Analysis of a radial distribution network and mitigating losses by strategic allocation of Distributed Generation

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Abstract
Power system having a centralized network operation and experiences numerous drawback while communicating and transmitting power to long distance. Conventional system majorly rely on the fossil fuel sources that leave CO2 emission footprints leading to environmental pollution. In this work, analysis of voltage profile and power loss issue of IEEE 15 bus radial system is achieved. Network is modified by strategically integrating the distributed generation (DGs) to the system. For the simulation of radial network and load flow algorithm, the MATLAB platform is used. Different cases are studied and simulated to observe the voltage improvement and power loss reduction of the system.
Keywords:
Distributed Generation (DG), Transmission System, Power System, Distribution Network.

1. Introduction

Power system comprises of centrally operating system network that look after the power delivery to the consumers. [1]. Power generation in Pakistan, takes place at two different levels i.e. 13.8 and/or 11 kV, and this majorly rely on the fossil fuel resources like thermal plant that even placed at far long distance from the load centers [2].
Electrical power transmission system conventionally follows the stream of power from higher to lower potential level and this causes power loss in the system during the delivery of power to the consumers. The generation of power has no any coordination with the delivery of power to the consumer as some amount of power is being lost in the transmission system [3, 4 & 5].
The conventional power system has many other drawbacks along with distant transmission network. Nowadays, the pollution has become a great concern for the researchers. Currently, fossil is main source of power generation in Pakistan which leads to great amount of CO2 emission, nuclear-power generation's left-over. Not only the environmental issue but the efficiency also plays a great role as the fossil fuel depleting and the system is not in a situation to increase the generating capacity which leads to poor efficiency, power outage and security concerns [6, 7].
As the conventional transmission network, in Pakistan, is already operating on full capability and further increase may lead to the great voltage drop, power losses and even there are chances of power blackout as well. Globally, the power system is diverting towards the renewable energy sources particularly the integration of renewable sources with the conventional system in order to meet the energy demand by complementing the orthodox transmission system without being altered or modified. Integration of DG provides great ecological, technical and lucrative benefits and this is mainly because of DG location closer to the consumer [8].

2. Literature Review

Researchers have been giving keen interest to the proper sizing and siting of DG in the distribution network. Many researchers have worked on different scenarios to identify the best solution to this problem.
Mari et al (2018) incorporated 11kV radial distribution feeder with PV generation framework and dissected the influences. Joining of PV system to the feeder is accomplished in three diverse ways, utilizing SINCAL programming and its significance was investigated. PV system association to the load came about as noteworthy addition in voltage and a slighter augmentation in short circuit level. Results likewise brought some improvement in LT and HT losses
Sahito et al (2017) selected strategic locations for the DG integration to the existing radial distribution network and analyzed the reduction in power loss. The author studied three different cases and comparatively analyzed the power quality improvement with the existing distribution network. Simulation was achieved with the help of PSS Sincal software.
Sahito et al (2015) examined the effects of DGs over power misfortunes, voltages and the short circuit level of the network. The influences DG over power framework were examined with the help of PSS SINCAL software. Contingent on the size and vital areas the Significant power misfortunes and the voltage enhancement were witnessed and the minor increment in the short circuit levels were seen inside allowable cutoff points of gadgets.

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Mahmud et al (2014) obtained an analytical approach to tackle the voltage stability issue. The estimation of voltage variation is done using analytical approach and the formula is drived for the same to build relation between the voltage variation and DG capacity available.
Davda et al (2014) evaluated a real 3.9 MVA network and built up a strategy for choosing suitable area of inserted embedded generators. Through the exploitation of simulations it uncovered the eradication of low voltage issue within the chosen territory. Energy loss decline and expanded reserve capacity, likewise accomplished
Zhao et al (2014) acknowledged the susceptible nodes within the system using small-world network theory. At that point genetic algorithm was suggested to address the ideal size and site for DG associated with grid. Efficiency was enhanced enormously and turned out to be reasonable for adaptable DN topology in active distribution network
Zulpo et al (2014) suggested a model to address the optimal size and location of DG that brought about decrease in power misfortune and voltage deviance minimization. Moreover, it is programming model with sporadic derivatives that exploit binary variables for outlining the spot through traditional optimization method
Many authors have demonstrated the benefits of DG and its integration to the convention network but the optimum selection of size and location is still a challenging zone as this require autonomous system to cope up with the challenge.
In this work, IEEE 15 bus radial system is analyzed. Network is modified by strategically integrating the DGs to the system. For the simulation of radial network, MATLAB platform is used. Different cases are studied and simulated to observe voltage improvement and power loss reduction of the system.

3. Distributed Generation

Distributed Generation (DG) alludes to the concept of power generation near to the consumer end, for example renewable energy sources like solar and wind [2-5]. IEEE describes DG as, “The generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system” [7]. DGs can be utilized as a solitary structure like as home or a commercial building and it might also be presented as a micro grid, a small grid associated with large distribution network. When associated with the low voltage transmission lines, DG can support the deliverance of clean energy along with reliability of power supply to the client end, bringing about elimination of power loss.
DG is very useful and beneficial for the utilization at the immediate locations. As it compensate the power loss at immediate location so this eradicates the construction of large network and results in enormous reduction in expenditures.

4. Problem formation

Integration of DG to conventional distribution network has enormous benefits but there are complications as well. Proper placement and sizing of DG plays a very crucial role in the distribution system as improper selection of size and location may cause the system to respond more destructively. Keeping in view the electrical system complication due to widespread distribution network and complex infrastructure, the identification of nodes with poor voltage level is very crucial and this needs to be identified.
For the radial distribution network to be analyzed it is important to calculate the voltage at bus and the power loss in each branch i.e. within two buses.
The voltage at specified bus can be calculated with the help following equation.

$$\boldsymbol{V_b = V_a - I_i * (R_i + jX_i)}$$
$$\boldsymbol{= V_a - \left\{P_i - j\left(Q_i + \frac{V_k^2 + Yi}{2}\right)\right\} * \frac{R_i + jX_i}{V_k}}$$

Where V_a and V_b are sending and receiving end voltage. P_i and Q_i are active and reactive power respectively. R_i and X_i are the resistance and reactance of a branch.
Similarly the active and reactive power loss can be calculated as

$$\boldsymbol{P_{loss}(a,b) = \left(\frac{P_a^2 + Q_a^2}{|V|^2}\right) * R_i}$$

$$\boldsymbol{Q_{loss}(a,b) = \left(\frac{P_a^2 + Q_a^2}{|V|^2}\right) * X_i}$$

P_{loss} and PQ_{loss} are the active and reactive power of branch from bus a to b in a two bus network.
The total loss within a branch is given by the following equation.

$$T_{loss} = \sum_{i=1}^{i=n-1} P_{i\ loss} + j\sum_{i=1}^{i=n-1} Q_{i\ loss}$$

5. System Description

In this work, standard IEEE 15 Bus radial distribution system is studied to analyze the effect of integrating DG over the power loss and voltage drop. The illustration of IEEE 15 Bus system is shown below in (**Figure. 1**).

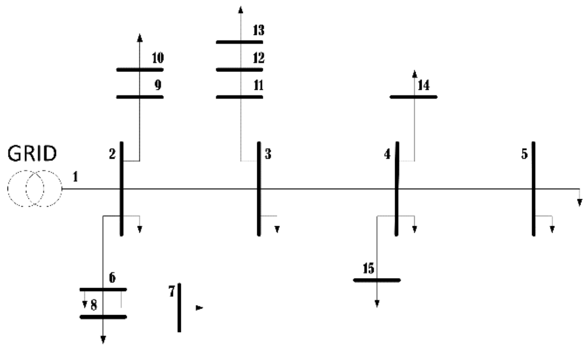

Fig. 1 One-Line Diagram

Three different buses are selected for integrating DG. The cases are done on the same standard power i.e. 1 MW. Strategically, 30% of the load is added as DG to three different selected nodes. Four cases are simulated for the observation of voltage drop and power loss improvement. Below is the table showing four different cases being taken under consideration.

Table. 1: Cases under consideration

Case No.	***Description***
1	Basic network (without integration of DG)
2	Addition of 30% of Load as DG at Bus # 15
3	Addition of 30% of Load as DG at Bus # 05
4	Addition of 30% of Load as DG at Bus # 13

6. Results and Discussion

Cases listed in (Table. 1) are simulated to observe the improvement in voltage drop and power loss. The load impedance of each branch in the above illustrated network is given below in (Table. 2). DG plays a very crucial role in the improvement of active and reactive power of the system. With the integration of DG to the system, the voltage profile has improved in all cases instead the level of improvement varies with the variation of DG placement. After the evaluation of above mentioned four cases it can be clearly stated that the integration of DG can improve the voltage drop and power loss of the system, eventually the system efficiency is improved. (Figure.2 - a, b and c) illustrates the voltage profile of the network with the installation of DG source at three different locations respectively.

Table. 2: Load Impedance of all branches

Branches (Sender to Receiver)			***Load Impedence***	
Branch No.	***Sending End***	***Receiving End***	***R (Ω)***	***X(Ω)***
1	1	2	1.35309	1.32349
2	2	3	1.17024	1.14464
3	3	4	0.84111	0.82271
4	4	5	1.52348	1.0276
5	2	9	2.01317	1.3579
6	9	10	1.68671	1.1377
7	2	6	2.55727	1.7249
8	6	7	1.0882	0.734
9	6	8	1.25143	0.8441
10	3	11	1.79553	1.2111
11	11	12	2.44845	1.6515
12	12	13	2.01317	1.3579
13	4	14	2.23081	1.5047
14	4	15	1.19702	0.8074

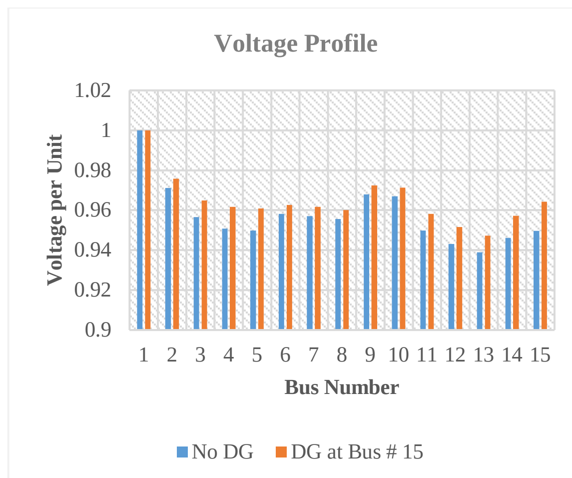

Fig. 2(a) Voltage Profile with DG at Bus # 15

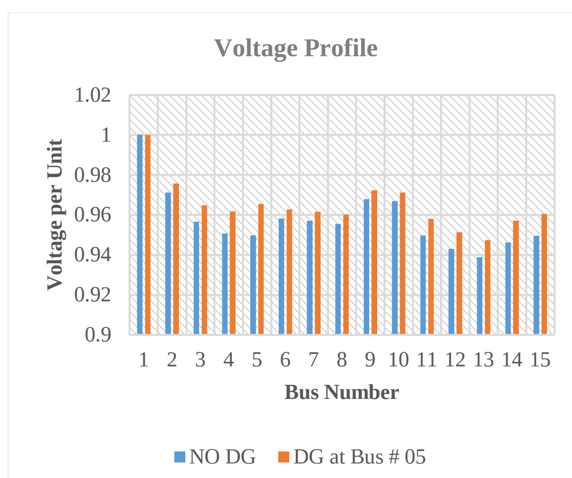

Fig. 2(b) Voltage Profile with DG at Bus # 05

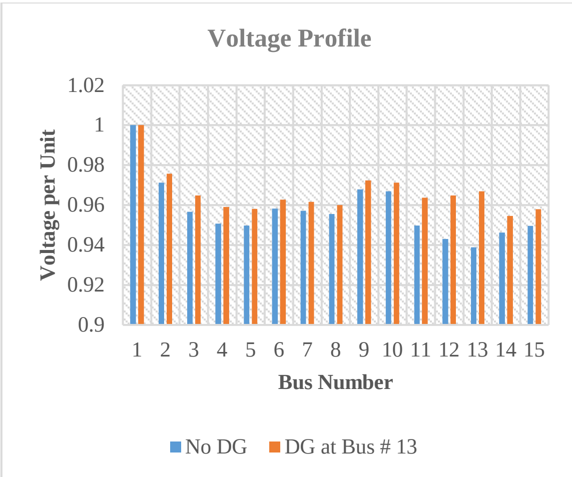

Fig. 2(c) Voltage Profile with DG at Bus # 13

Table. 3: Active and Reactive power before and after DG

Bus No.	*Before DG*		*After DG*					
	Active Power Loss (kW)	*Reactive Power Loss (kvar)*	*Active Power Loss (KW)*	*Reactive Power Loss (kvar)*	*Active Power Loss (KW)*	*Reactive Power Loss (kvar)*	*Active Power Loss (KW)*	*Reactive Power Loss (kvar)*
-----	*Case No. 1*		*Case No. 2*		*Case No. 3*		*Case No. 4*	
2	37.8001	36.9732	27.9751	27.3631	27.9965	27.3841	27.9821	27.37
3	11.3388	11.0908	6.9891	6.8362	6.9982	6.8451	6.9929	6.8399
4	2.4464	2.3929	1.2279	1.201	1.2302	1.2033	2.4043	2.3517
5	0.0554	0.0373	0.0541	0.0365	1.4431	0.9734	0.0544	0.0367
6	0.4721	0.3184	0.4678	0.3155	0.4678	0.3156	0.4678	0.3156
7	0.0592	0.0399	0.0586	0.0395	0.0586	0.0395	0.0586	0.0395
8	5.768	3.8906	5.7144	3.8544	5.7145	3.8545	5.7145	3.8545
9	0.0982	0.0662	0.0972	0.0656	0.0972	0.0656	0.0972	0.0656
10	0.4529	0.3055	0.4486	0.3026	0.4487	0.3026	0.4486	0.3026
11	2.1996	1.4837	2.1612	1.4578	2.1613	1.4578	1.2856	0.8672
12	1.5836	1.0681	1.5558	1.0494	1.5558	1.0494	1.4973	1.01
13	0.7546	0.509	0.7413	0.5	0.7413	0.5	1.2864	0.8677
14	0.8234	0.5554	0.8046	0.5427	0.8046	0.5427	0.8091	0.5458
15	0.1097	0.074	0.9982	0.6733	0.1072	0.0723	0.1078	0.0727

(Table. 3) gives a comparative analysis of the active and reactive power for all the cases under consideration including the condition before integration of DGs. The active and reactive power is identified for each and every branch for insight observation of the power loss improvement. 'Case No. 1' is a base case that shows the active and reactive power loss of the system before network modification. Case No.4 shows the most satisfactory results in total power loss improvement from '0.0640 + 0.0588i' to 0.0492 + 0.0445i. Further detailed study of each bus is given for all cases is given below in table.

7. Conclusion

In this work, IEEE 15 bus network is analyzed for the voltage drop and power loss using network simulation. MATLAB is used for simulation of selected radial distribution network. Comparative analysis of existing network is given with the modified network by integration of DG at strategic locations.

The simulation analysis was achieved on three different cases with the same level of DG integration. All the three cases showed satisfactory results for the reduction in both active and reactive power losses. The approach used in this paper can be utilized efficiently in future perspectives for planning of distribution network effectively.

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