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Faults Analysis Theory and Schemes of Three-Phase Power Systems

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Abstract— In this paper the analysis of unsymmetrical transversal faults that can occur on a three-phase networks is presented by means of Fortescue Symmetrical Component Transformation (SCT). The various types of fault are analyzed and the connections between sequence networks and the related sequence equations are used to evaluate the phase fault currents. The obtained results are compared with those obtained for three-phase and six-phase systems. The related considerations are also extended to the generic n-phase systems.

***Keywords*—**Fortesque Theorem, Symmetrical Fault, Unsymmetrical Fault, Sequence Network

I. INTRODUCTION

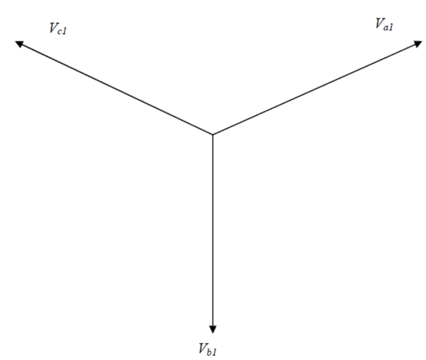
The analysis of poly-phase networks gives, nowadays, a particularly importance to the three phase case [1]. In fact, for a long time, the knowledge of all the advantages coming increasing the number of phases n - related to land occupation, the energetic aspect, the power limit, and reliability - has started a series of theoretical and experimental researches with the aim of quantifying the advantages derived from an increase to n phases compared to the classical three phase system. These researches have initially investigated, with reference to the transmission issue, the twelve- and six phase configurations thanks to their easy applicability, by simple modification of the connections of the windings of a three-phase traditional transformer [4]-[5]. In these cases, the transpositions introduce high complexity as well as high costs. In an analogous way, the high number of fault configurations has highlighted the difficulty in developing fault analysis and protection design. Under these circumstances, the twelve- and six-phase transmissions did not evolve towards concrete application, except in a few particular cases. In particular, the various types of transversal fault that can occur in the single-phase-to-ground fault, the two phase-to-ground fault, the two-phase fault, the three-phase-to ground fault, and the three-phase fault – are analyzed. So much attention will be debit to the methodological aspects and to the comparison with three-phase and six-phase cases.

In a three-phase system, the possible types of faults are in number of five, compared with seven in the case of four-phase systems but eleven of six-phase. The fault is firstly divided into two parts

I. Open circuit fault II. Short circuit fault
Short circuit fault are two types
a) Symmetrical Fault
b) Unsymmetrical fault
Symmetrical fault are two types:
1.Three phase fault
2.Three phase to ground fault
Unsymmetrical faults are three types:
1.Single phase to ground fault
2.Two phase to ground fault
3.Two phase fault

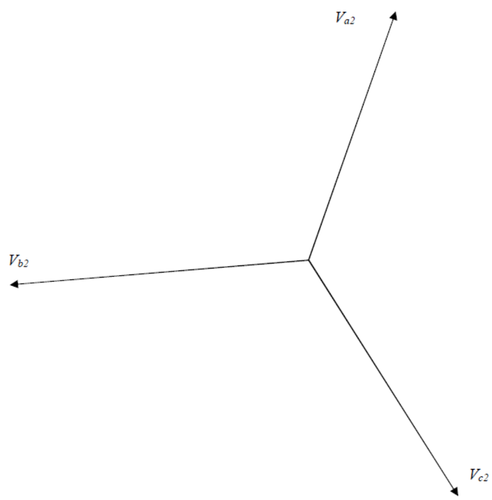
II. FORTESCUE THEOREM

Any set of unbalanced 3-phase voltages (or current) can be transformed into 3 balanced sets. These are:
A **positive sequence** set of three symmetrical voltages (i.e. all numerically equal and all displaced from each other by 120^0) having the same phase sequence *abc* as the original set and denoted by Va1,Vb1,Vc1 as shown in the fig(i).



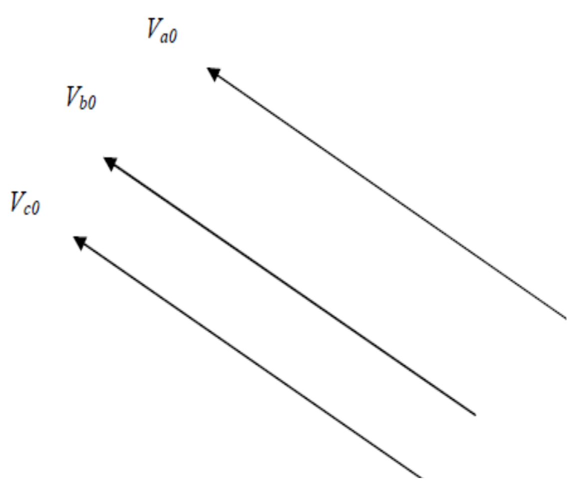
Fig(i): Positive Sequence

A negative sequence set of three symmetrical voltages having the phase sequence opposite to that of the original set and denoted by Va2, Vb2, Vc2 as shown in fig(ii).



Fig(ii): Negative Sequence

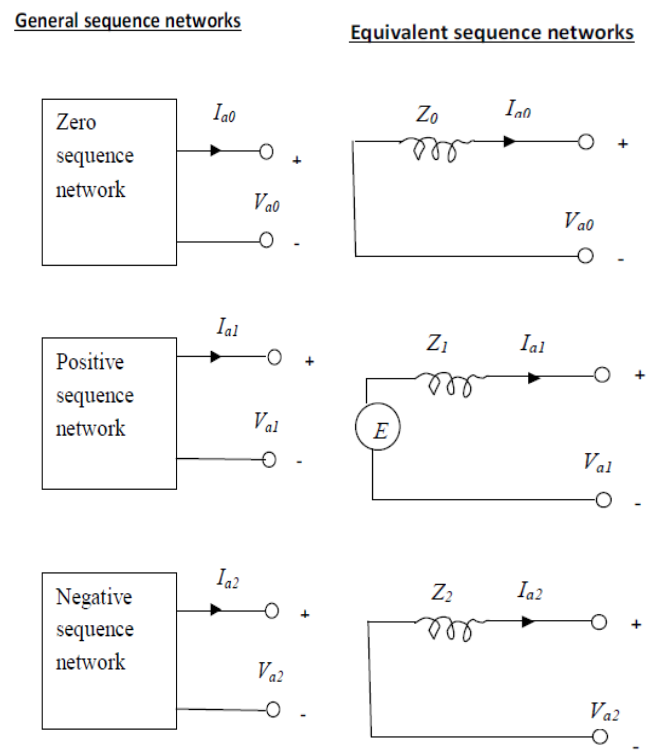
A zero sequence set of three voltages, all equal in magnitude and in phase with each other and denoted by Va0, Vb0, Vc0 as shown in fig (iii) below:



Fig(iii): Zero Sequence

The positive, negative and zero sequence sets above are known as symmetrical components.
Thus we have,

Va = Va1 +Va2 +Va0
Vb = Vb1 +Vb2 +Vb0
Vc = Vc1 + Vc2 +Vc0



Fig(iv): Phase sequence network

Let an operator '**a**' be defined such that **a** = 120^0. Any phasor multiplied by '**a**' undergoes a counter clockwise rotation of 120^0 without any change in the magnitude. Further,

$$\mathbf{a} = 1 \angle 120^\circ$$

$$a^2 = 1 \angle 240^\circ$$

$$a^3 = 1 \angle 360^\circ$$

$$\text{also } 1 + a + a^2 = 0$$

$$\begin{bmatrix} \bar{I}_a \\ \bar{I}_b \\ \bar{I}_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \mathbf{a}^2 & \mathbf{a} \\ 1 & \mathbf{a} & \mathbf{a}^2 \end{bmatrix} \begin{bmatrix} \bar{I}_{a0} \\ \bar{I}_{a1} \\ \bar{I}_{a2} \end{bmatrix}$$

III.SYMMETRICAL FAULTS

A three phase **symmetrical fault** is caused by application of three equal fault impedances $\bar{Z}_f$ to the three phases, as shown in Fig. If $Z_f = 0$ the fault is called a solid or a bolted fault. These faults can be of two types:

(a) line to line to line to ground fault (**LLLG** fault)

(b) line to line to line fault (**LLL** fault).

Since the three phases are equally affected, the system remains balanced. That is why, this fault is called a symmetrical or a balanced fault and the fault analysis is done on per phase basis. The behaviour of **LLLG** fault and **LLL** fault is identical due to the balanced nature of the fault. This is a very severe fault that can occur in a system and if $\bar{Z}_f = 0$, this is usually the most severe fault that can occur in a system. Fortunately, such faults occur infrequently and only about 5% of the system faults are three phase faults.

IV. UNSYMMETRICAL FAULT

Faults in which the balanced state of the network is disturbed are called **unsymmetrical or unbalanced faults**. The most common type of unbalanced fault in a system is a single line to ground fault (**LG fault**). Almost 60 to 75% of faults in a system are **LG faults**. The other types of unbalanced faults are line to line faults (**LL faults**) and double line to ground faults (**LLG faults**). About 15 to 25% faults are **LLG faults** and 5 to 15% are **LL faults**.

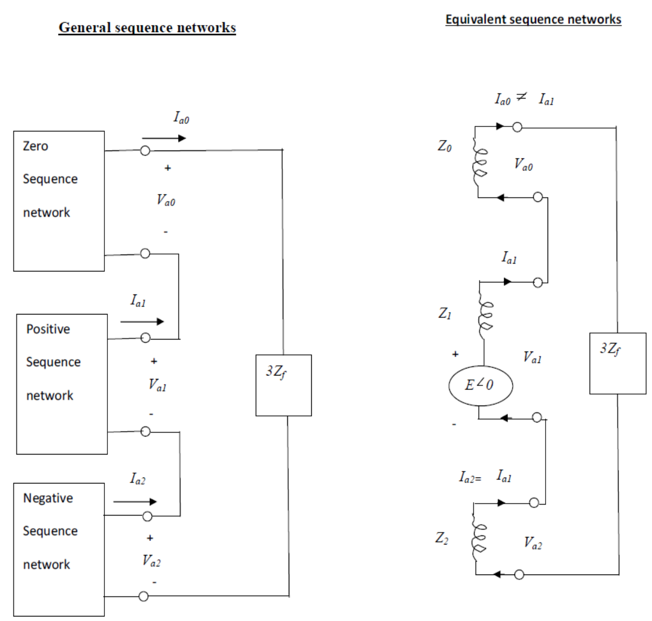
(i). Single line to Ground Fault (L-G Fault)

Typically, Z_f is set to zero in all fault studies. I include Z_f in the analysis for the sake of generality. The terminal conditions at the fault point give the following equations:

$I_b = 0$

$I_c = 0$

$V_a = I_a Z_f$



(ii). LINE TO LINE FAULT (L-L FAULT)

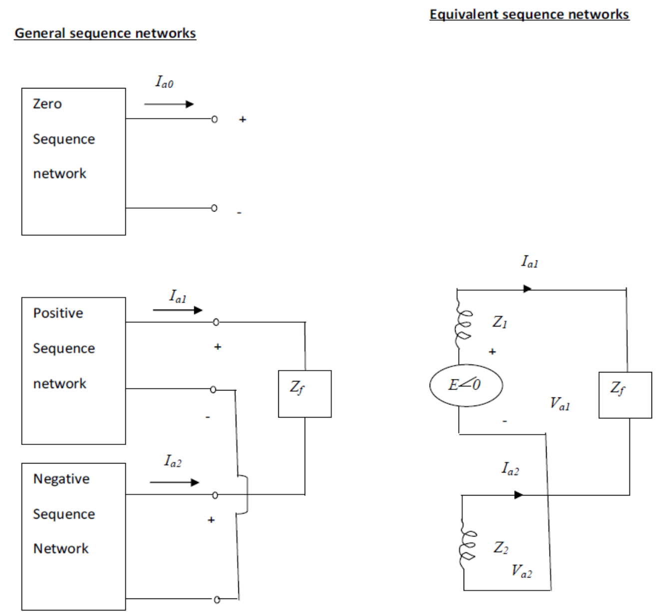
The terminal conditions at the fault point give the following equations,

$I_a = 0$

$I_b = -I_c$

$V_b = V_c + Z_f I_b$

$I_b = -I_c = I_{a0} + a^2 I_{a1} + a I_{a2}$

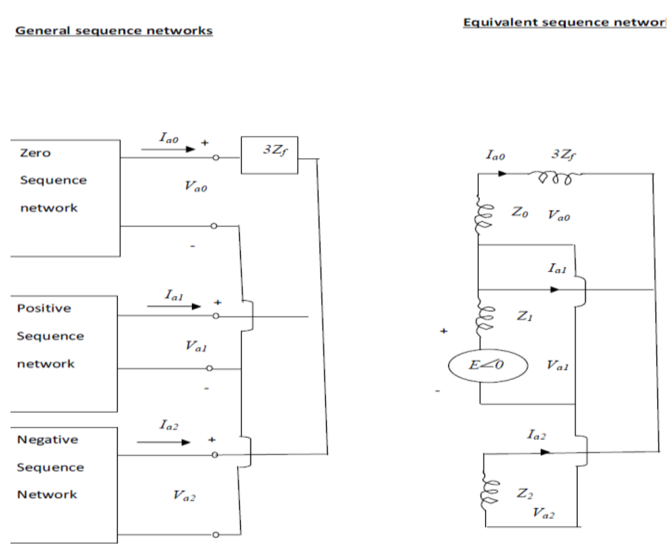


(iii)LINE TO LINE TO GROUND FAULT (L-L-G FAULT)

The terminal conditions at the fault point give the following equations,

$I_a = 0$

$V_b = V_c = (I_b + I_c) Z_f$



V. CONCLUSIONS

The general theory and the methodological approach to study unsymmetrical faults in three-phase symmetrical systems are presented. Furthermore, thanks to the general proprieties of the Fortescue transformation applied to multi-phase networks, the general rules for the sequence networks connection, for every types of fault that can occur on a multi-phase system, are presented. Further research work on the subject could consult on the generation to the dynamical condition and analysis of simultaneous faults.

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