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Voltage Profile Improvement of 11kV Distribution Feeder using Distributed Generation

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***Abstract*— Increasing demand for electricity has overburdened the distribution networks as a result; violation of voltage limits has become major issue in rural India. Most of the distribution networks for rural & suburban areas are of radial type. These feeders are simply extended to achieve complete electrification in rural areas without considering the future load growth. With the increased length of low voltage distribution feeder, catering variety of loads results in increased line losses and further gives rise to reduction in voltage levels at the downstream of radial feeder. Methods like feeder reconfiguration, capacitor placement, conductor grading & distributed generation unit placement are used to reduce line losses and improve voltage profile.**

Distributed Generator (DG) to a passive distribution network becomes an active distribution network. Distributed Generators effectively reduce the real power losses and improve the voltage profile in Radial Distribution Networks (RDN). In this paper, feasibility of connecting DG unit into existing distribution network is analyzed. A 11kV distribution feeder is simulated to understand line losses & voltage drops at various sections of the network. An algorithm for obtaining the optimal location for DG unit into distribution system is presented and results are summarized to demonstrate the effectiveness of this method to improve voltage profile.

Keywords*— *Distributed generation (DG), Radial Distribution Networks (RDN), Line losses, optimal location, Trunk line, Spur line .

I. INTRODUCTION

Ever growing demand for electricity has overburdened the distribution networks and as a result violation of voltage limits has become major issue in rural India in particular. Voltage fluctuation, low voltage conditions are very common in rural areas particularly during peak hours. This is largely resulting in reduced productivity, equipment damage of poor people and also resulting into socio-economic problems. Most of the distribution networks for rural & suburban areas are of radial type. These radial feeders are simply extended to achieve complete electrification in rural areas without considering the future load growth. With the increased length of low voltage feeder, catering variety of loads resulting into too much of line losses in the present scenario. With increased losses in various sections of lines gives raise to further reduction in voltage levels at the downstream of radial feeder. Reduction in the voltage level is found to be 10-24% from its rated value depending upon length of line & magnitude of load connected to it. Line length reduction & installation of transformers are not the viable solution when feeders are feeding highly scattered loads. There are many other alternative methods like feeder reconfiguration, capacitor placement, HV distribution system, conductor grading & distributed generation unit placement. Out of these, capacitor placement & DG unit placement methods reduce power losses & improve voltage regulation [1]. But DG unit placement can cause impact on both active & reactive power while capacitor banks have impact on reactive power flow only.

Distributed generation [2] is nothing but installation & operation of small modular generating systems in conjunction with energy management & storage systems. These systems can employ range of technological options from renewable to non-renewable and can operate either in grid connected or off grid connected mode. If the technology uses renewable energy sources for power generation then it is termed as Renewable Distributed Generation (RDG) [3],[4],[5].

There are many approaches proposed to find appropriate location for placing DG on distribution system. Willis [6] employed 2/3 rule to determine appropriate location for DG. In this method DG unit of capacity (2/3) of total load and placed at (2/3) of total length of feeder is considered. But this method assumes uniformly distributed load in radial configuration. Rau [7] presented a power flow algorithm for optimal placement of DG. But this method is not efficient because of large computations involved. Chiradeja [8] presented a general approach and set of indices to assess and quantify technical benefits of DG. In this paper, an algorithm based on analytical method is presented for obtaining the optimal location for DG unit into distribution system.

II. ANALYSIS OF 11KV TEST FEEDER

In all traditional distribution systems, voltage is regulated by means of tap changing at substation transformer. It is also accomplished through voltage regulators & capacitors on feeders. Hence power flow is from substation to loads. Integration of DG into existing distribution system poses several challenges as control of voltage is usually based on radial power flows. Inappropriate placement of DG can cause under voltages or over voltages in network too. Hence thorough analysis of distribution system is required before placing DG into it. The distribution network selected for analysis is a radial feeder feeding suburban loads. It has trunk line length of 7.64kms & total spur line length of 3.97kms. Rabbit type conductor is used with line impedance of (0.584+j0.36619) ohm/km & nominal voltage is 11kV. Total connected load to the feeder is 8278 kVA. Table I shows details of connected load to test feeder.

TABLE I. Details of connected load to feeder

Sl. No	KVA rating	No. of transformers	Total KVA capacity
1	50	1	50
2	63	6	378
3	100	31	3100
4	250	19	4750

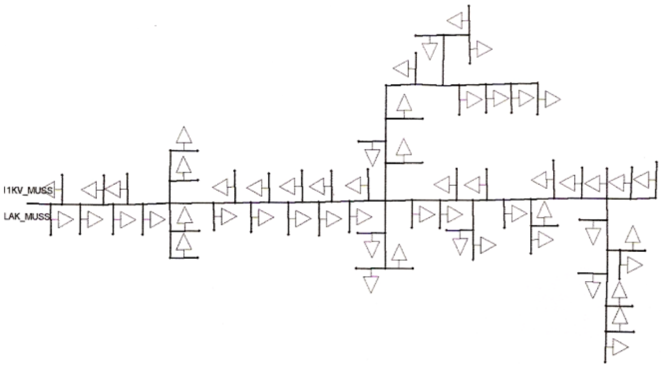

Fig.1 Single line diagram of distribution feeder

Fig.1 shows single line diagram of distribution feeder which is simulated using CYMDIST simulation software. Load flow analysis is carried out for maximum load of 3907 kVA recorded in load curve and power factor is assumed to be 0.8 constant throughout the feeder. For thorough analysis of results obtained from load flow analysis the entire feeder is divided into three zones as indicated in Table II. The feeder is simulated for maximum load of 3907 kVA which is recorded on the hourly load curve. Power factor is assumed to be 0.8 constant throughout the feeder and system is assumed to be balanced. Table III shows entire summary of load flow analysis. Zone wise loss obtained during peak load is shown in Table IV. It is observed that total loss during peak hour is nearly 9.93% and low voltage condition is observed on spur line SL19_U24. Voltage drop at this section is found to be more than 11.42%. Table V shows details of abnormal conditions for peak load conditions. Voltage profile of feeder during peak load is shown in Fig. 2. Fig.3 shows zone wise losses for three peak load conditions, when load on feeder is 1000kW, 1100kW and 1360kW respectively. It is evident from the graph that during peak loads trunk line sections of zone 1 are getting overloaded & majority of losses are occurring in zone 1.

TABLE II. Details of connected load to feeder

Zones	Trunk line sections	Trunk line length in km	Spur line length in km
1	TL1 to TL8	2.036	0.43
2	TL9 to TL18	2.5	1.23
3	TL19 to TL31	2.88	2.3

TABLE III. Summary of Load flow analysis

	Total load			
	kW	kVAR	kVA	PF(%)
Total load read (Non adjusted)	2823.31	2139.95	3542.66	79.69
Total load used (Adjusted)	2823.27	2139.92	3542.61	79.69
Total shunt capacitor (Adjusted)		0.00		
Total shunt reactor (Adjusted)		0.00		
Total power from generator	0.00	0.00	0.00	0.00
Total losses	310.51	193.91	366.09	84.82
Total power from sources	3133.78	2333.83	3907.34	80.20

TABLE IV. Details of zone wise loss on feeder

Zone	Loss in kW	power in kVAR
1	142.2	88.8
2	130.8	81.7
3	36.3	23.1

TABLE V. Details of abnormal conditions on feeder

Conditions	phase	Worst condition	Percentage
Overload	A	TL1	112.07
	B	TL1	112.07
	C	TL1	112.07
Low voltage	A	SL19_U24	88.58
	B	SL19_U24	88.58
	C	SL19_U24	88.58
High voltage	A	SOURCE_NODE_1	100.00
	B	SOURCE_NODE_1	100.00
	C	SOURCE_NODE_1	100.00

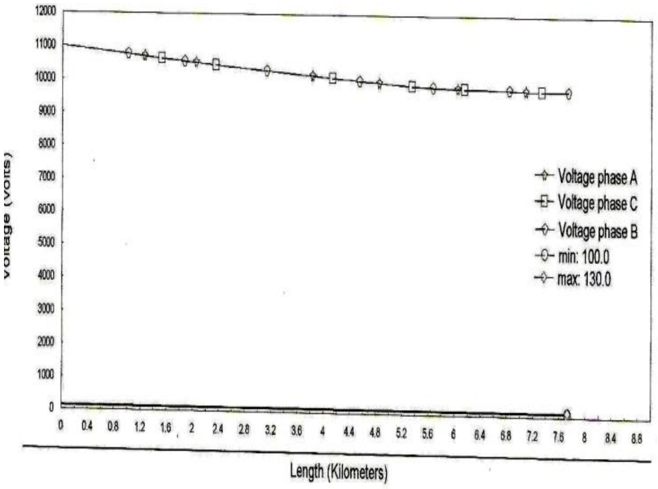

Fig.2 Voltage profile of feeder during peak load

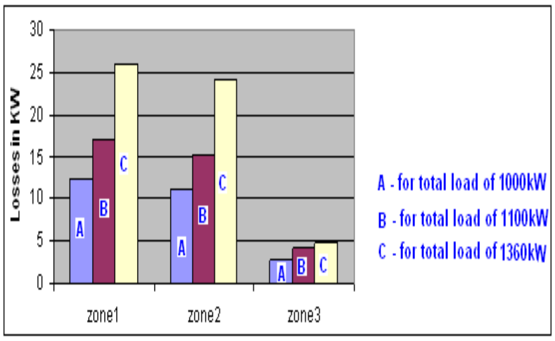

Fig.3 zone wise losses for various peak loads

III. DG INTEGRATION FOR VOLTAGE PROLFILE IMPROVEMENT

The problem of over loading & low voltage in some branches of feeder can be minimized by connecting distributed generation unit at appropriate place on feeder [9]. Usually the capacity of such distributed generation unit is of the order of 10-25% of total load on feeder. An algorithm based on simple analytical technique to find optimal place for integrating DG into distribution feeder for voltage profile improvement and active power loss reduction is presented below.

Step 1: Simulate the feeder & run load flow analysis program based on forward/backward sweep methods.
Step 2: Identify the buses having low voltages and designate these buses as B1, B2, B3, B4 in the ascending order of voltages.
Step 3: Connect DG unit of appropriate size & power factor at bus B1.
Step 4: Perform load flow analysis to find line losses and voltages at various sections of feeder.
Step 5: Repeat step (3) to (4) for other low voltage buses identified in step 2.
Step 6: Identify the bus number for which line losses are minimum. This gives optimal location on feeder to connect DG.

It is to be noted that by placing DG at a location identified using above procedure causes significant enhancement in voltage profile. Line losses and voltages at selected sections of feeder obtained after performing load flow analysis in both the cases of with DG and without DG are put together in the form of generalized code. The code is written in MATLAB to give optimal location on feeder based on comparison of results.

IV. RESULTS AND DISCUSSIONS

Supplying electricity to consumers at proper voltage as per regulatory norms has forced the supply authorities to explore the alternate ways to improve voltage profile of feeder & to reduce line losses. Simulation results of test feeder without DG clearly indicates some spur lines of feeder in Zone 3 are facing severe under voltage problem during peak hours. The level of voltage drop is around 11.42% at section SL19_U24 which is the violation of voltage regulatory norms. Also line losses are found to be around 9.93% at the same peak load. This is clearly due to the increase in line currents during peak hours which is causing overloading problem in trunk line sections of zone 1, increased voltage drops resulting into poor voltage profile in zone 3 and increased line losses. Hence this problem can be overcome by connecting DG to the feeder at a location determined by using algorithm presented in this paper. DG of 750 kVA and power factor of 0.8 is considered for analysis. As per the algorithm, DG is connected to most low voltage line SL19_U24 as shown in Fig.4. The results obtained after simulating the network is shown in Table VI. Zone wise losses are indicated in Table VII. Overloading & under voltage status are indicated in Table VIII.

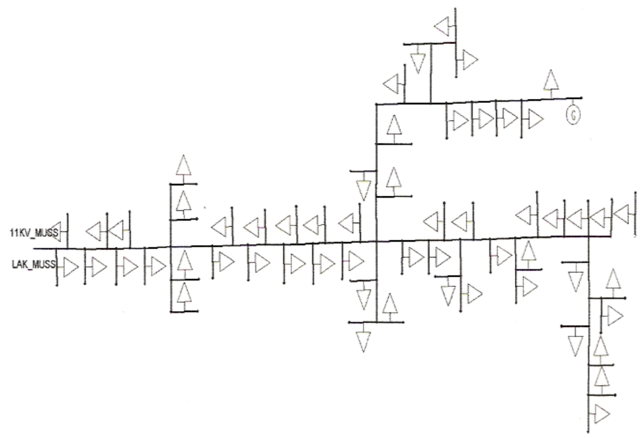

Fig.4 Single line diagram of feeder with DG at line SL19_U24

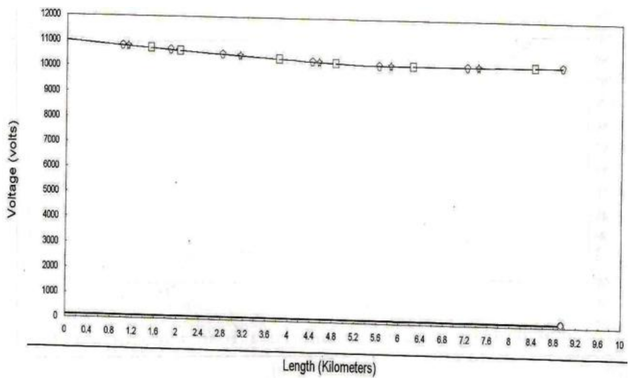

Fig.5 Voltage profile of feeder after the inclusion of DG.

Fig. 5 shows voltage profile of test feeder with inclusion of DG. From the results it is clear that percentage of line loss is found to be 5.609% thereby achieving nearly 44% reduction in line loss. Also trunk line sections of zone 1 are released from over loading conditions. Further under voltage problems at line SL19_U24 is eliminated and improved voltage profile is observed in most of the sections of zone 3. Under voltage problem at SL29_D12 can be eliminated by reducing the rating of DG used by small amount or by connecting two reduced capacity DGs at both these locations.

TABLE VI. Summary of Load flow analysis after inclusion of DG.

	Total load			
	kW	kVAR	kVA	PF(%)
Total load read (Non adjusted)	2823.28	2139.94	3542.63	79.69
Total load used (Adjusted)	2823.27	2139.94	3542.63	79.69
Total shunt capacitor (Adjusted)	--	0.00	--	--
Total shunt reactor (Adjusted)	--	0.00	--	--
Total power from generator	600	450	750	80.00
Total losses	167.77	104.77	197.79	84.82
Total power from sources	2391.04	1794.70	2989.65	79.98

TABLE VII. Detail of zone wise loss on feeder after inclusion of DG.

Zone	Loss in kW	Power in kVAR
1	81.9KW	51.1KVAR
2	65.6KW	40.9KVAR
3	19.9KW	47.4KVAR

TABLE VIII. Details of abnormal conditions on feeder

Conditions	phase	Worst condition	Percentage
	A	TL1	85.75
Overload	B	TL1	85.75
	C	TL1	85.75
Low voltage	A	SL29_D12	92.51
	B	SL29_D12	92.51
	C	SL29_D12	92.51
High voltage	A	SOURCE_NODE_1	100.00
	B	SOURCE_NODE_1	100.00
	C	SOURCE_NODE_1	100.00

Placement of DG to the remaining buses is not found to be feasible. A simulation result obtained by connecting DG at other buses is as shown in Table IX. Hence SL19_U24 location is found to be ideal location for connecting DG which yields reduced line losses & improved voltage profile.

TABLE IX. Details of abnormal conditions on feeder

Zone	DG at line SL19_U1			DG at line SL11		
	kW	kVAR	Line loss (%)	kW	kVAR	Line loss (%)
1	82.3	51.4	5.76	86.4	51.4	7.62
2	65.9	41.2		110.4	68.7	
3	24.4	14.9		36	22.2	

V. CONCLUSION

DG helps in overcoming voltage limit violation problem and in turn improving power quality. This is true particularly when feeder is a long, radial type distribution system feeding highly scattered load where voltage support by grid is very difficult to achieve. The results show that integration of DG is highly effective in reducing power losses and improving voltage profile. However placement of DG is one of the crucial elements in planning & operation of distributed generation. The studies reveal that, maximum benefits from DG can be obtained by placing DG at a suitable location which is determined by using generalized algorithm presented in this paper. The optimal DG location varies from system to system, depending upon system configuration, types of connected load and a tradeoff among the objectives of DG usage.

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