

PSCAD/EMTDC Simulation of Power System to Study Influence of Network Parameters on Characteristic of Voltage Sag.

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Abstract— The parameters of power system are having great influence on the characteristic of voltage sag. The faults in the power system are the most common reason for occurrence of important power quality problem, voltage sag in the system. Due to increasing use of sensitive and sophisticated control in almost all modern devices at industrial and residential consumer level, the Voltage sag which causes severe problem to these devices is necessary to analyze. The parameters which affects the characteristic of voltage sag as type of fault in the system, location of fault in the system, type of transformer, X/R ratio of transmission lines, type of transmission as single or double circuit transmission, Point on wave of sag initiation are studied in this paper. The system under study is simulated in PSCAD/EMTDC.

Keywords- faults, type of transformer, X/R ratio, point on wave of sag initiation.

I. INTRODUCTION

Now a day , in power system the term “Power Quality” is commonly used. Users as well as producers of Electricity are more concerned about the Power Quality. Any power problem manifested in voltage, current, or frequency deviation that results in failure or disoperation of customer equipment is Power Quality problem. Now a days load equipments are more sensitive to power quality variations than equipments applied earlier, because in order to improve power system efficiency there is continuous growth in the application of devices with micro-processor and power electronics control. These devices are sensitive to power quality variations along with ,they are the sources of power quality problems.

Out of different power quality problems as transients, voltage fluctuations, harmonics, inter-harmonics, voltage unbalance, waveform distortion, dc offset, noise, notches etc. voltage sag is most important [1]. Severe voltage sag may cause tripping of equipment which will result in stopping of process which in tern leads to financial losses. Study says that voltage sags are severe than interruptions as there frequency in the power system is more.

Voltage sags are usually associated with system faults, energization of heavy loads or starting of large induction motor. But faults in the system are most important reason for voltage sag. These voltage sags are the one which causes the majority of equipment trips. The characteristic of sag is mainly defined by the magnitude of sag and its phase-angle [2]. The parameters which affect these characteristics of voltage sag are studied in this paper. In this paper a study system used in [3] is simulated using PSCAD/EMTDC software package as a tool for simulation [4].

II. VOLTAGE SAG

Short- duration Under-voltages are called “voltage sags” or “Voltage dips”. Voltage sag is reduction in supply voltage magnitude followed by voltage recovery after a short period of time. In the IEEE Standard 1159-1995, the term “sag” is defined as a decrease in rms voltage to values between 0.1 to 0.9 p.u., for durations of 0.5 cycles to 1 min. Voltage sag due to faults in the power system are studied in this paper.

Voltage sag is characterized in terms of following parameters [2],

1. Magnitude of sag
 2. Three phase balance
 3. Duration of sag
 4. Phase-angle jump.
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1. Magnitude of sag : One common practice to characterize the sag magnitude is through the lowest per unit rms remaining voltage during the event of sag . It means a deep sag is the sag with low magnitude and shallows sag has a large magnitude.
 2. Three phase unbalance: In the power system depending on the type of fault the sag in all the three phases can be balanced or unbalanced. For three phase short circuit in the system during fault all the three phase sag will be of equal magnitude

called as balanced fault. And if the fault is single line to ground, line to line or double line to ground depending on the faulty phase the sag in all the three phases will be unbalanced in nature.

3. Duration of fault: The duration of sag is mainly determined by the fault-clearing time. For the fast clearing of the fault, duration of sag will be less and vice- versa.
4. Phase-angle jump: The Phase-angle jump manifests itself as a shift in zero crossing of the instantaneous voltage. Phase-angle jumps during three phase faults are due to the difference in X/R ratio between the source and the feeder. Phase-angle jumps are not of concern for most of the equipments but power electronics converters using phase angle information for their firing instants may be affected.

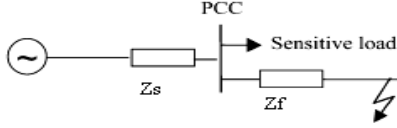


Figure 1. Voltage divider model

III. VOLTAGE SAG DETERMINATION

The basis of voltage sag determination is fault analysis. With accurate information of all impedances including the positive, negative and zero sequence resistances and reactances of the power components, and the fault impedances, the system can be simulated to predict the sag characteristic at the node where the sensitive load is connected. To quantify sag in a radial system, the voltage divider model is as shown in Fig.1. In this figure Z_s is source impedance at the point of common coupling (PCC) and Z_f is the impedance between PCC and the fault. The PCC is the point from which both the fault and the load is fed. In the voltage divider model the load current before as well as during fault is neglected. The voltage at the PCC which is voltage at the terminal of sensitive equipment will be as per (1)

$$\vec{V}_{sag} = \vec{E} * \vec{Z}_f / (\vec{Z}_f + \vec{Z}_s) \quad (1)$$

With the assumption that prefault voltage is 1 pu., $E=1$. Now the expression of sag will be as (2)

$$\vec{V}_{sag} = \vec{Z}_f / (\vec{Z}_f + \vec{Z}_s) \quad (2)$$

Here fault impedance is included in feeder impedance Z_f .

Equation (2) can be used to calculate the sag as a function of the distance to the fault. Let $Z_f = zl$, with z as the impedance of the feeder per unit length and l as the distance between the fault and the PCC. Equation (2) will be now,

$$\vec{V}_{sag} = zl / (\vec{Z}_s + zl) \quad (3)$$

In above equations V_{sag} , Z_f , Z_s , zl are complex quantities.

From equation (3) the magnitude of sag voltage at PCC will be,

$$|V_{sag}| = |Z_f| / (|Z_f| + |Z_s|) \quad (4)$$

And the phase-angle jump associated with voltage sag at PCC is given by

$$\Delta\Phi = \arctan(X_f/R_f) - \arctan((X_s+X_f)/(R_s+R_f)) \quad (5)$$

Where $Z_f = X_f + jR_f$ and $Z_s = R_s + jX_s$.

Thus the phase-angle jump be present if the X/R ratio of the source and the feeder are different.

Duration of sag is determined by fault clearing time which is considered as constant for this study.

For three phase to ground fault i.e. balanced fault the voltage sag (during fault voltage) will be balanced in all the phases and its calculations can be carried out on single phase basis using positive sequence values of all the parameters.

But for unbalanced faults the voltage divider model has to be split into its three components: a positive-sequence network, a negative-sequence network and a zero sequence network. The three component networks have to be connected into equivalent circuit at the fault position. The connection of the component networks depends on the fault type [2].

IV. FACTORS AFFECTING SAG CHARACTERISTICS

1. Type of fault: Type of fault in the power system is the first factor which affects characteristic of the sag. Depending on the type of fault as balanced or unbalanced, the sag will be balanced or unbalanced in all the three phases. The magnitude and phase angle of the sag will also depend on the type of fault[2].
2. Location of fault: Along with the type, the location of fault in the system is having great impact on the magnitude as well as phase-angle jump of the sag. The sensitive load is at distribution level but the faults at distribution as well as at hundreds of kilometers away at the transmission level will have influence on the magnitude as well as phase-angle of the sag at PCC[2].
3. Type of Transformer: Transformers come with many different winding connections, but a classification into only three types is sufficient to explain the propagation of three-phase unbalanced sags from one voltage level to another [6].

Type I: Transformer that do not change anything to the voltages. For this type of transformer the secondary-side per unit voltage is equal to the primary side per unit voltage. The only type of transformer in this category is star-star transformer with both the windings grounded. This type of transformers can be defined mathematically by means of following transformation matrix:

$$T_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Type II: The transformer that removes the zero-sequence voltage. The per unit voltages on the secondary sides are equal to per unit voltages on primary side minus the zero-sequence component. Transformers with star-star windings and one or both windings ungrounded and delta-delta winding transformers are the examples of this category. This type of transformers can be defined mathematically by means of following transformation matrix:

$$T_2 = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}$$

Type III: Transformer that swaps line and phase voltages. For this type of transformers each secondary-side voltage equals the difference between two primary-side voltages. Examples are delta-star, star-delta transformers and star-zigzag transformers. This type of transformers can be defined mathematically by means of following transformation matrix:

$$T_3 = \frac{j}{\sqrt{3}} \begin{bmatrix} 0 & 1 & -1 \\ -1 & 0 & 1 \\ 1 & -1 & 0 \end{bmatrix}$$

Within each of these categories there will be transformers with different clock numbers leading to a different phase shift between primary-side and secondary-side voltages. This difference is not of any importance for voltage sags as experienced by the equipment. All that matter is the change between the pre-fault voltages and the during fault voltages, in magnitude and in phase-angle.

In the power system the propagation of sags due to different types of symmetrical and unsymmetrical faults depends on the type of transformer. The voltage sag equations for the different types of faults at the primary and secondary of transformer can be derived. The equations of phase voltages at the fault point and after different types of transformer are given in [6]. From these equations it is clear that magnitude as well as phase angle of voltages undergo change when it is propagated through transformer. Thus the magnitude and phase angle of sag at the terminal of equipment depends on the type, location of fault as well as on the type of transformer

4. X/R ratio of the lines: With change in the X/R ratio of the line there is change in the X/R ratio of fault to source impedance which will affect the magnitude as well as phase-angle jump [1]. To study the effect the X/R ratio of one of the lines can be changed and magnitude and phase angle jump of voltage at node under study can be analysed.
5. Point on wave of sag initiation: The point on wave of sag initiation is the phase angle of fundamental voltage wave at which the voltage sag starts. This angle corresponds to the angle at which the short circuit fault occurs. As most of the faults are associated with a flashover, they are more likely to occur near voltage maximum than near voltage zero. Upward crossing of the fundamental voltage is an obvious choice for reference to quantify the point of wave initiation [2]. With

change in point on wave of sag initiation it is expected that phase-angle jump will change more as compared to magnitude of sag.

Table 1. Transmission and distribution line impedances

Line(s)	Positive & Negative sequence impedances (ohm/km)	Zero sequence impedance (ohm/km)
1-2,2-3,3-4	$0.22+j0.37$	$0.37+j1.56$
2-5,3-6	$1.26+j0.42$	$1.37-j1067$
7-8,8-9,7-9	$0.097+j0.39$	$0.497+j2.349$

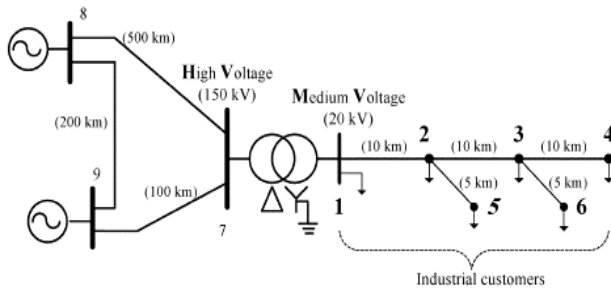


Figure 2. System under study

- Single/Double circuit transmission: In the power system it is a common practice to have double circuit transmission to improve reliability. Another interesting analysis on studying the influence of disconnection of line on magnitude and phase angle of sag can be carried out by keeping any the transmission line as double circuit. The results are compared with single circuit configuration of the same line. With change in the transmission configuration basically there will be change in X/R ratio of the impedances, which will affect the characteristic of sag.

V. CASE STUDY

The diagram of test system is shown in Fig.2. [3]. Six critical industrial customers are connected at six nodes of the same 20-kV distribution line(40-km total length) through a solidly grounded delta-wye transformer. It should be noted that this network represents a typical distribution network with several hundred nodes spread along the main feeder and lateral but only the node supplying the most critical customer need to be examined. The equivalent transmission system consists of three 150-kV lines and is relatively of large size(800-km total length) to take into account the fact that fault at 100 km away from the critical customer will cause severe sags. The data of the transmission and distribution lines is as given in Table-1. In [3] this system is solved analytically. Here it is simulated using PSCAD/EMTDC software package by Fault position method. To study the effect of factors affecting the sag characteristic the system is simulated by taking that particular factor into consideration. In order to study the effect of all said parameters line 7-8 is taken as line under consideration and the node 1 voltage is the voltage of interest where sensitive load is connected. The most sagged voltage for particular fault is plotted. For A-G fault most sagged voltage is of phase a, for BC and BC-G fault the most sagged voltage is of phase B.

- Type of fault: Depending on the type of fault the sag can be balanced or unbalanced. To study that different faults are created in the line 7-8 at a fixed distance of 50% of its complete length. Naturally for Three phase to ground (ABC-G) fault the sag is symmetrical(balanced) in all the three phases whereas for unbalanced faults like A-G, B-C, BC-G the sag is unsymmetrical(unbalanced) in all the three phases as shown in Fig.3.

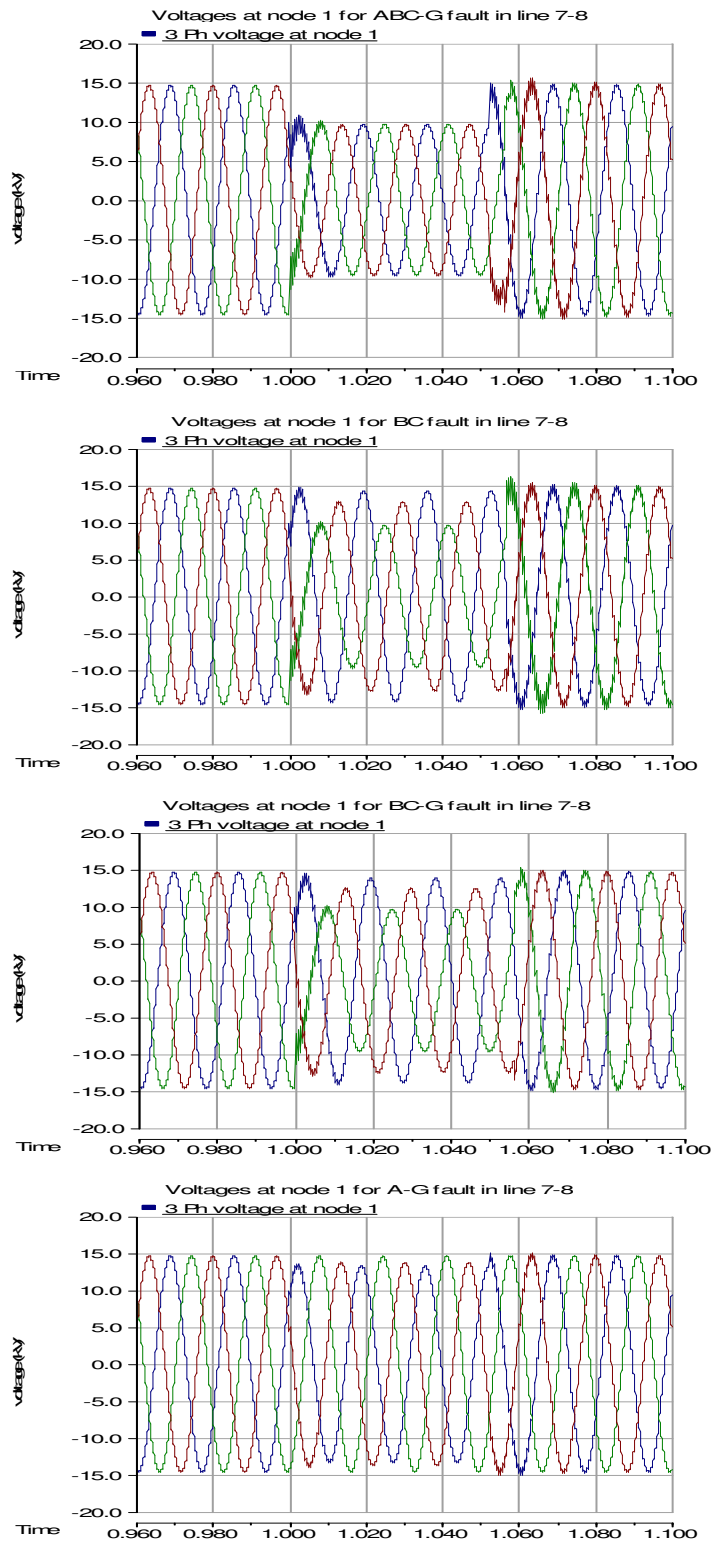


Figure 3. Balanced and unbalanced sags due to faults in line 7-8.

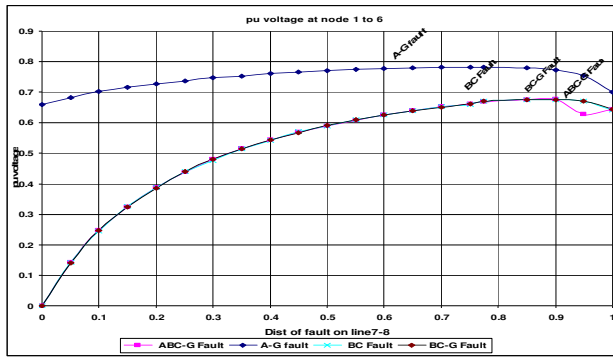


Figure 4. Magnitude of sag Vs distance of fault for different types of faults.

2. Location of fault: To study the effect of location of fault on the characteristic of sag, different types of faults are created at different locations along the transmission line 7-8 and the results of sag magnitude and phase-angle jumps are plotted as a function of distance of that line in Fig.4 and Fig.5 respectively. Fault near the PCC is having prominent effect on the sag.
3. Type of Transformer: To study the effect of transformer on the characteristic of voltage sag , different types of faults are created on line 7-8 . The magnitude and phase angle jump at node 1 are as plotted in Fig.6. and Fig.7.
4. X/R ratio of the line: To study the effect of change in X/R ratio, the X/R ratio of line 7-8 is changed and magnitude and phase angle jump of voltage at node 1 is as shown in Fig. 8. and Fig.9.
5. Point on wave of sag initiation: To study the effect of this factor, along the line 7-8 A-G fault is created at two different instants, one near zero crossing of voltage wave and second at maximum value of the voltage. The results of sag magnitude and phase –angle jump are as shown in Fig.10, and Fig.11 respectively. This factor has more effect on phase-angle jump as compared to sag magnitude.
6. Single/Double circuit transmission: To study the effect of transmission configuration as single or double circuit transmission, the configuration of line 8-9 in the system is changed and with A-G fault on line 7-8 which is under consideration, the sag magnitude and phase-angle jump is studied and is as plotted in Fig.12 and Fig.13 respectively.

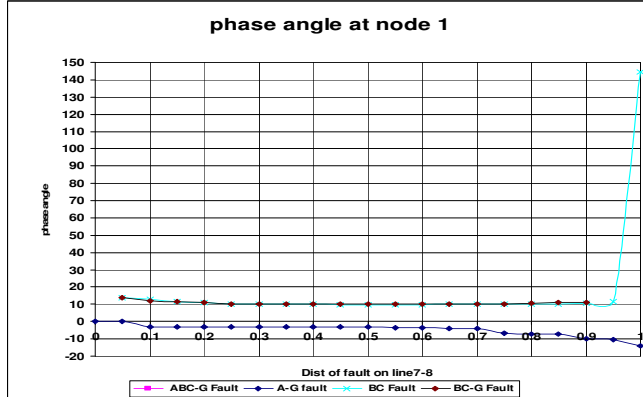


Figure 5. Phase-angle of sag Vs distance of fault for different types of faults.

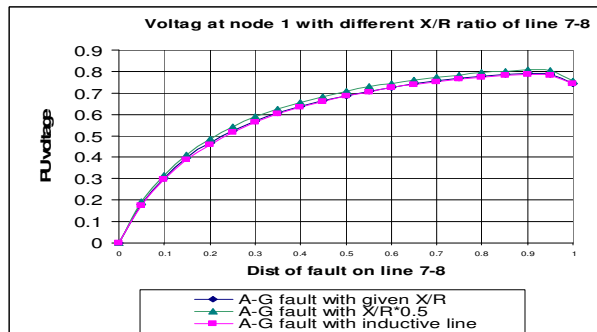


Figure 6. Effect of X/R ratio on the magnitude of sag.

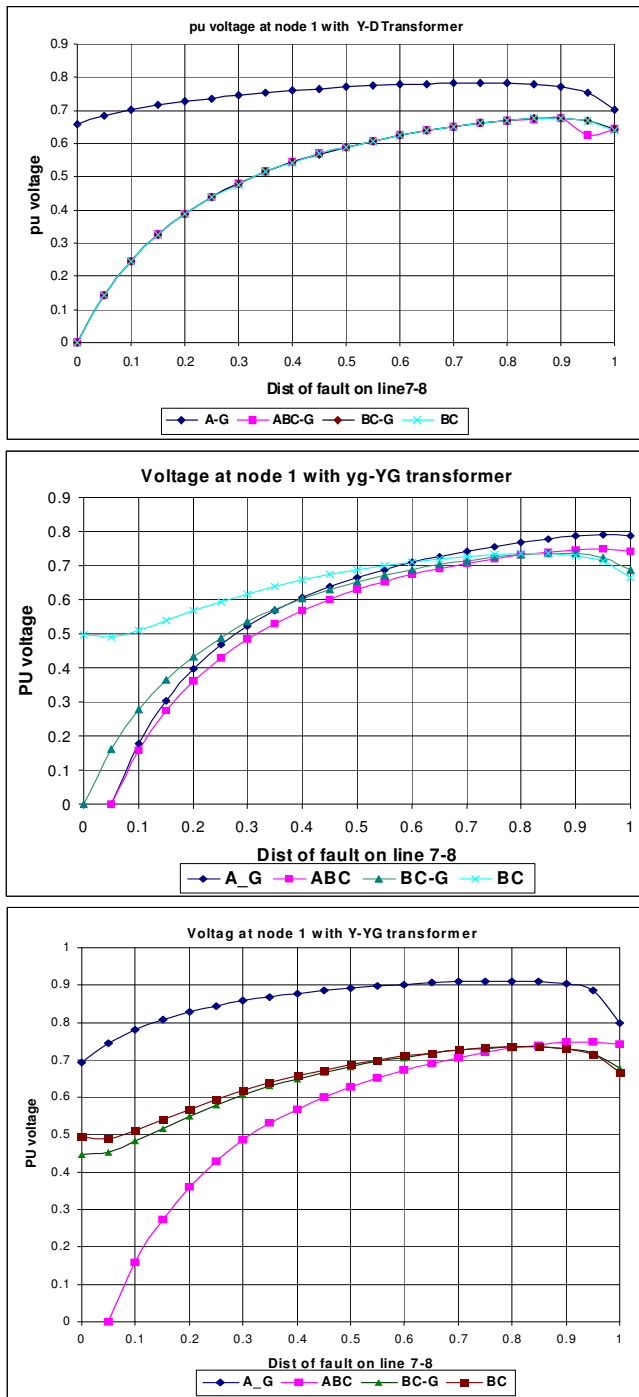


Figure 7. Most sagged phase voltage at node 1 in pu due to fault along the 150kV line 7-8 of length 500 km

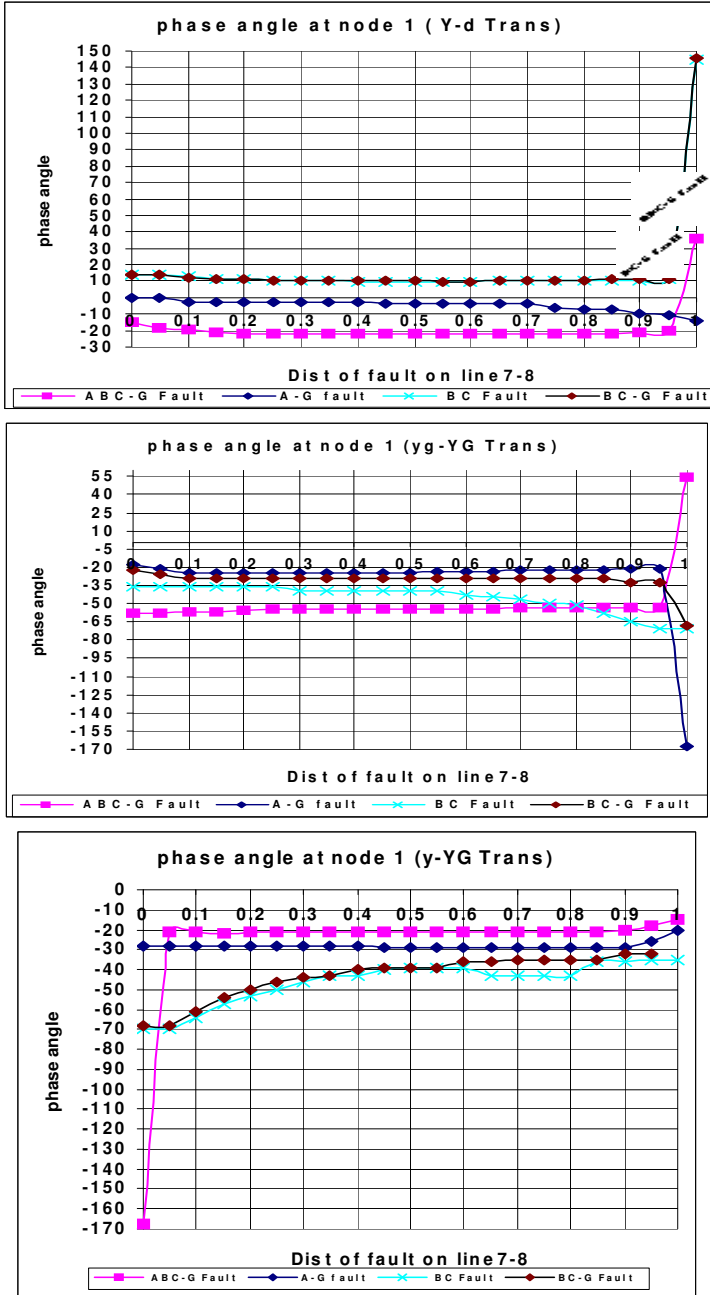


Figure 8. Phase angle of most sagged phase voltage at node 1 in pu due to fault along the 150kV line 7-8 of length 500 km

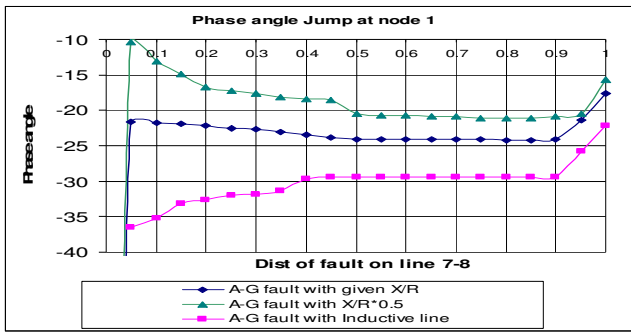


Figure 9. Effect of X/R ratio on the phase-angle jump of sag.

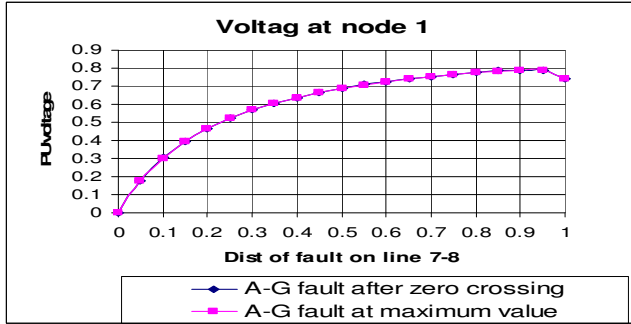


Figure 10. Effect of point on wave of sag initiation on magnitude of sag

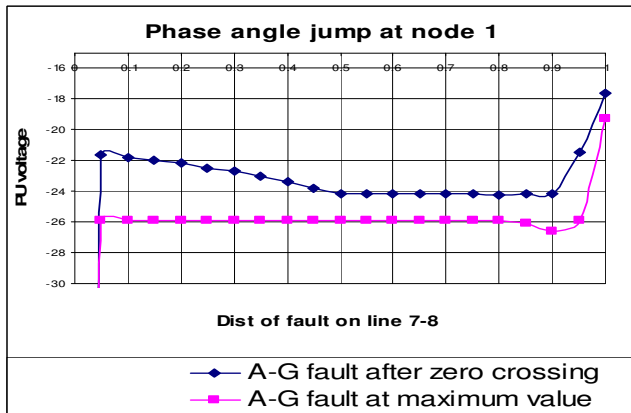


Figure 11. Effect of point on wave of sag initiation on phase-angle jump of sag

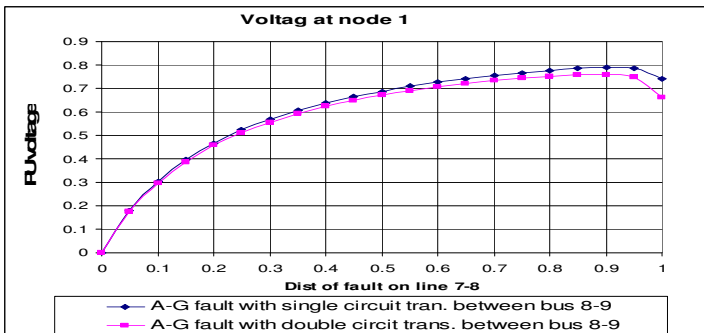


Figure 12. Effect of transmission configuration on magnitude of sag.

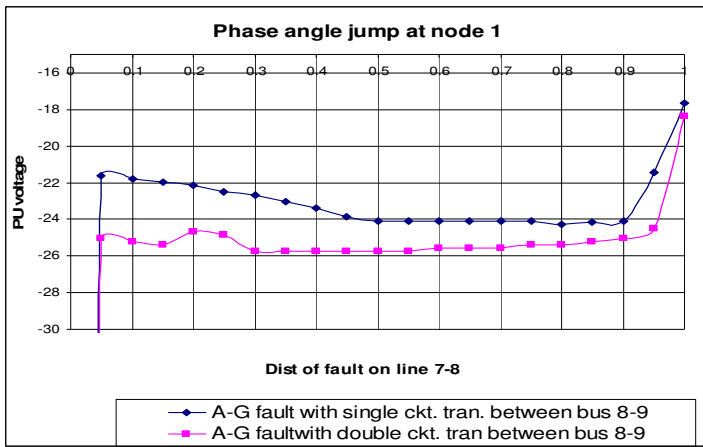


Figure 13. Effect of transmission configuration on phase-angle jump of sag.

VI. CONCLUSION

Out of different reasons of voltage sag, faults in the system are main reason for voltage sags in the power system. The type and location of fault in the system is definitely important parameter in characterizing sag. But the characteristic of sag in the system due to faults also depends on the other parameters of circuit configuration as type of transformer, X/R ratio of lines, point on wave of sag initiation, single or double circuit transmission. Sag may cause tripping of sensitive loads if its magnitude is below the critical voltage that equipment can sustain. These parameters will also affect that number of trips of the equipment. While designing any mitigating methodology, it is necessary to consider all above said parameters which influences the characteristic of voltage sag.

VII. REFERENCES

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