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Impact of Distributed Generation on Power Distribution Systems

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Abstract

In order to reduce the green house gas emissions all over the world the investment on renewable energy infrastructure is increasing particularly in the distribution network. The penetration of generating sources in the distribution network changes the characteristics of distribution system and will have impact on various technical parameters based on its size and location in the network. This paper modeled the IEEE 34 Node distribution test feeder using the commercial software package DIgSILENT power factory version 14. Solar photovoltaic generators are introduced as Distributed Generators (DGs) at various nodes and the impacts that DG produces on real and reactive power losses, voltage profile, phase imbalance and fault level of distribution system is studied. Simulated results obtained using load flow and short circuit studies are presented and discussed.

Keywords: Distributed generators; power distribution; renewable energy sources; impact of distributed generators

1. Introduction

Motivated by pressures to reduce CO_2 emissions, today's generation planning efforts increasingly focus on the integration of renewable (Solar PV plants, wind systems and fuel cells etc) energy sources and different kinds of distributed generation [1]. The key drive towards Singapore's smart grid initiative is also to enable integration and management of distributed energy resources and renewable sources

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predominantly from solar energy [2].

Distribution systems initially designed to operate without any generation on the distribution system or at customer loads. The introduction of generating sources in to the distribution network called distributed generation (DG) can produce significant impact on power flow through the network, voltage condition at various utility consumer equipments and switchgear fault ratings. The severity of impact depends on the location (site) and size (penetration level) of the generating sources. The network has to be designed or existing network should enable DG connections without violating the statutory technical limits or standards such as voltage variation, phase imbalance and fault current limit etc. Reducing power losses is an environmental and economical concern. By producing power from distributed renewable sources and also reducing the distribution losses will help to reduce the output requirements from conventional plants which in turn reduce the greenhouse gas emissions. Since DGs are placed near to the load centre, appropriately placed DGs in the distribution network will contribute to reduction of power losses. Reducing distribution network losses alone can contribute to 1% of total greenhouse gas emissions.

The objective of this paper is to simulate the distribution test feeder and study the impacts that DG produces on real and reactive power losses, voltage profile, phase imbalance and fault level of distribution system by varying the penetration ratio and as well changing the placement of DGs at various nodes.

2. System Description

The IEEE 34 node test feeder [3, 4] shown in Fig. 1 is an actual feeder located in Arizona and characterised by long, lightly loaded, multiple three and single phase laterals and unbalanced distribution feeder with a total load of 1769 kW and 1044 MVAr and two different operating voltages of 24.9 kV and 4.16 kV. The test feeder is modeled using the DIgSILENT power factory 14.0 simulation package. This software enables steady state, dynamic and transient modelling of distributed energy resources and has the ability to simulate using both phasor and instantaneous value models [5].

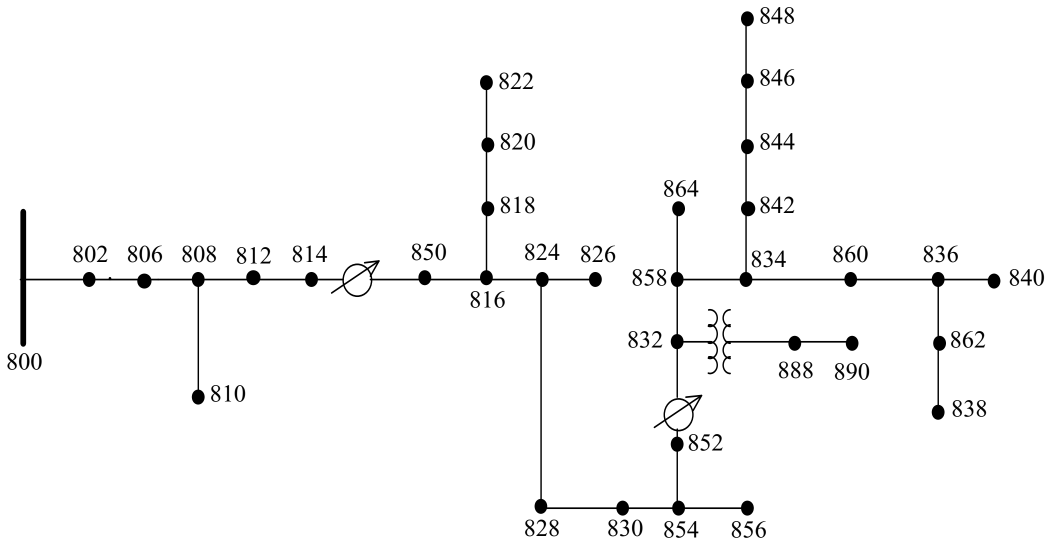

Fig. 1. IEEE 34 node test feeder

Distributed loads have been modeled as two thirds of the load is connected at a dummy node located at the one-quarter point of the line and the remaining one third of the load is connected at the load end of the line segment [6]. Voltage dependent load models have been used with a mix of constant power, constant current and constant impedance loads. Three phase autotransformer is used to simulate the voltage regulator. The external grid connected to the bus 800 is represented by an infinite bus with 1.05 p.u voltage and 20MVA short circuit capacity. The Z&B matrices of the feeder in phase components are converted to sequence components using Eq. (1) and Eq. (2) in order to enter the values in line type model of the feeders.

$$Z_1 = Z_2 = Z_s - Z_m \quad (1)$$

$$Z_0 = Z_s + 2Z_m \quad (2)$$

where,

$$Z_S = \frac{Z_{aa}+Z_{bb}+Z_{cc}}{3} \quad (3)$$

$$Z_m = \frac{Z_{ab}+Z_{ac}+Z_{ba}+Z_{bc}+Z_{ca}+Z_{cb}}{6} \quad (4)$$

The terms used in the calculation of *Zs* are self impedances and *Zm* are mutual impedances of phase a, b and c.

Solar photovoltaic (PV) generators are used as distributed generators. Three phase PV generator model available in the static generator library of the software is used. Single phase PV generators are modeled as negative loads, i.e. PQ element with injected current. Most of the commercial Grid connected PV inverters are designed to operate at unity p.f [7]. Hence it is acceptable to set the PV generator p.f to unity and it is treated as PQ for load flow calculation. Short circuit contribution from each DG is limited by its converter characteristics and control to a maximum of twice the rated current of the unit. Hence the short circuit contribution of the DG is set to twice its rating.

3. Impact of penetration level

The penetration level of distributed generation (DG) on the distribution network is measured against total load demand or the percentage of DG power referred to the rated power of the network [8]. The impact of penetration level is observed by installing the DGs at two different weak nodes of the network. Node 848 & 890 are identified as weakest points of the network where the system voltage is low (refer Fig. 2). Node 890 experiences the lowest per unit (pu) voltage because it is the heavily loaded node and high voltage drop in that low voltage branch due to high current. The single phase distributed DG penetration is analysed by distributing single phase DGs at nodes 810, 826, 856 and 838 for phase ‘B’ and at nodes 822 and 864 for phase ‘A’. The impact is evaluated by varying the penetration ratio as 10% and 20%. The voltage profile without DG penetration (Fig. 2) indicates that it is decreasing over the network length. In between due to voltage regulators and shunt capacitors the voltage gets boosted. From Table 1, it is observed that when the penetration level goes higher system losses gets reduced. The line losses in the distribution system are due to resistance of the over head lines and underground cables. As the DG capacity increases the power flow from the grid to the distribution network reduces to meet the demand and hence the total losses decreased. Minimum and maximum voltages represented in Table 1 represent the lowest and highest voltages of the network when DG is placed at particular node. Figures 2 and 3 represents the voltages of all the three phases at all the nodes without DG and with 20% DG penetration at node 890 respectively. It shows better voltage profile with DG penetration due to the reduction in reactive power loss as indicated in Table 1. The power quality aspect of phase imbalance also gets reduced as indicated in Table 1 with increase in penetration of three phase sources. The voltage unbalance factor (VUF) is used to define the degree of unbalance as given in Eq. (5).

$$VUF(\%) = \frac{V^-}{V^+} \times 100 \tag{5}$$

where, V^- is the pu negative sequence voltage and V^+ is the pu positive sequence voltage [9].

It is observed that the phase imbalance of the system gets increased due to single phase penetration of DG sources. Hence it is essential for the utility companies to restrict or distribute the max. capacity of single phase sources (among the phases) connected per phase as not to violate statutory limits.

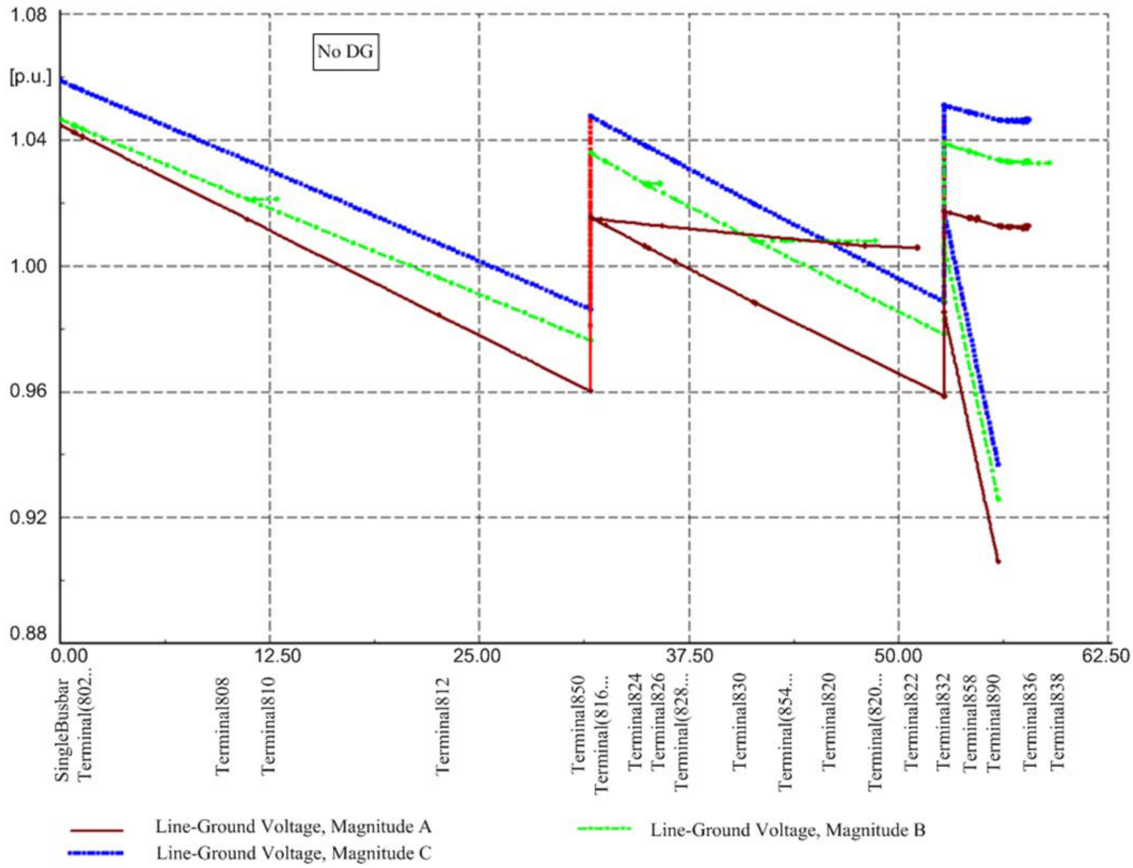

Fig. 2. Voltage profile – No DG penetration

Table 1. Impact of penetration level

DG Node/ % penetration	No DG	DG at 848		DG at 890		1 Phase DGs	
		10% DG	20% DG	10% DG	20% DG	10% DG	20% DG
Losses (MW)	0.2665	0.2223	0.1852	0.2017	0.1556	0.2357	0.2081
Losses (MVAr)	0.1190	0.0766	0.0404	0.0540	0.008	0.0887	0.0615
Min. Voltage	0.90619	0.9219	0.9371	0.9538	0.9753	0.9125	0.9186
Max. Voltage	1.05694	1.067	1.0823	1.0686	1.0839	1.0608	1.0822
Max. Phase imbal. (%)	1.9477	1.9357	1.9255	1.8769	1.8323	2.3553	3.0857
Max. Short Cir. current (KA)	1.1298	1.2034	1.2109	1.3020	1.3090	1.156	1.224

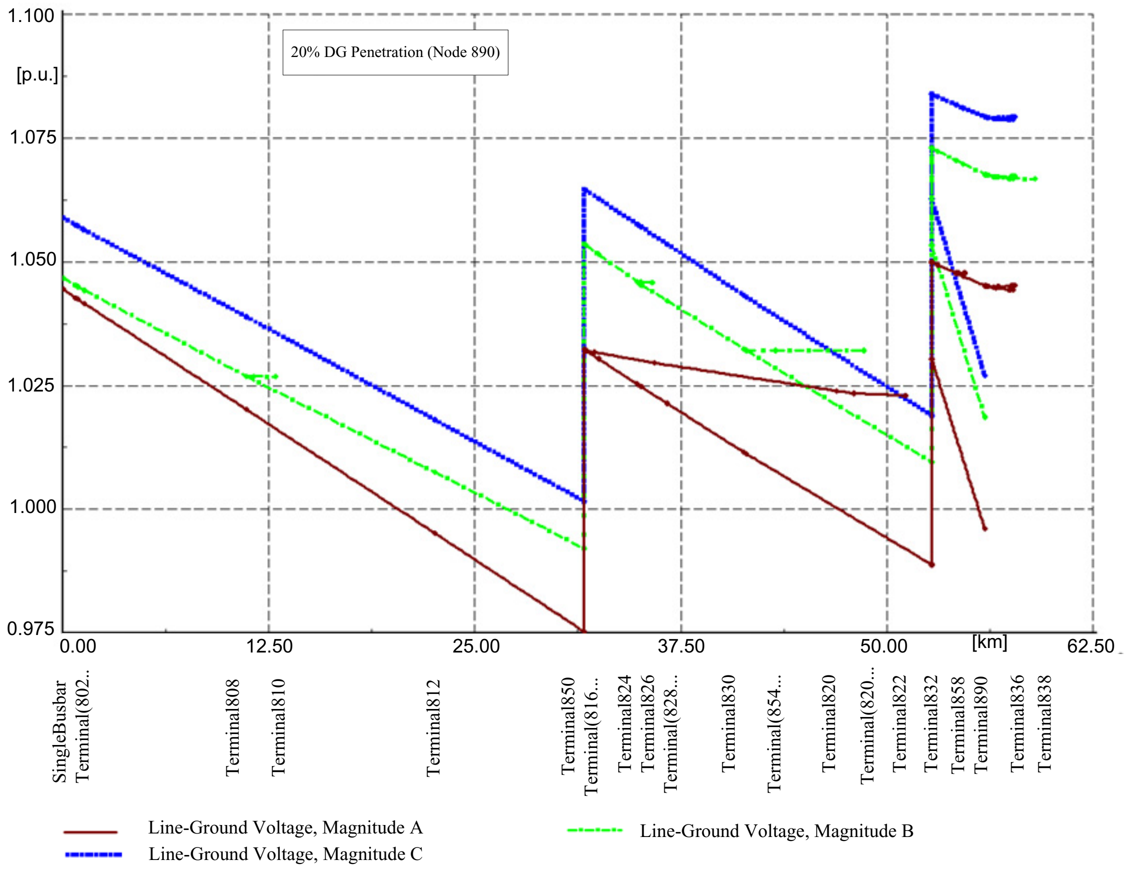

Fig.3. Voltage profile – 20% DG penetration

4. Impact of sitting

Impact of sitting is analysed by placing DGs individually at other junction nodes 808, 816, 854, 832, 834 and 840 (where laterals are branching out) assuming constant 20% penetration.

For each DG location the voltages of all the phases of every node is observed and compared with the equivalent voltages of the circuit without DG. For each DG location the minimum and maximum per unit voltage of the network and its corresponding node is recorded in Table 2. Over voltages are observed at node 832 when DGs are placed at nodes 832 and the on the nodes of three phase lateral branching from node 834. This is due to the capacitors placed on that lateral. By adjusting the capacitor switching this over voltage can be avoided.

Table 3 shows the summary of effect on distribution network's power losses and phase imbalance when the DGs are located at various nodes of the network. All the DG locations decreased the power losses in the circuit compared to no DG scenario. This is due to supply of whole power to the loads supplied from substation (bus 800) need to flow through many branches where as DGs closer to the loads scenario most of the power supplied by DGs and the balance power only flow through many branches leads to less loss. There is not much change in the % phase imbalance values for DGs at various nodes compared to no DG scenario. But there is a significant increase in phase imbalance due to the distributed single phase DG penetration as discussed in the previous section.

By introducing DGs the fault level of the distribution system will go higher. This is due to the fault current contribution by DGs. The increase in fault level may lead to malfunction or miscordination between fuse and circuit breaker which will affect the distribution system reliability and safety. Three phase short circuit faults are created at the various nodes as indicated in the Table 4 and short circuit calculations are carried out which includes three phase load flow. Fault current ratios are calculated using Eq. (4) and recorded as in Table 4. It is found from Table 4 that, the maximum value of fault current ratios occur for the fault at the generation node.

Table 2. Impact of DG locations on nodal voltages

	Min. Voltage		Max. Voltage	
DG node	Mag. (p.u)	Node	Mag. (p.u)	Node
No DG	0.90619	890	1.05694	800
808	0.91112	890	1.057267	800
816	0.921633	890	1.066514	832
854	0.92826	890	1.073279	832
832	0.936834	890	1.082037	832
834	0.937035	890	1.082285	832
840	0.937035	890	1.082277	832
848	0.937095	890	1.082341	832
890	0.975326	814	1.083875	832
1 phase DGs	0.918615	890	1.08223	832

Table 3. Impact of DG locations on losses and phase imbalance

DG Node	Losses (MW)	Losses (MVAr)	Max. % phase imbalance
No DG	0.2665	0.1190	1.9477
808	0.2527	0.1078	1.9394
816	0.2239	0.0718	1.9230
854	0.2074	0.0626	1.9222
832	0.1884	0.0421	1.9224
834	0.1853	0.0405	1.9252
840	0.1852	0.0404	1.9252
848	0.1852	0.0404	1.9255
890	0.1556	0.008	1.8323
1 phase DGs	0.2081	0.0615	3.0857

When DG is placed at node 890 there is a significant impact on fault current due to the low voltage circuit. This indicates that special attention should be paid to the adjustment and selection of protective devices when DG is placed at node 890.

$$\text{Fault current ratio} = \frac{Fault\ current\ with\ DG}{Fault\ current\ with\ out\ DG} \quad (6)$$

Table 4. Impact of DG on fault current ratio

	Fault current ratio								
Faulted Node/DG Node	808	816	854	832	834	840	848	890	1 phase DGs
800	1.090	1.078	1.071	1.065	1.063	1.063	1.063	1.036	0.993
808	1.143	1.128	1.118	1.110	1.108	1.107	1.107	1.062	0.993
816	1.078	1.264	1.244	1.231	1.226	1.224	1.224	1.129	0.993
854	1.064	1.210	1.318	1.304	1.297	1.295	1.294	1.168	0.996
832	1.050	1.160	1.238	1.426	1.416	1.412	1.412	1.229	0.997
834	1.048	1.152	1.226	1.402	1.444	1.440	1.439	1.218	0.998
840	1.047	1.149	1.220	1.390	1.431	1.454	1.426	1.212	0.998
848	1.020	1.149	1.220	1.390	1.430	1.426	1.454	1.212	0.998
890	1.143	1.058	1.083	1.133	1.131	1.130	1.130	2.127	1.017

5. Conclusion

The IEEE 34 node test feeder is modeled using DIgSILENT power factory software package. Load flow and short circuit study are carried out to find the various parameters to study the impacts of DGs.

Increase in penetration level shows positive impact on losses and voltage profile, i.e. reduction in power losses and improvement in the voltage profile of the system. DGs introduced in the distribution network reduces the losses since the DGs are closer to the loads avoids large amount power flow from substation to loads through many branches. The siting of DGs at various locations also shows positive impact on losses and voltage profile. The over voltage conditions observed due to the location of DGs at some specified nodes necessitates the adjustment of capacitor switching or voltage regulator setting to maintain the voltage at the consumer terminals within the statutory limits. Node 890 can be selected as the best node for introducing three phase DGs due to comparatively good reduction in power losses, better voltage profile and not much violation of phase imbalance. The only special attention required when DG is placed at node 890 is the adjustment or change of protective devises due to considerable increase in fault level. When introducing distributed single phase DGs care should be taken in allocating the DGs at different phases such that statutory limit on phase imbalance is not violated.

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