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IMPACT OF EMBEDDING RENEWABLE DISTRIBUTED GENERATION ON VOLTAGE PROFILE OF DISTRIBUTION SYSTEM: A CASE STUDY

Akash T. Davda[1], M. D. Desai[2] and B. R. Parekh[3]
[1]Research Scholar, Institute of Technology, Nirma University, Ahmedabad, India
[2]Department of E and C Engineering, Kalol Institute of Technology and Research, Kalol (NG), India
[3]Department of Electrical Engineering, Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar, India
E-Mail: aakashdavda@yahoo.com

ABSTRACT
Present scenario of Power system operation is contingency-constrained, and often associated with voltage limit violation problems. In this paper, the low voltage problems in an existing 2.2 MVA conventional electricity distribution network of a particular area of Gujarat State, India, have been identified and solved by injecting Renewable Distributed Generation at appropriate locations. The results of the simulations carried out using distribution system software were analyzed with respect to voltage at different nodes thereby identifying low voltage areas which were again studied by injecting RDGs at different locations and the results were analyzed. The final analysis revealed that there was no low voltage problem at any node on the network. It has been concluded that looking to serious environmental problems like pollution, greenhouse gas emissions, and long and over loaded lines attached to conventional electric power generation, transmission and distribution Networks, the injection of Renewable Distributed Generation can give a solution to low voltage problems. Reduction in losses and increased reserve capacity of the distribution network are the added advantages.

Keywords: distribution system, forward / backward sweep, renewable distributed generation, voltage profile.

1. INTRODUCTION
The traditional approach in electric power generation is to have centralized plants distributing electricity through an extensive transmission and distribution network [1]. Serious environmental problems like pollution, greenhouse gas emissions etc. are related with the conventional power generation. Long and over loaded lines are inherently attached to conventional distribution networks. This has resulted into serious low voltage problems being faced by consumers in general and by consumers of rural area in particular. The conventional methods of resolving low voltage problems include load balancing, bifurcation of overloaded lines, installation of shunt capacitors, High Voltage Distribution System etc [2].

'Distributed Generation' (DG) can be defined and is generally agreed upon as any power generation that is integrated within the distribution system. DG encompasses a wide range of generator technologies such as photovoltaic systems, wind turbines, fuel-cells, internal combustion engines, gas turbines etc. If the technology uses renewable energy source for power generation, it is appropriately known as 'Renewable Distributed Generation' (RDG). Though the amount of energy produced by RDGs is relatively small compared to the ratings of large centrally located power plants as at present, they are situated close to the electricity users giving maximum benefit of Generation even in small quantum. Many a times it is even integrated at consumers' installations, called 'Embedded Generation'.

This paper deals with integration of Distributed Generation and looks at feasibility of addition of renewable generation in today's long and over loaded existing distribution systems. It is aimed at analyzing the impact of addition of RDGs on voltage profile, losses and expansion options etc. providing guidelines for arriving at appropriate locations for RDGs etc.

This paper is structured as follows: Section I introduces the subject. Section II describes the problem formulation and gives the data of existing Network, section III details the modeling of Distribution System under study along with RDGs, required for simulation purposes and section IV describes the methodology developed for the study. Section V is about simulation of Network along with integration of RDGs. Section VI covers the results of the study and finally in section VII, the study is concluded.

2. PROBLEM FORMULATION
The network expands with time as per requirement depending up on new demands and anticipated overall future expansion/development of the area. Distributed Generation contributes to the improvement of power quality in the areas where voltage support by grid is difficult [4].

Firstly, the existing network is required to be analyzed as regards to its meeting consumers' expectations of power supply at proper voltages which is also a regulatory requirement in today's power scenario. Several methods are available for this purpose.

Secondly, with the injection of local energy source like RDG, not only the voltage profile will improve the current will also reduce thereby reducing overall Power losses [5] [6]. At the same time it will also create reserve capacity in the network. As such, this is the area of interest of Distribution Network Operators. Several methods are also available to evaluate losses of the network.

The issue of supplying the power to consumers at proper voltage as per regulatory requirement has been studied and presented in this paper. Loss reduction and increased reserve capacity of the Network are the added advantages [8].

The Network selected for study is a radial Network which has a total line length of 27 kilometers with 55 buses, supplying power to single phase and three phase balance load.

The details of the connected load to the Radial Network under study are given in the table below.

Table-1. Details of connected load.

Connected transformer capacity (kVA)	**No. of transformer connected**	**Load connected to each transformer** (kVA)	**Load** (kVA)
25	06	17	102
63	13	42	546
100	13	67	871
TOTAL	32	--	1519

3. MODELING

Modeling of the selected radial network is done in CYMDIST software. Load Flow Analysis (LFA) has been performed. The minimum voltage in the network is 89.02pu at node number 848, as shown in the below diagram. Permissible voltage range has been considered as ± 5%.

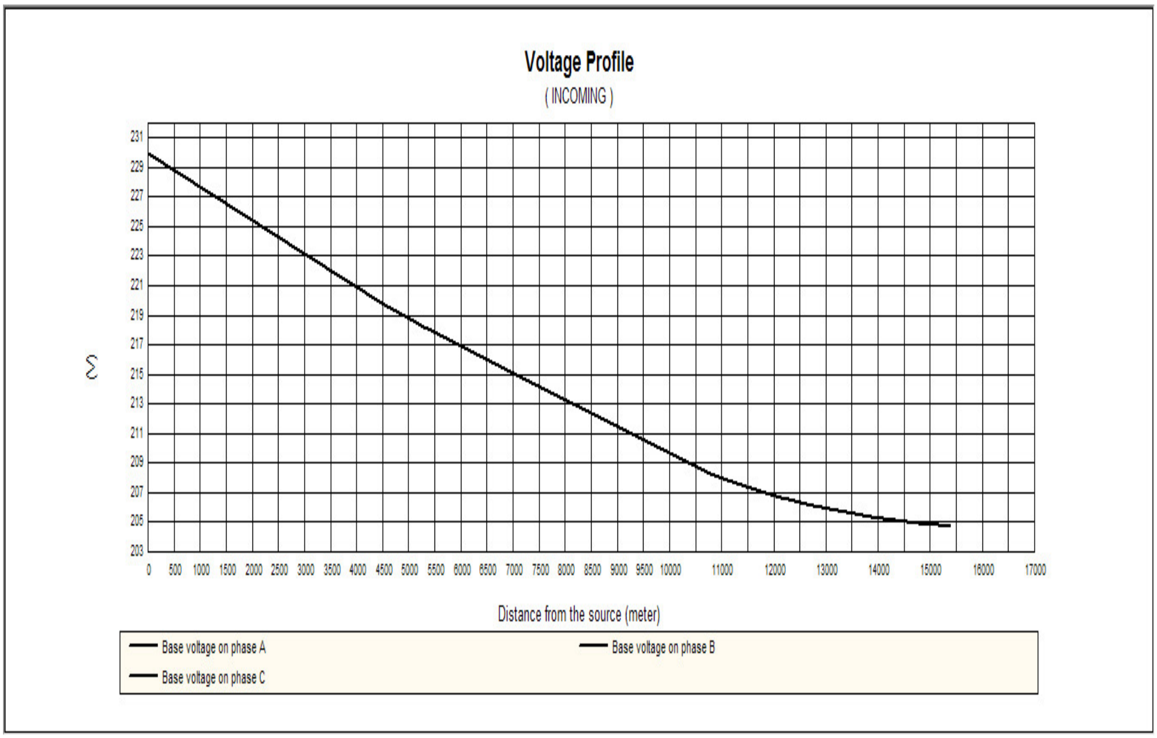

Figure-1. Voltage profile of existing network.

The losses in the existing network are 151 kVA under peak loading conditions.

Similarly, modeling of the RDGs is also done in CYMDIST software. The study is initialized by performing Load Flow Analysis (LFA) of existing Network. The next step is to add RDGs in the existing network at locations where maximum voltage improvement in the network is achieved.

RDG 1 (W1) is a 2.1 MW wind turbine generator with an average output of 655 kVA and RDG 2 (S1) is a 1.8 MW solar photovoltaic system with 300 kVA inverter average outputs.

Details of RDGs are tabulated below.

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Table-2. Details of distributed generators.

Generator	Type	Rated power (kVA)	Rated output voltage	Active generation for 24 hours*** (kW)
W1*	Wind turbine	2100	690	655
S1**	Solar PV system	1800	480	300

*Average wind speed of 5.6 m/s (wind power density of 200-250 watts/m^2), measured at 30mts height
**Peak sun hours/day: 4
***Output derived with simulations on HOMER Software.

The model of the existing radial network under consideration is shown below.

Figure-2. Existing network model.

By performing LFA, as shown by thick red line in the Figure-2, it is observed that voltage limit violation problems exist in major portion of the radial network.

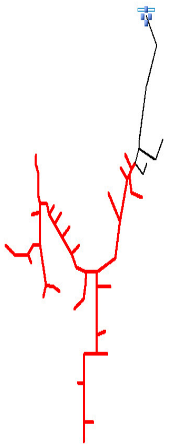

Figure-3. Voltage limit violation problem.

4. METHODOLOGY

The method used for performing LFA is forward / backward sweep method for calculating voltage drops and losses of Network at different buses / nodes. The forward / backward sweep method is explained in brief hereunder.

The Backward-Forward Sweep is used as an iterative means to solve the load flow equations of radial distribution systems. The Backward - Forward Sweep method exploits the radial topology of a distribution network. i.e., there is a unique path from any given bus to the source. There are two steps in this method, the Backward sweep, which is primarily a current summation based on the voltage updates from the far end of the feeder to the sending end and the forward sweep, mainly a voltage drop calculation from the sending end to the far end of a feeder or a lateral. By using KVL and KCL, the voltage drop can be obtained. These two steps are repeated until convergence is achieved.

The Backward Sweep calculates the current injected into each branch as a function of the end node voltages. It performs a current summation while updating voltages. Bus voltages at the end nodes are initialized for the first iteration. Starting at the end buses, each branch is traversed toward the source bus updating the voltage and calculating the current injected into each bus. These calculated currents are stored and used in the subsequent Forward Sweep calculations. The calculated source voltage is used for mismatch calculation as the termination criteria by comparing it to the specified source voltage. The Forward Sweep calculates node voltages as a function of the currents injected into each bus. The Forward Sweep is a voltage drop calculation with the constraint that the source voltage used is the specified nominal voltage at the beginning of each forward sweep. The voltage is calculated at each bus, beginning at the source bus and traversing out to the end buses using the currents calculated in previous the Backward Sweep.

Convergence is achieved when the magnitude of the voltage mismatch between the calculated source voltage in the Backward Sweep and the specified source voltage is less than or equal to a specified tolerance. The currents of all branches so calculated during the final iteration of the backward sweep are used for calculation of losses.

The detailed methodology is described below.

Step 1: Model the Network and RDGs.

Step 2: Perform LFA.

Step 3: Check Voltage profile and compute losses.

Step 4: Identify 2 main branches with strategic locations, having minimum Voltages.

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Step 5: Give names B1, B2 in ascending order of Voltages.

Step 6: Select two different RDGs and name them as G1, G2 in descending order of their kVA capacities.

Step 7: Place G1 in B1 at various nodes, perform LFA and select the most optimized location (L1) considering Voltage profile improvement.

Step 8: Repeat the above procedure for G2 on B2 and locate L2.

Step 9: Perform LFA for various combinations of G1, G2 at L1, L2 and check Voltage profile and compute losses for all cases.

Step 10: Give recommendations based on maximum.

5. SIMULATION OF NETWORK WITH RDGS

RDGs are integrated in the Radial Network under study at locations derived by the above methodology. Different cases were considered, first with individual RDG, and thereafter the network with both RDGs was considered. Voltage profile was checked for each case. Details of various cases are given in Table-3.

Table-3. RDG capacities for various cases.

Case No.	RDG capacity (kVA)	Remarks
0	0	Existing Network
1	655	RDG: W1
2	300	RDG: S1
3	955	RDG: W1 + S1

Model of the distribution network with integration of RDGs is shown below.

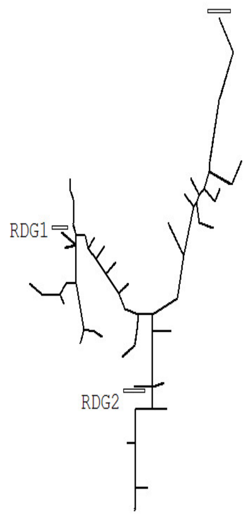

Figure-4. Network model with integration of RDGs.

The analysis of first stage study of existing network reveals that there is low voltage problem at number of nodes. Keeping in the view the low voltage problems at various nodes, addition of 2100 kW Wind Generator (RDG 1) at or around the node having least voltage i.e., node No. 848 has been considered (Case 1). The proposed 2100 kW wind Generator will provide 655 kW average powers. The same study is carried out on the network with the 1800 kW Solar Photovoltaic Generator (RDG 2) with 300 kVA inverter average outputs. The analysis of second stage study of having network reveals that there is low voltage problem still persists at number of nodes.

Again to improve voltage profile, a similar third stage study with both the RDGs connected to the network has been carried out.

The analysis of third stage study revealed that the voltage limit violation problem is entirely eliminated for the network.

6. RESULTS

The results of simulation for Voltage profile of various cases are tabulated below.

Table-4. Simulation results for voltage profile.

Case	Minimum voltage	
	Node No.	Voltage
0	847, 848	89.04
1	848	93.87
2	847, 848	90.95
3	847, 848	95.60

The graphical presentation showing the minimum voltage for various cases is given below.

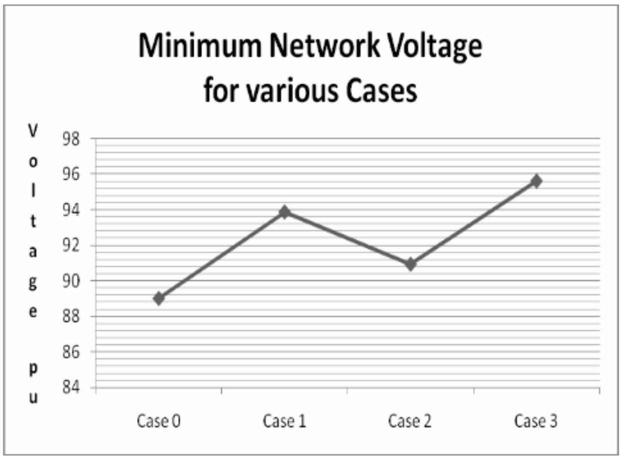

Figure-5. Minimum network voltages.

The Figure showing the case wise losses is given below.

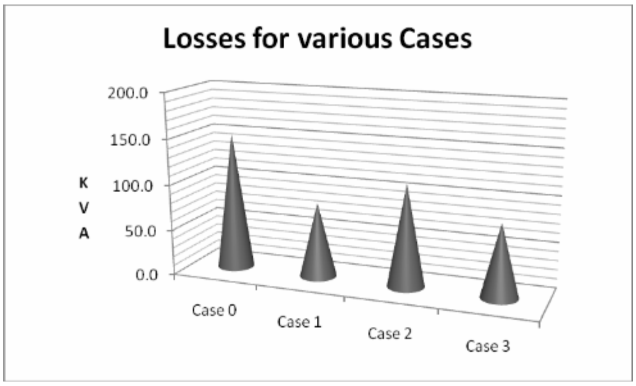

Figure-6. Losses for various cases.

Saving in losses for various cases is given in the following chart.

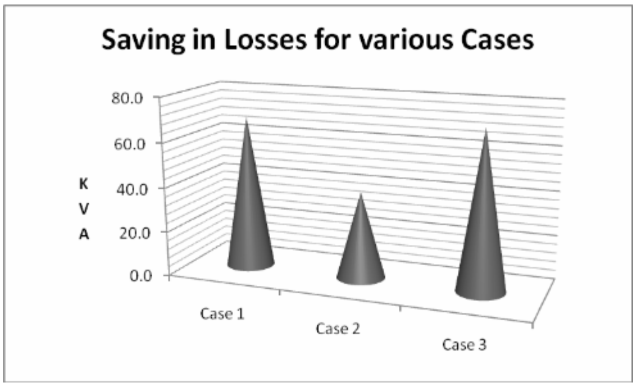

Figure-7. Saving in losses for various cases.

It is observed that with the addition of RDG 1 and RDG 2 in the existing network, the minimum voltage increases from 89.04pu (case 0) to 93.87pu in case 1, 90.95pu on case 2 and 95.60 in case 3. In addition to improvement in Voltage profile, saving in losses of the order of 71 kVA for case 3 is achieved as a by-product, which is an added advantage.

7. CONCLUSIONS

To overcome the voltage limit violation problems, proper selection of RDG capacity and it's citing at appropriate location following the methodology described in this paper, considerable improvement in voltage profile is achieved, which has completely eliminated the voltage limit violation problems entirely from the network. Additionally, reduction in losses is also achieved.

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