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Stochastic Estimation of Voltage Sag Due to Faults in the Power System by Using PSCAD/EMTDC Software as a Tool for Simulation

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Summary: **Faults in the power system are major cause of voltage sag. Voltage sag in the power system due to fault can be symmetrical or unsymmetrical. For sensitive loads it is necessary to estimate how many times in year the voltage at their terminal will experience sag to avoid tripping of operation. Several stochastic methods for estimation of number of sags are developed in recent years. In different methods of sag prediction there is need to do lengthy programming or calculations. Here PSCAD/EMTDC software package is used to estimate number of sag with uniform distribution of faults along the lines.**

Keywords:
voltage sag, PSCAD/EMTDC, stochastic method, uniform fault distribution

1. INTRODUCTION

Voltage sags are short duration reductions in rms voltage, caused by short circuits, overloads, and starting of large motors. The interest in voltage sag is mainly due to the problem they cause on several types of equipments like adjustable speed drives, process control equipments, and computers are notorious for their sensitivity. Some piece of equipment trip when the rms voltage drops below 90% for longer than one or two cycles and damage due to this can be enormous. Even voltage sags are not damaging to the industry as interruptions but as number of voltage sags are more than interruptions the total damage due to sags are larger. Voltage sag at the equipment terminal can be due to short circuit fault hundreds of kilometers away in the transmission system. Voltage sag is thus much more of a “global” problem than interruption. Reducing the number of interruptions typically requires improvements on one feeder but, reducing number of voltage sags requires improvement on several feeders, and often even at transmission lines far away. Most of the current interest in voltage sag is directed to voltage sag due to short circuit faults. These voltage sags are the ones which causes the majority of equipment trips [1].

System performance, expressed as the expected number of voltage sags in the site, can be estimated through monitoring of the supply or through stochastic prediction methods. Even though monitoring is a direct way to get information about system performance, its important drawback is that very lengthy process. Several stochastic prediction methods have been proposed like method of critical distance, method of fault position, Monte Carlo method and analytical approach [1–3]. The method of fault position is most suitable for implementation in a software tool [5].

In this paper PSCAD/EMTDC [4] has been used to perform the modeling and analysis of power system used in [3] for estimation of number of sags due to different types of faults on different lines at the sensitive node in the system for uniform distribution of fault along the lines.

2. PSCAD/EMTDC SIMUATION PACKAGE

PSCAD/EMTDC is an industry standard simulation tool for studying the transient behavior of electric networks. Its graphical user interface enables all the aspects of the simulation to be conducted within a single integrated environment including circuit assembly, run-time control, analysis of results, and reporting. Its comprehensive library model supports most ac and dc of power plant components and control, in such a way that Power system can be modeled with speed and precision. It provides a powerful resource for assessing the impact of new power technologies in the power network. Simplicity is one of the outstanding features of PSCAD/EMTDC. Its grate many modeling capabilities and highly complex algorithms and methods are transparent to the user, leaving them free to concentrate their efforts on the analysis of results rather than on mathematical modeling. For the purpose of modeling user can either use the large base of build-in components available in PSCAD/EMTDC or their own user-defined models [4, 5].

3. VOLTAGE SAG CHARACTERISTIC

Out of different Power Quality problems, voltage sags have become one of the major power quality concerns in recent years due to applications of power electronics in the commercial and industrial sectors grows rapidly. The severity of sag is less than interruption but the frequency is more. These sensitive loads can be easily interrupted by voltage sag and resulting losses are significant.

The characteristic of sag depends on type as well as location of fault in the system. As the faults moves away from the point of interest its magnitude will vary.

In the IEEE Standard 1159–1995, the term “sag” is defined as a decrease in rms voltage or current to values between 0.1 to 0.9 p.u., for durations of 0.5 cycles to 1 min. The parameters used to characterize voltage sag are magnitude, duration, unbalance and phase angle jump.

3.1. Magnitude of sag

One common practice is to characterize the sag magnitude through the remaining voltage during the sag, called as 'retained voltage'. The magnitude of voltage sag can be determined in number of ways like one cycle or half cycle rms voltage, magnitude of fundamental component of voltage sag, and peak voltage over each cycle or half cycle. In this study pu value of rms voltage is considered.

Sag magnitude (retained voltage) increases for increasing distance to the fault and for increasing fault level. It also depends upon cross section of overhead lines or cables as it effects the impedance of that. Also as the transformer have rather large impedance , the presence of transformer between the fault and the point of interest lead to relatively less sag magnitude.

3.2. Duration of sag

The duration of sag is mainly determined by the fault-clearing time. Generally speaking faults in transmission systems are cleared faster than faults in the distribution system, which affects the duration of faults depending on its location in the system.

3.3. Unbalance of sag

Faults in the power systems are classified as symmetrical and unsymmetrical faults. Voltage sag due to faults in the system can be symmetrical or unsymmetrical depending on the type of fault. Due to three phase fault the sag will be symmetrical but due to single phase, double phase or double phase to ground faults the sag in three phases will not be symmetrical, and called as unbalanced sag.

3.4. Phase-Angle Jump

Phase angle-jump manifest itself as a shift in zero crossing of the instantaneous voltage during fault. Phase-angle jump during three phase faults are due to the difference in X/R ratio between the source and the feeder. A second cause of phase-angle jump is the transformation of sags through transformer to lower voltage level.

Phase-angle jump are not of concern for most equipment except power electronics converter using phase-angle information for their firing instants. Also duration of sag is decided by the speed of fault clearing device. In this study only two parameters of sag i.e. magnitude and unbalance are taken into consideration.

4. STUDY SYSTEM

The diagram of test system is shown in Figure 1 [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

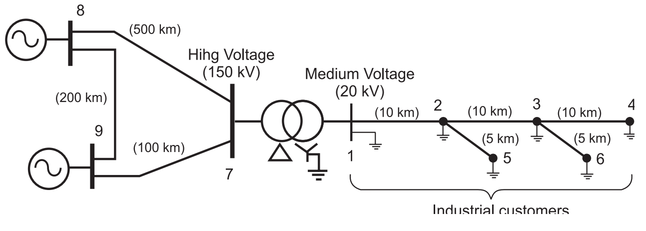

Fig.1 Single line diagram of test system

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

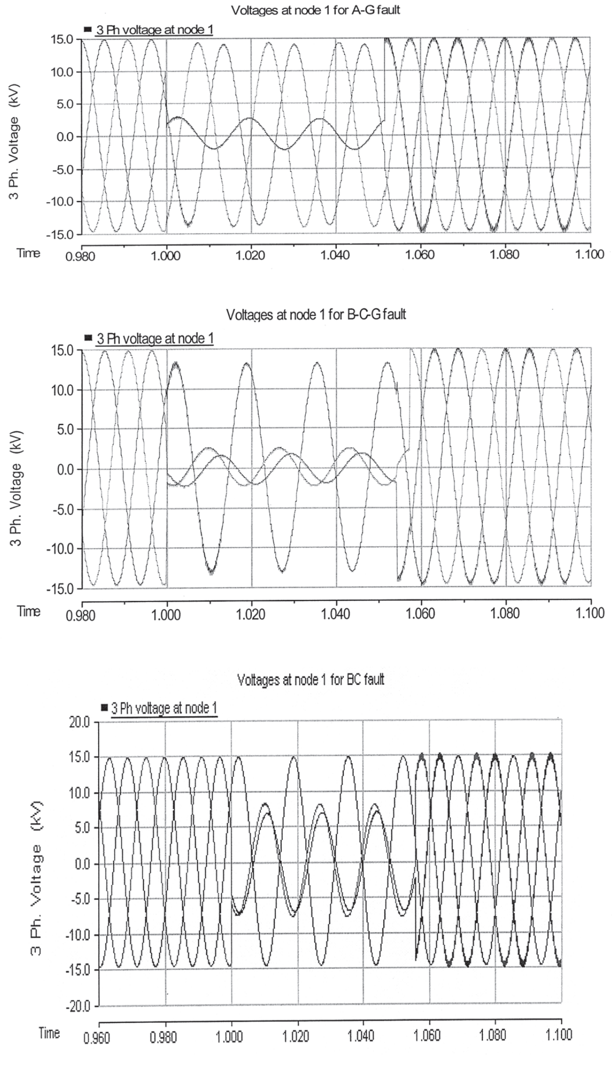

Fig. 2. Unsymmetrical fault due to Line to ground, double line to ground and line to line fault on the line 1-2 at a distance of 5% from node 1(top to bottom)

Fault position method. The analytical expressions in general form for the voltage at the node of our interest are given in [2, 3]. As in PSCAD/EMTDC environment there is no need of complex programming different types of faults can be created throughout all the lines. The voltage at critical node 1 is observed for different types of faults throughout the length of all the lines and graphs are plotted for these voltages versus length of lines.

The sag can be symmetrical or unsymmetrical depending on the type of fault. The unsymmetrical and symmetrical faults are shown in Figures 2 and 3.

The test system is simulated in PSCAD/EMTDC software package. Each type of fault is created at time of 1 sec at number of points in all the lines at a distance of 5% and the fault is cleared in 0.05 sec. The sag magnitude observed at node 1 versus distance at which fault takes place on that line are plotted on graphs are as shown in Figure 4a to Figure 4f. Voltage at node 1 before fault is 1 pu.

The most sagged phase depends on the type and location of fault. If the fault in on transmission side then type of transformer plays an important role. For study circuit for three phase and Single line to ground faults on phase A , the during fault voltage of phase A is most sagged phase. And for two phase and two phase to ground fault between phase B and C, the most sagged phase is phase C. This is as shown in graphs of Figure 2 and 3., which are matching with [3].

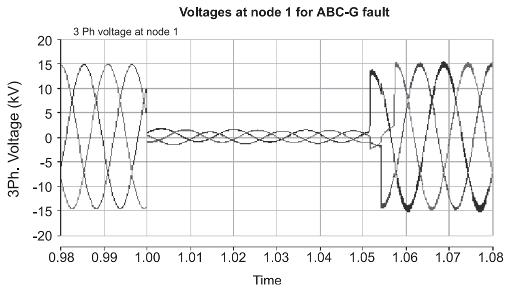

Fig.3. Symmetrical Fault on the line 1-2 at a distance of 5% from node 1

5. STOCHASTIC ESTIMATION OF VOLTAGE SAG

At sensitive load terminals, it is required to know number of voltage sag of particular magnitude when fault takes place in the system. In this study the fault rate considered as per [3] and fault distribution along the line is assumed as uniform as per [2]. The magnitude of sag at the node of interest depends on the type as well as location of fault along the lines. The probability that the sag magnitude at node ‘a’ is within the limits of V_{low} to V_{up} is given by (1):

$$P^a (V_{low} \le V \le V_{up}) = \qquad (1)$$

$$= P^a (l_{low} \le l \le l_{up}) * \int_{l\,low}^{l\,up} g(l)\, dl$$

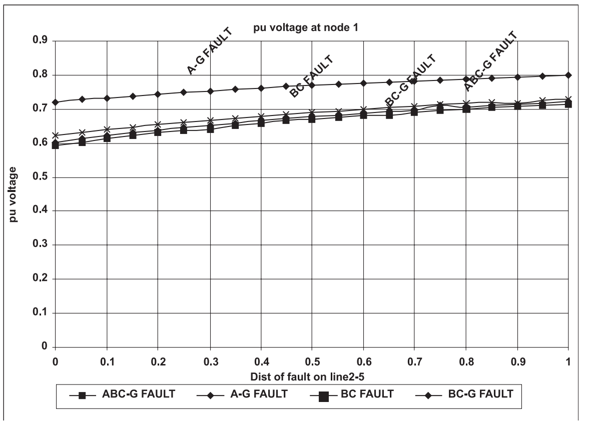

Fig. 4a. Most sagged phase voltage at node 1 in pu due to fault along the 20kV line 1-2-3-4 of length 30 km

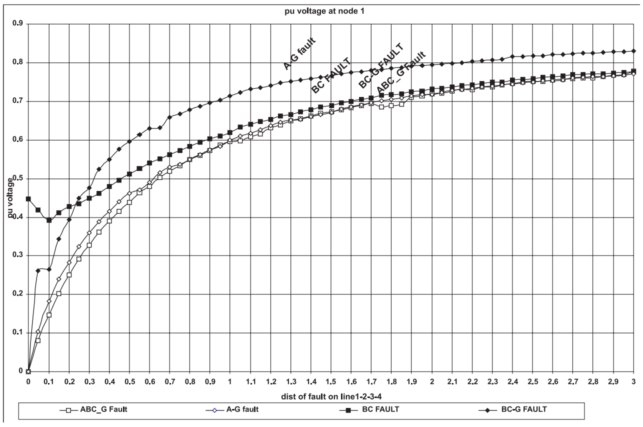

Fig. 4b. Most sagged voltage at node 1 in pu due to fault along the 20kV line 2–5 of length 5 km

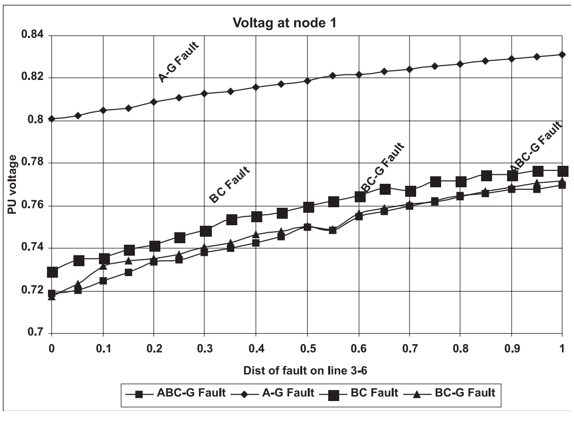

Fig. 4c. Most sagged voltage at node 1 in pu due to fault along the 20kV line 3-6 of length 5 km

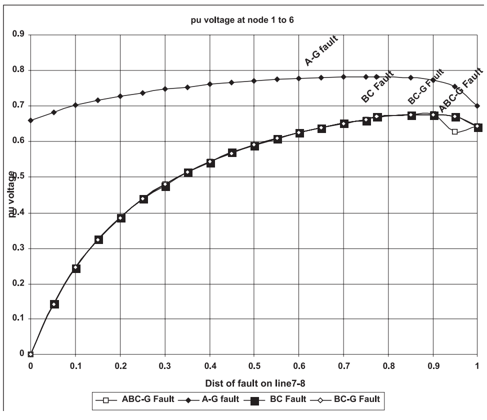

Fig. 4d. Most sagged voltage at node 1 in pu due to fault along the 150kV line 7-8 of length 500 km

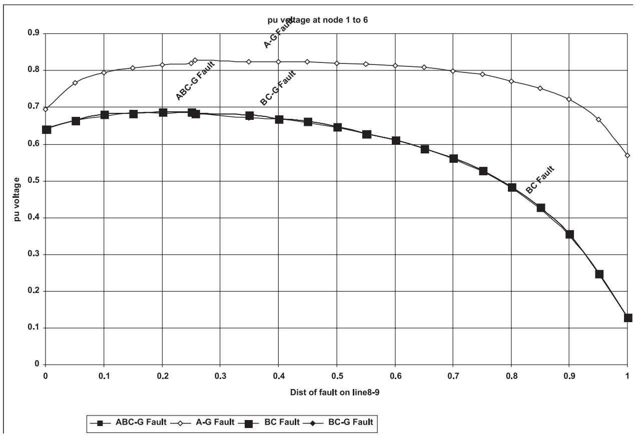

Fig. 4e. Most sagged voltage at node 1 in pu due to fault along the 150kV line 8-9 of length 200 km

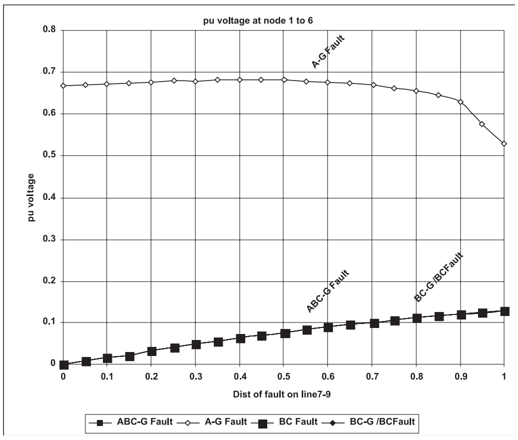

Fig. 4f. Most sagged voltage at node 1 in pu due to fault along the 150kV line 7-9 of length 100 km

Where $P^a(V_{low} \le V \le V_{up})$ is the probability that voltage magnitude at node "a" is within the limits of V_{low} to V_{up} and $P^a(l_{low} \le l \le l_{up})$ is probability that fault takes place between the length specified by l_{low} to l_{up} for any particular line and g(l) is probability distribution function. For uniform distribution of fault along the lines:

$$P^a(V_{low} \le V \le V_{up}) = l_{up} - l_{low} \tag{2}$$

Now the number of sags within limits V_{low} to V_{up}, at node "a" due to fault along any line with uniform fault distribution along the line is given by (3):

$$N^a(V_{low} \le V \le V_{up}) = \lambda\,(l_{up} - l_{low}) \tag{3}$$

Where, λ is total number of faults on that line.

Thus total number of sags within limits V_{low} to V_{up} for any one type of fault can be calculated by adding number of sags at node "a" due to all lines in the system.

$$N^a_{Total}(V_{low} \le V \le V_{up}) = \sum_{Line} N^a(V_{low} \le V \le V_{up}) \tag{4}$$

To estimate number of sags experienced by node 1 of study system following the probability of fault is as shown in Figure 5 [3]. And the fault rate is as shown in Table 2.

From the sag magnitude curves for fault on different lines and of different types, along with particular fault rate for the sag magnitude of 0.8, the estimated number of sags for A-G fault are calculated and shown in Table 3 as sample calculations. Same thing is repeated for all other types of faults and for sag magnitude of 0.8, 0.7, 0.6 pu which are as shown in Figure 6.

With the help of the curves of Figure 4 number of sags at node 1 can be calculated for any magnitude of sag. Same curves can be plotted for voltage at any other node for the calculation of number of sags experienced by that node due to faults of any type along all the lines of the system.

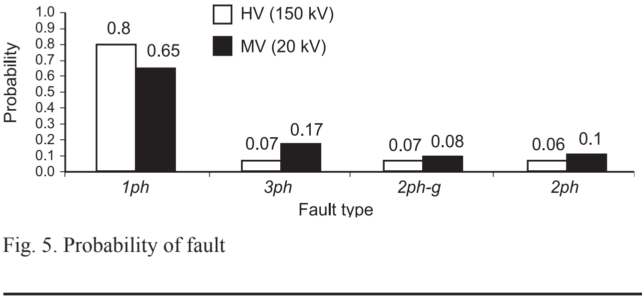

Fig. 5. Probability of fault

Table. 2. Fault rate at each voltage level.

Voltage level	Fault rate (events/km/ year)	Total Length (km)	Annual expected number of faults
MV(20 KV)	1	40	40
HV(150kV)	0.1	800	800

6. CONCLUSION

In this paper a simple power system is studied for voltage sag at node where sensitive load is connected due to faults of any type on any line at any distance. Voltage sag magnitude depends on the type as well as location of fault. The sag can be symmetrical or unsymmetrical in all the three phases. For uniform fault distribution along the lines and with assumed fault rate, the numbers of sags of different magnitudes experienced by load at node 1 are estimated. Simulation in PSCAD/EMTDC software environment was very simple. Further the study of estimation of phase angle of sag can be done and effect of transformers on sag can be studied.

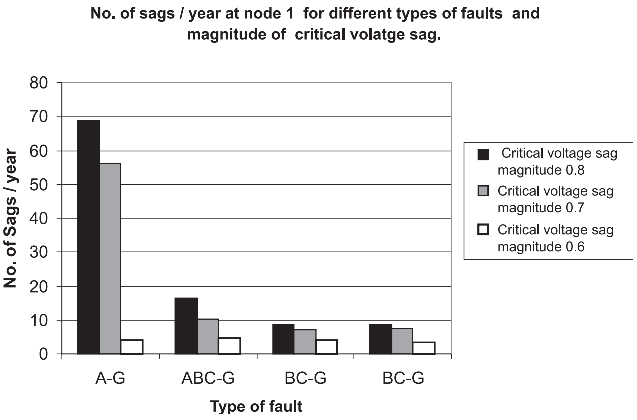

Fig. 6. Prediction of No. of sags at node 1

Table. 3. Calculations of expected no. of sags for critical sag voltage magnitude 0.8 pu for A-G fault.

Type of fault	Voltage level	Line	Length of the for which the voltage is less than critical voltage	Total length	Annual expected Fault numbers	Expected No. of sags	Total No of sags at node 1
A-G	HV Level	Line 8-9	0.4*200=80	680	680*0.1=68	68*0.8=54.4	68.7
		Line 7-8	1*500=500				
		Lin7-9	1*100=100				
	LV Level	Line 1-2-3-4	2.1*10=21	22	22*1=22	22*0.65=14.3	
		Line 2-5	.1*10=1				
		Line 3-6	0*1=0				

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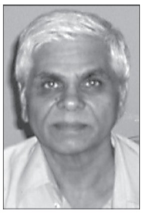

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