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Impact of Distributed Generation on Three Feeder Radial Distribution System

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ABSTRACT
In twenty first century deregulated environment provides an opportunity to the electric utilities for a variety of technologies forces to rediscovered Distributed Generation (DG) systems. Distributed Generating systems provide good reliability and quality of supply with good voltage profile, reduced power loss and reduced emission of pollution. Distributed Resources (DR) that encompasses Distributed generation and Distributed energy Storage (DS). To achieve its goal a Distributed utility will use both distributed resources and load management. Several compact distributed generation technologies are fast becoming economically feasible. The main object of this paper is to evaluate the benefit of the DG on a simple radial distribution system which consists of three feeders at which the DG is placed only on heavily loaded feeder. The percentage of loss reduction and voltage profile improvement is calculated for the system with, without considering DG; the analysis is done for different power factors of the system and for varying output capacities of DG. The results are tabulated and presented in the graphical form.
Index Terms—Distributed resources, Distributed Generation, line loss reduction, Voltage profile, Wind power.

I. INTRODUCTION

The origins of Distributed Generation arguably go back as far as Thomas Edison's invention of the electric bulb because of that the need for electrical power is extensive. The original light bulb was powered by direct current (DC), which became Edison's preferred method of transmitting power. Because of the implementation of AC power Distributed generation gave way to more centralized power generation away from load centers and high voltage stepup transformers and insulation materials allowed high voltage transmission over high voltage lines. Because of the following several recent trends the DG technology is now reestablished.

1) Advanced power electronic systems have allowed many ways of converting electrical energy.
2) DG concerns eco-friendly technology.
3) A greater demand for power quality especially from industries.
4) The deregulation of power industry.

Distributed Generation provides many benefits for both consumers and producers of power, but it also has many drawbacks. The methods of converting alternative fuels into electric power are inefficient when used solely for power. For example, commercial solar photovoltaic cells tend to yield efficiencies that hover around 10%, wind turbines do not exceed 40% mechanical efficiency at most wind speeds, and micro turbines achieve electrical efficiencies of only 30% when used solely for power.

To provide good power quality and reliability to the customers, we require new technologies in electric utilities. In many countries generation from the nonconventional sources is becoming an attractive solution because these will produce energy with less environmental impacts [1-3].

"Taking power to the load" can be referred to as Distributed Generation. DG assures to generate electricity with low pollution and good reliability. The rating of a DG can be ranges from 5KW to 100MW and it is placed at or near the load point. The cost for maintenance is also very less for Photovoltaic and fuel cells because of the absence of moving parts [4]. We can reduce the real power loss and can improve voltage profile in the distribution system by using appropriate DG system [5].

The classification of Distributed Generation (DG) is mainly four types based on their terminal characteristics in terms of real and reactive power delivering capability as follows:

1) TYPE I: DG injecting active power P only.
2) TYPE II: DG injecting reactive power Q only.
3) TYPE III: DG injecting active power P and reactive power Q.
4) TYPE IV: DG injecting active power P but consuming reactive power Q.

Distribution companies have no control on installation of DG units it is most preferable for DG owners to provide incentives in the form of a certificate such as renewable energy certificate (REC). Many studies have been conducted to find loss variations in distribution networks in the presence of DG units. Both technical and economic benefits can be achieved by employing DG in existing distribution networks [6] and the Disadvantage [7] associated with them are listed below in addition to Benefits.

A. Technical Benefits:

1) Line losses can be reduced.
2) Improves voltage profile.
3) Pollutants emission can be reduced.
4) Energy efficiency can be improved.
5) System security and reliability can be achieved.
6) Power quality can be improved.
7) T&D congestion can be relieved.

B. Economic benefits:

1) Some DG technologies provide less O&M costs.
2) Productivity can be enhanced.
3) Health care costs are less because of the improved environment.
4) Fuel cost is also very less because of the increased overall efficiency.
5) Reserve requirements and associated costs are also very less.
6) Because of the peak saving on load curve the operating cost is very less.
7) Security for critical loads has improved.

C. Disadvantages:

1) Because of connecting DG in Distribution system causes to flow reserve power flow results in malfunction of protection circuits as they are configured at present.
2) Stability issues.
3) Increased fault current.
4) Asynchronous DG sources which use inverter for interconnection will inject Harmonics into the system.

A general approach is presented to establish the technical benefits of DG. A set of indices is proposed to quantify Voltage profile improvement and Line loss reduction in the test system.

II. SYSTEM MODELING

Consider the Figure 1, which is a one line diagram of a radial network which helps to quantify the line losses, for this purpose we use a set of power flow equations.

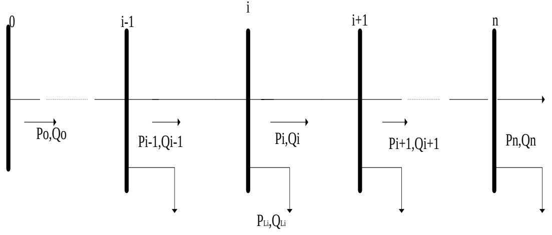

Fig. 1. One line diagram of a radial network.

The forward Distflow equations are given below

$$P_{i+1} = P_i - r_i \frac{P_i^2+Q_i^2}{V_i^2} - P_{Li+1} \quad (1.a)$$

$$Q_{i+1} = Q_i - x_i \frac{P_i^2+Q_i^2}{V_i^2} - Q_{Li+1} \quad (1.b)$$

$$V_{i+1}^2 = V_i^2 - 2(r_iP_i + x_iQ_i) + (r_i^2 + x_i^2)\frac{P_i^2+Q_i^2}{V_i^2} \quad (1.c)$$

Similar to forward Distflow equations the Backward Distflow equations can be written as,

$$P_{i-1} = P_i + r_i \frac{P_i^2+Q_i^2}{V_i^2} + P_{Li} \quad (2.a)$$

$$Q_{i-1} = Q_i + x_i \frac{P_i^2+Q_i^2}{V_i^2} + Q_{Li} \quad (2.b)$$

$$V_{i-1}^2 = V_i^2 + 2(r_iP_i + x_iQ_i) + (r_i^2 + x_i^2)\frac{P_i^2+Q_i^2}{V_i^2} \quad (2.c)$$

Where $P'_i=P_i+P_{Li}$, $Q'_i=Q_i+Q_{Li}$.

The power balance in the Electrical system is the power drawn out of the system equals to the sum of the system load demand and power losses. According to power balance the power input to the feeders was in direct proportions to the power loss in the same load condition.

Two simple radial systems are considered:

i. System without DG.
ii. System with the inclusion of DG.

Both systems have a concentrated load at the line end.

The Distributed system has two simple configurations, one is a simple radial system without Distributed Generation (DG) and the other is with the addition of DG. A concentrated load is at placed at the end of both systems with an assumed line length of L km. the system configuration are shown in Figure 2 &3.

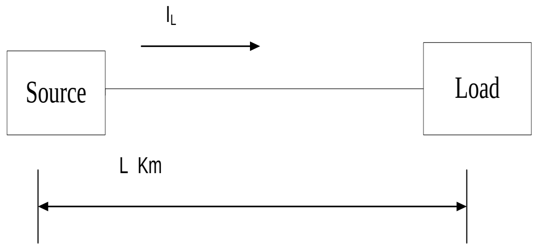

Fig. 2. A simple radial distribution system without DG.

For the system with DG, the location of DG is assumed to be G km from source.

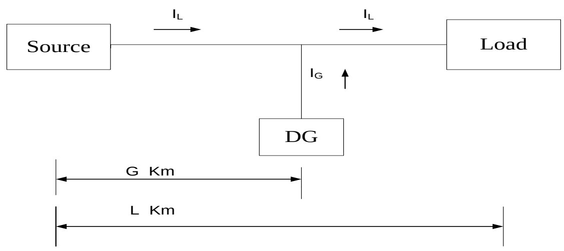

Fig. 3. Schematic of a radial system with the inclusion of DG.

The assumptions which are considered in this system are:

1) The load is connected in balanced star manner.
2) Load consumes active power at a particular power factor.
3) The active power output of a DG is at any desired power factor.
4) The rms phase voltage of the load is V_p and it is taken as reference phasor $V_p < 0^0$.

$S_L = P_L + jQ_L$ is the apparent power of the load, hence the current taken by the load is

$$I_L = \frac{(P_L - jQ_L)}{3V_p} \quad (3)$$

Where

I_L Load current per phase, A/Φ.
P_L Active power of Load, W.
Q_L Reactive power of Load, Var.

III. LINE LOSS REDUCTION ANALYSIS

The loss in the distribution system depends on the amount of current magnitude and the resistance offered by the line. The line loss in the distribution system can be reduced by providing energy locally to the load by using Distributed Generation (DG), which decreases the part of current magnitude in the distribution line and that result in loss reduction.

A. Line Loss Analysis for System without DG

Figure 2 shows the configuration of the distribution system without DG. The line loss in the distribution system is proportional to the product of square of the current magnitude and line resistance. Hence, the loss equation can be given as:

$$Loss_B = \frac{rL({P_L}^2 + {Q_L}^2)}{3{V_p}^2} \quad (4)$$

Where

L Total length of distribution line, km.
R Line resistance per phase per unit length, Ω/km/ Φ.
$LOSS_B$ Total line loss before the inclusion of DG, W.

B. Line Loss Analysis with DG

Figure 3 shows the schematic of a radial system with the inclusive of DG. The apparent power delivered by the DG equal to $S_G = P_G + jQ_G$ thus the magnitude of outp.u.t current is given as

$$I_G = \frac{(P_G - jQ_G)}{3V_p} \quad (5)$$

Where

I_G DG outp.u.t current per phase, A/Φ.
P_G Real power of DG, W.
Q_G Reactive power of DG, Var.

With the addition of DG the real power loss in the system has two parts one is loss from load to DG location and the other is from DG location to source.

1) Line Loss from Source to DG Location

From Figure 3, we can write the souse current per phase (I_s) is

$$I_S = I_L - I_G \quad (6)$$

Therefore, the expression for $LOSS_{ASG}$ can be given as:

$$Loss_{ASG} = \frac{rG({P_L}^2 + {Q_L}^2 + {P_G}^2 + {Q_G}^2 - 2P_LP_G - 2Q_LQ_G)}{3{V_P}^2} \quad (7)$$

Where $LOSS_{ASG}$ is Line loss from source to the DG location after the inclusion of DG, W

2) Line Loss from the Location of DG to Load Location

The line current from DG to load is I_L, which is same without DG.

$$Loss_{AGL} = \frac{r(L-G)({P_L}^2 + {Q_L}^2)}{3{V_P}^2} \quad (8)$$

Where

$LOSS_{AGL}$ is Line loss from DG location to the location of load after the inclusion of DG, W.

3) Total Line Loss

The total losses in the system can be found by the addition of loss from load to the DG location and from DG location to the load. This can be expressed as:

$$Loss_{AT} = \frac{R}{3{V_P}^2}\left[{P_L}^2 + {Q_L}^2 + \left({P_G}^2 + {Q_G}^2 - 2P_LP_G - 2Q_LQ_G\right)\left(\frac{G}{L}\right)\right] \quad (9)$$

Where

R=rL Total resistance per phase, Ω/km/ Φ.
G Distance from source to the DG location, km.
$LOSS_{AT}$ Total line loss after the inclusion of DG, W.

C. Line Loss Reduction

The difference in the loss with DG and without DG can be give as loss reduction (LR). When the loss in the system is reduced then LR is of positive sign if not LR is indicated by the negative sign.

$$LR = Loss_B - Loss_{AT} = \frac{RG}{3{V_P}^2L}\left(2P_LP_G + 2Q_LQ_G - {P_G}^2 - {Q_G}^2\right) \quad (10)$$

IV. NUMERICAL EXAMPLE

A. Test system data and description of simulation conditions

The single line diagram of a simple radial distribution network of 132/33 KV, 30 MVA substation consists of three 33 KV feeders shown in

Figure 4 .The impedance offered by the line is 0.157+j0.337 Ohm/km. The Feeders named F#1, F#3 serving suburban are and feeder F#2 is serving a small scale industrial area. The feeders in this numerical example are considered as voltage drop limited feeders with a voltage drop limitation of +6% to -9% and the normal maximum operating current is limited to 400 amperes. For simulation studies Diesel Generator is used as a Distributed Generation (DG) unit which is of 10 MW capacity with an electrical efficiency of 85-90% and which is operating at a power factor of 0.85 PF.

The simulation cases were illustrated as follows

CASE#A: Distribution system is operating at 0.707 PF.

CASE#B: Distribution system is operating at 0.85 PF.

CASE#C: Distribution system is operating at 0.95 PF.

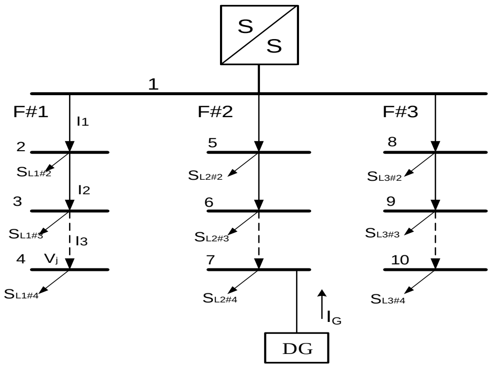

Fig. 4. The one line diagram of the sample three feeder system.

For the detailed analysis of numerical system the above mentioned cases were simulated by considering two conditions, they are as follows:

Condition#1: The Distributed Generation (DG) unit is placed at Bus 6.

Condition#2: The Distributed Generation (DG) unit is placed at Bus 7.

TABLE I. ILLUSTRATION OF SIMULATION CASE

Feeder	Bus no		Load (KVA)	Length (meters)
	From	To		
F#1	1	2	2360	5250
	2	3	3150	5750
	3	4	3280	6100
F#2	1	5	3850	8250
	5	6	4350	8100
	6	7	4685	8500
F#3	1	8	2340	5400
	8	9	3110	6850
	9	10	3250	6100

B. Simulation results

The simulation is carried out on a simple radial distribution system by varying the DG location among Bus 6 and Bus 7 for different DG outputs and for different operating power factors at a constant load on the system. Figures 5, 6, 7, shows the percentage of loss reduction in the distribution system for different capacities of DG (i.e., 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, and 1.4) p.u. which is placed at Bus 6 and Bus 7 as mentioned in earlier sections. It is clearly observed that the maximum percentage of loss reduction is achieved for a DG capacity of 0.70 p.u. at Bus 6 and 0.60 p.u. at Bus 7, 0.80 p.u. at Bus 6 and 0.70 p.u. at Bus 7 and 1.0 p.u. at Bus 6 and 0.8 p.u. at Bus 7 as shown in Table II. when the substation is operating at different power factors 0.707 PF, 0.85 PF and 0.95 PF respectively.

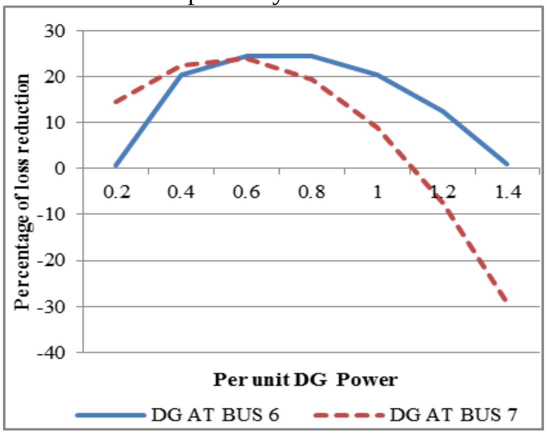

Fig.5. percentage of loss reduction at 0.707 PF.

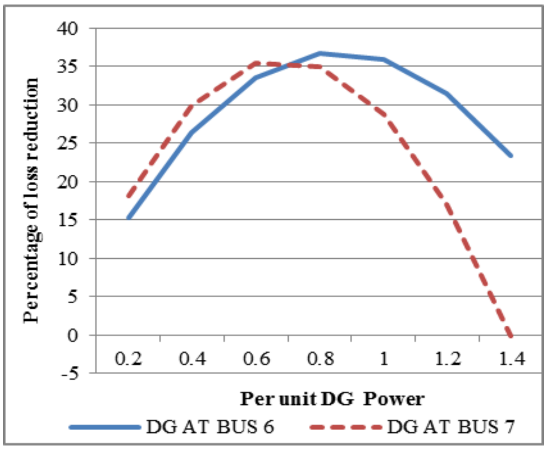

Fig.6. percentage of loss reduction at 0.85 PF.

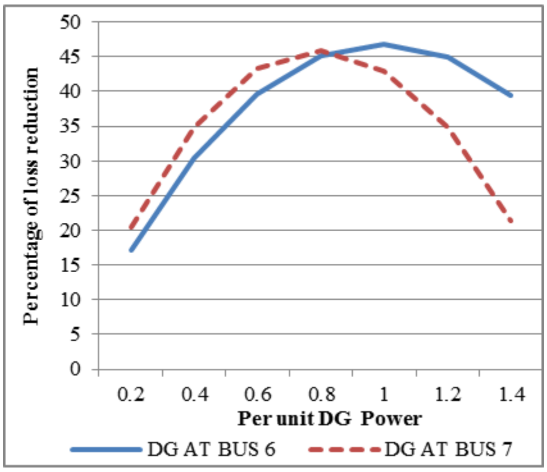

Fig.7. percentage of loss reduction at 0.95 PF.

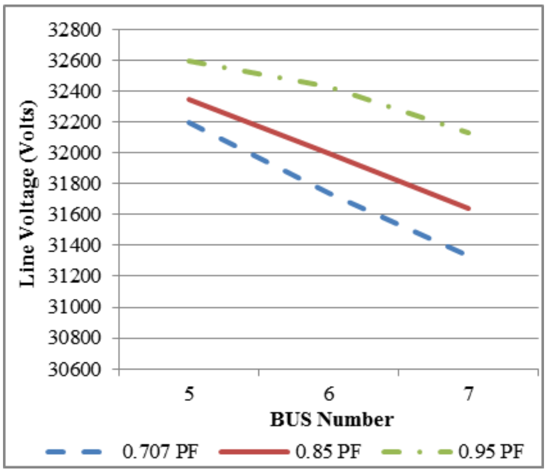

Fig.8. Voltage profile of F #2 for radial system.

Figure 8 shows the voltage profile of the F#2 when the system is operating in radial configuration and figures 9, 10 shows the voltage profile at Bus 6 for a specified p.u. DG capacity at which the system can attains maximum percentage of loss reduction at different operating power factors 0.707 PF, 0.85 PF and 0.95 PF.

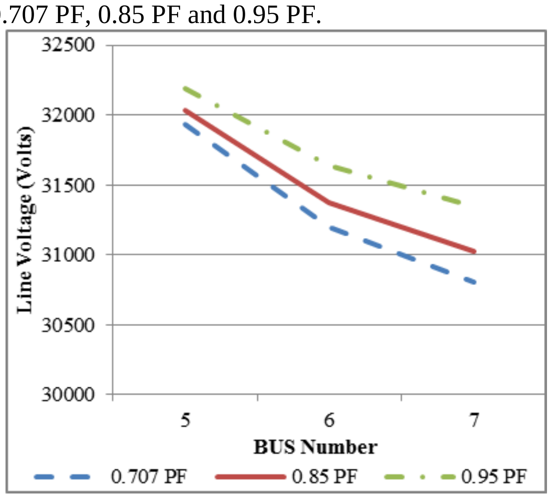

Fig.9. Voltage profile of F #2 (DG at BUS 6).

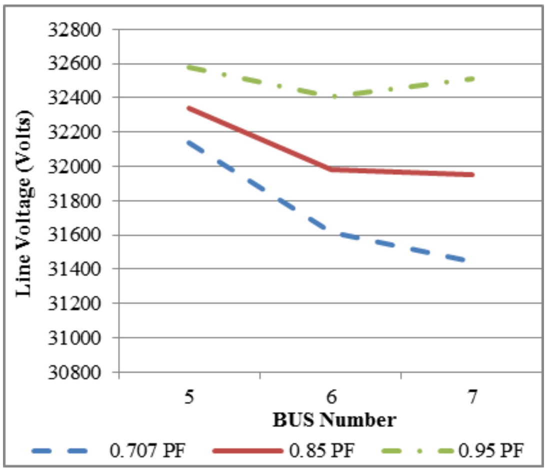

Fig.10. Voltage profile of F #2 (DG at BUS 7).

V. CONCLUSION

Distributed Generation (DG) is one of the strategies to improve the performance of electrical distribution system. The simulation results clearly evidence the line loss reduction and voltage profile improvement in the system. From Figures 5, 6, 7 it is noted that DG placement cannot always results to effective loss reduction i.e., it depends on the rating and location of DG unit. The graphs shows that up to a particular rating and location of DG unit only the maximum power loss reduction can be achieved if it is not the line loss reduction is less and in some cases it leads to more power losses in the system. Therefore the implementation of DG is depends on rating, location and system power factor and it is always not possible and necessary to place DG unit in distribution system in that case it is better to go for another method or strategy which will fulfill the system needs.

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TABLE II. THE SIMULATION RESULTS

CASE	Per Unit DG Placed(P.u.) / Power Loss (KW)	0	0.2	0.4	0.6	0.8	1	1.2	1.4
CASE#A	**Condition 1**	483.6	423.8	384.5	365.3	365.6	384.9	422.8	478.8
	Condition 2	483.6	413.1	374.8	367.3	389.5	440.4	519.2	625.2
	Percentage of Line Loss Reduction 1	**0**	**12.37**	**20.49**	**24.46**	**24.40**	**20.41**	**12.57**	**0.99**
	Percentage of Line Loss Reduction 2	**0**	**14.58**	**22.50**	**24.04**	**19.45**	**8.93**	**-7.36**	**-29.28**
CASE#B	**Condition 1**	488.1	413.5	359.1	324.5	309.2	312.5	334.2	373.8
	Condition 2	488.1	399.3	342	315	317.1	347.3	404.9	488.9
	Percentage of Line Loss Reduction 1	**0**	**15.28**	**26.43**	**33.52**	**36.65**	**35.98**	**31.53**	**23.42**
	Percentage of Line Loss Reduction 2	**0**	**18.19**	**29.93**	**35.46**	**35.03**	**28.85**	**17.05**	**-0.164**
CASE#C	**Condition 1**	495	409.8	344.6	298.8	271.8	263.3	272.6	299.5
	Condition 2	495	393.3	322.4	281	268	282.3	323.1	389.6
	Percentage of Line Loss Reduction 1	**0**	**17.21**	**30.38**	**39.64**	**45.09**	**46.81**	**44.93**	**39.50**
	Percentage of Line Loss Reduction 2	**0**	**20.54**	**34.87**	**43.23**	**45.86**	**42.97**	**34.73**	**21.29**