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Minimization of power loss and improvement ofvoltage profileby optimal placement ofwind generator in distribution network

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Abstract

Nowadays, distribution losses accounts to 25 to 30 percent, so minimization of these losses gain major role to maintain power system performance. Distributed generation (DG) could be considered as one of the viable options toease some of the problems (e.g. high loss, low reliability,poor power quality)faced by the power systems, apart from meeting theenergy demand of ever growing loads.Inclusion of a wind generator into distribution system will minimise the power losses and improves the voltage profile. Determination of optimal location of wind generator in the given distribution system is very important, as studies indicate that inappropriate selection oflocation and size of wind generator, may lead to greater system losses than the losses without placing it in the given distribution system. In this work, Analytical approach and Particle Swarm Optimization technique are used to determine wind generator size and its optimal placement.A conventional load flow technique called backward forward sweep load flow is used for calculation. The results for the two approaches are compared and voltage profile of the 33-bus, 69-bus and 13-bus radial distribution test systems is observed.

Index terms: Wind generator, power loss, optimum size and location, Distributed generation, Particle Swarm Optimization.

1. INTRODUCTION

The objective of power system operation is to meet the demand at all the locations within power network as economically and reliably as possible. The traditional electric power generation systems utilize the conventional energy resources, such as fossil fuels, hydro, nuclear etc. for electricity generation. The operation of such traditional generation systems is based on centralized control utility generators, delivering power through an extensive transmission and distribution system, to meet the given demands of widely dispersed users. Nowadays, the justification for the large central-station plants is weakening due to depleting conventional resources, increased transmission and distribution costs, deregulation trends, heightened environmental concerns, and technological advancements. Distributed Generations (DGs), a term commonly used for small-scale generations, offer solution to many of these new challenges.Distributed or dispersed generation may be defined as a generating resource, other than central generating station, that is placed close to load being served, usually at customer site.International Energy Agency (IEA) define distributed generation as generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at distribution level voltages. In term of size,DG may range from few kilowatts to over 100 megawatts. Supplying peaking power to reduce the cost of electricity,reduce environmental emissions through clean andrenewable technologies (Green Power), combined heat and power (CHP), high level of reliability and quality of supplied power and deferral of the transmission and distribution line investment through improved loadability are the major applications of the DG Because of the considerable advantages of DG-unit application (e.g., power loss reduction, environmental friendliness, voltage improvement, postponement of system upgrading, and increasing reliability), there has been a significant rise in interest by researchers. Wind turbine, photovoltaic, fuel cells and micro turbines are the recent developments in small scale renewable energy generation technology. In this work wind generator is used, and the purpose of installing only wind turbine is availability of wind everywhere and also of its minimal fuel consumption.If this eco-friendly power is supplied to the consumers, without disturbing the reliability and security of the power system then both the technical and economic losses can be reduced.

2. IMPORTANCE OF SIZE AND LOCATION OF WIND GENERATOR

As the size of DG is increased, the losses are reduced to a minimum value and increased beyond a size of DG (i.e. the optimal DG size) at that location. If the size of DG is further increased, the losses starts to increase and it is likely that it may overshoot the losses of the system. Also notice that location of DG plays an important role in minimizing the losses [1]. The size of distribution system in term of load(MW) will play important role is selecting the size of DG.The reason for higher losses and high capacity of DG can beexplained by the fact that the distribution system was initiallydesigned such that power flows from the sending end (sourcesubstation) to the load and conductor sizes are graduallydecreased from the substation to consumer point. Thuswithout reinforcement of the system, the use of highcapacityDG will lead to excessive power flow throughsmall-sizedconductors and hence results in higher losses.

3. PROBLEM FORMULATION

Researchers have developed various methods for finding the optimal size and location of wind generator, such as Analytical expression, Particle Swarm Optimization, Fuzzy Logic, Genetic Algorithm have been proposed. In this work, analytical approach and Particle Swarm Optimization technique are used. Theadvantage of using analytical approach is that we just have to calculate the voltage profile of the busses using any load flow method without any DGs in the network and we can calculate the power losswith DGs without running the load flow method. The main objective of placing wind generator is to minimize the real power loss [2]. The real power loss in the system is given by equation (1). This formula is popularly referred as "Exact Loss" formula [3].

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - PiQj \quad \text{- (1)}$$

Where,

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$$

And

$$Z_{ij} = r_{ij} + jx_{ij}$$

$P_i = P_{DGi} - P_{Di}$

And

$Q_i = Q_{DGi} - Q_{Di}$

P_{DGi}&Q_{DGi} are power injection of generators to the bus.

P_{Di}&Q_{Di}arethe loads.

P_i &Q_i are active and reactive power of the buses.

For wind turbines, induction generators are used to produce

real power and reactive power will be consumed in the process[1].The reactive power consumed by the wind turbine can be represented by equation (2).

$$Q_{DG} = -(0.5+0.04P_{DG}^2) \text{ ---- (2)}$$

After substituting the above terms, exact power loss equation will be

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}\begin{bmatrix}(P_{DGi} - P_{Di})P_j + \\ (-0.5 - 0.04P_{DGi}^2 - Q_{Di})Q_j\end{bmatrix} + \beta_{ij}\begin{bmatrix}(-0.5 - 0.04P_{DGi}^2 - Q_{Di})P_j \\ -(P_{DGi} - P_{Di})Q_j\end{bmatrix}\right] \dots (3)$$

At minimal losses the rate of change of losses with respect to injected power becomes zero. The total power loss against injected power is a parabolic function [4].

$$\frac{\partial P_L}{\partial P_{DGi}} = \left[\begin{matrix}2\alpha_{ii}(P_i - 0.08P_{DGi}Q_j) + \\ 2\sum_{\substack{j=1\\ j\neq i}}^{N}\beta_{ij}(-0.08P_{DGi}P_j - Q_j)\end{matrix}\right] = 0 \quad \dots (4)$$

Or

$$\left[\begin{matrix}\alpha_{ii}[P_{DGi} - P_{Di} + 0.08P_{DGi}(0.5 + 0.04P_{DGi}^2 + Q_{Di})] \\ + \sum_{\substack{j=1\\ j\neq i}}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) - 0.08P_{DGi}\sum_{\substack{j=1\\ j\neq i}}^{N}(\alpha_{ij}Q_j + \beta_{ij}P_j)\end{matrix}\right] = 0$$

Let us assume

$$X_i = \sum_{\substack{J=1\\ J\neq i}}^{n}(A_{ij}P_j - B_{ij}Q_j) \dots (5)$$

$$Y_i = \sum_{\substack{J=1\\ J\neq i}}^{n}(A_{ii}Q_j + B_{ij}P_j) \qquad \dots (6)$$

From equations (5) and (6), (4) can be written as

$$0.0032\alpha_{ii}P_{DGi}^3 + (X_i - \alpha_{ii}P_{Di}) + P_{DGi}[1.004\alpha_{ii} + 0.08\alpha_{ii}Q_{Di} - 0.08Y_i] ---- (7)$$

Solving the equation (7)forP_{DGi}, the amount of real power that the wind turbine has to produce at various locations so as to minimize the real loss can be calculated. The bus, at which the total loss is minimum thatwill be the optimal location and corresponding size will be the optimal size, respectively.

4. BACKWARD FORWARD SWEEP LOAD FLOW METHOD

The Gauss-Seidel powerflow technique, another classical power flow method,although very robust, has shown to be extremely inefficient in solving large power systems.This powerflow solution scheme was developed for practical distribution networks with radial and weaklymeshed structure.This method has excellent convergence characteristics and is very robust and can be applied to thesolution of both the three-phase (unbalanced) and single-phase (balanced) representation of the network. In this work, however, only the single phase representation is used.The radial network is solved efficiently by thedirect application of Kirchhoff's voltage and currentlaws (KVL and KCL).In contrast to all classical power flow techniques which use nodal solution methods for the network, this algorithm is branch-oriented [5]. Regardless of its originaltopology, the distribution network is first converted to a radial network.Given the voltage at the root node and assuming a flat profile for the initial voltages at all other nodes, the iterative solution algorithm consists of three steps:

1. Nodal current calculation
2. Backward sweep
3. Forward sweep

Steps 1, 2 and 3 are repeated until convergence isachieved.

4.1. BACKWARD – FORWARD SWEEP METHOD ALGORITHM:

The iterative sequence of steps followed by the Backward – Forward sweep method is as following:

Step 1: Divide the Distribution Network into layers as explained
Step 2: Assume Flat Voltage Profile and set iterationcount k = 1.
Step 3: Backward Sweep: Calculate Line flows from last layer to first for all the branches of layers.
Step 4: Forward Sweep: Compute V_T (i) and δ_T (i)
Step 5: Stopping Criteria: if $\Delta P_i \leq \varepsilon_P$ and $\Delta Q_i \leq \varepsilon_Q$then Stop iterations otherwise increment iteration i.e. k=k+1 and continue Steps 2-4.

5. PARTICLE SWARM OPTIMIZATION TECHNIQUE (PSO)

Particle swarm optimization (PSO) is a population-based optimization method first proposed by Kennedy and Eberhart in 1995, inspired by social behaviour of bird flocking or fish schooling.Particle swarm optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality [6]. PSO optimizes a problem by having a population of candidate solutions and moving these particles around in the search-space according to simple mathematical formulae over the particle's position and velocity. Each particle's movement is influenced by its local best known position (PBEST) and it's also guided toward the best known positions in the search-space (GBEST), which are updated as better positions are found by other particles. This is expected to move the swarm toward the best solutions.Such methods are commonly known as heuristics as they make few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions.PSO can therefore also be used on optimization problems that are partially irregular, noisy, change over time, etc.

Velocity of each agent can be modified by the following equation:

$$v_{id}^{k+1} = \omega v_{id}^{k} + c_1 rand \times \left(pbest_{id} - s_{id}^{k}\right) + c_2 rand \times \left(gbest_{id} - s_{id}^{k}\right)$$

Using the above equation, a certain velocity, which gradually gets close to pbest and gbest can be calculated. The current position (searching point in the solution space) can be modified by the following equation:

$$S_{id}^{k+1} = S_{id}^{k} + v_{id}^{k+1}, i = 1,2, \dots, n$$

And d=1,2,…,m

Where,

sk	is current searching point,
sk+1	is modified searching point,
vk	is current velocity,
vk+1	is modified velocity of agent i,
vpbest	is velocity based on pbest, ,
vgbest	is velocity based on gbest,
n	is number of particles in a group,
m	is number of members in a particle,
pbesti	is pbest of agent i,
gbesti	is gbest of the group,
ωi	is weight function for velocity of agent i,
ci	is weight coefficients for each term.

An Inertia weight ω is a proportional agent that is related with the speed of last time. The influence that the last speed has on the current speed can be controlled by inertia weights.The following weight function is used:

$$\omega_i = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{k_{max}} . k$$

ω_{min} and $\omega_{max}$are the minimum and maximum weights respectively.
k and k_{max} are the current and maximum iteration. Appropriate value ranges for $C_1$and $C_2$are 1 to 2, but 2 is the most appropriate in many cases. Appropriate values for ω_{min} and ω_{max} are 0.4 and 0.9 respectively [7].

5.1. STOPPING CRITERIA

There are two ways to determine stopping criteria.
1. Set a maximum number of iterations after which it has to stop which depends upon the number of variables the problem, complexity of the objective function and number of particles of the PSO being implemented.
2.Stop when change in pbest from the previous iteration to the current iteration is below a certain value ε or taken as zero.

5.2. ALGORITHM FOR PSO

The PSO-based approach for solving the optimal placement of DG problem to minimize the loss takes the following steps.
Step 1: Input line and bus data.
Step 2: Calculate the loss using distribution load flow based on backward sweep-forward sweep method.
Step 3: Randomly generates an initial population (array) ofparticles with random positions and

velocities on dimensions (Size of DG and Location of DG) in the solution space. Set the iteration counter $k = 0$.

Step 4: For each particle, compare its objective value with
the individual best. If the objective value is lowerthan *Pbest*, set this value as the current *Pbest*, and record the corresponding particle position.
Step 5: Choose the particle associated with the minimum *individual best Pbest* of all particles, and set the value of this *Pbest* as the current *overall best Gbest*.
Step 6: Update the velocity and position of particle using (8) and (9) respectively.
Step 7: If the iteration number reaches the maximum limit, go to Step 9. Otherwise, set iteration index $k = k + 1$, and go back to Step 4.
Step 8: Print out the optimal solution to the target problem.
The best position includes the optimal locations and sizes of DG and the corresponding fitness value representing the minimum total real power loss.

6. TEST SYSTEMS

The system under study is a typical 33-bus distribution system, contains 33 buses and 32 branches as shown in Figure. It is a radial distribution system with a total load of 3.72 MW and 2.3 MVAR [8]. A computer program is written in MATLAB 7.9 to find the optimal size of DG at various buses and approximate total loss with placement of wind generator at various locations to find out the best location by analytical method and PSO.

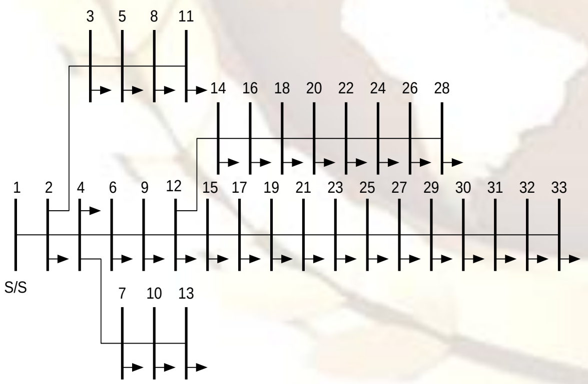

Figure 1:Single line diagram of 33 bus distribution test system.

The second test system is a 69-bus radial distribution system with a total load of 3.80 MW and 2.69 MVAR [9]. Thesingle line diagram of the typical 69-bus distribution system is shown in Figure.The third test system is a 13-bus radial distribution system and the single line diagram of 13-bus is shown in figure

7. RESULTS AND DISCUSSION

The optimum sizes and losses of the three distribution test systems are calculated based on the analytical expression. For 33-bus test system optimal location is 12 and the total loss after placing wind generator is 163.3kW. At 12th location 1.52MW is supplying and absorbing 0.592MVAR. For 69-bus test system, optimal location is 61st bus. The total power loss after placing wind generator is 160.6kW and it supplies 1.43MW and absorbs 0.582MVAR. Similarly for 13-bus system, optimal location is optimal location is 8th bus.Total power loss after placing wind generator is 119.7kW. The details of three test systems are shown in table-1.

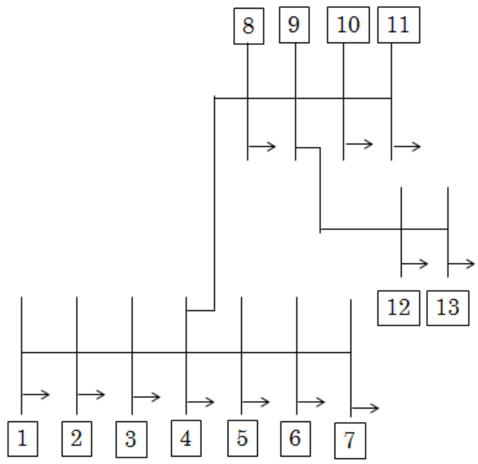

Figure 3: Single line diagram of 13 bus distribution test system.

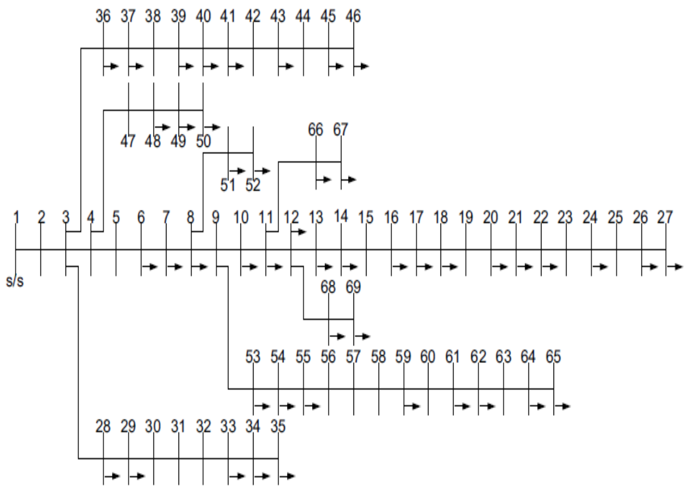

Figure 2: Single line diagram of 69 bus distribution test system.

Graphs for all the three test systems are shown below

The optimum real power generation for 33 bus system is observedat 12th bus and its Value is 1.52MW.

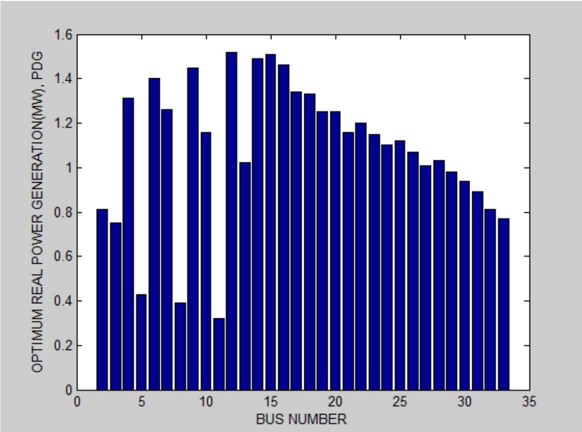

Figure 4: Optimum Real power generation at various locations for 33 bus distribution system

Power Loss at bus 12 (Optimal location) of33 bus distribution system is 163.3KW

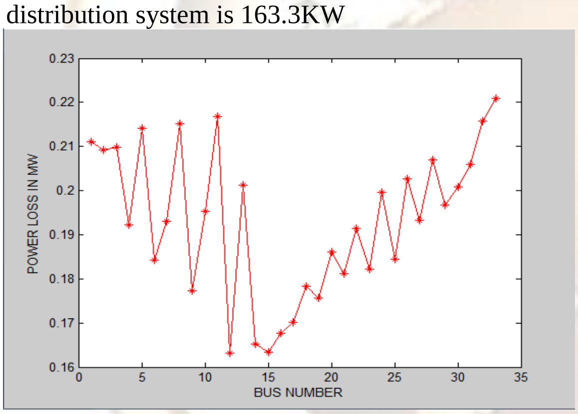

Figure 5: Accurate Total Power Loss of 33 bus distribution system.

The optimum real power generation for 69 bus system is observedat 61st bus and its Value is 1.43MW.

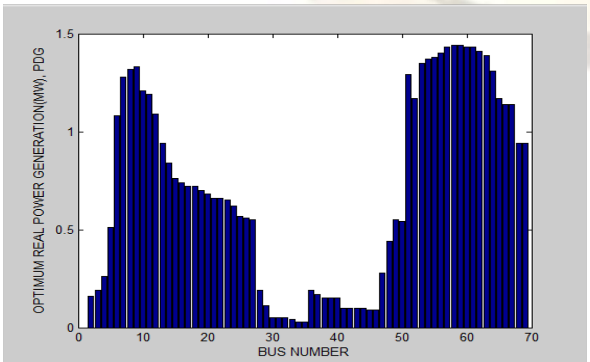

Figure 6: Optimum Real power generation at various locations for 69 bus distribution system

Power Loss at bus 61 (Optimal location) of69 bus distribution system is 160.6KW

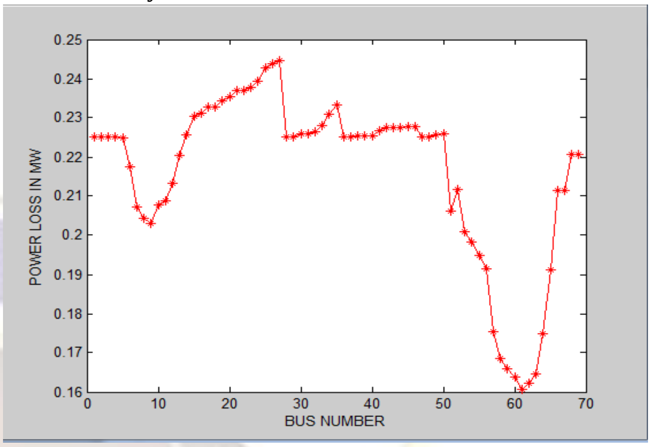

Figure 7: Accurate Total Power Loss of 69 bus distribution system.

The optimum real power generation for 13 bus system is observedat 8th bus and its Value is 1.70 MW.

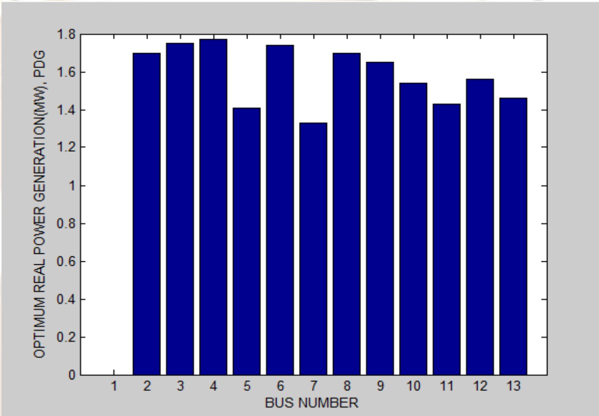

Figure 8: Optimum Real power generation at various locations for 13 bus distribution system

Power Loss at bus 8 (Optimal location) of13 bus distribution system is 119.7KW

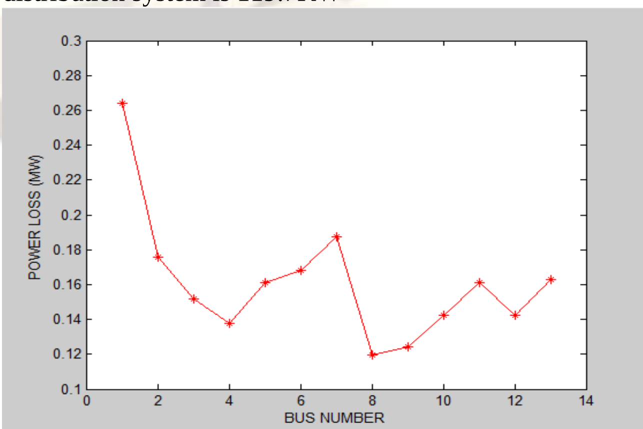

Figure 9: Accurate Total Power Loss of 13 bus distribution system.

TEST SYSTEM	CASE	OPTIMAL LOCATION OF WG	OPTIMUM SIZE OF WG		REAL POWER LOSS		% REDUCTION IN LOSS
			(MW)	(MVAR)	Without DG	With DG	
33 bus	Analytical	12th bus	1.52	0.592	211	163.3	22.61%
	PSO		2.18	0.691	211	155.3	26.40%
69 bus	Analytical	61st bus	1.43	0.582	225	160.6	28.62%
	PSO		1.72	0.618	225	158	29.78%
13 bus	Analytical	8th bus	1.70	0.616	264.1	119.7	54.67%
	PSO		1.93	0.649	264.1	106.9	59.52%

Table 1: Real power loss with and without wind generator for 33-bus, 69 bus and 13-bus Distribution test systems withAnalytical and PSO techniques

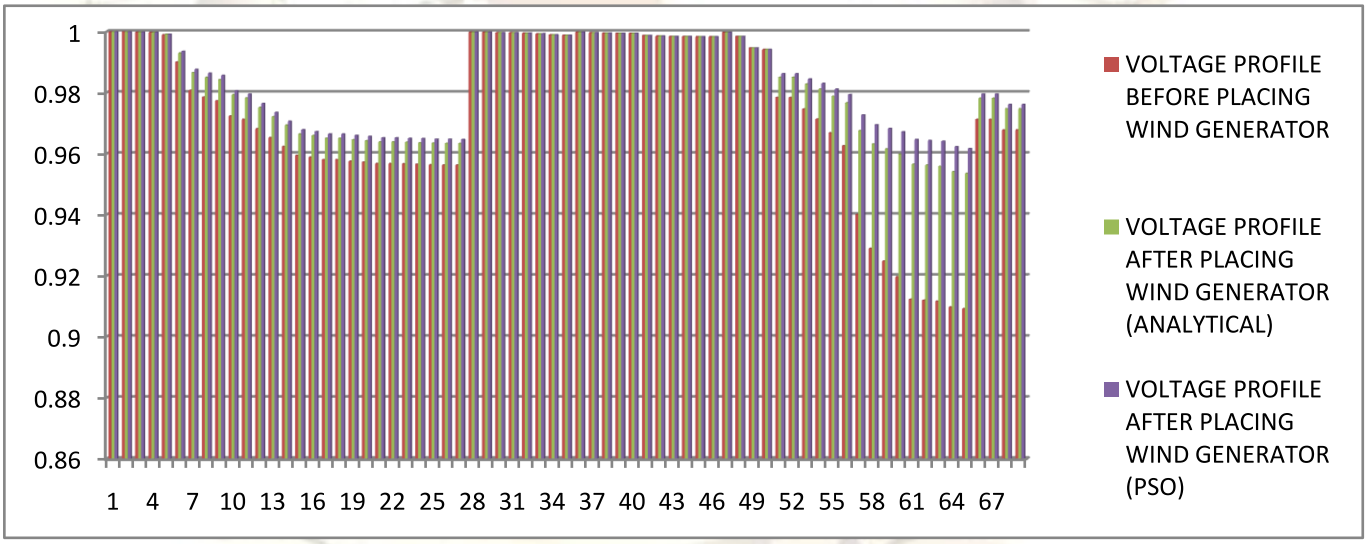

Figure 10: Variation of voltage profile with DG and without DG of 69 bus distribution system

8. CONCLUSION

The objective of this work, i.e. minimization of losses is attained by the optimal placement of wind generator in the considered distribution system. Analytical methods have a small error in deciding size of DG, whereas heuristic methods are accurate in finding optimal DG placement. Using heuristic techniques like PSO eliminates even the smallest possible error as the change in voltage profile before and after optimal DG placement is considered. The wind generator installed in the optimal location minimizes the losses in the 33-bus, 69-bus, 13-bus distribution test systems by supplying real power. The size of wind generator to be installed in the optimal location is calculated. Voltage profile of 33-bus, 69-bus,13-bus distribution test systems is improved after the installation of wind generator.The load flow technique mentioned in normally said to work well when the system considered is large. This thesis also shows that it can work with small grids too, such as 13-bus distribution system.

10. REFERENCES

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