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EFFECT ON VOLTAGE SAG DUE TO INCREASED PENETRATION LEVEL OF WIND BASED DG

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Abstract

This paper discuss the effect on voltage sag with increased penetration level of wind based DG in a transmission network. The analytical method is applied for assessment of voltage sag in meshed network. The 30 bus reliability test system is considered for the study. The DGS with synchronous and induction generators are assumed to be connected at different buses of the network in order to evaluate the effect of distributed generation. Number of voltage sag is predicted and presented for all fault types without DG, 3.6% penetration of DGS and 6% penetration of DGS. The analytical method is used to predict number of voltage sags in MATLAB. The results are presented for deep and shallow voltage sags in order to deduce severity of voltage sags with connection with DG. Total voltage sags are also evaluated in order to predict reduction of voltage sags with connection of DGs.

Keywords: voltage sags, Distributed generation, stochastic assessment

Introduction

Nowadays power industry is experiencing lot of changes as issue of environmental protection and depletion of energy resources are of great concern. Nuclear disaster in 2011 in Japan propelled nations to move away from nuclear energy and countries such as Germany plan to end the use of nuclear energy by 2022 and increase its targets for share of renewables in electricity. India has set for itself an ambitious target under the National Action Plan on Climate Change (NAPCC) and seeks to increase the percentage of electricity generated from renewable sources from 5% in 2009-10 by 1% every year to reach 15% by 2019-20.[12]

The period from 2006 to 2011 witnessed a sharp growth in renewable energy technologies with solar photovoltaic (PV), biomass, wind energy. The renewable energy source connected to distribution system or consumer end is considered as Distributed Generation. The small scale renewable energy power generation ranges from 5 KW to 5 MW. The range of DG has been widening up to 300 MW [3] hence increasing penetration in power system.

Over the last few years, size and numbers of DG connected to electric power system are growing. This penetration leads to change in modeling and analysis of power system. The inclusion of DG affects the power quality issues of power system. The voltage sag is an issue of concern in power quality. It incurs technical and economic losses to commercial, residential and commercial consumers [1][2]. The inclusion of DGs has an impact on the evaluation of the voltage sag. In particular, DGs influence the pre-fault operating conditions, modifying the voltage profiles in the network by the injection of active and reactive powers. Moreover, during a fault; DGs contributes to short circuit current which depends upon size, type of DG and their controlling methods [8]. So, it is necessary to assess and analyze the impact on voltage sag with inclusion of DG in power system.

In previous study voltage sag assessment is done with Monte-Carlo, fault position and method of critical distance. An analytical method was also suggested to assess voltage sag for finding fast evaluation of expected sag frequency (ESF) and area of vulnerability [4-7]. This paper presents the influence on voltage sag with inclusion of DG in 30 bus test system. The assessment of voltage sag is done by analytical method by considering short circuit faults. Number of voltage sag is predicted and presented for all fault types without DG, 3.6% penetration of DGS, 6% penetration of DGS.

Modeling of DG

During the fault, contribution of DGs to the short circuit current can be evaluated by modeling the generation devices on the basis of type of connection to the network: directly or via a power electronic device. In the case of direct connection, each DG unit is modeled be means of the corresponding equivalent positive sequence short circuit impedance. In the following the short circuit impedance three types of generators are installed in DGs [9]

a. Synchronous generators are modeled by equivalent positive sequence short circuit impedance Z_{syn} equal to

$$Z_{syn}=R_G + jX_d'' \qquad (1)$$

Where RG is the resistance and X_d”is the positive sequence subtransient reactance.

b. Asynchronous generators are modeled by the equivalent positive sequence short circuit impedance Zasynequal to

$$Z_{asyn}=R_G + jX_G \qquad (2)$$

c. Double fed asynchronous generators (DFIGs) are treated as conventional asynchronous generators when calculating their maximum fault current contribution.

In the case of connection by power converters, in spite of the type of installed generator, each DG unit can be modeled by means of current generator. In fact during the fault, the fault power converters inject an overcurrent not exceeding, 150-200% of their rated current. Consequently the DG is modeled by a current injection I_{DG} equal to the variation ΔI_{DG} between the current injected during the fault $I_{DG,f}$ and that injected in pre-fault conditions $I_{DG,pf}$[8]

$$\Delta I_{DG}=I_{DG,f} - I_{DG,pf} \tag{3}$$

Analytical method for voltage sag

For the calculation of voltage sag magnitude, load flow analysis is performed to get pre-fault voltage. In load flow analysis DGs are also included to get modified pre-fault voltages. In various studies, it is suggested that in load flow DGs can be modeled as PV bus with power factor control mode, as slack bus and can be modeled as negative load (PQ) bus. In addition, various driving point and transfer impedances are calculated using Zbus building algorithm including DGs.

Now let us assume fault position is moving along the line connecting bus m-n. Let us consider fault occurring at position p which is λ distance from bus m. The parameter λ varies 0 to 1 as a fault position moves from bus m to n.

$$\lambda = \frac{L_{mp}}{L_{mn}} \tag{4}$$

The driving point impedance s and the transfer impedances and the transfer impedances of three sequence circuit can be expressed in terms of the sequence impedances. The sequence transfer impedance between the sensitive load bus k and fault position p can be expressed as

$$z_{kp}^{0} = (1-\lambda) z_{km}^{0} + \lambda z_{kn}^{0} \tag{5}$$

$$z_{kp}^{1} = (1-\lambda) z_{km}^{1} + \lambda z_{kn}^{1} \tag{6}$$

$$z_{kp}^{2} = (1-\lambda) z_{km}^{2} + \lambda z_{kn}^{2} \tag{7}$$

The pre-fault voltage at fault position p is expressed as follows

$$V_p^{pf} = (1-\lambda) V_m^{pf} + \lambda V_n^{pf} \tag{8}$$

Single phase to ground (SLGF)

When an SLGF occur at phase A, the residual phase voltages at bus k can be expressed [10] as

$$V_A^f = V_A^{pf} - \frac{Z_{kp}^0 + Z_{kp}^1 + Z_{kp}^2}{Z_{pp}^0 + Z_{pp}^1 + Z_{pp}^2} V_p^{pf} \tag{9}$$

$$V_B^f = a^2 V_A^{pf} - \frac{Z_{kp}^0 + a^2 Z_{kp}^1 + a Z_{kp}^2}{Z_{pp}^0 + Z_{pp}^1 + Z_{pp}^2} V_p^{pf} \tag{10}$$

$$V_C^f = a V_A^{pf} - \frac{Z_{kp}^0 + a Z_{kp}^1 + a^2 Z_{kp}^2}{Z_{pp}^0 + Z_{pp}^1 + Z_{pp}^2} V_p^{pf} \tag{11}$$

Line to Line fault (LLF)

When an LLF occur between phase B and C, the residual phase voltages at bus k can be expressed as [10]

$$V_A^f = V_A^{pf} - \frac{Z_{kp}^1 - Z_{kp}^2}{Z_{pp}^1 + Z_{pp}^2} V_p^{pf} \tag{12}$$

$$V_B^f = a^2 V_A^{pf} - \frac{a^2 Z_{kp}^1 - a Z_{kp}^2}{Z_{pp}^1 + Z_{pp}^2} V_p^{pf} \tag{13}$$

$$V_C^f = a V_A^{pf} - \frac{a Z_{kp}^1 - a^2 Z_{kp}^2}{Z_{pp}^1 + Z_{pp}^2} V_p^{pf} \tag{14}$$

Double Line to Ground Fault (DLGF)

When a DLGF occur at phases B and C involving ground the residual phase voltages at bus K is expressed as [10]

$$V_A^f = V_A^{pf} - \frac{\left(Z_{kp}^1 - Z_{kp}^0\right) Z_{kk}^2 + \left(Z_{kp}^1 - Z_{kp}^2\right) Z_{kk}^0}{Z_{pp}^0 Z_{pp}^1 + Z_{pp}^1 Z_{pp}^2 + Z_{pp}^2 Z_{pp}^0} V_p^{pf} \tag{15}$$

$$V_A^f = a^2 V_A^{pf} - \frac{\left(a^2 Z_{kp}^1 - Z_{kp}^0\right) Z_{kk}^2 + \left(a^2 Z_{kp}^1 - a Z_{kp}^2\right) Z_{kk}^0}{Z_{pp}^0 Z_{pp}^1 + Z_{pp}^1 Z_{pp}^2 + Z_{pp}^2 Z_{pp}^0} V_p^{pf} \tag{16}$$

$$V_A^f = a V_A^{pf} - \frac{\left(a Z_{kp}^1 - Z_{kp}^0\right) Z_{kk}^2 + \left(a Z_{kp}^1 - a^2 Z_{kp}^2\right) Z_{kk}^0}{Z_{pp}^0 Z_{pp}^1 + Z_{pp}^1 Z_{pp}^2 + Z_{pp}^2 Z_{pp}^0} V_p^{pf} \tag{17}$$

Three Phase Fault (3PF)

In balanced fault only positive sequence matrix is required. When a 3-ph fault occurs, the residual voltage at bus k can be expressed as [10]

$$V_k^f = V_k^{pf} - \frac{Z_{kp}^1}{Z_{pp}^1} V_p^{pf} \tag{18}$$

Table I. Failure rate for buses and lines

Type of fault	Bus failure rate (Event/Year)	Line Failure Rate (Event/100 km/year)
SLGF	0.064	2.00
LLF	0.004	0.125
DLGF	0.008	0.300
3PF	0.003	0.100

Result and Discussion

The voltage sag stochastic prediction method is applied to the IEEE 30 bus reliability test system represented in Figure 1, in order to analyses the impact of DG on the predicted number of voltage sags.

The IEEE 30 bus reliability test system consists of five generating units, 30 buses interconnected by 37 lines, and 4 transformers. The failure rate for buses and line is given in TableI.The positive, negative and zero sequence internal impedances of all generators are j0.3, j0.2 and j0.05 respectively [10]. The system data are available from [11].

The stochastic assessment of voltage sags has been performed for three scenarios of network:

- Case 1 Original transmission network, without any DG in the system.
- Case 2 Inclusion of three DGs capacity of 3.6 MW each at bus 7, 29, 30 respectively with power factor control mode. With 3.6% penetration of DG in the system
- Case 3 Inclusion of five DGs capacity of 3.6 MW each at bus 7, 19,26,29,30 respectively with power factor control mode. With 6% penetration of DG in the system.

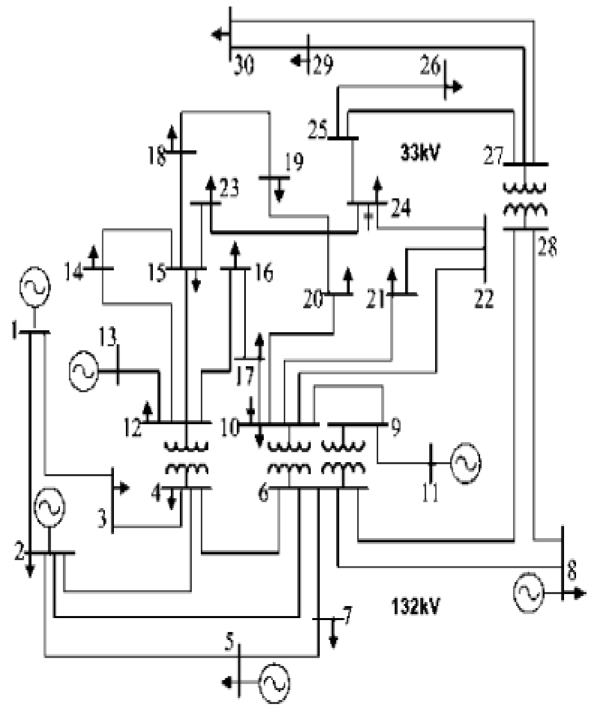

Figure 1. Single-line diagram of the IEEE-30 bus system.

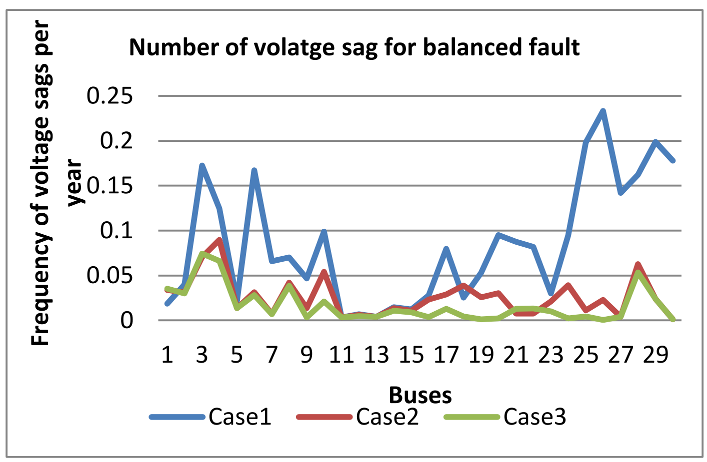

Figure 2. Number of voltage sags for 3ph fault for 0.3<Vsag<0.4

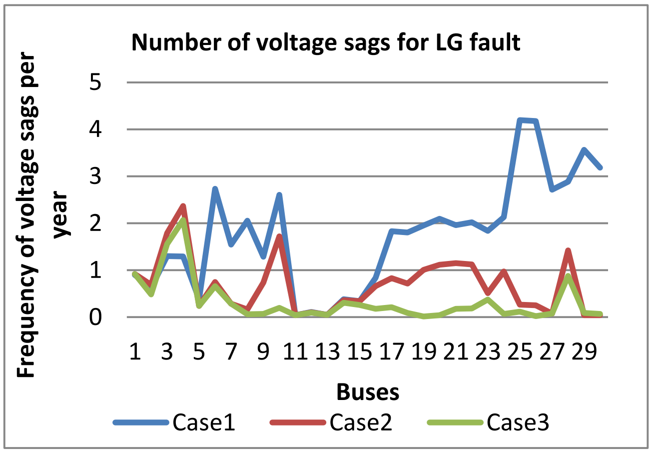

Figure 3. .Number of voltage sags for LG fault for 0.3<Vsag<0.4

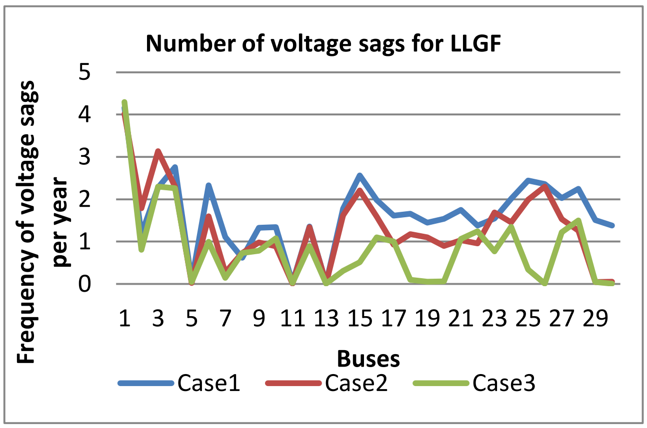

Figure 5. Number of voltage sags for 3ph fault for magnitude 0.7<Vsag<0.8p.u

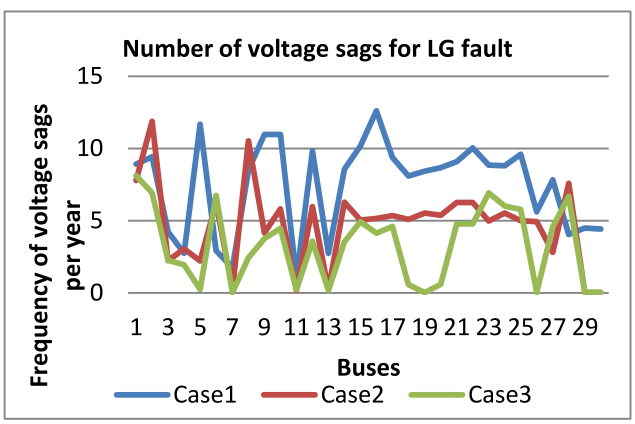

Figure 6. Number of voltage sags for LG fault for magnitude 0.7<Vsag<0.8p.u

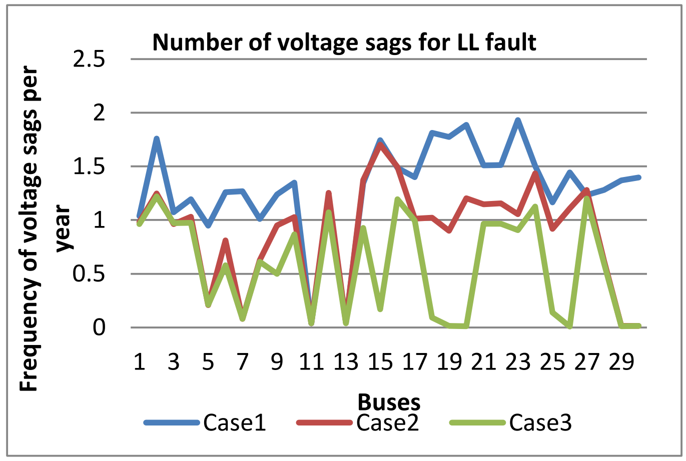

Figure 7. Number of voltage sags for LL fault for magnitude 0.7<Vsag<0.8p.u

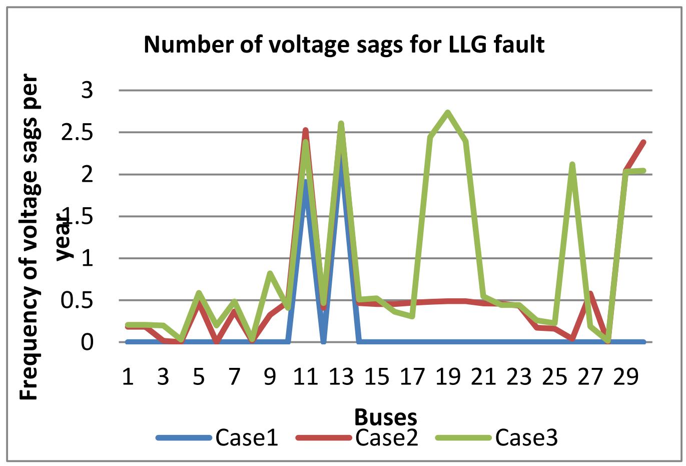

Figure 8. Number of voltage sags for LLG fault for magnitude 0.7<Vsag<0.8p.u

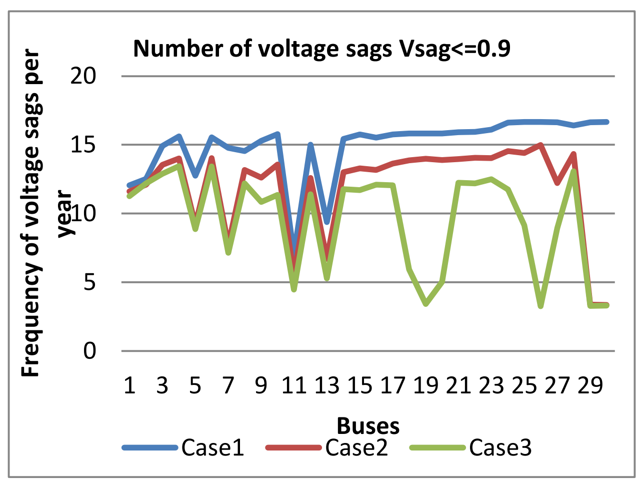

Figure 9. Number of voltage sags for all fault for voltage sag magnitude <0.9 p.u

Table II. Percentage reduction of overall voltage sags (<0.9 p.u) for Case 2

Bus	Case 1	Case2	% reduction
1	12.050	11.602	3.72
2	12.514	12.110	3.22
3	14.925	13.541	9.28
4	15.614	14.006	10.30
5	12.739	9.174	27.98
6	15.549	14.030	9.77
7	14.781	7.690	47.97
8	14.532	13.159	9.45
9	15.282	12.600	17.55
10	15.767	13.571	13.93
11	7.007	5.484	21.74
12	14.999	12.577	16.15
13	9.384	6.699	28.61
14	15.426	13.018	15.61
15	15.762	13.291	15.68
16	15.524	13.173	15.15
17	15.765	13.632	13.53
18	15.813	13.867	12.31
19	15.827	13.986	11.63
20	15.815	13.899	12.12
21	15.917	13.970	12.23
22	15.942	14.044	11.90
23	16.096	14.031	12.83
24	16.609	14.549	12.40
25	16.652	14.406	13.49
26	16.655	14.984	10.03
27	16.628	12.211	26.56
28	16.394	14.331	12.59
29	16.648	3.362	79.80
30	16.650	3.355	79.85

Table III. Percentage reduction of overall voltage sags (<0.9 p.u) for Case 3

Bus	Case 1	Case3	% reduction
1	12.050	11.257	6.58
2	12.514	12.201	2.50
3	14.925	12.888	13.65
4	15.614	13.444	13.90
5	12.739	8.866	30.40
6	15.549	13.423	13.67
7	14.781	7.152	51.61
8	14.532	12.197	16.07
9	15.282	10.832	29.12
10	15.767	11.348	28.03
11	7.007	4.467	36.25
12	14.999	11.408	23.94
13	9.384	5.288	43.65
14	15.426	11.779	23.64
15	15.762	11.710	25.70
16	15.524	12.087	22.14
17	15.765	12.061	23.49
18	15.813	5.937	62.45
19	15.827	3.415	78.42
20	15.815	5.025	68.23
21	15.917	12.244	23.07
22	15.942	12.199	23.48
23	16.096	12.492	22.39
24	16.609	11.738	29.32
25	16.652	9.138	45.12
26	16.655	3.259	80.43
27	16.628	8.936	46.26
28	16.394	13.065	20.31
29	16.648	3.288	80.25
30	16.650	3.289	80.25

A. Impact of DG on severe voltage sag

This section presents the impact on severe voltage sag with inclusion of DGs. The number of voltage sags for all the three cases have been assessed for sag magnitude of 0.3-0.4 p.u, which is considered as severe voltage sag. The Figure 2 shows the voltage sag for 3-ph fault. With the increase of DG a significant reduction in lower sag has been observed. Similarly, this effect has been observed with LG fault except at buses 1-5. Buses 1-5 shows increase in number of voltage sags, as shown in Figure 3.

The lower order voltage sag is absent in case of L-L fault for all the three cases i.e with DG and without DG. The reduction of lower voltage sag in case of LLG fault is shown in Figure 4. Reduction in number of voltage sag due to LLG fault with DG has been observed. More reduction in number of lower sags has been observed in case of 3-ph and LG fault as compare to LLG fault. It has been observed that reduction in severe voltage sag has been observed with inclusion of DG. But at buses 1-5, increased number of voltage sags has been observed.

B. Impact of DG on less severe voltage sags

This section presents result of stochastic assessment of less severe voltage sags due to all the faults. The stochastic assessments of all the buses are done for voltage sag magnitude between 0.7 to 0.8 p.u. It has been seen from the graph that moderate reduction in number of voltage sag is there for 3ph fault and LG fault as shown in Figure 5 and 6 respectively. Almost 50% buses shows reduction of less severe voltage sags as compared to network without DG. A significant reduction in LL fault in case 3 and a moderate reduction in Case 2 have been observed, as shown in Figure 8. As compared to less severe sags, more severe sags (magnitude of 0.3-0.4 p.u.) for LLG fault has been reduced whereas increase in less severe sags (magnitude of 0.7 -0.8) has been observed, as shown in fig 4. So, we can converge that with inclusion of DG in test system, reduces the number of severe voltage sags for LLG faults.

C. Impact of DG on total number of voltage sags

This section represents the overall reduction of number of voltage sags. The assessment of number of voltage sags for magnitude of 0.9 p.u is done for single phase. The Figure 9 shows number of voltage sags for balanced and unbalanced voltage sag magnitude of 0.9 p.u. This can be seen that with connection of DG in the system total number of voltage sag reduces. It reduces further with increase in penetration of DGs. Case 3 shows significant reduction of overall voltage sags. Moreover, significant reduction in number of voltage sags is observed at buses which are connected to DG.

Table II and III shows percentage reduction of number of overall voltage sags for Case 2 and Case3 with inclusion of DGS. In Case 2 reductions at buses 7, 29, 30 are 47.97%, 79.80% and 79.85% respectively. It is clearly seen that buses at which inclusion of DGs have been done, reduces the number of voltage sags. Moreover voltage sag performance for the nearby buses is also improved due to the inclusion of DGs. In case 3 reductions at buses 7, 19,26,29,30 are 51.61%, 78.42%, 80.43%, 80.25% and 80.25% respectively. It clearly shows that increase in penetration of DGs reduces the number of voltage sags.

Conclusion

This paper discusses the effect on the voltage sags with increased penetration of wind based DG in 30 bus reliability test system. The sag performance is evaluated for three case studies, without DG, 3.6% penetration level, 6% penetration level of DGs respectively. Overall sag frequency has been reduced due to inclusion of DGS. The reduction of severity of voltage sag is observed in case of LLG faults for both the case studies (Case2 and Case3) by decrease in frequency of deeper voltage sags and increase in frequency of shallow voltage sags. It can be concluded that with the increase in penetration level of DGS, severity of voltage sags and reduction in frequency of voltage sags is observed.

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