Integration of Renewable Distributed Generation in Distribution System for Loss Reduction: A Case Study

A. T. Davda, M. D. Desai, and B. R. Parekh

***Abstract*—Conventional Transmission and Distribution systems do not envisage at present any generation on consumer side. However, with the enactment of Indian Electricity Act 2003 and due to the major changes in the Power Sector and the fast move towards liberalization of the energy markets, utilities are inclined to install small capacity generating units to distribution systems. Integration of small capacity generators at load points in the existing electrical network will have impact on voltage regulation, losses, reserve capacity of network etc. In this paper, Renewable Distributed Generators (RDGs) are introduced at suitable locations of a heavily loaded distribution network to study the impact on minimization of distribution losses. Case study has been performed on a real 4.2 MVA distribution system of a particular area of Gujarat state, India. A methodology has been developed for citing the RDGs at a suitable location in the Network.**

***Index Terms*—Distribution losses, forward / backward sweep, renewable distributed generation, Voltage profile.**

I. Introduction

Over last few years, the reserve capacity in the Transmission system has been falling due to increased electricity demand and increasing generation capacity. This has resulted in an over-utilized transmission and distribution system with an increased level of losses and higher probability of disturbances.

As a result of increased demand in the distribution network, the distribution lines (especially in radial distribution systems) would be carrying current at their maximum capacity, in some cases, exceeding the limit, resulting in increased losses. The conventional methods of reducing the distribution losses include load balancing, bifurcation of overloaded lines, installation of shunt capacitors, high voltage distribution system etc.

In these types of distribution networks, addition of new loads becomes very difficult and practically impossible. Even a marginal increment in the connected load would violate the thermal loading conditions of the initial sections of the conductors.

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Conventional Transmission and Distribution systems do not envisage at present any generation on consumer side. However, with the enactment of Indian Electricity Act 2003 and due to the major changes in the Power Sector and the fast move towards liberalization of the energy markets, utilities are inclined to install small capacity generating units to distribution systems.

'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).

Integration RDG in the existing electrical network will have impact on many factors such as voltage regulation, losses, reserve capacity etc. In this paper, RDGs are introduced at a suitable location of a heavily loaded distribution network to minimize distribution losses. Case study has been conducted on a real 4.2 MVA distribution system of a particular area of Gujarat state. This distribution network is modeled in the software, RDGs are added, simulations are performed, load flow study is conducted and loss reduction is analyzed.

This paper is structured as follows: Section I introduces the subject. Section II describes the existing Network under study, section III deals with Network modeling 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. Sections VI & VII covers the Results of the study and Recommendations based on results. Finally, in section VIII, the study is concluded.

II. Existing Network

Network under consideration is a distribution system with 121 buses having a total line length of 32 kilometers and supplying power to single phase as well as three phase balance load.

A. Connected Load

The detail of the connected load to the system is given in the table below.

TABLE I DETAILS OF CONNECTED LOAD

Connected Transformer Capacity (KVA)	No. of Transformers connected	Load Connected to each Transformer (KVA)	Load (KVA)

25	20	17	340
63	31	42	1302
100	21	67	1407
150	02	100	200
200	02	134	268
500	02	334	668
TOTAL	78	--	4185

B. *Reserve Capacity of Network*

Initial sections of the network are overloaded under peak loading conditions. Hence it does not have any reserve capacity. Addition of new loads is currently not possible in this network.

III. Modeling

Modeling of the above distribution system is done in CYMDIST software. Load Flow Analysis (LFA) has been conducted. The line losses in the existing network are 251 KVA under peak loading conditions.

The minimum voltage in the network is 92.14 pu at node number 964, as shown in the below diagram. Permissible voltage range has been considered as ±5%.

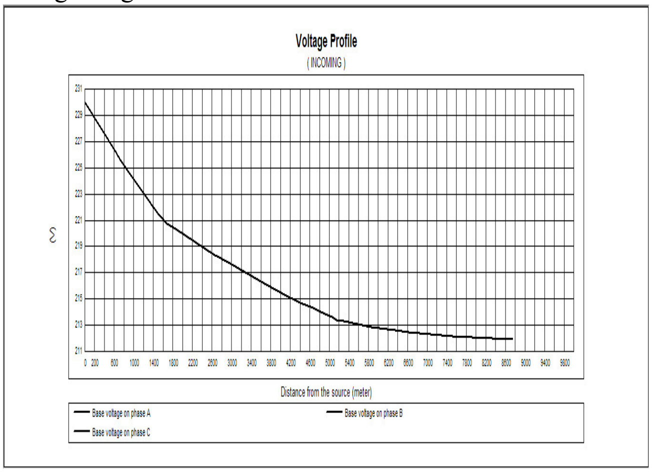

Fig. 1. Voltage Profile of existing Network

Next step is to add RDGs in the existing network at locations where maximum loss reduction is achieved.

RDG 1 (W1) is a 2.1 MW wind turbine generator and RDG 2 (W2) is a 1.5 MW wind turbine generator with an average output of 655 KVA and 476 KVA respectively. Similarly RDG 3 (S1) is a 1.8 MW solar photovoltaic system with 300 KVA inverter average output. These RDGs are also modeled in CYMDIST software.

Details of RDGs are tabulated below.

TABLE II DETAILS OF DISTRIBUTED GENERATORS

Generator	Type	Rated Power (KVA)	Rated Output Voltage	Active Generation for 24 hours*** (KW)
W1*	Wind Turbine	2100	690	655
W2*	Wind Turbine	1500	690	476
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 30 mts height

**Peak sun hours/day: 4

***Output derived by simulations on HOMER Software.

The model of the distribution network under consideration is shown below.

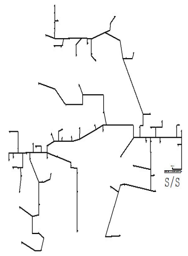

Fig. 2. Existing Network Model

IV. Methodology

The method used for performing LFA is forward / backward sweep method for calculating voltage drops and losses of Network at different buses / nodes [1]. The forward / backward sweep method is explained in brief hereunder.

The forward / backward 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 real and reactive power losses in the network are computed using following formulae:

Real Power Loss, $$P = \sum_{b=1}^{n} |I_b|^2 R_b \quad (1)$$

Reactive Power Loss, $$Q = \sum_{b=1}^{n} |I_b|^2 X_b \quad (2)$$

The detailed methodology is described below.

Step 1: Model the Network and RDGs.
Step 2: Perform LFA
Step 3: Check Voltage profile & compute losses
Step 4: Identify 3 main branches with strategic locations, having minimum Voltages
Step 5: Give names B1, B2, B3 in ascending order of Voltages
Step 6: Select three different RDGs and name them as G1, G2, G3, 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 Loss Reduction
Step 8: Repeat the above procedure for G2 on B2 & G3 on B3, and locate L2 & L3
Step 9: Perform LFA for various combinations of G1, G2, G3 at L1, L2, L3 and compute losses for all cases
Step 10: Compare losses of all the cases with the original Network losses
Step 11: Compute saving in losses per RDG size
Step 12: Give recommendations on the comparison of Losses

V. Simulation Of Network With RDGs

RDGs are integrated in the existing network under study at locations derived by the above methodology. Different cases were considered, first with individual RDG, thereafter various combinations of RDGs and lastly the network with all three RDGs was considered. Losses are computed for every case and compared with the losses of original network without RDG. Details of various cases are given in the table below.

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

TABLE III RDG CAPACITIES FOR VARIOUS CASES

Case No.	RDG Capacity (KVA)	Remarks
0	0	Existing Network
1	655	RDG: W1
2	476	RDG: W2
3	300	RDG: S1
4	1131	RDG: W1 + W2
5	955	RDG: W1 + S1
6	776	RDG: W2 + S1
7	1431	RDG: W1 + W2 + S1

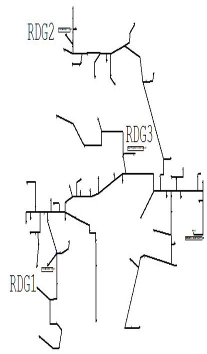

Fig. 3. Network model with integration of RDGs

VI. Results

The results of simulation for power loss of various cases are tabulated below.

TABLE IV SIMULATION RESULTS FOR POWER LOSS

Case	Total Power Loss (KVA)	Saving in Power Loss (KVA)	Saving in KVA/100 KVA RDG Size
0	251	--	--
1	195	59	9.01
2	205	46	9.66
3	232	19	6.33
4	157	94	8.31
5	182	69	7.23
6	190	61	7.86
7	152	99	6.92

The graphical representation of total power losses for various cases is given below.

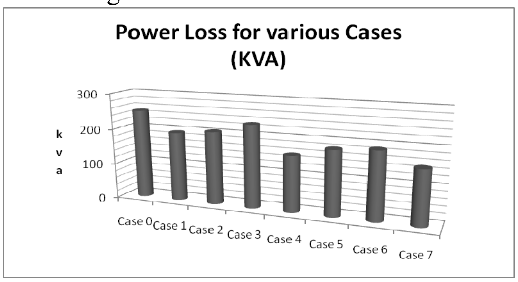

Fig. 4. Power Loss for various cases

Saving in power loss for various cases is shown in the chart below.

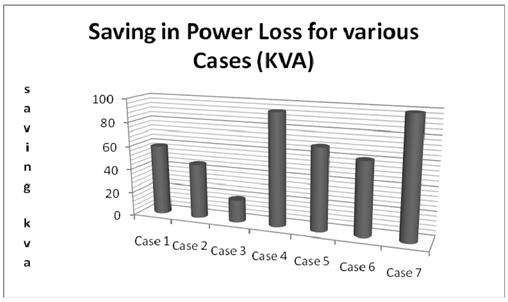

Fig. 5. Saving in Power Loss for various cases

The graphical representation of the saving in power loss per 100 KVA RDG size for various cases is given below.

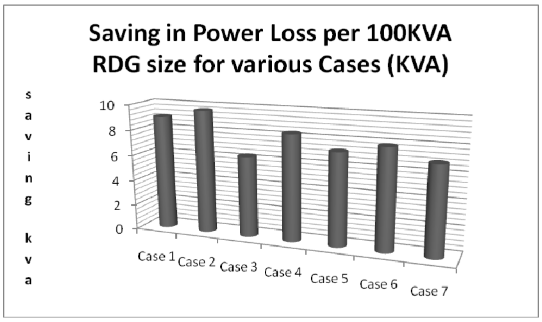

Fig. 6. Saving in Power Loss per 100KVA RDG size

From the results of the simulations of Network with and without RDGs, it is observed that by placing the RDGs in the existing Network at appropriate locations, the Voltage profile of the Network is also improved, as shown below.

TABLE V MINIMUM NETWORK VOLTAGE FOR VARIOUS CASES

Case	Minimum Voltage	
	Node No.	Voltage (pu)
0	964	92.14
1	927	93.67
2	964	92.61
3	964	92.59
4	964	94.94
5	927	93.95
6	964	93.05
7	964	95.37

The chart showing minimum Voltage in the Network for various cases is shown below.

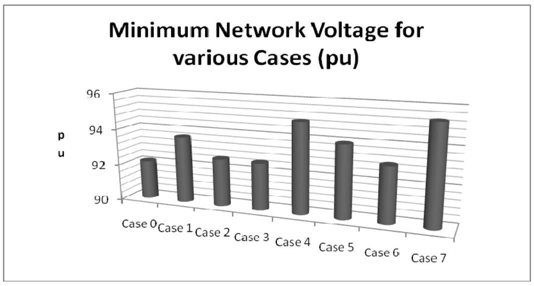

Fig. 7. Minimum Network Voltage

It can be observed from above tables that in addition to saving in losses, the minimum voltage in the existing network which was 92.14 pu is increased to 95.37 pu as an added advantage. Additional benefit is the availability of increased reserve capacity of the Network.

VII. Recommendations

For comparison purposes, the analysis of saving in losses per 100 KVA RDG size is performed. It can be observed from above table that the maximum saving per 100 KVA RDG size is achieved in case 2, where it works out to 9.66 KVA / 100 KVA RDG size.

VIII. Conclusion

Selection of proper capacity of RDG and citing it at appropriate location following the methodology described in this paper, maximum loss saving is achieved which works out to 39.44% of the existing losses. At the same time, considerable voltage improvement and increased reserve capacity are also achieved which are added advantages.

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