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New method for voltage sag classification on power system network

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ABSTRACT

Voltage sags, is one of the most common power quality disturbances, that cause misoperation of an electronic and electric sensitive load such as computers, power electronic devices and programming logic controllers (PLCs), …. etc.

This research paper presents new method for the classification of voltage sag types by using phase-impedance. The network simulation and protection coordination software (SIMP) was included in the CD with Digsi software introduced in this research paper to calculate the impedance (phase-to-phase and phase-to-earth) in any network points for normal mode and fault condition as well as for different types of network faults and network structures.

This method is based on a comparison between the phase impedance in the load mode and the phase impedance in the electrical fault mode and gives more accurate results in classifying the voltage sag.

Keywords: Voltage sags, power quality, phase-impedance, simulation and protection coordination software (SIMP), Digsi software.

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طريقة جديدة لتصنيف الانحدار في الجهد على نظام الشبكة الكهربائية

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الملخص

الانحدار في الجهد أكثر الاضطرابات شيوعا في جودة القدرة الكهربية مما يسبب اضطرابات في تشغيل الأحمال الكهربية والالكترونية الحساسة مثل الكمبيوتر وأجهزة القدرة الكهربية والالكترونية وأجهزة التحكم الالكترونية و...... ،الخ.

هده الورقة البحثية تعرض طريقة جديدة لتصنيف أنواع الانحدار في الجهد بواسطة طور المعاوقة الكهربية، وذلك باستخدام برنامج محاكاة الشبكة وتنسيق الحماية (SIMP) الموضح في هذه الورقة البحثية لحساب المعاوقة الكهربية (طور مع طور وكذلك طور مع الأرض) عند أي نقطة من الشبكة الكهربية قبل حدوث الخطأ وعند حدوث الخطأ.

حيث تعتمد هذه الطريقة على المقارنة بين معاوقة الطور في وضع الحمل ومعاوقة الطور في وضع العطل الكهربائي وتعطي نتائج أكثر دقة في تصنيف الانحدار في الجهد.

الكلمات المفتاحية: الانحدار في الجهد، جودة الطاقة، طور المعاوقة، برنامج محاكاة الحماية (SIMP)، برنامج (DIGSI).

Introduction

All existing standard documents on voltage sag characterize a dip through one magnitude (remaining voltage or voltage drop) and one value for the duration [1, 2, and 3]. There are obvious

limitations to this method as one e.g. neglects the phase-angle jump and the post-fault voltage sag. For the majority of sensitive single-phase equipment, the existing characterization enables a prediction of the behavior of the equipment during and after the event. Further, the phase-angle jump can be incorporated by using a complex dip voltage; the post-fault voltage sag can be incorporated by giving the magnitude as a function of time [2].
Three-phase equipment will typically experience three different magnitudes, as the majority of voltage sag are due to single-phase or phase-to-phase faults. The existing method of characterization uses the lowest of the three voltages and the longest duration. An example of a three-phase unbalanced dip is shown in Figure 1.

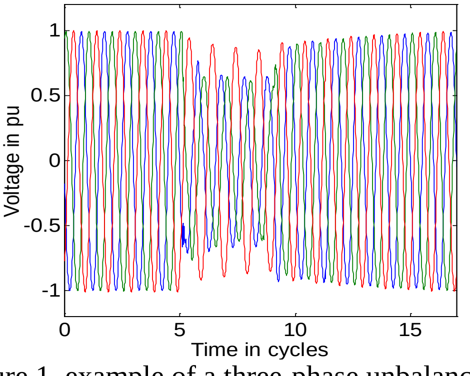

Figure.1. example of a three-phase unbalanced dip.

Voltage sag characterization is often part of the voltage characteristics power quality in general. In that case, the results should be applicable both to single-phase and three-phase equipment. Using the lowest of the three voltages to characterize the voltage sag will result in erroneous results for both single-phase and three-phase equipment. An alternative technique is proposed in this document, which enables a characterization through one complex voltage, without significant loss of information. The method is based on the decomposition of the voltage phasors in symmetrical components [3, 4].

Basic Classification of voltage sag

The classification considers three- phase, single-phase and phase-to-phase faults, star and delta-connected equipment and all types of transformer connection. It was further assumed that positive and negative-sequence source impedances are equal. This resulted in four types of three-phase unbalanced sag, shown as a phasor diagram in Figure 2. Type A is due to three-phase faults, types B, C and D are due to single-phase and phase-to-phase faults. Type B contains a zero-sequence component which is rarely transferred down to the equipment terminals. Three-phase equipment is normally connected in delta or in star without neutral connection. Single-phase low-voltage equipment is connected between phase and neutral, but the number of dips originating in the low-voltage system is small. Therefore, the vast majority of three-phase unbalanced dips at the equipment terminals are of type C or type D, so that a distinction between type C and D is sufficient, together with a characteristic magnitude and phase-angle jump. The definition of characteristic magnitude and phase-angle jump is such that these do not change when the sag transfers from one voltage level to the other. The characteristic magnitude and phase-angle jump are defined as the absolute value and the argument of the complex phasor representing the voltage in the lowest phase for a type D, and the voltage between the two lowest phases for a type C [5].

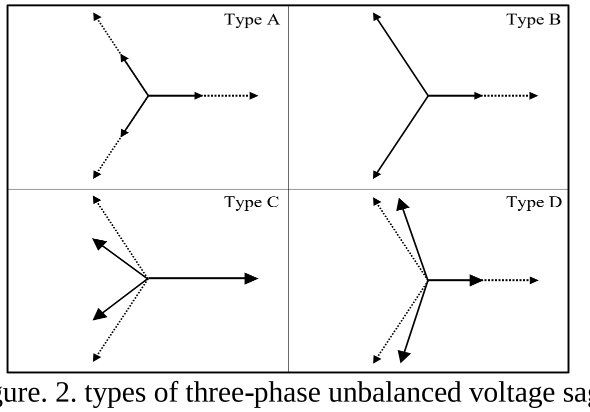

Figure. 2. types of three-phase unbalanced voltage sags

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Voltage sag types based on symmetrical components

The voltage sag type indicates which phases are involved in the event. The seven basic types are given in Figure 2. Balanced voltage sag (voltage sag type A) is due to an equal drop in the values of voltage in the three-phases. Unbalanced voltage sag (types C and D) is due to a drop but not all the three phases are equally involved. The C-types are voltage drops between two phases: type Ca is a voltage drop between phases b and c, type C_b between phases a and c, and type Cc between phases a and b. The D-types are voltage drops in one phase: type Da is a voltage drop in phase a, type Db in phase b, and type Dc in phase c [4].

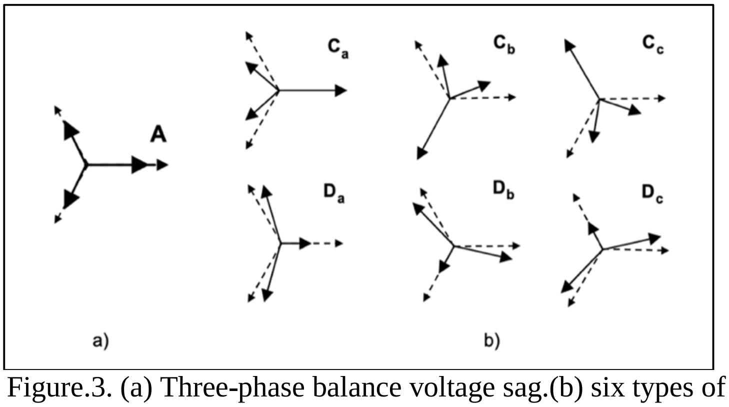

Figure.3. (a) Three-phase balance voltage sag.(b) six types of three- phase unbalanced voltage sags

Comparison between New Method and Old Method

The old technical classification method of voltage sag types may be obtained from the angle between the negative-sequence voltage of the measured dip and the negative-sequence voltage of the prototype dip. Due to various approximations made and measurement errors, this angle is not exactly an integer multiple of 60º so that the following expression may be used to obtain the sag type [5].

$$k = \text{round}\left(\frac{\text{angle}\left(\overline{U}_2, 1-\overline{U}_1\right)}{60^\circ}\right) \tag{1}$$

Where:

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k=0 sag type C_a , k=3 sag type D_a
k=1 sag type D_c , k=4 sag type C_c
k=2 sag type C_b , k=5 sag type D_b
Knowing the voltage sag type, the negative-sequence voltage can be calculated back to the corresponding value for the prototype voltage sag:

$$\overline{V}_2{}' = \overline{V}_2 e^{-jk60^\circ} \tag{2}$$

Where: k is obtained according to Eqn. (1) and the negative sequence voltage of the measured voltage sag. Characteristic voltage $\overline{V}$ and PN-factor $\overline{F}$ are obtained from[5]:

$$\begin{aligned} \overline{V} &= \overline{V}_1 - \overline{V}_2{}' \\ \overline{F} &= \overline{V}_1 + \overline{V}_2{}' \end{aligned} \tag{3}$$

The new method introduced in this thesis for voltage sag characterization can obtain the voltage sag types by using phase-impedance. This method depends on the comparison between the phase impedance of the load mode and the phase impedance of the fault mode.

The phase-impedance is calculated from the complex phase voltages V_A, V_B, V_C and complex phase currents I_A, I_B, and I_C as follows:

$$\begin{bmatrix} U_A \\ U_B \\ U_C \end{bmatrix} = \begin{bmatrix} Z_A & 0 & 0 \\ 0 & Z_B & 0 \\ 0 & 0 & Z_C \end{bmatrix} \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} \tag{4}$$

Where:

$$Z_A = \frac{U_A}{I_A}, \quad Z_B = \frac{U_B}{I_B} \quad \text{and} \quad Z_C = \frac{U_C}{I_C} \tag{5}$$

Phase-to-phase impedance can be calculated from:

$$\begin{bmatrix} U_{AB} \\ U_{BC} \\ U_{CA} \end{bmatrix} = \begin{bmatrix} U_A & - & U_B \\ U_B & - & U_C \\ U_C & - & U_A \end{bmatrix}, \quad \begin{bmatrix} I_{AB} \\ I_{BC} \\ I_{CA} \end{bmatrix} = \begin{bmatrix} I_A & - & I_B \\ I_B & - & I_C \\ I_C & - & I_A \end{bmatrix} \tag{6}$$

Where:

$$Z_{AB} = \frac{U_{AB}}{I_{AB}}, Z_{BC} = \frac{U_{BC}}{I_{BC}} \text{and } Z_{CA} = \frac{U_{CA}}{I_{CA}} \quad (7)$$

The result of this method is shown in table 1:

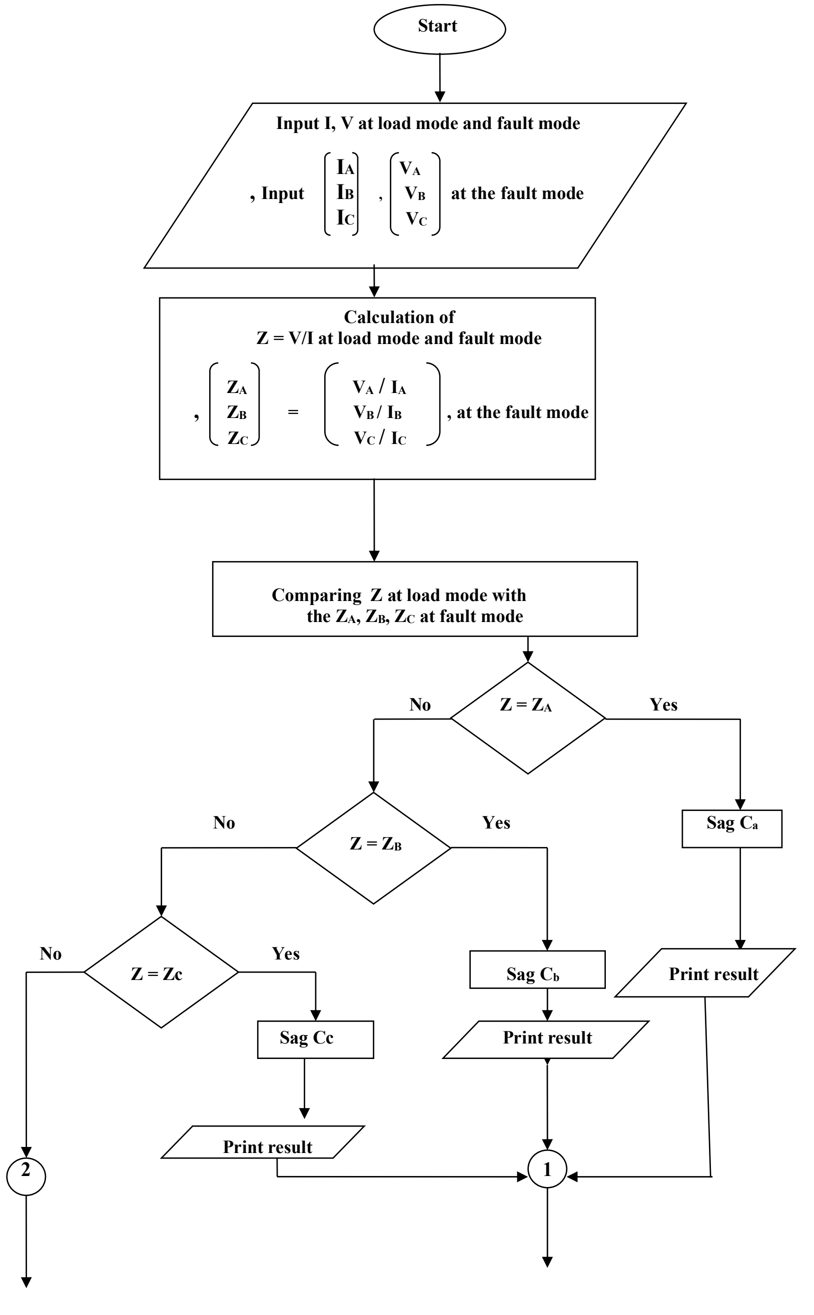
Table (1) new method for voltage sag type

Voltage sag type	Impedance of load mode	Impedance of fault mode
A	Z unequal to	All impedance
C_a	Z equal to	Z_A
C_b	Z equal to	Z_B
C_c	Z equal to	Z_C
D_a	Z equal to	Z_{BC}
D_b	Z equal to	Z_{CA}
D_c	Z equal to	Z_{AB}

Where:
Z - Load mode impedance.
Z_A- The impedance in phase (a) during the fault.
Z_B - The impedance in phase (b) during the fault.
Z_C - The impedance in phase (c) during the fault.
Z_{AB}- The impedance between phase (a) and (b) during the fault.
Z_{BC}- The impedance between phase (b) and (c) during the fault.
Z_{CA} - The impedance between phase (c) and (a) during the fault.

Verification Software

This program presented in this research paper to classification types of voltage sag by calculate the impedance before and during fault occur and comparison between the phase impedance of load mode and phase impedance of fault mode. This program uses simple equation, minimum parameters and can be used with distance protection program for the classification of voltage sag types. The program statements are written below and flow chart is shown in figure 4.


Start
Input I, V at load mode and fault mode
, Input
IA IB IC
VA VB VC
at the fault mode
Calculation of
Z = V/I at load mode and fault mode
ZA ZB ZC
VA / IA VB / IB VC / IC
, at the fault mode
Comparing Z at load mode with
the ZA, ZB, ZC at fault mode
Z = ZA
No
Yes
Sag Ca
Z = ZB
Sag Cb
Z = Zc
Sag Cc
Print result
1
2

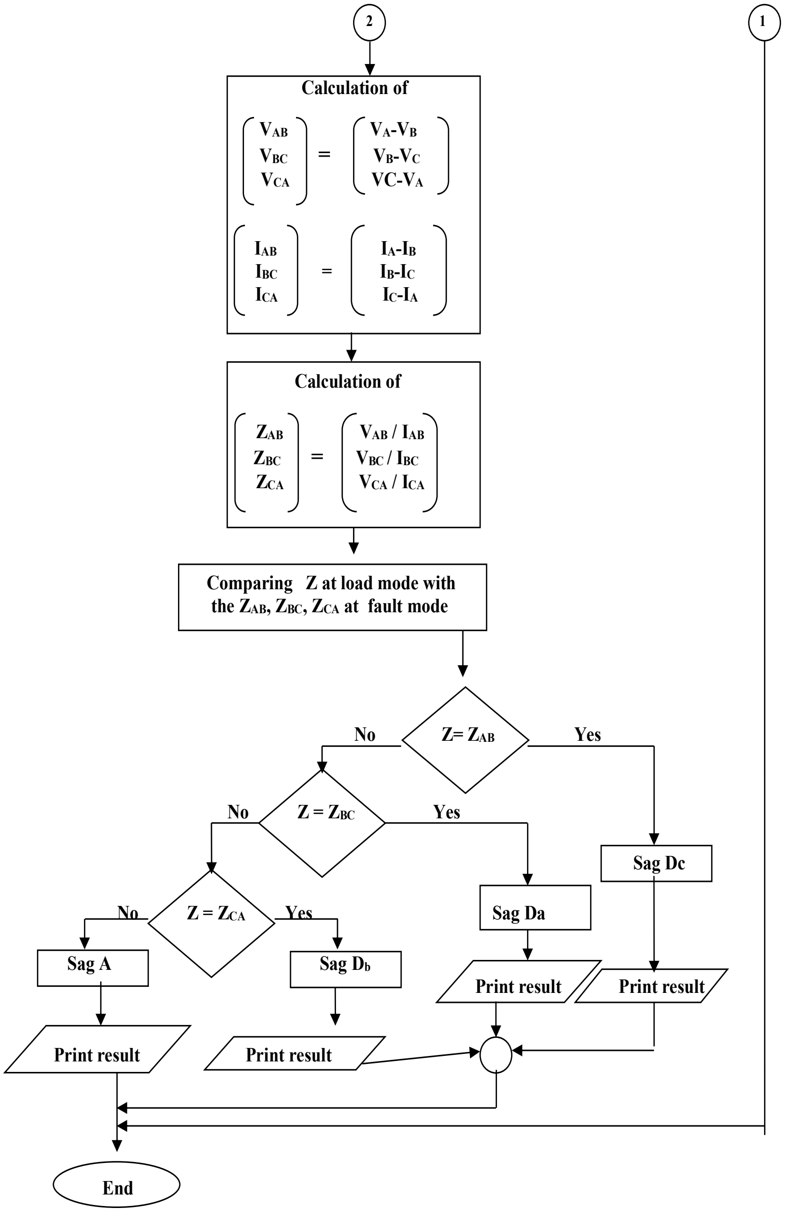


Figure. 4. Flow chart of the new method for the classification of voltage sag types

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Results and analysis

The results obtained from sample system used in simulation and protection coordination software (SIMP) is shown in Figure5.

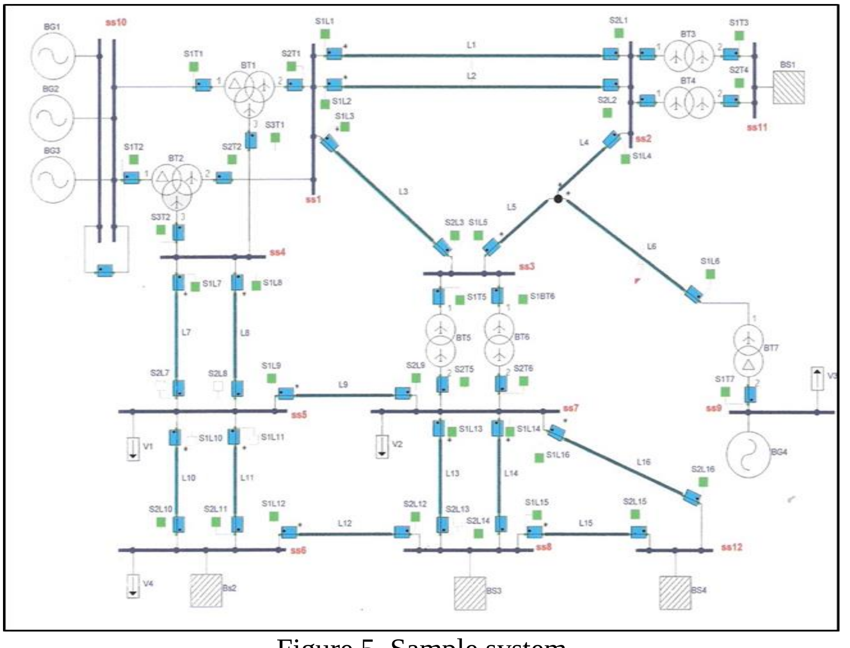

Figure.5. Sample system

The simulation done by applying different fault cases(single-phase, phase-to-phase and three-phase faults) at different fault location on the network shown in figure 5. Also, detection and comparison this method with old method to classification of voltage sag types is introduced.

Case (1) . In this case phase-to-phase fault (BC), occur between phase B and C shown in Figure6, which is applied on load (V2).

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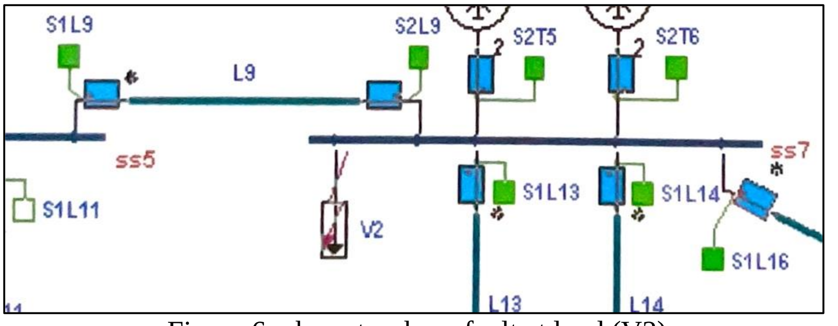

Figure.6. phase-to-phase fault at load (V2)

The result of the simulation for this case is shown in table 2:

Table (2) result of the phase-to-phase fault

Fault: BC <V2>Protection: S2L9
Load mode. (t < 0.0s)
U 56.943V -0.7°I 0.0372A -37.9°**Z 1531.398ohm 37.2°**
Fault mode.(t=0.0s).
I_A0.0372A -37.9° I_B 1.2187A 13.3° I_C 1.2423A -168.1°
U_A56.943V -0.7° U_B 28.472V 179.3° U_C 28.472V 179.3°
I_1 0.6961A 101.6°. I2 0.7248A -76.5°. I_0 0.0A 0.0°
U_1 28.472V -0.7° U_2 28.472V -0.7° U_0 0.0V 0.0°
Z_{AN} 1531.398ohm 37.2° Z_{BN} 23.363ohm 166.1°Z_{CN} 22.918ohm
Z_{AB} 71.434ohm 164.7° Z_{BC} 0.0ohm 0.0° Z_{CA} 67.434ohm

The results shown the phase and symmetrical components voltages, current and also gives the phase impedance at load mode and fault mode

- Calculation by applying the previous method for voltage sag type based on the obtained result of positive-sequence voltage (U_1) and negative-sequence voltage (U_2) and angle between them is done as follows:

U_1 = 28.472v -.0.7°,　　　U_2 = 28.472v -0.7°

Where:

$$k = \text{round}\left(\frac{\text{angle}\left(\overline{V}_2, 1-\overline{V}_1\right)}{60^\circ}\right),$$

1- U_1 = 27.472v 180°

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$$k = round\left(\frac{angle(0.7°, 180°)}{60°}\right), \qquad k = round\left(\frac{0.7°}{60°}\right)$$

$k = round\ (0.0116)$, $\qquad k = 0$

Voltage sag type is (C_a).

- The new method to obtain the voltage sag types by using the phase impedance is as follows:

Where:

Z = 1531.398 ohm 37.2°, $\qquad Z_{AN}$ = 1531.398 ohm 37.2°

It clearly shows that the load mode impedance (Z) is equal to fault mode impedance (Z_{AN}) then from table [1], the voltage sag type is [C_a] with a magnitude of 50%.

Case (2). In this case single-phase fault (AN), occur in phase (a) as shown in figure.7, which is applied on load (V1).

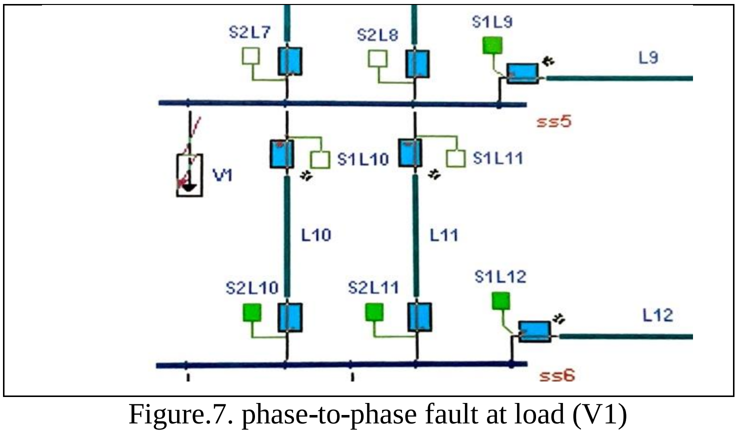

Figure.7. phase-to-phase fault at load (V1)

The result of the simulation for this case is shown in table 3.

Table (3) result of single-phase fault

Fault: AN **<V1>,**	**Protection: S2L10**
Load mode. (t < 0.0 s).	
U56.313V -1.1° I 0.0119A -18.4° **Z 4723.47ohm 17.3°**	
Fault mode.(0, t=0.0s).	

I_A 0.9486A -75.6°	I_B 0.027A 164.5°	I_C 0.0331A 126.0°
U_A38.207V -0.8°	U_B 57.707V -122.1°.	U_C 56.545V 120.7°
$I_1$0.327A -73.7°	I_2 0.3203A -75.5°	I_0 0.3017A -77.9°
U_1 50.808V -0.7°	U_2 5.514V 175.8°	U_0 7.106V -178.0°
Z_{AN}37.954ohm57.4°	Z_{BN}207.518ohm-136.8°	Z_{CN}195.068ohm102.5°
Z_{AB}87.464ohm109.3°	**Z_{BC}4723.467ohm 17.3°**	Z_{CA}84.865ohm38.7°

- Calculation by applying the previous method for voltage sag type based on the obtained result of positive-sequence voltage (U_1) and negative-sequence voltage (U_2) and angle between them is done as follows:

U_1 = 50.808v -.0.7° , U_2 = 5.514v 175.8°
Where:
$k = round$ (2.916)
$k = 3$, Voltage sag type is (D_a).

- By comparison of phase impedance for load and fault mode, the new method directly shows that the load mode impedance (Z =4723.47ohm 17.3°) is equal to fault mode impedance (Z_{BC} =4723.47ohm 17.3°) and as consequence the voltage sag type is [D_a] with a magnitude of 67.8%.

Case (3). In this case three- phase fault (ABC), occur in phase A, B, and C, is applied on load (V1) as shown in figure.8.

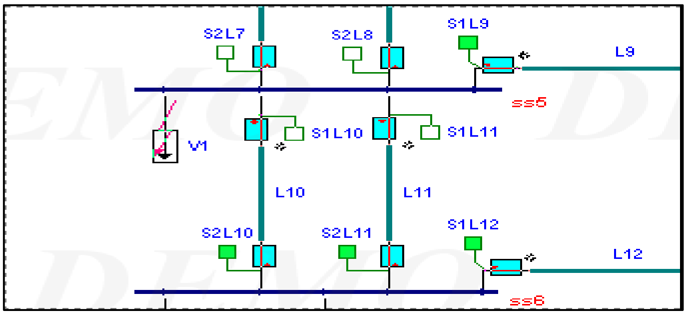

Figure.8. Three-phase fault in load (V1)

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The result of the simulation for this case is illustrated in table 4.

Table (4) Result of three-phase fault

Fault type: ABC <V1>, **Protection:** S2L10
Load mode. (t < 0.0 s)
U 56.313V -1.1° I 0.0119A -18.4 Z 4723.47ohm 17.3°
Fault mode.(t=0.0s)
I_A 1.4931A -74.7° I_B 1.4931A 165.3° I_C 1.4931A 45.3°
U_A 30.782V 1.2° U_B 30.782V -118.8° U_C 30.782V 121.2°
I_1 1.4931A -74.7° I_2 0.0A 0.0° I_0 0.0A 0.0
U_1 30.782V 1.2° U_2 0.0V 0.0° U_0 0.0V 0.0°
Z_{AN} 20.616ohm 76.0° Z_{BN} 20.616ohm 76.0° Z_{CN} 20.616ohm 76.0°

In this case three-phase impedance and phase-to-phase impedance are equal, and as consequence the voltage sag type is (A) with a magnitude of 54.66%.

- Results of classification of voltage sag types due to phase-to-phase, single-phase, and three-phase faults using the new method are summarized in table 54.

Table (5) Sag types due to two-phase faults

Fault type	Sag type	Sag magnitude
Phase-to-phase fault (BC)	C_a	50%
single-phase fault (AN)	D_a	67.8%
three- phase fault (ABC)	**A**	54.66%.

Conclusion

New method is introduced in this research paperfor classification of voltage sag types by using phase-impedance, the protection simulation program (SIMP) introduced in this research papercalculates the impedance (phase-to-phase and phase-to-earth) in any network points for normal mode and fault condition as well as for different network faults and network structures.This method is very simple when compared with the previous method because it requires only minimum parameters and depends on the

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comparison between the phase-impedance for load mode and the phase impedance for fault mode.

The classification of voltage sag types depended on the various types of faults. For a three-phase fault in case [3] at any level and any load connection, the sag is of type (A). For a phase-to-phase fault in case (1) the resulting sags are types (Ca, Cb, and Cc). For a single-phase fault in case (2) the resulting sags are types (Da, Db, and Dc). Also, from these results the percentage of sag magnitude depending on the fault types.

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