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APPLICATION OF PHASE CO GRDINATES REFERENCE FRAME AN FAULT LEVEL CALCULATION PART 1 THEORETICAL ANALYSIS

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Abstract

The analysis of unbalanced system by applying phase co ordinate method is very simple, easy, does not need any lengthly calculations, and can be solved by hand. In this paper the principles of transformers models of different vector groups in phase co-ordinates are developed.

Nomenclatures

Y	nodal admittance matrix.
Z	nodal impedance matrix.
Yd(-)	vector group of star-delta transformer.
Z_{abc}, Y_{abc}	3x3 matrices of impedances and admittances between two sets of 3-phase terminals.
Z_{012} Y_{012}	3x3 matrices of sequence impedances and admittances.
Y_0, Y_1, Y_2	Zero, positive and negative-sequence admittances of a balanced 3-phase element.
E_j	Machine phase e.m.f connected to busbar J.

1. Introduction

The analysis of unbalanced polyphase networks under fault conditions can be developed in terms of the familiar symmetrical components, or in the phase co-ordinate reference frame.

The analysis of unabalnced polyphase networks by means of symmetrical components is achieved by using positive, negative and zero components [3].

The analysis of power system polyphase network under faults can be carried out using the phase co-ordinate representation i.e. phase voltages, currents and impedances using phase admittance or impedance matrices [1], [2].

The Alexandria Electric Power Network (220 kv - 66 KV - 33 KV - 11 Kv) includes power transformers of different vector groups i.e. Yd1, Yd11 YYd5, Yd11d11, YYd11 and YdY.

First we define the vector groups of power transformer (Appendix 1), then how to build the 3-phase admittance matrix of different vector group of Yd Transformers, finally table (1) contains the 3-phase admittance matrix for all possibilities of vector group Yd transformers.

According to the vector group of three-phase ideal transformer the per unit data bases for fault calculation may contain thirty or ninety or one hundred-fifty degree rotations of the base voltage every time a Yd or dY transformer is encounterd. An ideal transformer having a vector group Yd1 necessitates thirty degree rotation of the base voltage in clockwise direction while Yd11 colls for thirty degree rotation in anticlockwise direction, similary Yd3, Yd9, have $\pm$ 90 degree, and Yd5, Yd7 have $\pm$150 degree.

This presents a potential problem in the modeling of simultaneous faults occuring at different sides of Yd transformers modeled in the usual per-unit manner.

Potential problems are described in [5]. A more satisfactory approach to the problem is to use ideal turns-tatio transformers in the collapsing operation as described in [6].

In [7] the v-equivalent is incorporated into the network matrix Z_{Bus} which is then used in the short circuit equation for a line-to-ground fault. A single - line-to-ground fault can occur on either side of the Yd-transformer bank, and the correct values of the currents and voltages at fault and throughout the system can be obtained directly from the solution of the system model by the V-equivalent.

2. Solution in the Phase Co-ordinate Reference Frame [2]

To solve fault analysis by phase co ordinates method we follow these steps:

1. Draw the system in three phase, illustrate the node-numbering sequence used.
2. From the sequence impedences given calculate the 3-phase admittance matrices for all elements from the relationship:

$$Y_{abc} = Y_{phase} = 1/3\ TY_{012}T^{*}$$

$$=1/3 \begin{bmatrix} y_o+y_1+y_2 & y_o+\partial\, y_1+\partial^2 y_2 & y_o+\partial^2 y_1+\partial y_2 \\ y_o+\partial^2 y_1+\partial y_2 & y_o+y_1+y_2 & y_o+\partial y_1+\partial^2 y_2 \\ y_o+\partial y_1+\partial^2 y_2 & y_o+\partial^2 y_1+\partial y_2 & y_o+y_1+y_2 \end{bmatrix}$$

where

Y_{phase} = 3x3 matrix of admittances between two sets of 3-phase terminals

Z_{o12} = 3-phase element symmetrical-component impedance 3x3 matrix

Y_{012} = Z_{012}^{-1}=3- phase element symmetrical-component admittance 3x3 matrix.

$$T = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \partial^2 & \partial \\ 1 & \partial & \partial \end{bmatrix}$$

$\partial = 1 \angle 120$

$= -0.5 + j0.866$

$\partial^2 = -0.5 - j0.866$

y_o, y_1, y_2 = balanced 3-phase element symmetric components components zero, positive and negative sequence admittances.

3. Construct admittance matrix Y for the System.
4. Calculate the inverse Z or Y^{-1}.
5. Assume the type of faults and location of faults.
6. Define the prefault voltages at location of fault.
7. Calculate the fault currents from:

$$\begin{bmatrix} I_p \\ I_q \\ I_r \end{bmatrix} = - \begin{bmatrix} Z_{pp} & Z_{pq} & Z_{qr} \\ Z_{pq} & Z_{qq} & Z_{qr} \\ Z_{rp} & Z_{rq} & Z_{rr} \end{bmatrix}^{-1} \begin{bmatrix} V_p \\ V_q \\ V_r \end{bmatrix}$$

where

v_p, v_q, v_r being the respective prefault busbar-to-earth voltage (magnitude and phase).

Ip,Iq,Ir being the fault currents injected into the busbars p,q,r

The above equations can be represented for any of the following foults:

- 3-phase short circuit occurs on buses p,g,r
- simultaneous fault (2-phase short circuit on buses p,q and single phase on bus r)
- simultaneous fault (2-phase short circuit on buses p,r and single phase on bus q)
- Simultaneous fault (2-phase short circuit on buses r,q and single phase on bus p) .

In general the numbers of rows and columns of above matrix depend on the number of faulted buses and nodes numbering sequence used.

8. Calculate the busbar voltage by superposition of the voltage drops due to the short circuit current Ij acting alone, on to the prefault voltages v_i, thus.

$$V_{ifault} = V_i + \sum_j Z_{ij} I_j \qquad i = 1,2,3, \ldots, n$$

$$j = p,q,r$$

9. Using matrices Y phase for all elements, the currents flowing in the network can be obtained. For the currents in lines between busbars i,j,k and p,q,r, the currents in the lines (i-p), (j-q) and (k-r) are:

$$\begin{bmatrix} I_{i-p} \\ I_{j-q} \\ I_{k-r} \end{bmatrix} = \begin{bmatrix} Y_{ijk-pqr} \end{bmatrix} \begin{bmatrix} V_{i}-V_{p} \\ V_{j}-V_{q} \\ V_{k}-V_{r} \end{bmatrix}$$

Alternatively, using the Y matrix of the system, the currents in each listed branch can be found, and, by suitable addition of these currents, the current in the appropriate line may be determined.

Reference [1] gives the system representation in phase frame of reference, admittance matrices for transmission line, machine, and transformer.

Phase shift in Yd transformer must be taken into consideration when we establish the admittance matrix of power transformer.

The prefault voltages across the terminals of transformer depend on the phase shift in Yd transformer.

To know how to construct Y matrix of Yd transformer we must know the definition of "vector group" [Appendix 1]

3. Transformer representation [1]

3.1 Single phase transformer representation

Consider that an ideal single phase transformer has admittance y in per unit and turns ratio : as shown in Fig (1).

Fig. (2) represents the general symmetrical-lattice equivalent circuit of a single phase transformer where both primary and secondary windings may have either actual or equivalent variable turns and or both [1]

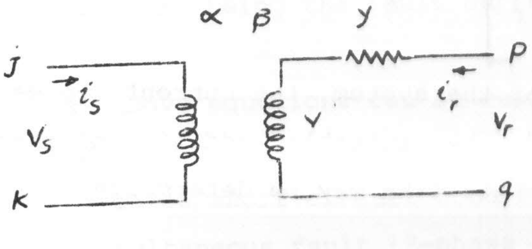


Fig (1)

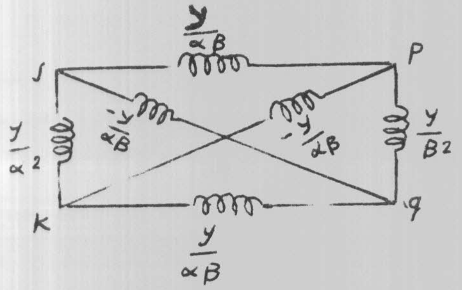


Fig (2)

From the relationships across the ideal transformer (assume $\alpha = 1+t$ and $\beta = 1$)

$$V_s = (1 + t)\, V'$$

$$i_r = -(1 + t) i_s$$

the terminal relationships can be deduced as

$$i_r = y\, V_r - \frac{yV_s}{1+t}$$

$$i_s = \frac{-i_r}{1+t} = \frac{yV_s}{(1+t)^2} - \frac{yV_r}{(1+t)}$$

letting j , k, p, q represent the nodes of the transformer where no earth connection is assumed: then

$$V_s = V_j - V_k \qquad \text{and} \qquad V_r = V_p - V_q$$

and the current injected into each node may for a n-node network be expressed in terms of these nodal voltages by equations of the form.

$$I_j = \sum_m I_{jm} + I_s$$

$$= \sum_m (V_j - V_m)\, y_{im} + \frac{y}{(1+t)^2}(V_j - V_k) - \frac{y}{(1+t)}(Vp - Vq)$$

where the summation is over the set of all nodes m connected to node j excluding the set k,p.q

Expanding the above equation for node j gives

$$I_j = \left(\sum_m y_{im} + \frac{y}{(1+t)^2}\right)V_j - \frac{y}{(1+t)^2}V_k - \frac{y}{(1+t)}V_p + \frac{y}{(1+t)}V_q + \sum_m -y_{im}\, V_m$$

and the same way for values I_k, I_p and I_q.

The phase admittance matrix Y of equivalent circuit in Fig. (2) is given by equation:

Y =

	j	k	p	q
j	y/α^2	$-y/\alpha^2$	$-y/\alpha\beta$	$y/\alpha\beta$
k	$-y/\alpha^2$	y/α^2	$y/\alpha\beta$	$-y/\alpha\beta$
p	$-y/\alpha\beta$	$y/\alpha\beta$	y/β^2	$-y/\beta^2$
q	$y/\alpha\beta$	$-y/\alpha\beta$	$-y/\beta^2$	y/β^2

This single-phase transformer model can be used to assemble equivalent circuits of polyphase transformer banks, some of which are derived in reference [1] but star-delta transformers having different vector groups are treated in the following section.

3.2 Star-Delta transformer equivalent circuit

The 3-phase equivalent circuit model of a star-delta transformer of Yd9 vector group may be assembled as in Figs. (3). (4).

The steps to build Y matrix are:

1. determination of numerical index (hor number) of vector group Yd9 (Fig. (3)).
2. Draw three 1-ph. transformer, parallel windings are taken into consideration (see Fig. (3) AN//bc represent the 1st single transfo. in Fig. (4)).
3. From Fig. (3) write the prefault voltage

V_a lead V_A by 90°

$$V_a = jV_A \qquad V_b = jV_B \qquad V_c = jV_C$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 \\ \partial^2 \\ \partial \end{bmatrix} \text{ p.u.}$$

$$\begin{matrix} V_A \\ V_B \\ V_C \end{matrix} = -j \begin{bmatrix} 1 \\ \partial^2 \\ \partial \end{bmatrix} \text{ P.u}$$

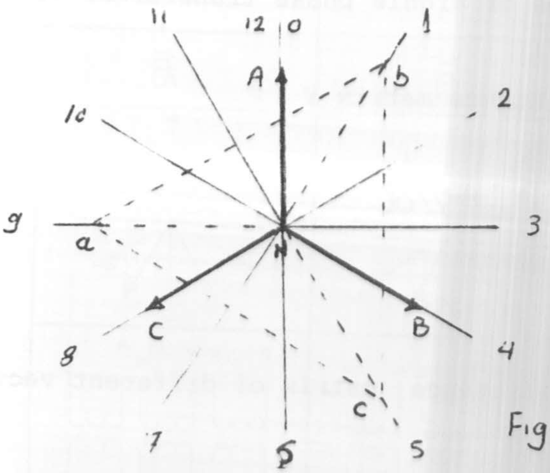


Fig (3)

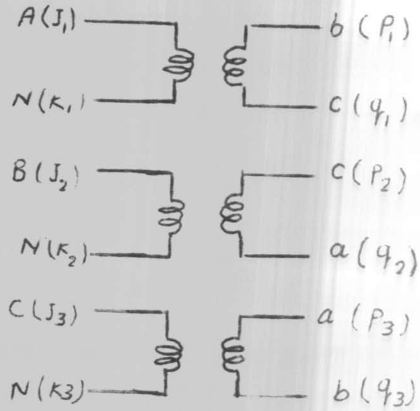


Fig (4)

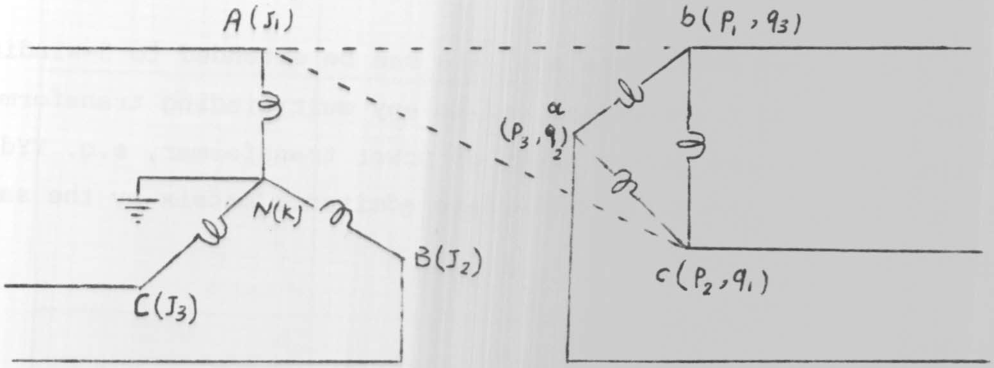


Fig (5)

[Y] =

	A	B	C	a	b	c	N
A	y/α^2				$-y/\alpha\beta$	$y/\alpha\beta$	$-y/\alpha^2$
B		y/α^2		$y/\alpha\beta$		$-y/\alpha\beta$	$-y/\alpha^2$
C			y/α^2	$-y/\alpha\beta$	$y/\alpha\beta$		$-y/\alpha^2$
a		$y/\alpha\beta$	$-y/\alpha\beta$	$2y/\beta^2$	$-y/\beta^2$	$-y/\beta^2$	
b	$-y/\alpha\beta$		$y/\alpha\beta$	$-y/\beta^2$	$2y/\beta^2$	$-y/\beta^2$	
c	$-y/\alpha\beta$	$-y/\alpha\beta$		$-y/\beta^2$	$-y/\beta^2$		
N	$-y/\alpha^2$	$-y/\alpha^2$	$-y/\alpha^2$				$3y/\alpha^2$

4. Draw star-delta windings Fig. (5) as Yd in vector group in Fig. (3)
5. Draw dotted line between nodes gf signle phase transformer (e.g. AN, be transformer in Fig. (5)).
6. Then full the first row if admittance matrix Y

$$Y_{AA}=y/\alpha^2,\ Y_{Ab}=-y/\alpha\beta,\ Y_{AC}=y/\alpha\beta,\ Y_{AN}=-y/\alpha^2$$

Then complete the matrix [Y]

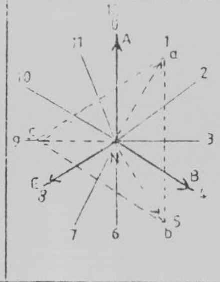
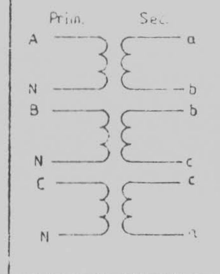
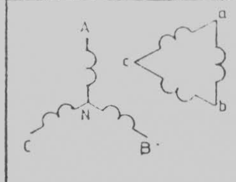
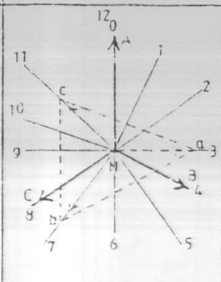
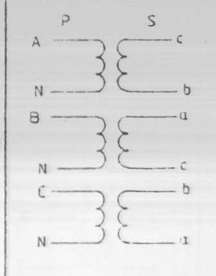
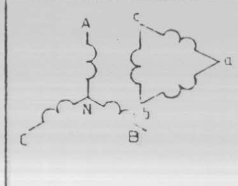
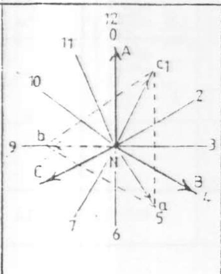
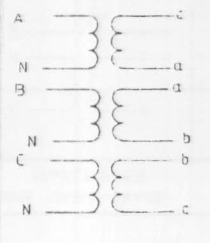
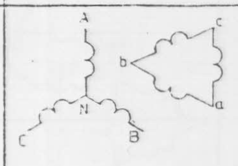
Table (1) represent 3-phase admittance matrix of different vector group of Yd and dY transformers.

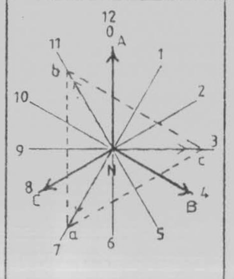
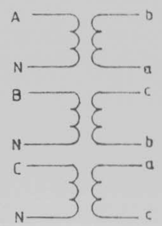
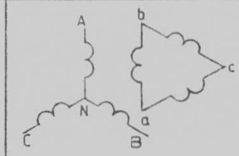
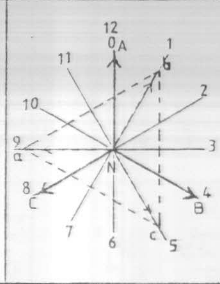
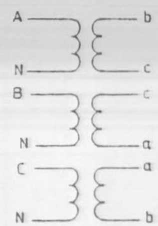
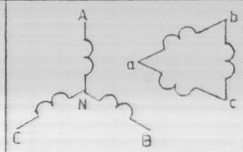
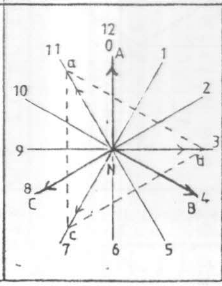
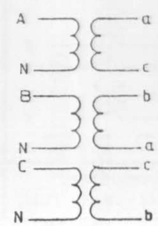
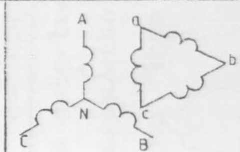
With the same assumption the analysis can be extended to 3-winding transformer and auto transformers and to any multiwinding transformer [1]. First define the vector group of power transformer, e.g. YYd3, Ydlddll or YYdll, then build the3-phase admitance matrix by the same sequence.

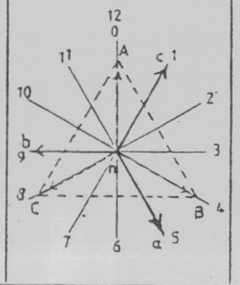
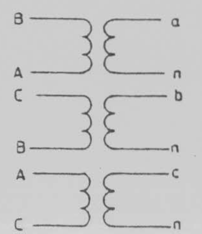
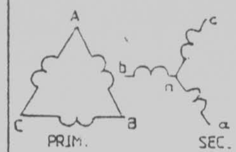
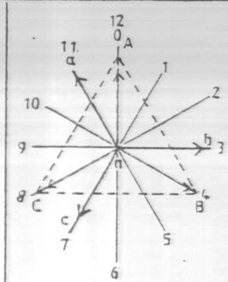
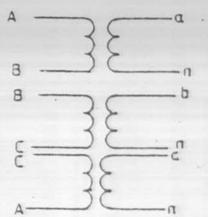
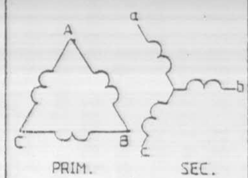
Conclusions

The phase co-ordinate method has been proved to be successful for handling polyphase system under simultaneous faults. Knowledge of the vector groups of power transformers in polyphase networks is necessary in order to construct the nodal admittance matrices, consequently fault level calculations can be obtained.

TABLE (1) 3-PHASE ADMITTANCE MATRICES OF Yd & dY TRANSFORMERS

[illegible]	VECTOR GROUP	VECTOR DIAGRAM	THREE SINGLE-PHASE TRANSFORMER	CONNECTION DIAGRAM	PREFAULT VOLTAGE (FROM VECTOR DIAG.)	ADMITTANCE MATRIX (Y_{3ph})
1	Yd1				V_c lead V_A by 90° $V_c = j V_A$ $V_b = j V_C$ $V_a = j V_B$ $\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}$ p.u $\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = -j \begin{bmatrix} a \\ 1 \\ a^2 \end{bmatrix}$ p.u	$\begin{array}{c\|ccccccc} & A & B & C & a & b & c & N \\ \hline A & Y/\alpha^2 & & & -Y/\alpha\beta & Y/\alpha\beta & & -Y/\alpha^2 \\ B & & Y/\alpha^2 & & & -Y/\alpha\beta & Y/\alpha\beta & -Y/\alpha^2 \\ C & & & Y/\alpha^2 & Y/\alpha\beta & & -Y/\alpha\beta & -Y/\alpha^2 \\ a & -Y/\alpha\beta & & Y/\alpha\beta & 2Y/\beta^2 & -Y/\beta^2 & -Y/\beta^2 & \\ b & Y/\alpha\beta & -Y/\alpha\beta & & -Y/\beta^2 & 2Y/\beta^2 & -Y/\beta^2 & \\ c & & Y/\alpha\beta & -Y/\alpha\beta & -Y/\beta^2 & -Y/\beta^2 & 2Y/\beta^2 & \\ N & -Y/\alpha^2 & -Y/\alpha^2 & -Y/\alpha^2 & & & & 3Y/\alpha^2 \end{array}$
3	Yd3				V_a lag V_A by 90° $V_a = -j V_A$ $V_b = -j V_B$ $V_c = -j V_C$ $\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}$ p.u $\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = j \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}$ p.u	$\begin{array}{c\|ccccccc} & A & B & C & a & b & c & N \\ \hline A & Y/\alpha^2 & & & & Y/\alpha\beta & -Y/\alpha\beta & -Y/\alpha^2 \\ B & & Y/\alpha^2 & & -Y/\alpha\beta & & Y/\alpha\beta & -Y/\alpha^2 \\ C & & & Y/\alpha^2 & Y/\alpha\beta & -Y/\alpha\beta & & -Y/\alpha^2 \\ a & & -Y/\alpha\beta & Y/\alpha\beta & 2Y/\beta^2 & -Y/\beta^2 & -Y/\beta^2 & \\ b & Y/\alpha\beta & & -Y/\alpha\beta & -Y/\beta^2 & 2Y/\beta^2 & -Y/\beta^2 & \\ c & -Y/\alpha\beta & Y/\alpha\beta & & -Y/\beta^2 & -Y/\beta^2 & 2Y/\beta^2 & \\ N & -Y/\alpha^2 & -Y/\alpha^2 & -Y/\alpha^2 & & & & 3Y/\alpha^2 \end{array}$
5	Yd5				V_b lead V_A by 90° $V_b = j V_A$ $V_a = j V_C$ $V_c = j V_B$ $\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}$ p.u $\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = -j \begin{bmatrix} a^2 \\ a \\ 1 \end{bmatrix}$ p.u	$\begin{array}{c\|ccccccc} & A & B & C & a & b & c & N \\ \hline A & & & & Y/\alpha\beta & & -Y/\alpha\beta & -Y/\alpha^2 \\ B & & Y_{ABC} & & -Y/\alpha\beta & Y/\alpha\beta & & -Y/\alpha^2 \\ C & & & & & -Y/\alpha\beta & Y/\alpha\beta & -Y/\alpha^2 \\ a & Y/\alpha\beta & -Y/\alpha\beta & & & & & \\ b & & Y/\alpha\beta & -Y/\alpha\beta & & Y_{abc} & & \\ c & -Y/\alpha\beta & & Y/\alpha\beta & & & & \\ N & -Y/\alpha^2 & -Y/\alpha^2 & -Y/\alpha^2 & & & & 3Y/\alpha^2 \end{array}$

NUMERICAL INDEX	VECTOR GROUP	VECTOR DIAGRAM	THREE SINGLE-PHASE TRANSFORMER	CONNECTION DIAGRAM	PREFAULT VOLTAGE (FROM VECTOR DIAG.)	ADMITTANCE MATRIX (Y_{3ph})
7	Yd7				V_c Lag V_A by 90° $V_c = -j V_A$ $V_a = -j V_B$ $V_b = -j V_C$ $\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}$ p.u $\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = j \begin{bmatrix} a \\ 1 \\ a^2 \end{bmatrix}$ p.u	$\begin{array}{cccccccc} & A & B & C & a & b & c & N \\ A & & & & y/\alpha\beta & -y/\alpha\beta & & -y/\alpha^2 \\ B & & Y_{ABC} & & & y/\alpha\beta & -y/\alpha\beta & -y/\alpha^2 \\ C & & & & -y/\alpha\beta & & y/\alpha\beta & -y/\alpha^2 \\ a & y/\alpha\beta & & -y/\alpha\beta & & & & \\ b & -y/\alpha\beta & y/\alpha\beta & & & Y_{abc} & & \\ c & & -y/\alpha\beta & y/\alpha\beta & & & & \\ N & -y/\alpha^2 & -y/\alpha^2 & -y/\alpha^2 & & & & 3y/\alpha^2 \end{array}$
9	Yd9				V_a Lead V_A by 90° $V_a = j V_A$ $V_b = j V_B$ $V_c = j V_C$ $\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}$ p.u $\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = -j \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}$ p.u	$\begin{array}{cccccccc} & A & B & C & a & b & c & N \\ A & & & & & -y/\alpha\beta & y/\alpha\beta & -y/\alpha^2 \\ B & & Y_{ABC} & & y/\alpha\beta & & -y/\alpha\beta & -y/\alpha^2 \\ C & & & & -y/\alpha\beta & y/\alpha\beta & & -y/\alpha^2 \\ a & & y/\alpha\beta & -y/\alpha\beta & & & & \\ b & -y/\alpha\beta & & y/\alpha\beta & & Y_{abc} & & \\ c & y/\alpha\beta & -y/\alpha\beta & & & & & \\ N & -y/\alpha^2 & -y/\alpha^2 & -y/\alpha^2 & & & & 3y/\alpha^2 \end{array}$
11	Yd11				V_b Lag V_A by 90° $V_b = -j V_A$ $V_c = -j V_B$ $V_a = -j V_C$ $\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}$ p.u $\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = j \begin{bmatrix} a^2 \\ a \\ 1 \end{bmatrix}$ p.u	$\begin{array}{cccccccc} & A & B & C & a & b & c & N \\ A & & & & -y/\alpha\beta & & y/\alpha\beta & -y/\alpha^2 \\ B & & Y_{ABC} & & y/\alpha\beta & -y/\alpha\beta & & -y/\alpha^2 \\ C & & & & & y/\alpha\beta & -y/\alpha\beta & -y/\alpha^2 \\ a & -y/\alpha\beta & y/\alpha\beta & & & & & \\ b & & -y/\alpha\beta & y/\alpha\beta & & Y_{abc} & & \\ c & y/\alpha\beta & & -y/\alpha\beta & & & & \\ N & -y/\alpha^2 & -y/\alpha^2 & -y/\alpha^2 & & & & 3y/\alpha^2 \end{array}$

NUMERICAL INDEX	VECTOR GROUP	VECTOR DIAGRAM	THREE SINGLE-PHASE TRANSFORMER	CONNECTION DIAGRAM	PREFAULT VOLTAGE (FROM VECTOR DIAG.)	ADMITTANCE MATRIX (Y_{3ph})
5	DY5				V_b lead V_A by 90° $V_b = jV_A$ $V_c = jV_B$ $V_a = jV_C$ $\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}$ p.u $\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = -j \begin{bmatrix} a^2 \\ a \\ 1 \end{bmatrix}$ p.u	Matrix 1 below
11	DY11				V_b lag V_A by 90° $V_b = -jV_A$ $V_c = -jV_B$ $V_a = -jV_C$ $\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}$ p.u $\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = j \begin{bmatrix} a^2 \\ a \\ 1 \end{bmatrix}$ p.u	Matrix 2 below

	A	B	C	a	b	c	N
A	$2Y/\alpha^2$	$-Y/\alpha^2$	$-Y/\alpha^2$	$Y/\alpha\beta$		$-Y/\alpha\beta$	
B	$-Y/\alpha^2$	$2Y/\alpha^2$	$-Y/\alpha^2$	$-Y/\alpha\beta$	$Y/\alpha\beta$		
C	$-Y/\alpha^2$	$-Y/\alpha^2$	$2Y/\alpha^2$		$-Y/\alpha\beta$	$Y/\alpha\beta$	
a	$Y/\alpha\beta$	$-Y/\alpha\beta$		Y/β^2			$-Y/\beta^2$
b		$Y/\alpha\beta$	$-Y/\alpha\beta$		Y/β^2		$-Y/\beta^2$
c	$-Y/\alpha\beta$		$Y/\alpha\beta$			Y/β^2	$-Y/\beta^2$
N				$-Y/\beta^2$	$-Y/\beta^2$	$-Y/\beta^2$	$3Y/\beta^2$

	A	B	C	a	b	c	N
A	$2Y/\alpha^2$	$-Y/\alpha^2$	$-Y/\alpha^2$	$-Y/\alpha\beta$		$Y/\alpha\beta$	
B	$-Y/\alpha^2$	$2Y/\alpha^2$	$-Y/\alpha^2$	$Y/\alpha\beta$	$-Y/\alpha\beta$		
C	$-Y/\alpha^2$	$-Y/\alpha^2$	$2Y/\alpha^2$		$Y/\alpha\beta$	$-Y/\alpha\beta$	
a	$-Y/\alpha\beta$	$Y/\alpha\beta$		Y/β^2			$-Y/\beta^2$
b		$-Y/\alpha\beta$	$Y/\alpha\beta$		Y/β^2		$-Y/\beta^2$
c	$Y/\alpha\beta$		$-Y/\alpha\beta$			Y/β^2	$-Y/\beta^2$
N				$-Y/\beta^2$	$-Y/\beta^2$	$-Y/\beta^2$	$3Y/\beta^2$

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[4] Stevenson, W.D. "Elements of power system analysis" (Mc Graw-Hill, 1955).

[5] Fernando L. Alvarado, sao Khai Mong, and Mark C. Enns "A fault program with macros, monitors, and direct compensation in mutual group" IEEE Trafsactions on Power Apparatus and system-vol. PAS-104, No.5, May 1985. pp 1109-1120.

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[9] A.O.M. Saleh and M.A. Laughton "Phase-coordifate load flow and fault analysis program" vol. 2 No. 4 October 1980, 0142-0615/ 040193-08 502.00 1980 IPC Business Press. pp 193-198.

[10] Siemens "Electrical Engineering Handbook" 1986.

Appendix 1

Vector groups [10]

The vector group shows the connection of the phase of twg windings of a transformer and the numericad index (hour number) for the displacement of the vectors of the two star voltages.

Phase displacement is expressed as the clock hour number and is designated by symbols O,1,2,...

The numerical index shows by what multiple of 30° ($360^{\circ}/12$) the low voltage vector lags (anti-clgckwise rotation of vectors) behind the high-voltage vector with the corresponding terminal designation Fig. (A-1) terminals a,b,c on the low voltage side are corresponding to terminals A,B,C on the high voltage side.

A 3-phase transformer, whose windings may be connected in star or delta or zigzag, may be classified into twelve phase displacement groups with the phase displacement between the vectors of the line e.m.f. varying from zero to 360° in steps of 30°, which corresponds to twelve clock hour Fig.(A-1). As an example a transformer with vector group symbol Tyo will mean a transformer having both the windings as star connected and with zero degree phase displacement Fig. (A-2)).

A transformer with vector group symbol Yd5 will mean a transformer having a high voltage in star (Y) connection, low voltage in delta (d) connection, phase angle between two star voltage is 150°, numerical index $150^{\circ}/30^{\circ} = 5$ Fig.(A-3).

Fig. (A-4) represents the vector diagram of YZ11.

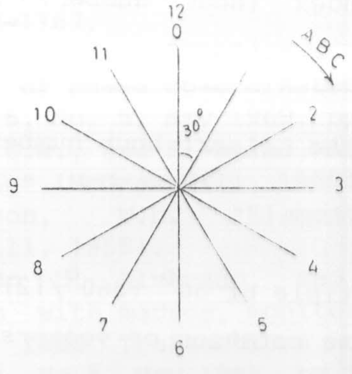

Fig. (A-1)

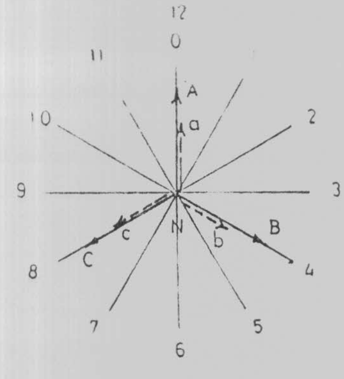

Fig.(A-2) Vector Group Yyo.

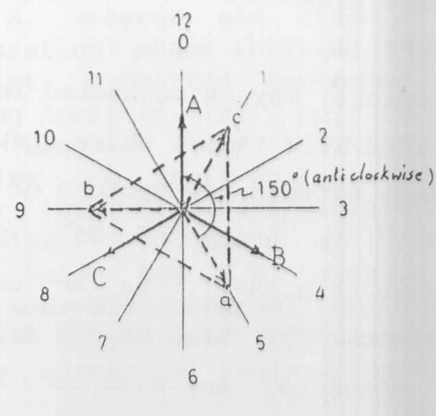

Fig. (A-3) Vector group Yd5

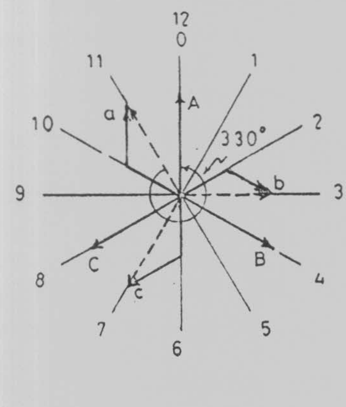

Fig. (A-4) Vector group YZ11