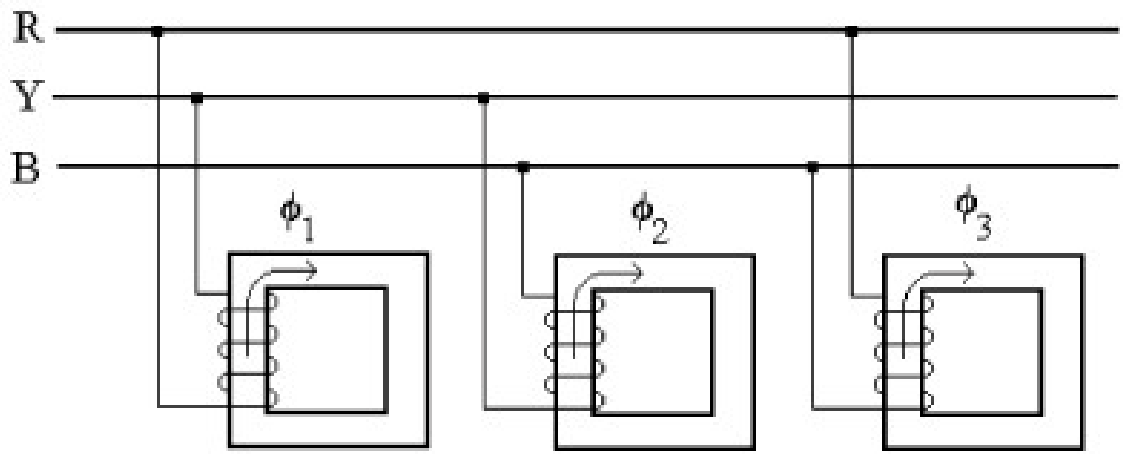
Electrical Machines 1

Hour 13

Three Phase Transformer (sect. 2.6)

A set of three similar single phase transformers may be connected to form a three-phase transformer (three-phase transformer bank). The primary and secondary windings may be connected in either star or delta configurations

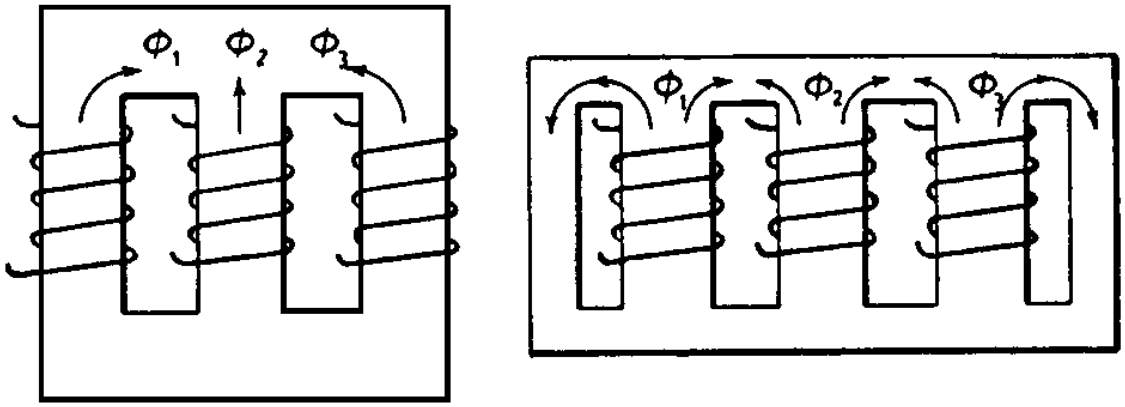


Three-phase Bank

- Ease of transportation
- Inefficient magnetic circuit, less efficient
- Higher capital cost than a single one
- 1-phase of the transformer at fault, the other two are not affected

Three-phase Transformer (sect. 2.6.2)

- Usually 3-limb core structure
- 5-limb core may be used to reduce the overall height of a 3-limb core
- Magnetic flux shares the magnetic circuit
- Fault on one-phase very likely affects the other



Tertiary Winding

A third set of windings usually exists in 3-phase transformer and used to:

- Providing voltage to auxiliary power purposes in the substation or to supply local distribution system
- Power factor correction
- Delta connected tertiary windings will provide a circuit for the third harmonics of the exciting current

BSEN60076 (BS 171) Terminal Marking System

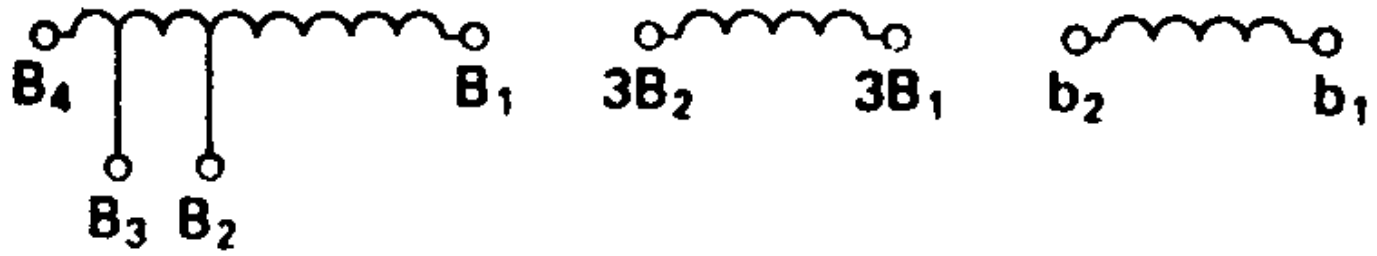
1. HV winding has a capital letter. The letters used are A B C.
2. LV winding has a small letter. The letters used are a b c.
3. Letters are the same for all windings on the same limb.

BSEN60076
Terminal Marking System

4. A third winding, known as a tertiary winding, is prefixed with the number 3 followed by the capital letter for that limb.

BSEN60076
Terminal Marking System

5. A suffix number indicates the potential or polarity of the terminal; with the number 1 being the lowest potential and the number increasing for tappings up the winding to the highest potential, as shown.



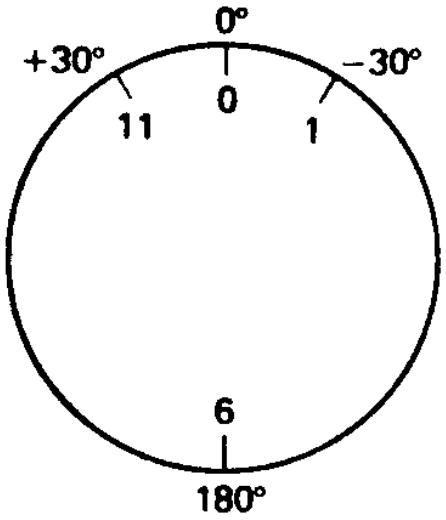
H.V. winding with tappings

BSEN60076
Terminal Marking System

6. The phase shift through a transformer refers the same alphabetical letters of the output and input connections to the windings. The phase shift is the angular displacement of the output with respect to the input.

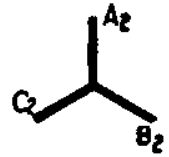
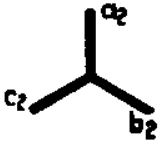
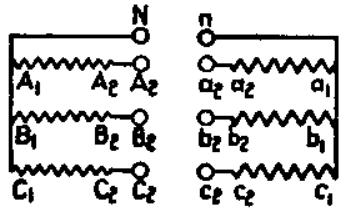
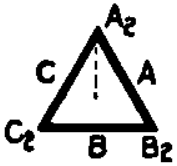
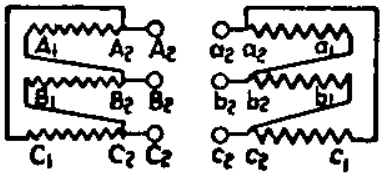
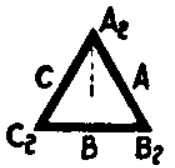
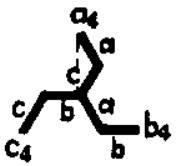
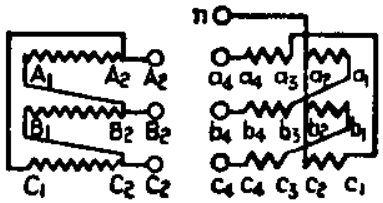
Standard Phase-shifts

BSEN60076 recognises only 4 phase-shifts and it is convenient to use a ‘clock face’ number reference instead of degrees to describe the phase shift.

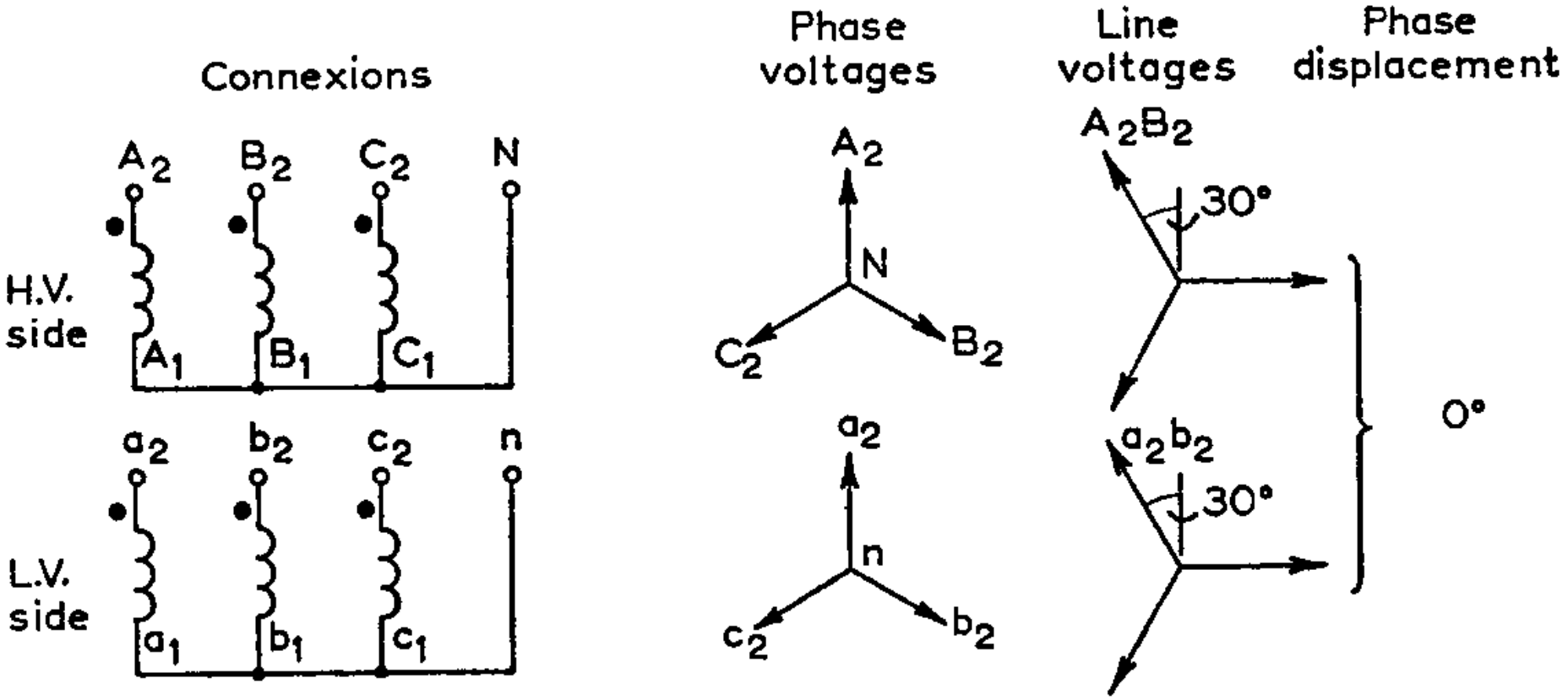


Clockface number	Phase shift	Group
0	0°	I
6	180°	II
1	−30°	III
11	+30°	IV

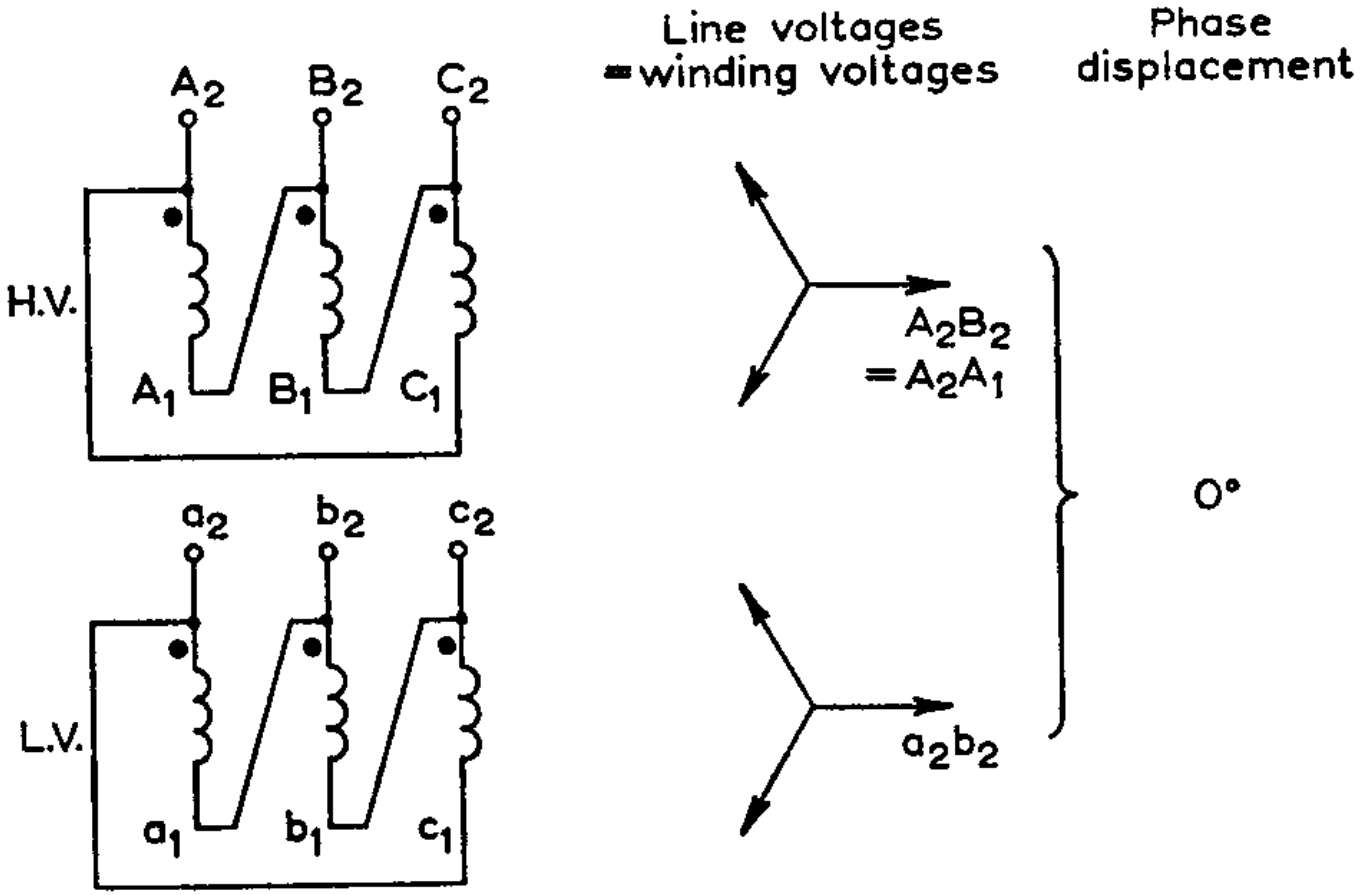
Group I Transformer

Phase Displacement.	Main Group No.	Vector Group Ref. No. & Symbol	Marking of Line Terminals and Vector Diagram of Induced Voltages.		Winding Connections and Relative Position of Terminals.
			H.V. Winding.	L.V. Winding.	
Col. 1	2	3	4	5	6
0°	I	11 Yy 0			
		12 Dd 0			
		13 Dz 0			

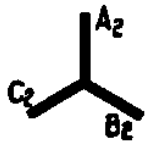
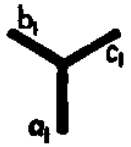
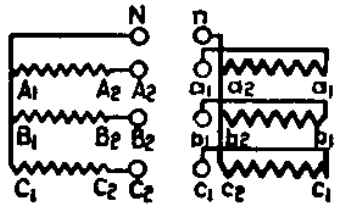
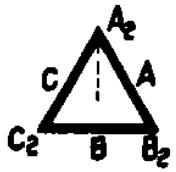
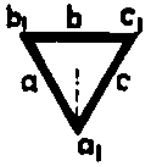
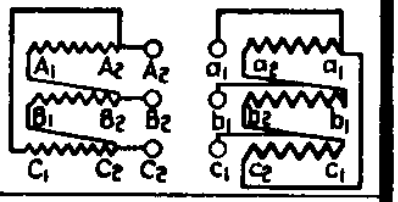
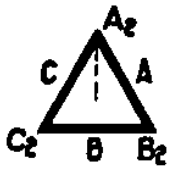
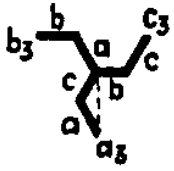
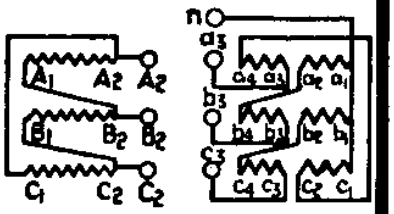
Group I Transformer



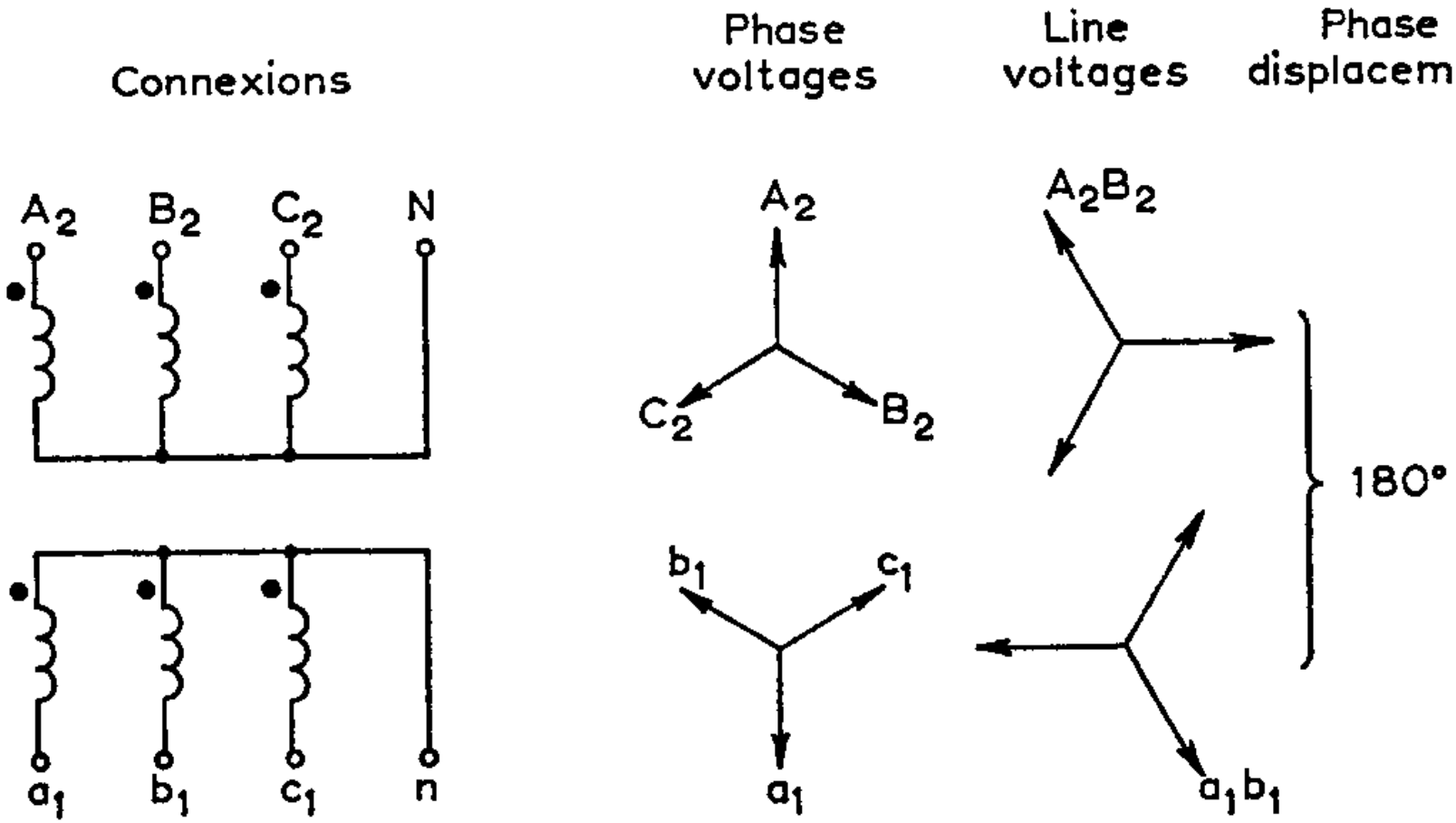
Group I Transformer



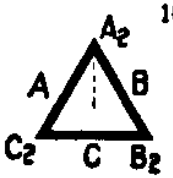
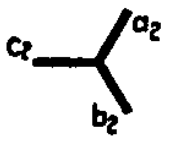
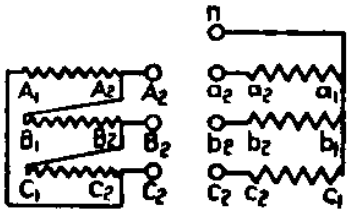
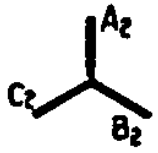
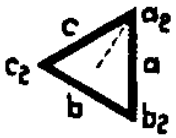
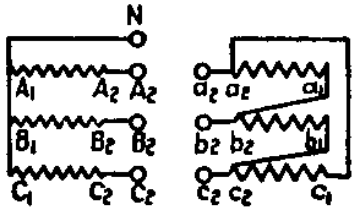
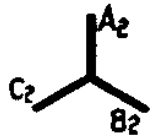
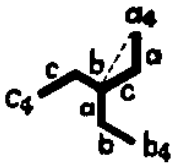
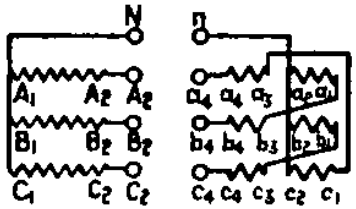
Group I I Transformer

Phase Dis-placement.	Main Group No.	Vector Group Ref. No. & Symbol	Marking of Line Terminals and Vector Diagram of Induced Voltages. H.V. Winding.	Marking of Line Terminals and Vector Diagram of Induced Voltages. L.V. Winding.	Winding Connections and Relative Position of Terminals.
180°	2	21 Yy 6			
		22 Dd 6			
		23 Dz 6			

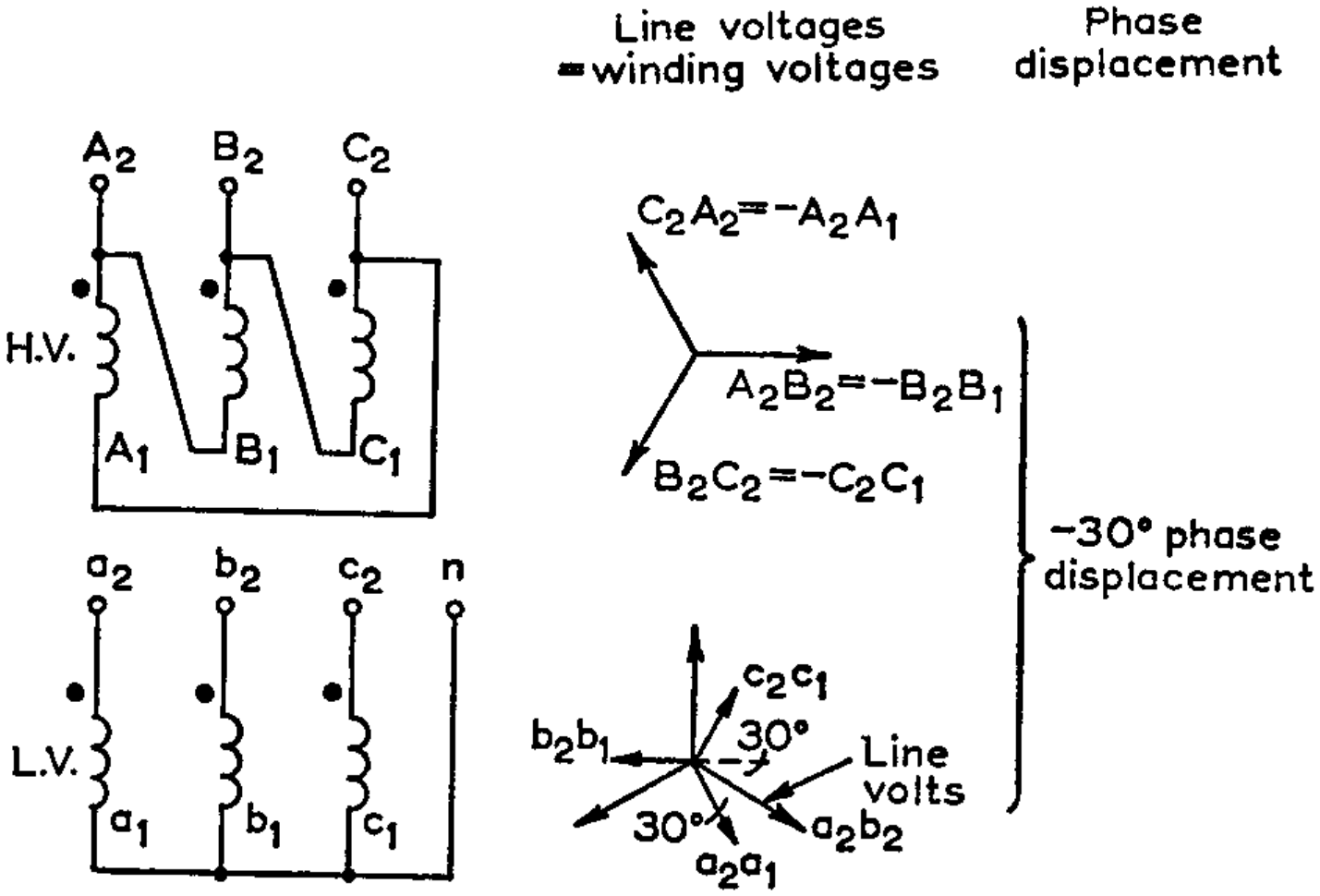
Group I I Transformer



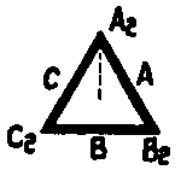
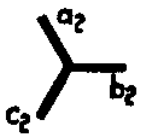
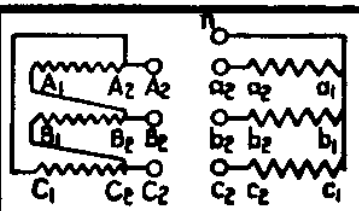
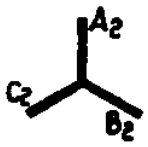
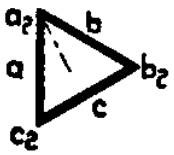
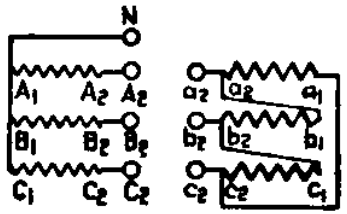
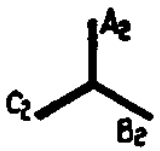
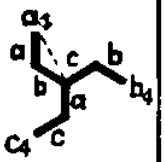
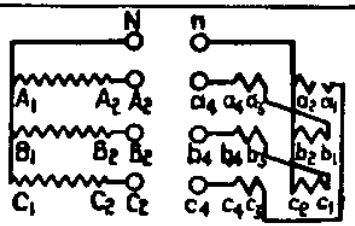
Group I I I Transformer

Phase Dis-placement.	Main Group No	Vector Group Ref. No. & Symbol.	Marking of Line Terminals and Vector Diagram of Induced Voltages.		Winding Connections and Relative Position of Terminals.
			H.V. Winding.	L.V. Winding.	
7	8	9.	10.	11	12.
-30°	3	31 Dy 1			
		32 Yd 1.			
		33 Yz 1			

Group III Transformer



Group IV Transformer

Phase Displacement.	Main Group No	Vector Group Ref. No. & Symbol.	Marking of Line Terminals and Vector Diagram of Induced Voltages.		Winding Connections and Relative Position of Terminals.
			H.V. Winding.	L.V. Winding.	
+30°	4	41 Dy 11			
		42 Yd 11			
		43 Yz 11			

Letter Description for Various Winding Methods

Winding connection	Description letter	
	H.V.	L.V.
Delta	D	d
Star	Y	y
Zigzag or Interstar	Z	z

Example

State the BSEN60076 description, using appropriate numbers and letters, of the following transformers and also state the phasor group number for each.

(a) Delta/star with a 30° lead phase shift. HV winding connected in delta.

(b) Star/star with a 0° phase shift. HV winding connected in star.

(c) Star/delta with a 30° lag phase shift. HV winding connected in star.

(d) Zigzag/star with a 30° lag phase shift. HV winding connected in zigzag.

Answer to Example

	Transformer Description	Phasor Group Number
(a)	Dy 11	IV
(b)	Yy 0	I
(c)	Yd 1	III
(d)	Zy 1	III

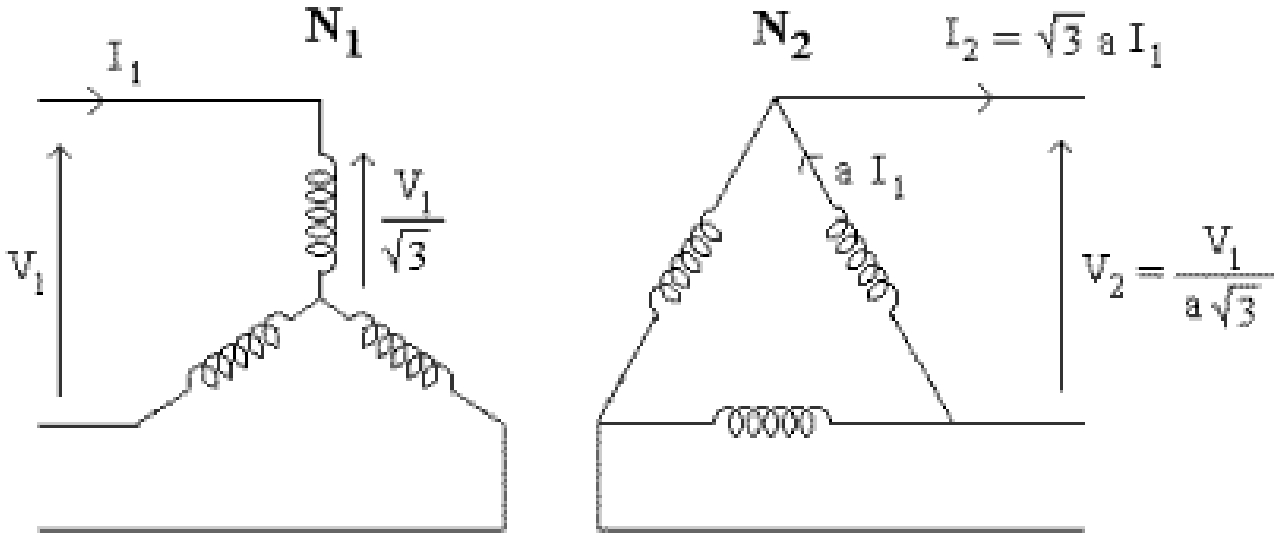
Electrical Machines 1

Hour 14

Turn Ratio/Voltage Ratio/ Current Ratio of 3-ph Tx

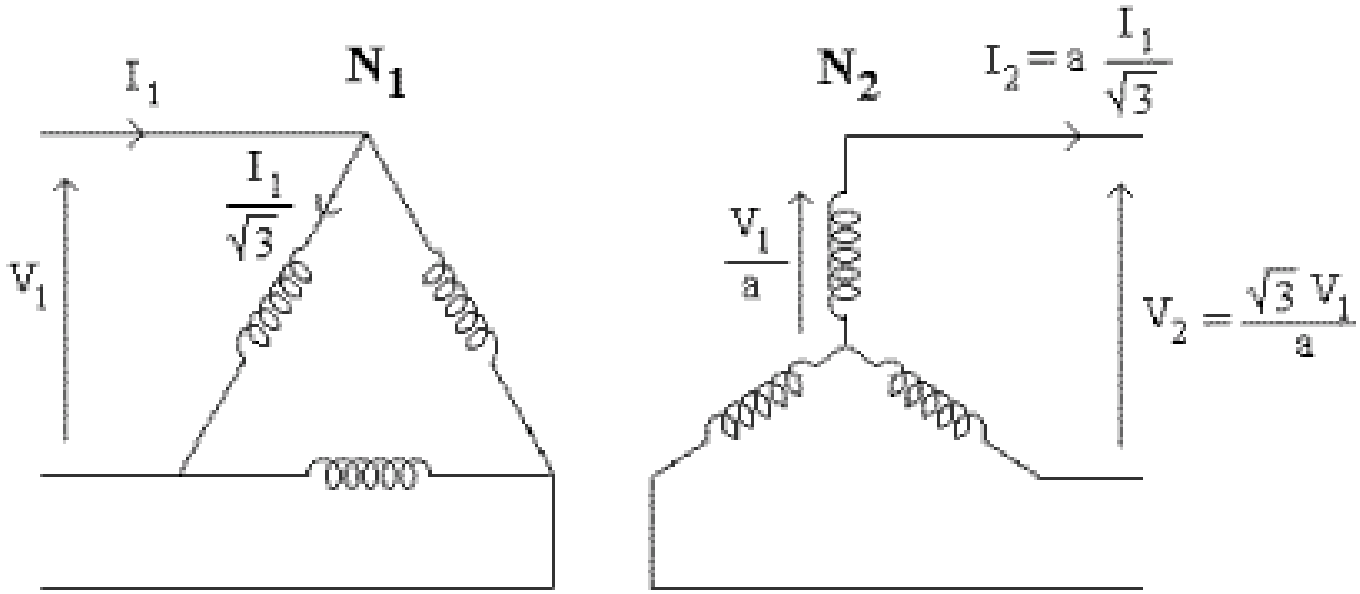
1. STAR/delta (Yd)
2. DELTA/star (Dy)
3. DELTA/delta (Dd)
4. STAR/star (Yy)

1. STAR/delta (Yd)



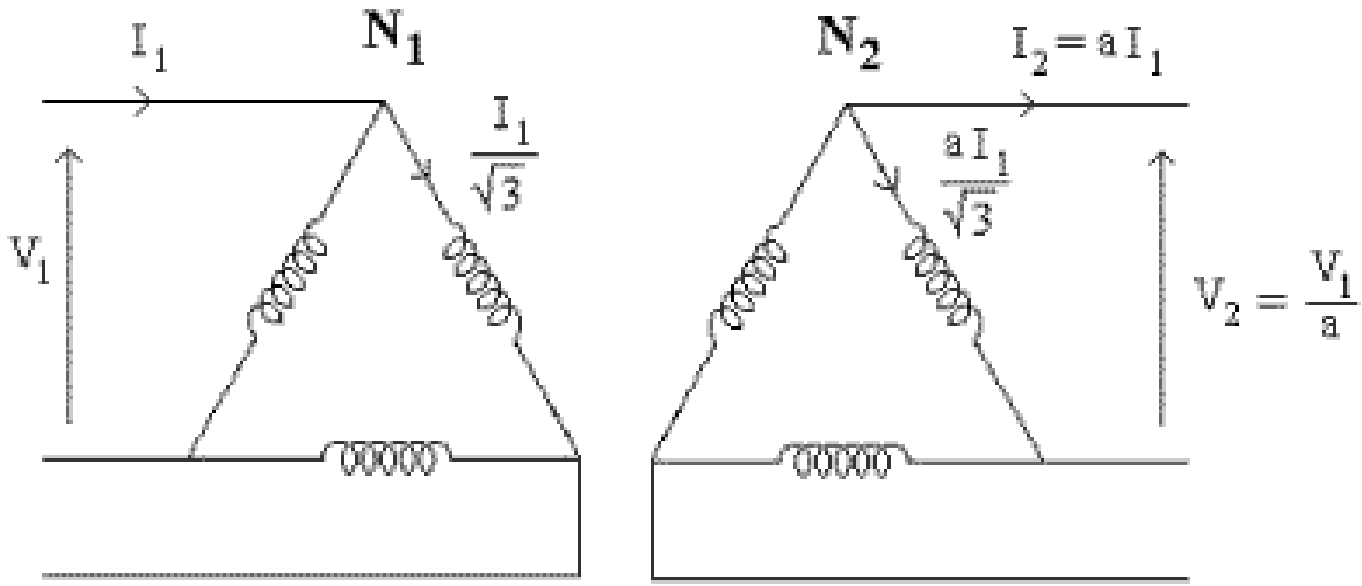
$$\frac{V_1}{V_2} = \sqrt{3}.a = \frac{\sqrt{3}.N_1}{N_2} \quad ; \quad \frac{I_1}{I_2} = \frac{1}{\sqrt{3}.a} = \frac{N_2}{\sqrt{3}.N_1}$$

2. DELTA/star (Dy)



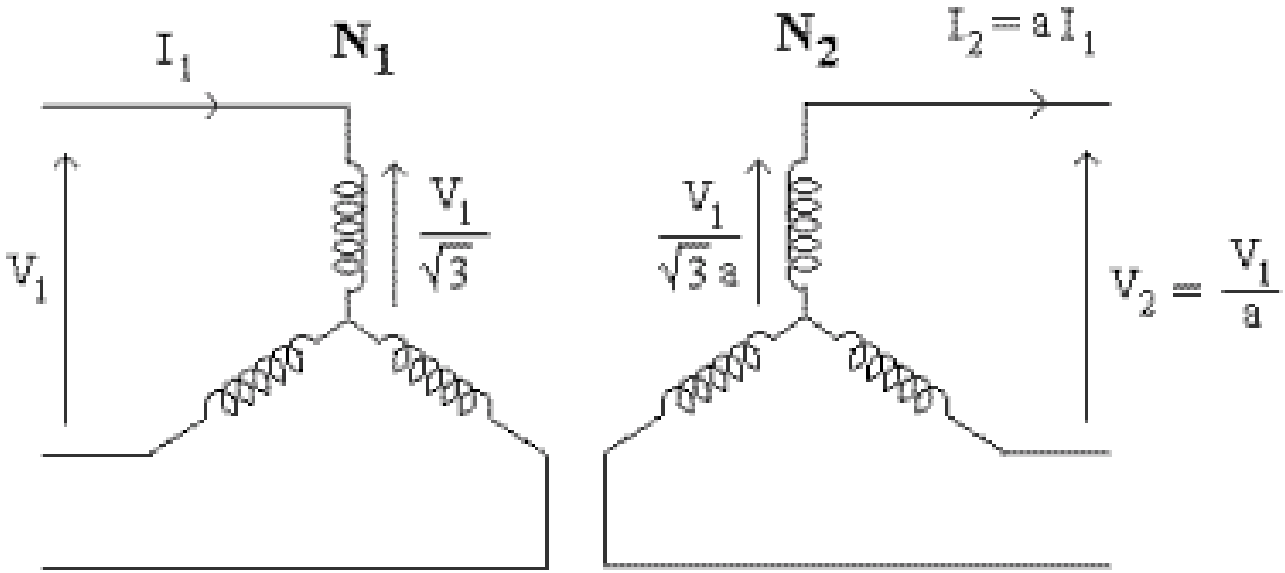
$$\frac{V_1}{V_2} = \frac{a}{\sqrt{3}} = \frac{N_1}{\sqrt{3}.N_2} \quad ; \quad \frac{I_1}{I_2} = \frac{\sqrt{3}}{a} = \frac{\sqrt{3}.N_2}{N_1}$$

3. DELTA/delta (Dd)



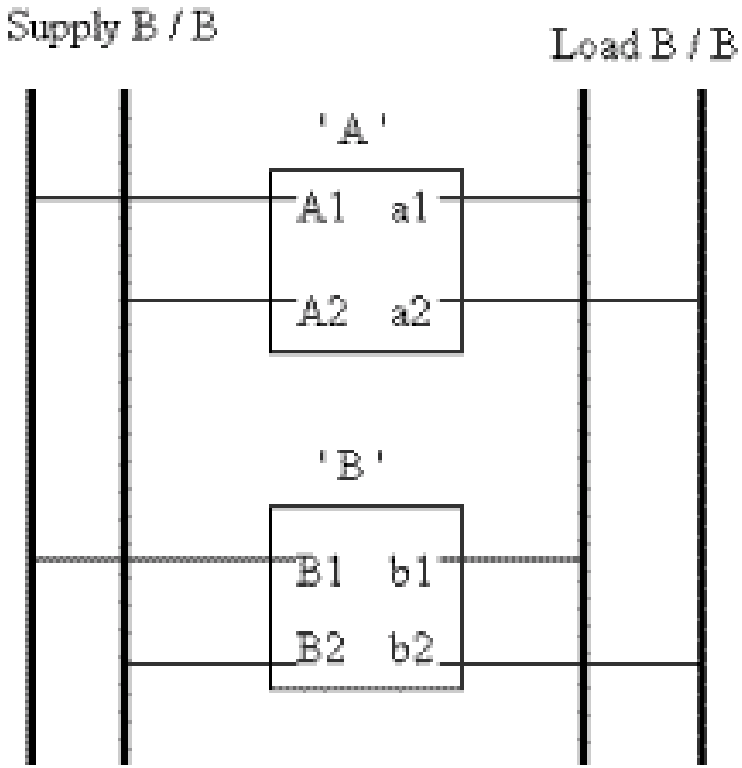
$$\frac{V_1}{V_2} = a = \frac{N_1}{N_2} \quad ; \quad \frac{I_1}{I_2} = \frac{1}{a} = \frac{N_2}{N_1}$$

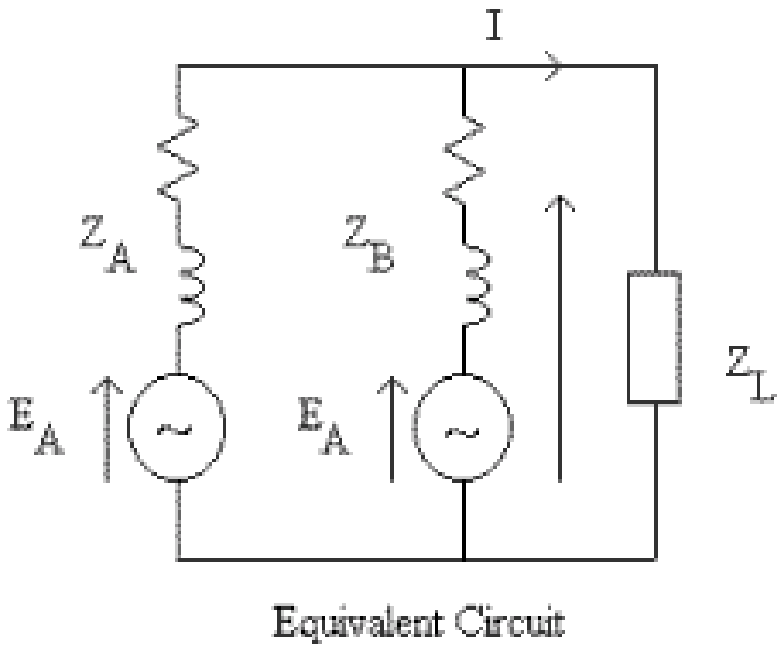
4. STAR/star (Yy)



$$\frac{V_1}{V_2} = a = \frac{N_1}{N_2} \quad ; \quad \frac{I_1}{I_2} = \frac{1}{a} = \frac{N_2}{N_1}$$

Parallel Operation





Equivalent Circuit

Condition for Parallel Operation

- The transformers must have the same phase displacement between primary and secondary line voltage i.e. they must belong to the same group number
- The phase sequence must be the same
- The line-voltage ratios must be the same
- The per-unit impedance of the transformers should be the same

Harmonics in Transformer

Harmonics in transformer occur due to the effect of saturation and hysteresis which are to produce non-sinusoidal current if the applied voltage is sinusoidal. Upon saturation, the flux waveform is flat topped and contains mainly 3rd harmonic component.

Effects of harmonic currents

(i) Additional I^2R losses due to circulating currents .

(ii) Increased iron loss in core.

(iii) Magnetic interference with protective gear and communication circuits.

Effects of harmonic voltages

(i) Increased dielectric stress.

(ii) Electric field interference with communication circuit.

(iii) Harmonic resonance may occur between the inductance of transformer windings and the capacitance of a feeder to which it is connected.

In 3-ph Supply System (1/2)

- Star-connected with isolated neutral the line voltage contains no 3rd harmonic component and 3rd harmonic current is precluded.
- Star connected with neutral wire, the 3rd harmonic currents can flow and still no 3rd harmonic line voltages.

In 3-ph Supply System (2/2)

- Delta Connected, the 3rd harmonic emfs around the 3-phase windings are summed, which causes a circulating 3rd harmonic current around the 3-phase windings.
- But the line voltages across any two lines contain no 3rd harmonic component, since they are short circuited by the windings.