A Detailed Comparative Study of ABC and Symmetrical Component Classification for Fault Analysis

Muhammad Saufi Kamarudin, Shamsul Aizam Zulkifli, Erwan Sulaiman, Nur Hidayah Mokhtar

Abstract -- **This paper is study about symmetrical and unsymmetrical faults. Symmetrical fault which is also known as balanced fault while unsymmetrical fault is representing an unbalanced fault. Generally this paper is focused on modeling the 3 busbar network systems which concerns numerical studies of IEEE 3 busbar standard system testing. The +5% of industrial network will be considered in order to demonstrate the fault location in every different scenario of balanced and unbalanced condition. Moreover, the system is modeled in Simulink Matlab software then the simulation results are compared with manual calculation. The analysis consists of ABC Classification. Therefore, at the end of this paper a network will be development and study the characteristics of ABC and symmetrical sequences with the simulation data available.**

Keywords **: ABC, balanced fault, symmetrical, unbalanced fault**

I. INTRODUCTION

FAULT studies form an important part of power system analysis. Faults on power systems are divided into two components which are balanced faults and unbalanced faults. There are different types of unbalanced faults which are single line-to-ground fault, line-to-line fault, and double line-to-ground fault. The data available are used for proper relay setting and phase relay, while the line-to-ground fault is used for ground relay [2,11,14]. For the purpose of fault studies, the generator behavior can be divided into three periods which are subtransient period, lasting only for the first few cycles, the transient period, covering a relatively longer time, and finally, the steady state period. Balanced fault is defined as the simultaneous short circuit across all three phases. It occurs infrequently, but it is the most severe type of fault encountered. Because the network is balanced, it is solved on a per- phase basis. The other two phases carry identical currents except for the phase shift. It is different with unbalanced fault which is also known as unsymmetrical fault, which contains of three types of faults where examples are[1]:

- Line-to-line - a short circuit between lines, caused by ionization of air, or when lines come into physical contact, for example due to a broken insulator [2].
- Line-to-ground - a short circuit between one line and ground, very often caused by physical contact, for example due to lightning or other storm damage [2].

Traditionally, these faults can be isolated by using relays and circuit breakers which are used to separate the network from the high current. In fault analysis, value of this current is calculated for the different types of faults at various locations in the system. There is a simple worked to measure a fault when it happens in a small circuit rather than in a network [2]. All the techniques embody an accurate location by measuring only one local end data. The method provides an automatic determination of fault location, rather than requires engineer to specify them.

II. TECHNIQUES APPROACH

A. The ABC Classification

The ABC classification distinguishes between seven types of three phase unbalanced voltage sag. Expressions for the complex voltages for these seven types are given in Table I. The complex prefault voltage in phase a is indicated by E_1. The voltage in the faulted phase or between the faulted phases is indicated by $\boldsymbol{V*}$ while U$_a$, U$_b$, U$_c$ are the phase voltage.

TABLE I
SEVEN TYPES OF THREE PHASE UNBALANCED VOLTAGE SAG ACCORDING TO ABC CLASSIFICATION

	Voltage Phasors		**Voltage Phasors**
A	$U_a = V*$ $U_b = -\frac{1}{2}V* - \frac{1}{2}jV*\sqrt{3}$ $U_c = -\frac{1}{2}V* + \frac{1}{2}jV*\sqrt{3}$	**E**	$U_a = E_1$ $U_b = -\frac{1}{2}V* - \frac{1}{2}jV*\sqrt{3}$ $U_c = -\frac{1}{2}V* + \frac{1}{2}jV*\sqrt{3}$
B	$U_a = V*$ $U_b = -\frac{1}{2}E_1 - \frac{1}{2}jE_1\sqrt{3}$ $U_c = -\frac{1}{2}E_1 + \frac{1}{2}jE_1\sqrt{3}$	**F**	$U_a = V*$ $U_b = -\frac{1}{2}V* - \left(\frac{1}{3}E_1 + \frac{1}{6}V*\right)j\sqrt{3}$ $U_c = -\frac{1}{2}V* + \left(\frac{1}{3}E_1 + \frac{1}{6}V*\right)j\sqrt{3}$
C	$U_a = E_1$ $U_b = -\frac{1}{2}E_1 - \frac{1}{2}jV*\sqrt{3}$ $U_c = -\frac{1}{2}E_1 + \frac{1}{2}jV*\sqrt{3}$	**G**	$U_a = \frac{2}{3}E_1 + \frac{1}{3}V*$ $U_b = -\left(\frac{1}{3}E_1 + \frac{1}{6}V*\right) - \frac{1}{2}jV*\sqrt{3}$ $U_c = -\left(\frac{1}{3}E_1 + \frac{1}{6}V*\right) + \frac{1}{2}jV*\sqrt{3}$

D	$U_a = V^*, U_b = -\frac{1}{2}V^* - \frac{1}{2}jE_1\sqrt{3}$, $U_c = -\frac{1}{2}V^* + \frac{1}{2}jE_1\sqrt{3}$

Figure 1 to 7 show the graph for each type indicate by the Table 1

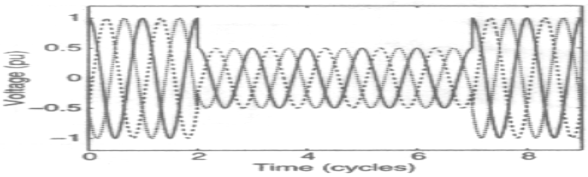


Fig. 1. Voltage sag type A: voltage waveform half-cycle [13]

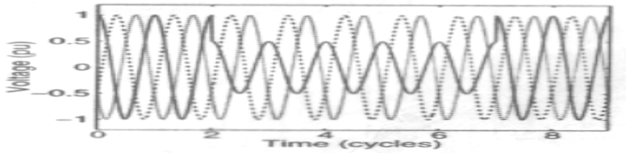


Fig. 2. Voltage sag type B: voltage waveform (left) half-cycle [13]

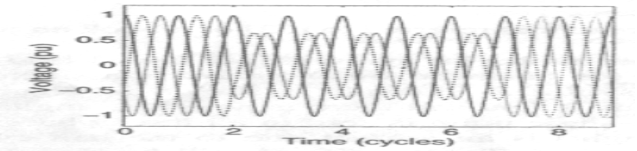


Fig. 3. Voltage sag type C: voltage waveform (left) half-cycle [13]

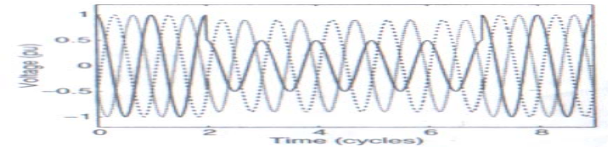


Fig. 4. Voltage sag type D: voltage waveform (left) half-cycle [13]

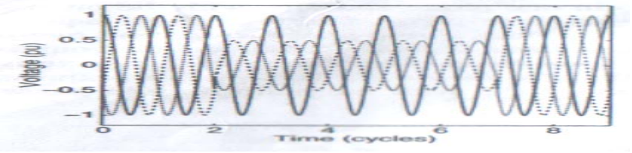


Fig. 5. Voltage sag type E: voltage waveform (left) half-cycle [13]

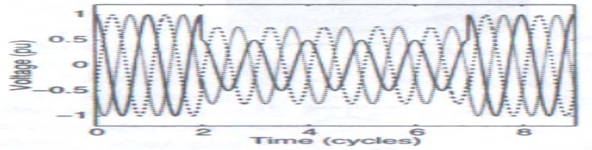


Fig. 6. Voltage sag type F: voltage waveform (left) half-cycle [13]

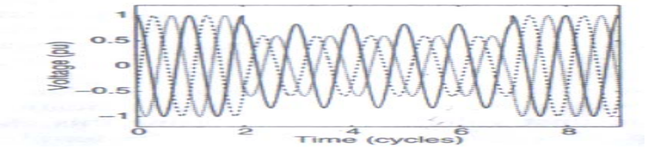


Fig. 7. Voltage sag type G: voltage waveform (left) half-cycle [13]

B. The Symmetrical Component Classification

The symmetrical-component classification does not suffer from the same limitation as the ABC Classification. The symmetrical-component classification distinguishes between dips with the main voltage drop in one phase and dips with the main voltage drop between two phases. Fig 8 shows the voltage divider model for three-phase unbalanced voltage sag.

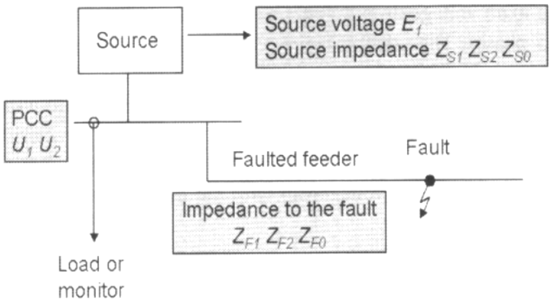


Fig. 8 . Voltage divider model for three-phase unbalanced voltage sag

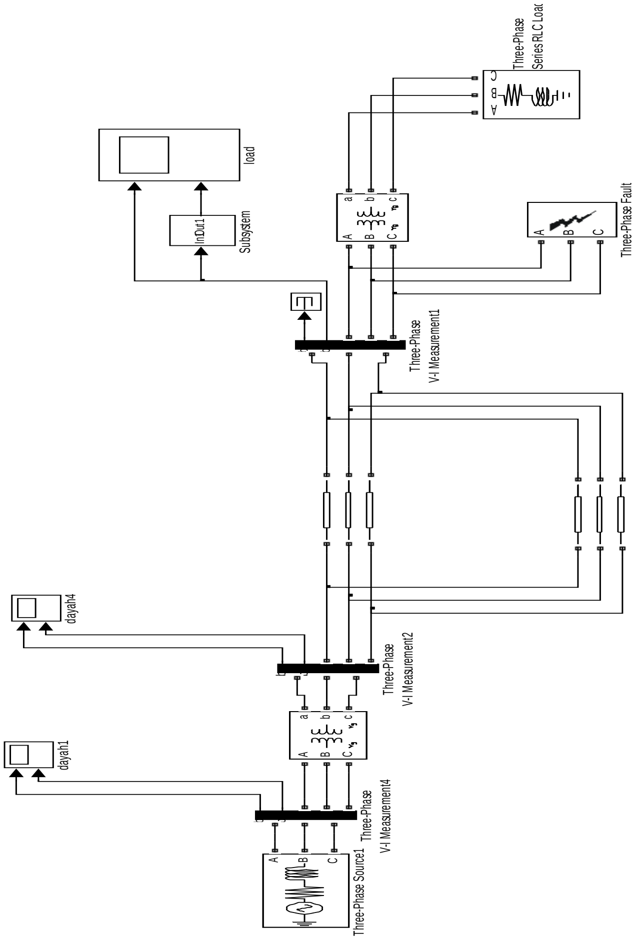


Fig 9: The simulink model of the 3 busbar network system

Table II. System Data

System Quantities	Values
Source Voltage	11 kV
System frequency	50 Hz
Source impedance	1+8jΩ
Load power	666.5kW+ 1154kVarj
Fault impedance	1000+0.1jΩ
Fault time	0.5s
Rated transformer	11/33kV
Transmission Lines	L= 0.766Ω/km R= 0.5613Ω/km

The process flow in determining the faults sequential by using both methods is shown in Fig. 10

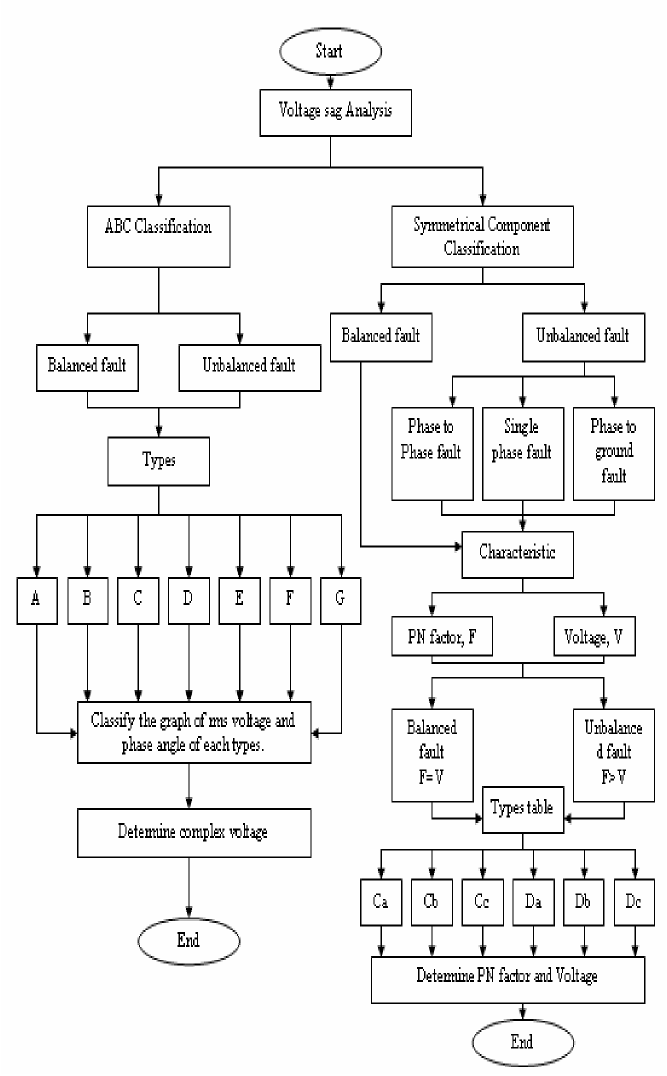


Fig.10. Methodology process.

The simulation of the network in fault condition was conducted based on balanced and unbalanced faults where the simulink model network system of the 3 busbar is shown in Fig 9. The data used in the simulation shown in Table II. In single line ground fault analysis, phase A is the faulted phase shown in Fig 12 and three phase fault at Fig 11.

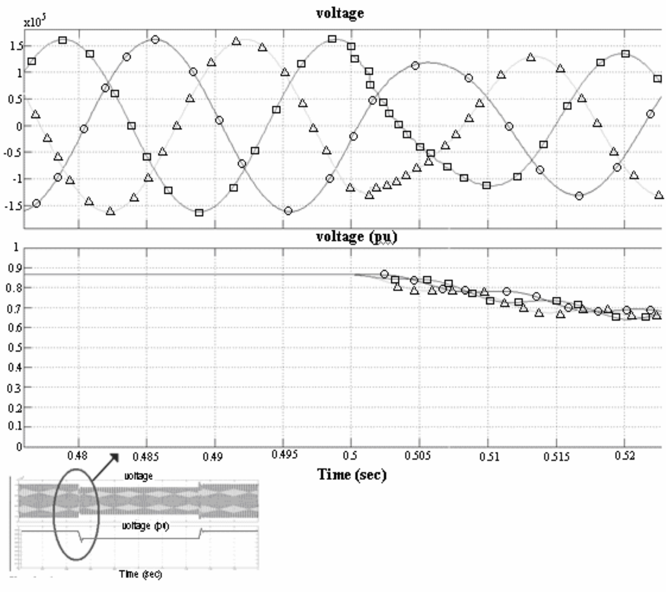


Fig. 11. Balanced three phase fault

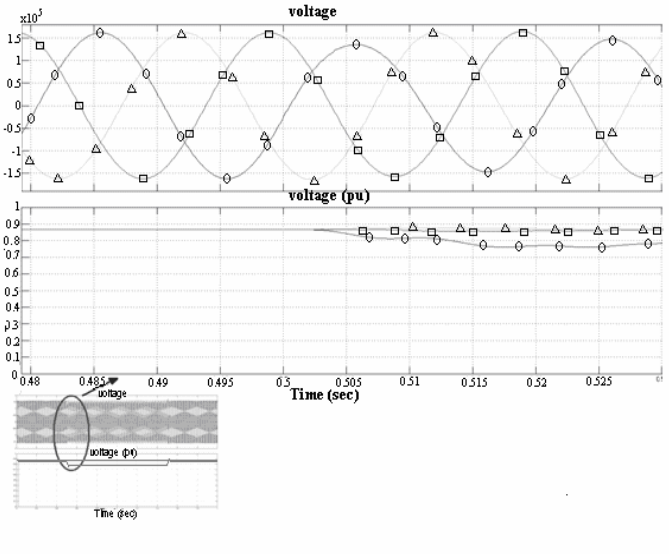


Fig. 12. Single line-to-ground fault

III RESULTS

A. *Balanced Three Phase Fault*

ABC Clasification

In order to analyze by using ABC classification method, the value of voltage in the faulted phase at the PCC (point of common coupling between the customer and the user must be calculated using Eq. (1)

$$V^* = \left(1 - \frac{Z_{S0}+Z_{S1}+Z_{S2}}{Z_{S1}+Z_{S2}+Z_{S0}+Z_{F0}+Z_{F1}+Z_{F2}}\right) E_1 \qquad (1)$$

V^* = 118.724kV

Voltage sag for each of phases of balanced three phase fault in found and compared with Fig. 11

$$U_a = V^*$$
$$U_b = -\frac{1}{2}V^* - \frac{1}{2}jV^*\sqrt{3} \qquad (2)$$
$$U_c = -\frac{1}{2}V^* + \frac{1}{2}jV^*\sqrt{3}$$

Therefore

$$U_a = 118.724kV \qquad U_{apeak} = 167.902kV, \quad U_b = -\frac{1}{2}V^* - \frac{1}{2}jV^*\sqrt{3}, \quad U_b = 118.724k\angle -120^0$$

$$U_{bpeak} = 167.901kV$$

$$U_c = -\frac{1}{2}V^* + \frac{1}{2}jV^*\sqrt{3}$$
$$U_c = 118.724k\angle 120^0$$
$$U_{cpeak} = 167.901kV$$

Symmetrical Components

Same as the data obtained in Fig 11. The result has been compared with this simulation result.

$$V = \frac{Z_{F1}}{Z_{S1} + Z_{F1}} E_1 \qquad (3)$$

$V = 117.531\text{kV}$

PN factor for balanced three phase fault is $F = E_1 = 132kV$

Voltage sag for each of phase can be calculated using Eq (2)

$$U_a = F$$
$$U_b = -\frac{1}{2}F - \frac{1}{2}jV\sqrt{3}$$
$$U_c = -\frac{1}{2}F + \frac{1}{2}jV\sqrt{3}$$

Therefore

$$U_a = 132\text{kV}$$
$$U_{rms} = \frac{U_{peak}}{\sqrt{2}}$$
$$U_{apeak} = 186.676kV$$
$$U_b = -\frac{1}{2}V - \frac{1}{2}jF\sqrt{3}$$
$$U_b = 121310\angle -122.96^0$$
$$U_{bpeak} = 171.558kV$$
$$U_c = -\frac{1}{2}V + \frac{1}{2}jF\sqrt{3}$$
$$U_c = 121310\angle 122.96^0$$
$$U_{cpeak} = 171.558kV$$

B. Single Line-to-Ground Fault

ABC Classification

Voltage sag for phase A, phase B and phase C of single phase-to-ground fault in this technique is compared with Fig. 12 where

$$U_a = V^*$$
$$U_a = 118.724kV$$
$$U_{apeak} = 167.902kV$$
$$U_b = -\frac{1}{2}V^* - \frac{1}{2}jE_1\sqrt{3}$$
$$U_b = 128.8k\angle -117.4^0$$
$$U_{bpeak} = 182.151kV$$

$$U_c = -\frac{1}{2}V^* + \frac{1}{2}jE_1\sqrt{3}$$
$$U_c = 128.8k\angle -117.4^0$$
$$U_{cpeak} = 182.151kV$$

Symmetrical Components

The characteristic voltage of single phase-to-ground fault in Fig. 12 can be describe by Eq (4)

$$V = U_1 + U_2 = \left(1 - \frac{Z_{S1} + Z_{S2}}{Z_{S1} + Z_{S2} + Z_{S0} + Z_{F0} + Z_{F1} + Z_{F2}}\right) E_1 \qquad (4)$$
$$U_1 + U_2 = 123.149\text{kV}$$

PN factor for single phase-to-ground fault is

$$F = U_1 - U_2 = \left(1 - \frac{Z_{S1} - Z_{S2}}{Z_{S1} + Z_{S2} + Z_{S0} + Z_{F0} + Z_{F1} + Z_{F2}}\right) E_1 \qquad (5)$$
$$F = U_1 - U_2 = 132\text{kV}$$

Voltage sag for phase A, phase B and phase C of single phase-to-ground fault have been calculated and compare to Fig. 11

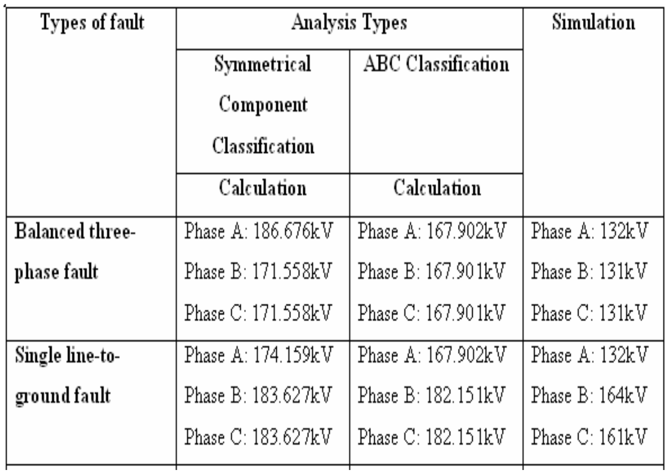
Therefore

$$U_a = 123.149kV$$
$$U_{apeak} = 174.159kV$$
$$U_b = -\frac{1}{2}V - \frac{1}{2}jF\sqrt{3}$$
$$U_b = 129843.83\angle -118.3086^0V$$
$$U_{bpeak} = 183.627kV$$
$$U_c = -\frac{1}{2}V + \frac{1}{2}jF\sqrt{3}$$
$$U_b = 129843.83\angle 118.3086^0V$$
$$U_{cpeak} = 183.627kV$$

IV. CONCLUSION

Systematic approach covers all cases and is therefore preferable above the ABC classification, which is a more intuitive approach [1-9,11,13,14]. The symmetrical component classification does not suffer from the same limitation as the ABC classification. The symmetrical component classification distinguishes between dips with the main voltage drop between two phases. This paper only considered in findings of the two other characteristics which are characteristic voltage *V* and the *PN* factor F. The value of fault impedance is set to $1000\,\Omega$ in order to get better picture of the voltage sag itself. The bigger value of fault impedance, the nearly value will be gained when compared to the theory. Therefore, the better choice is to use symmetrical component analysis in order to gain the types of fault in network analysis. The comparison study is shown in Table III.

TABLE III
COMPARISON BETWEEN CALCULATION AND SIMULATION VALUE OF SYMMETRICAL COMPONENT CLASSIFICATION AND ABC CLASSIFICATION ANALYSIS



Types of fault	Analysis Types		Simulation
	Symmetrical Component Classification	ABC Classification	
	Calculation	Calculation	
Balanced three-phase fault	Phase A: 186.676kV Phase B: 171.558kV Phase C: 171.558kV	Phase A: 167.902kV Phase B: 167.901kV Phase C: 167.901kV	Phase A: 132kV Phase B: 131kV Phase C: 131kV
Single line-to-ground fault	Phase A: 174.159kV Phase B: 183.627kV Phase C: 183.627kV	Phase A: 167.902kV Phase B: 182.151kV Phase C: 182.151kV	Phase A: 132kV Phase B: 164kV Phase C: 161kV

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VII. BIOGRAPHIES

Muhammad Saufi Kamarudin obtained his B.Eng degree in Electrical$ Engineering and M Eng at UTM, Malaysia in 2003 and 2005, repectively. Currently he is a lecturer and researcher in Universiti Tun Hussein Onn Malaysia. His interest areas are high voltage engineering and electric motors.

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