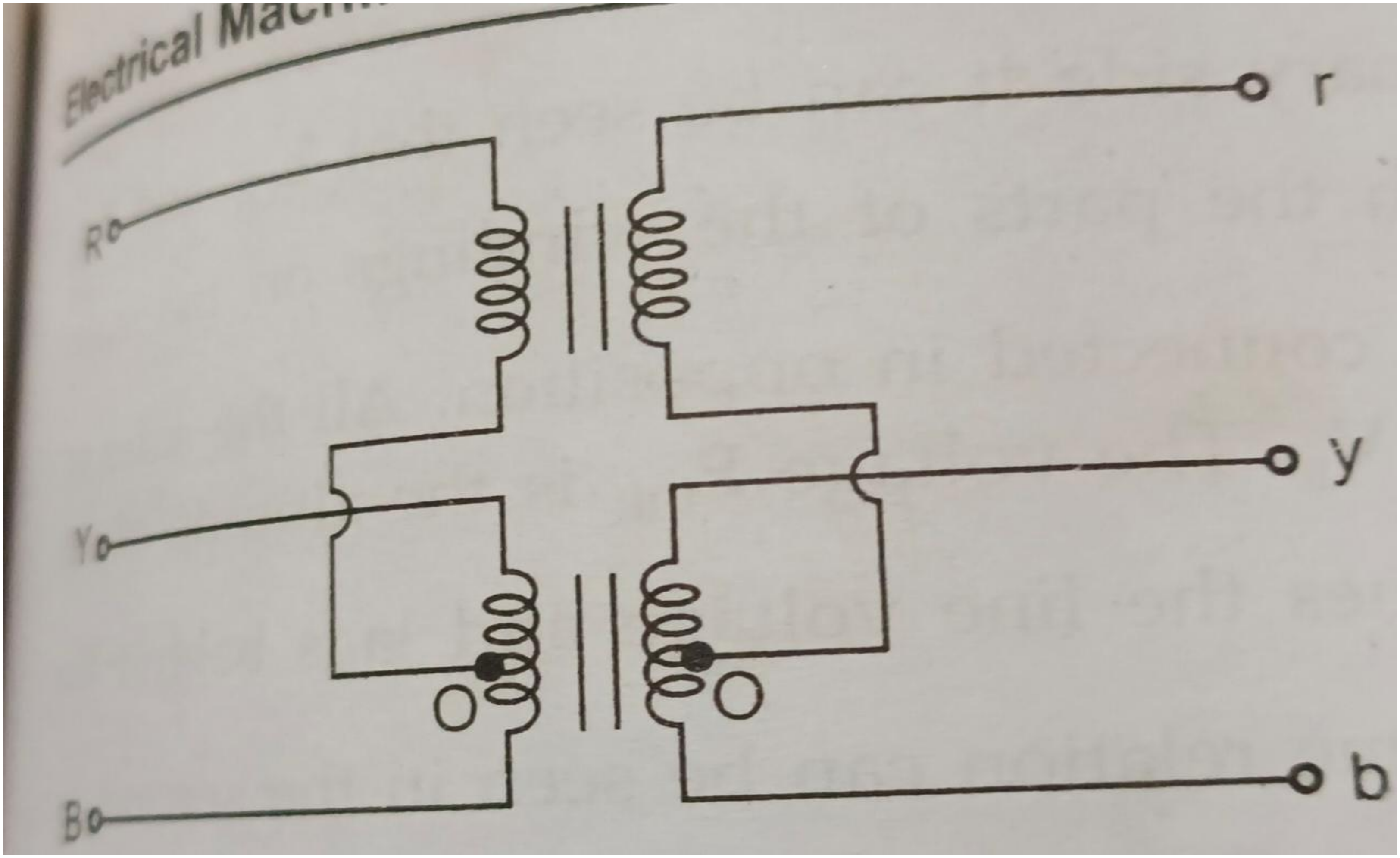
Thus in summary we can say that if two transformers are connected in V-V fashion and are loaded to rated capacity and one transformer is added to increase the total capacity by $\sqrt{3}$ or 173.2%. Thus the increase in capacity is 73.2% when converting from a V - V system to a $\Delta - \Delta$ system.

With a bank of two single phase transformers connected in V-V fashion supplying a balanced 3 phase load with cos ϕ as p.f., one of the transformer operates at a p.f. of cos $(30 - \phi)$ and other at cos $(30 + \phi)$. The powers of two transformers are given by,

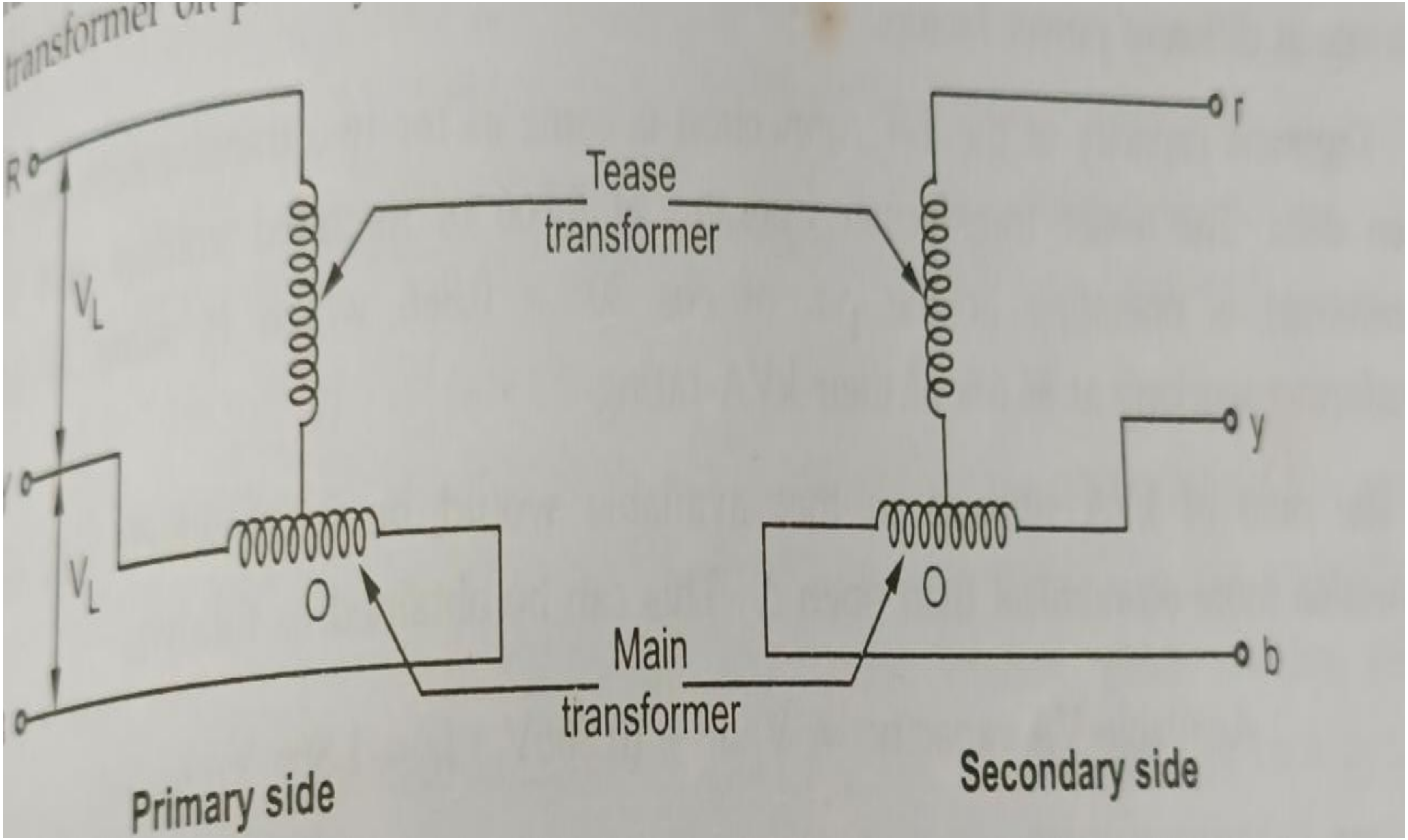
$$P_1 = \text{kVA} \cos(30 - \phi)$$

$$P_2 = \text{kVA} \cos(30 + \phi)$$

T-T Connection



T-T Connection



T-T Connection

connection more economical ...

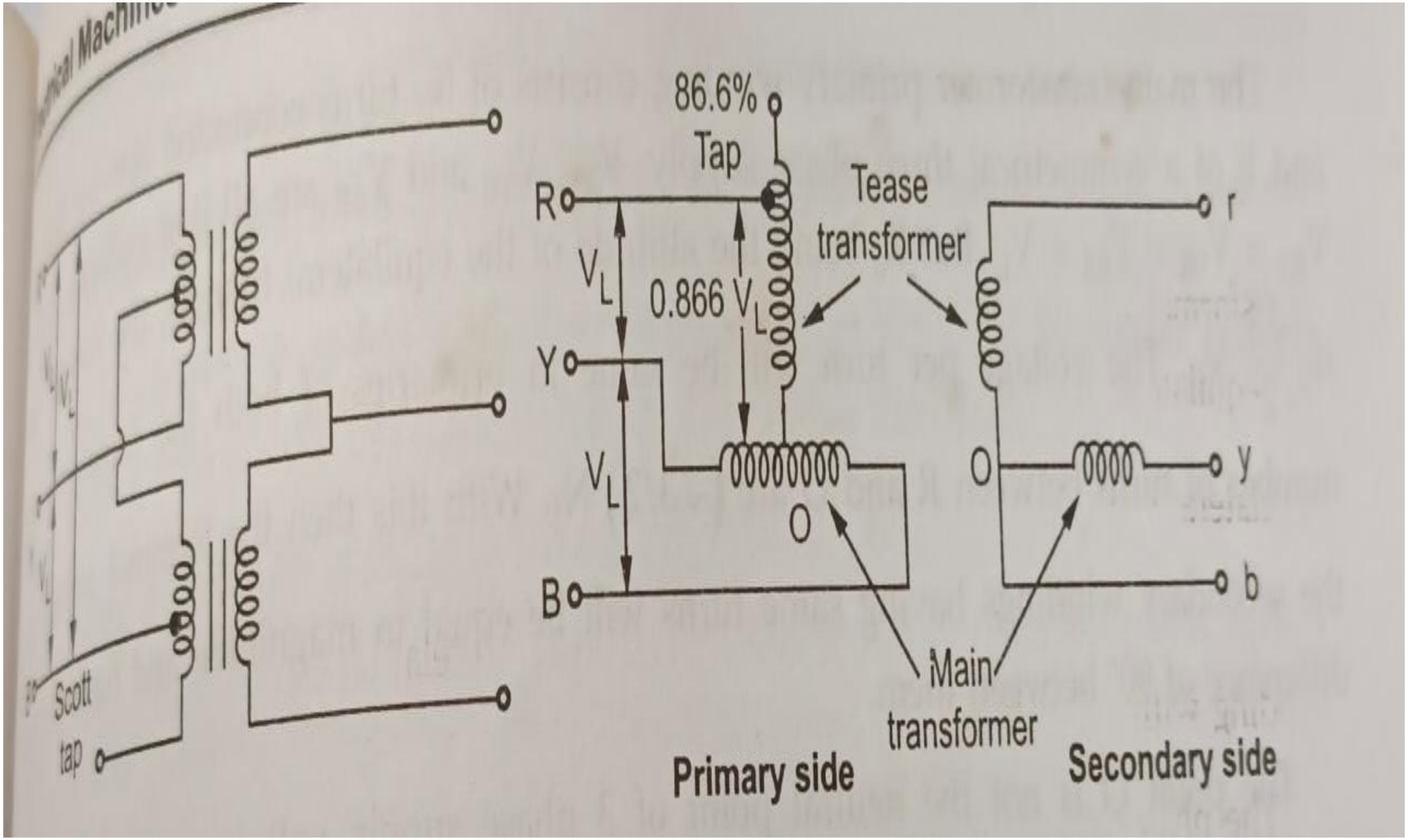
$$\text{Available VA capacity} = V_L I_L + (0.866 V_L) I_L = 1.866\, V_L I_L$$

$$\text{VA actually utilized} = 1.732\, V_L I_L \text{ since 3 phase power is supplied}$$

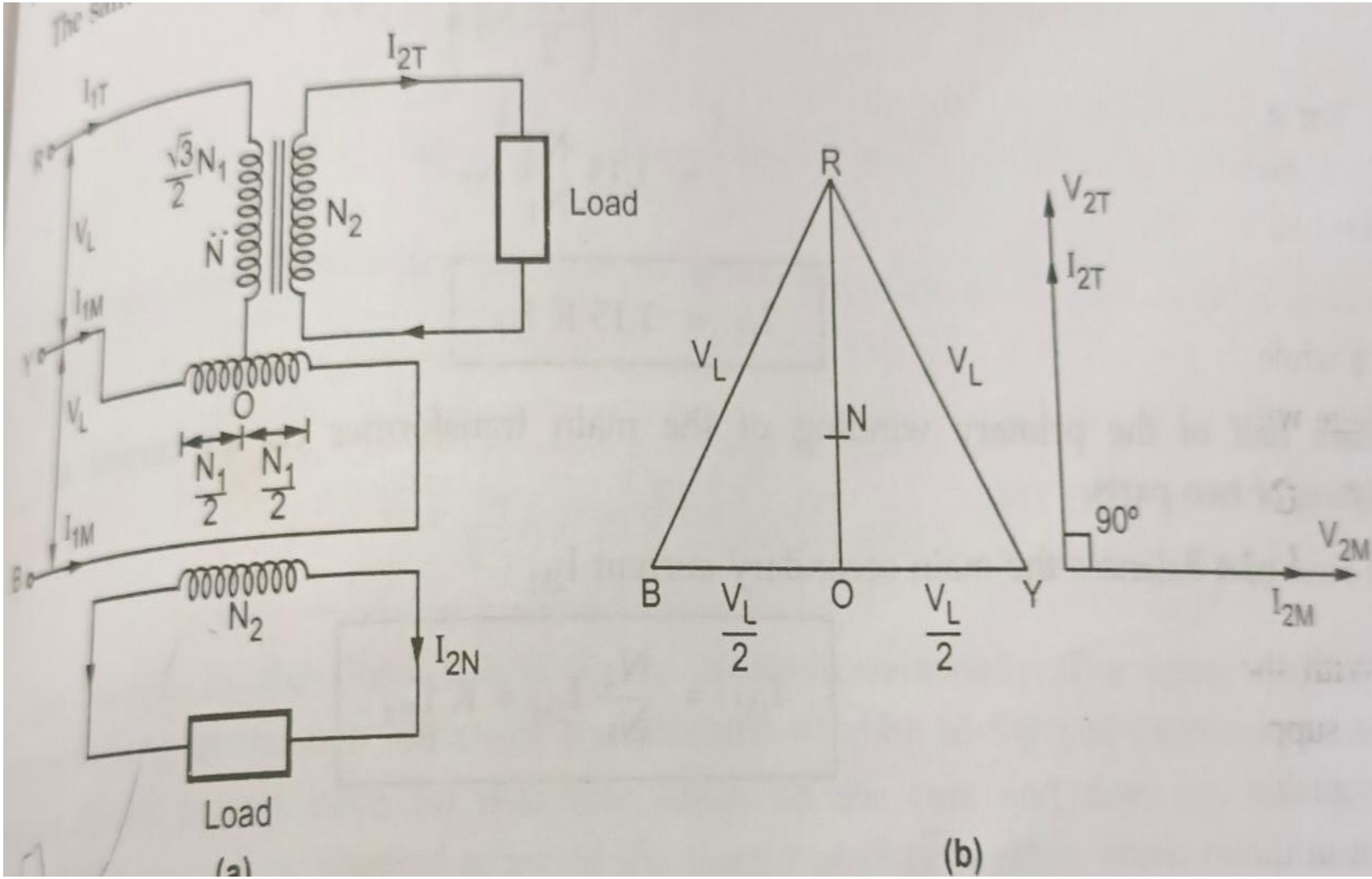
Taking the ratio of actual capacity to available capacity

$$\frac{\text{Actual capacity}}{\text{Available capacity}} = \frac{1.732\, V_L I_L}{1.866\, V_L I_L} = 0.928$$

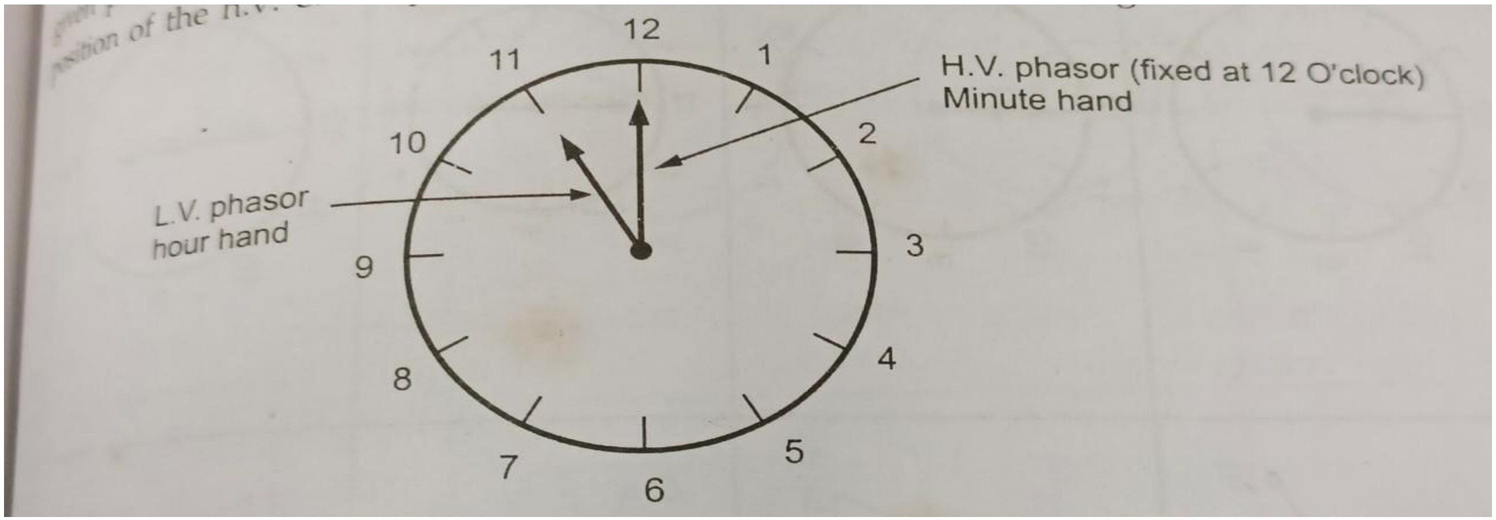
Scott Connection



Scott Connection



Nomenclature of Transformer Phasor Groups



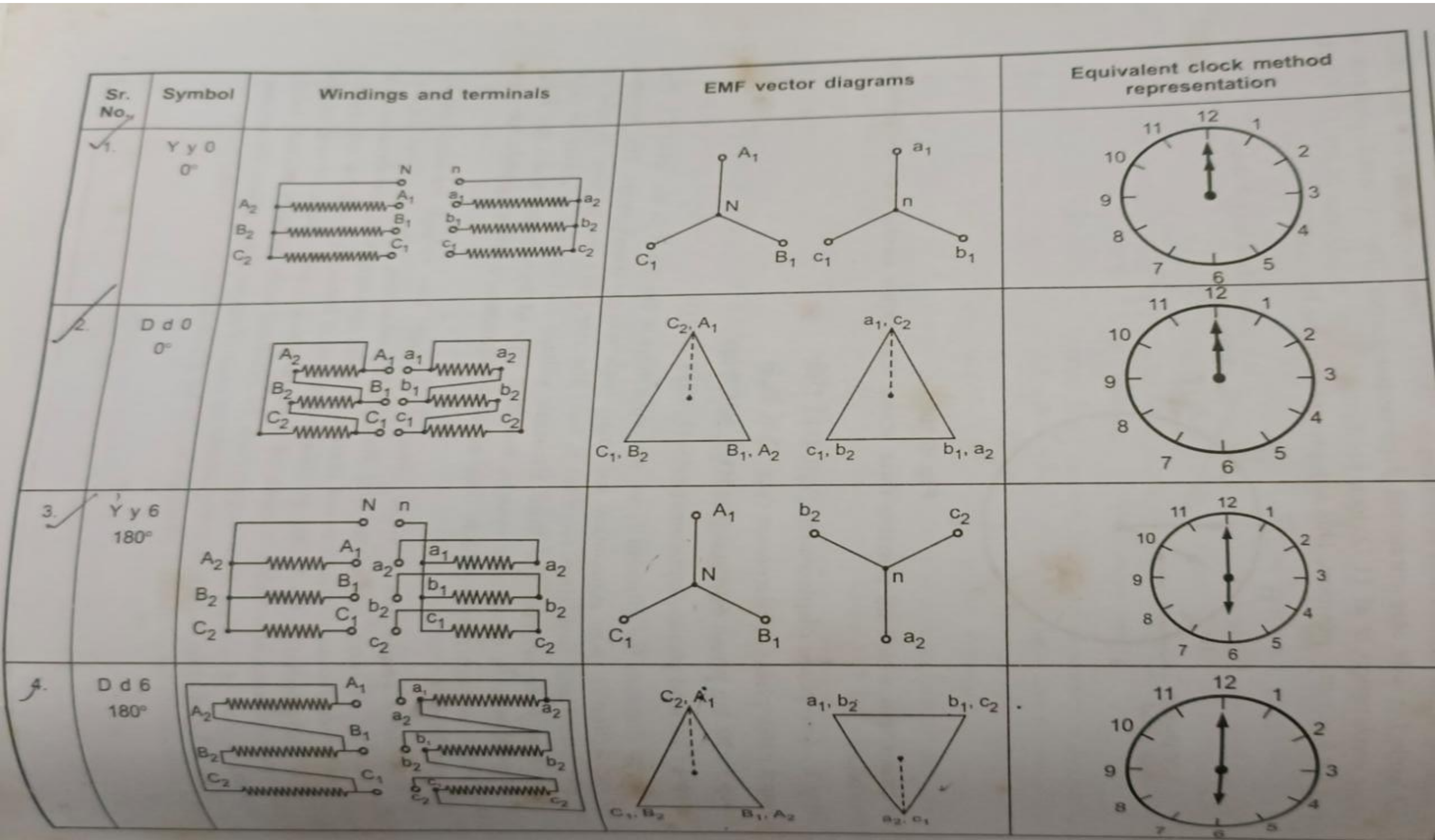
Group 1 : Zero Displacement (Yy0,Dd0,Dz0)

Group 2 : 180^0 phase displacement (Yy6,Dd6,Dz6)

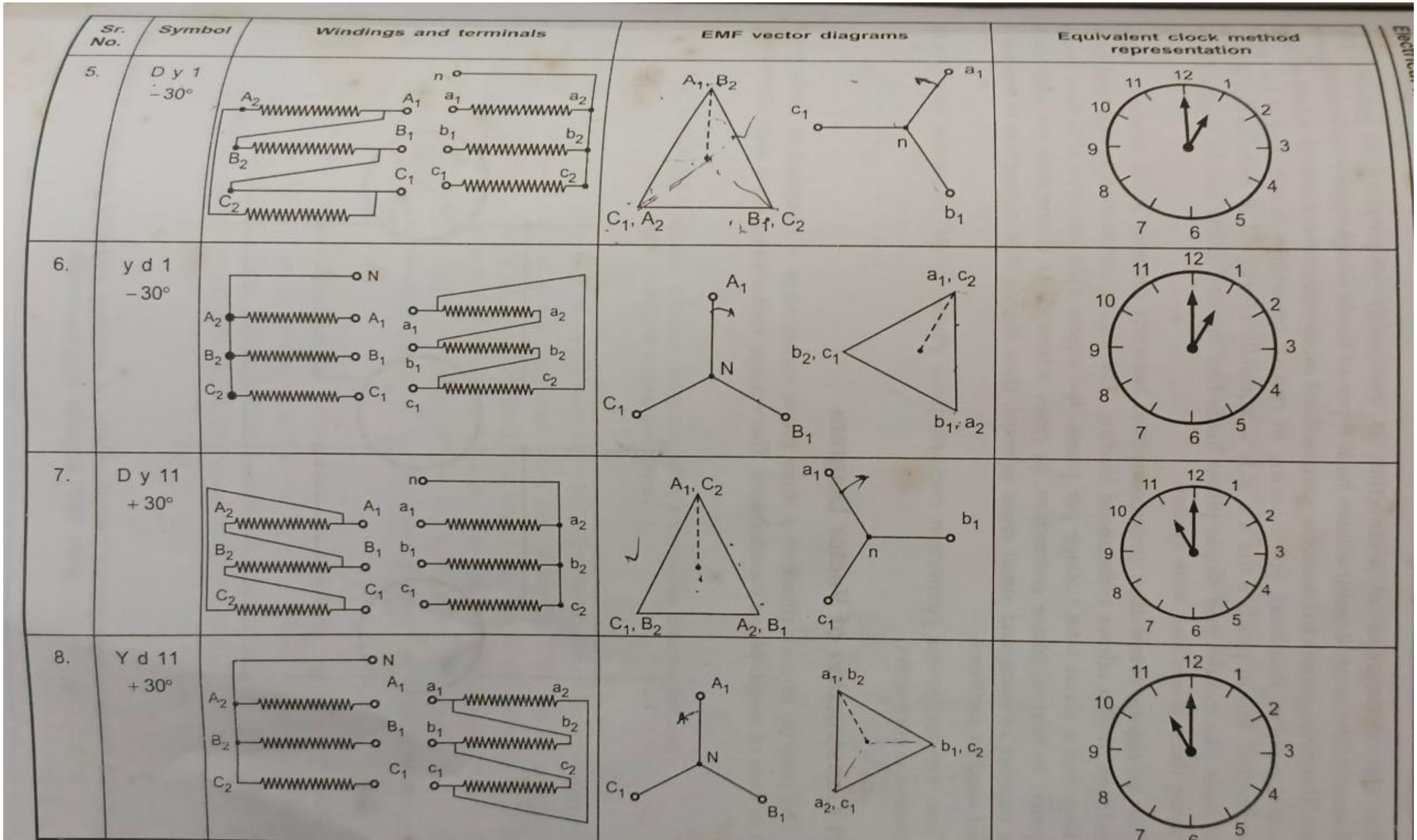
Group 3 : 30^0 lag phase displacement (Yd1,Dy1,Yz1)

Group 4 : 30^0 lead phase displacement (Yd11,Dy11,Yz11)

Nomenclature of Transformer Phasor Groups



Nomenclature of Transformer Phasor Groups



Sr. No.	Symbol	Windings and terminals	EMF vector diagrams	Equivalent clock method representation
5.	D y 1 – 30°			
6.	y d 1 – 30°			
7.	D y 11 + 30°			
8.	Y d 11 + 30°			