OPTIMAL PLACEMENT OF DG UNITS IN RADIAL DISTRIBUTION SYSTEMS USING SA AND FF ALGORITHM

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Abstract – **Growing concerns over the improvement of overall network conditions in terms of voltage profile, stability and reliability, environmental aspects have led to installation of distribution generation (DG) units into commercial and domestic distribution networks. It is known that non-optimal placement of DG units with non-optimal penetration levels may lead to high power loss, undesired voltage profiles and harmonic propagations. To accommodate this new type of generation the existing distribution network should be utilized and developed in an optimal manner. A new methodology is developed to determine the optimal allocation of DG capacity with respect to the technical constraints on DG. The methodology is implemented and tested on a section of 33-bus distribution network. Results are presented demonstrating that the proper placement and sizing of DG is crucial to the accommodation of increasing levels of DG on distribution networks. Therefore identification of optimal placement of DG unit into network is important. This thesis introduces a novel method of identifying optimal location for installation of DG units. DLF studies are performed based on forward and backward sweep algorithms. An objective function is created to minimize the total losses, average voltage distortions and cost. The proposed methodology was tested on both radial distribution networks with various test systems using Simulated Annealing(SA) method Fire Fly(FF) method . The proposed methodologies provides high efficiency for minimization of system losses by improving voltage profile.**

Key Words: forward/backward sweep load flow analysis, distribution generation, cuckoo search algorithm , firefly, performance indices.

1. INTRODUCTION

1.1 Distribution Load Flow(DLF)

 To meet the present growing domestic,   industrial and commercial load day by day, effective planning of radial distribution network is required. To ensure the effective planning with load transferring, the load flow study of radial distribution network becomes utmost important. The transmission system is loop in nature having low R/X ratio. Therefore, the variables for the load flow solution of transmission system are different from the distribution system which have high R/X ratio. The general load flow studies of transmission system are not applicable for distribution systems as they may not yield good results. Hence, load flow models need little modifications for distribution system analysis. Some methods are developed for the solution of ill conditioned radial distribution systems those may be divided into two categories. The first type of methods is utilized by proper modification of existing methods such as Newton Raphson and Gauss Seidal methods. On the other hand, the second group of methods is based on forward and/or backward sweep processes using Kirchhoff's laws or making use of the well-known bi-quadratic equation.

Backward sweep*:* the load currents and the subsequent shunt currents are computed on the basis of the voltage vector at the preceding iteration. Note that, in general, different voltage-dependent load representations are possible, as shown in the sequel.

Forward sweep*:* the node voltages are updated on the basis of the voltage at the root node and of the voltage drops on the distribution lines evaluated by using the current computed in the backward stage.

1.2 Voltage Profile Calculation:

Consider either a radial or meshed distribution system with 'N' nodes. By application of KVL at i^{th} bus yields   the   basic bus current equations in generalized

form as $I_i = Y_{11}V_1 + Y_{12}V_2 + \cdots$ (or)

$I_i = \sum_{k=1}^{n}(Y_{ik}V_k)$ $k = 1,2,\dots N$ (1.1)

Where, Y_{ik} (i≠k)= $-y_{ik}$;Negative of the total admittance connected between i^{th} and k^{th} bus

(i≢k)=0;if there is no transmission line between i^{th} and k^{th} bus.

Complex power injected by the source into the ith bus of a power system is given by ,

$$S_i = P_i + j Q_i = V_i I_i^* \tag{1.2}$$

By rearranging the above equations,

$$P_i - j Q_i = V_i^* I_i \qquad \text{(or)}$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{1.3}$$

From equation(1),

$$I_i = \sum_{k=1}^{n}(Y_{ik}V_k) \tag{1.4}$$

$$= \sum_{\substack{k=1 \\ \neq i}}^{n} Y_{ik}V_k + Y_{ii}V_i$$

We know that the equation,

$$Y_{ii}V_i = I_i - \sum_{\substack{k=1 \\ \neq i}}^{n} Y_{ik}V_k \qquad \text{(or)}$$

$$V_i = \frac{1}{Y_{ii}}\left[I_i - \sum_{\substack{k=1 \\ \neq i}}^{N} Y_{ik}V_k \right] \tag{1.5}$$

By substituting the bus current in real and reactive power component from equation (1.3) in the above equation (1.5) the bus voltages at each bus will be obtained. Starting from the source node to the ending node the voltage at each node by the following recursive equations at i^{th} bus is given by ,

$$V_i = \frac{\frac{P_i - jQ_i}{V_i^*} - \sum_{j=1}^{n} V_j Y_{ij}}{Y_{ii}} \tag{1.6}$$

By using the above equations the bus voltages calculated at each bus are compared with its original specified values or with initial voltage profile by equation (1.7). If the error between the specified values and the calculated values is beyond the limit the forward sweep is performed again to update the bus voltages along the feeder. In such a case, the specified source voltages already calculated in the previous forward sweep are used. The process keeps going back and forth until the voltage error at the source becomes within the limit.Updated voltages are compared with previous voltages in order to perform convergence check in

$$\varepsilon \le \left| V_i^{k+1} - V_i^k \right| \tag{1.7}$$

If the error calculated using above equation (1.7) are within the limits then system in converged and the branch currents are calculated at each branch by using these bus voltages. The branch current scan be calculated by using the following equations (1.8) by considering the line between i bus and k bus is shown in following figure.
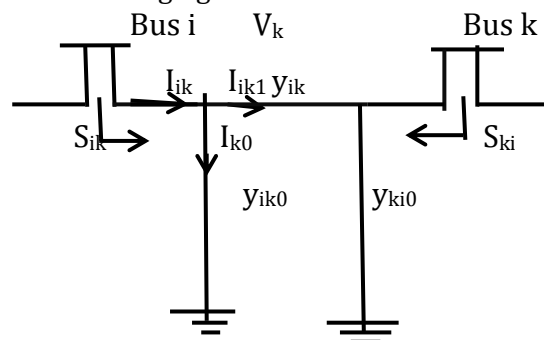

Fig.1.1. i-k line between i bus and k bus

The current fed by bus i into the line can be expressed as,

$$I_{ik} = I_{ik1} + I_{ik0} = (V_i - V_k)y_{ik} + V_i y_{ik0} \tag{1.8}$$

1.3 Power flow equations

Power fed into the line from bus i is given by,

$$S_{ik} = V_i I_{ik}^* \tag{1.9}$$

Substituting equation (1.8) into equation (1.9),

$$S_{ik} = V_i(V_i^* - V_k^*)y_{ki}^* + V_i V_i^* y_{ik0}^* \tag{1.10}$$

Similarly power fed to the line from bus k is,

$$S_{ki} = V_k(V_k^* - V_i^*)y_{ik}^* + V_k V_k^* y_{ki0}^* \tag{1.11}$$

Hence, the Power loss between the ith bus and k^{th} bus is ,

$$S_{L_{ik}} = S_{ik} + S_{ki} \tag{1.12}$$

Real power loss in i-k line is,

$$P_{L_{ik}} = \text{Re}\{S_{ik} + S_{ki}\} \tag{1.13}$$

Reactive power loss in i-k line is,

$$Q_{L_{ik}} = \text{Imag}\{S_{ik} + S_{ki}\} \tag{1.14}$$

The power loss in i-k line is the sum of the power flows determined from equation (1.12). Total distribution line loss can be computed by summing all the line flows (i.e., $S_{ik}+S_{ki}$ for all i, k)

or $\quad S_L = \sum_{i,k=1}^{N}(S_{ik}+S_{ki}\ )$

2. PERFORMANCE INDICES

Here some indices are given to study the distribution system performance with and without Distribution Generation. The following Performance Indices have been used for calculating the objective function to minimize losses,

1. **Voltage Deviation:**

$$VD = \sum_{i=1}^{N} |V_n - V_i|^2$$

where, N – Total number of buses

Vn – Nominal voltage

Vi – Actual voltage at bus 'i'

2. **Voltage Deviation Index:**

$$VDI = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{|V_{i-DG} - V_{nom}|}{V_{nom}}\right]$$

V_{nom} = Desired voltage at bus i(1 p.u)

3. **Voltage Profile Index:**

$$VPI = \frac{1}{n}\frac{\sum_{i=1}^{N}|V_{i-DG}-V_{i-NODG}|}{\sum_{i=1}^{N}V_{i-NODG}}X100\%$$

4. **Loss sensitivity factor:**

The Exact Loss Formula is given by,

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}[P_iP_j + Q_iQ_j] + \beta_{ij}[Q_iP_j + P_iQ_j]]$$

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

The sensitivity factor of real power loss with respect to real power injection from the DG is given by,

$$\alpha_i = \frac{\partial P_L}{\partial P_i} = 2\alpha_{ii}P_i + 2\sum_{j=1}^{N}\sum_{j\neq i}[\alpha_{ij}P_j - \beta_{ij}Q_j]$$

The bus having highest loss sensitivity factor will be best location for the placement of DG.

6. Voltage stability index:

$$VSI_{i+1} = |V_i|^4 - 4[P_{i+1}x_j - Q_{i+1}r_j]^2 - 4[P_{i+1}r_j + Q_{i+1}x_j]|V_i|^2$$

where, i= sending end bus.

i+1 = receiving end bus.

In this study the above simple stability criterion, given in eq., is used to find the stability index for each line receiving end bus in radial distribution networks.

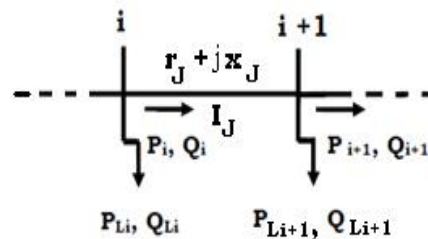## 2.1 Size of the Distributed Generation:

From Exact Loss Formula we get,

Fig.2.1 Representation of two nodes in distribution line

From Exact Loss Formula we get,

$$\frac{\partial P_L}{\partial P_i} = 2\alpha_{ii}P_i + 2\sum_{j=1}^{N}\sum_{j\neq i}[\alpha_{ij}P_j - \beta_{ij}Q_j] = 0$$

Since, the total power loss against injected power is a parabolic function and at minimum losses, the rate of change of losses with respect to injected power becomes zero.

Then the value of P_i is given by,

$$P_i = \frac{1}{\alpha_{ii}}[\sum_{j=1}^{N}\sum_{j\neq i}[\alpha_{ij}P_j - \beta_{ij}Q_j]]$$

where P_i is the real power injection at node i, which is the difference between real power generation and the real power demand at that node.

i.e., $\quad P_i = [P_{DGi} - P_{Di}]$

where P_{DGi} the real power injection from DG is placed at node i, and P_{Di} is the load demand at node i. By combining .From the above equation we get,

$$P_{DGi} = P_{Di} - \frac{1}{\alpha_{ii}}[\sum_{j=1}^{N}\sum_{j\neq i}[\alpha_{ij}P_j - \beta_{ij}Q_j]]$$

The above equation gives the optimum size of DG at buses i for the loss to be minimum. Any size of DG other than P_{DGi} placed at bus i, will lead to higher loss.

2.2 Objective function formulation:

The performance indices Loss Sensitivity Factor and Voltage Stability Index are taken into consideration for formulating the objective function.

The objective function is shown below,

F(i)=k(Performance indice)

Here, i=1,2,3…….n-number of nodes.

    k is the weighing factor.

    k= 1.

3. OPTIMIZATION TECHNIQUES
3.1 SIMULATED ANNEALING(SA):

Simulated Annealing (SA) is motivated by an analogy to annealing in solids. The algorithm in this paper simulated the cooling of material in a heat bath. This is a process known as annealing. If you heat a solid past melting point and then cool it, the structural properties of the solid depend on the rate of cooling. If the liquid is cooled slowly enough, large crystals will be formed. However, if the liquid is cooled quickly (quenched) the crystals will contain imperfections. Metropolis's algorithm simulated the material as a system of particles. The algorithm simulates the cooling process by gradually lowering the temperature of the system until it converges to a steady, frozen state. In 1982, Kirkpatrick et al (Kirkpatrick, 1983) took the idea of the Metropolis algorithm and applied it to optimisation problems. The idea is to use simulated annealing to search for feasible solutions and converge to an optimal solution. Much of this text is based on (Dowsland, 1995).

3.2 FIREFLY(FF):

The Firefly algorithm (FA) is a recently developed heuristic optimization algorithm by Yang and the flashing behavior of fireflies has inspired it. According to Yang, the three idealized rules of FA optimization are as follows. (a) All fireflies are unisex, so that one firefly is attracted to other fireflies regardless of their sex. (b) Attractiveness is proportional to brightness, so for any two flashing fireflies, the less bright firefly will move towards the brighter firefly. Both attractiveness and brightness decrease as the distance between fireflies increases. If there is no firefly brighter than a particular firefly, that firefly will move randomly. (c) The brightness of a firefly is affected or determined by the landscape of the objective function. There is two essential components to FA: the variation of light intensity and the formulation of attractiveness. The latter is assumed to be determined by the brightness of the firefly, which in turn is related to the objective function of the problem.

4. RESULTS AND DISCUSSIONS FOR 33-BUS SYSTEM

Below represents various waveforms with and without DG using Simulated Annealing with Loss sensitivity Factor(LSF). DG is placed at bus 7.
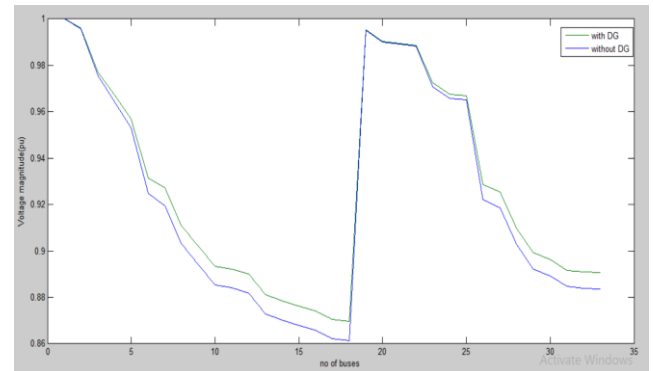
4.1 VOLTAGE MAGNITUDE

Fig.4.1 Voltage magnitude using SA for LSF

4.2 REAL POWER LOSSES
    Total Losses without DG=277.8841 KW
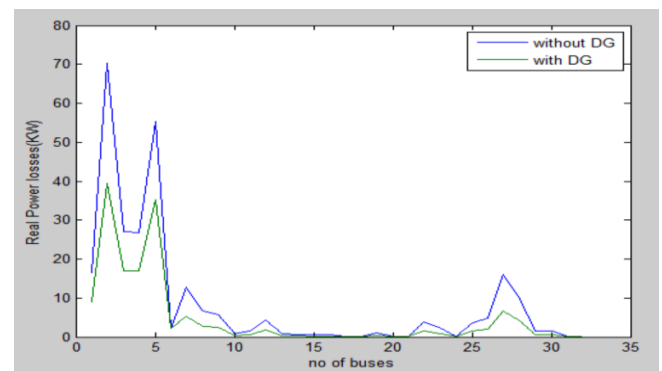   Total Losses with DG at Bus 7=152.4308 KW

Fig.4.2 Real Power Losses using SA for LSF

4.3 REACTIVE POWER LOSSES
    Total Losses without DG=187.179 KVAR
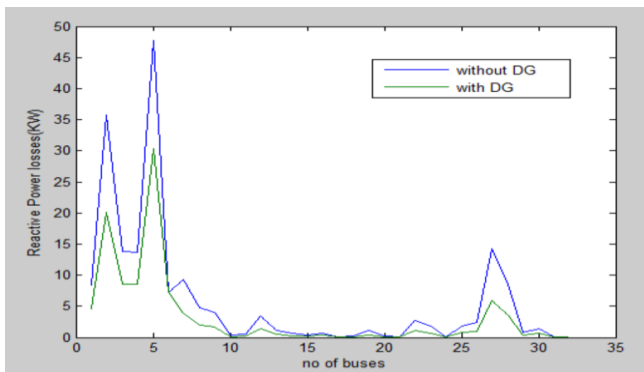   Total Losses with DG at Bus 7=104.3611 KVAR

Fig.4.3 Reactive Power Losses using SA for LSF
Below represents various waveforms with and without DG using Simulated Annealing with Voltage Stability Index. DG is placed at bus 17.
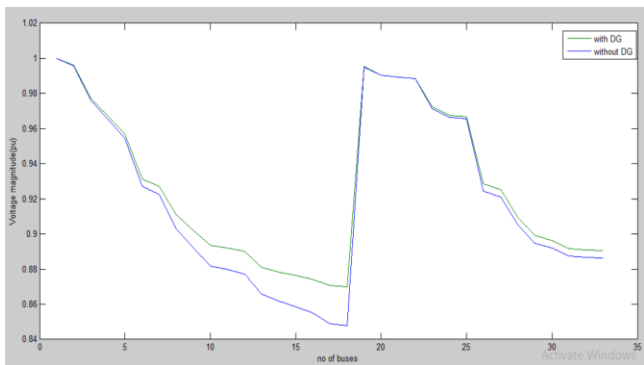
4.4 VOLTAGE MAGNITUDE

Fig 4.4 Voltage magnitude using SA for VSI

4.5 REAL POWER LOSSES
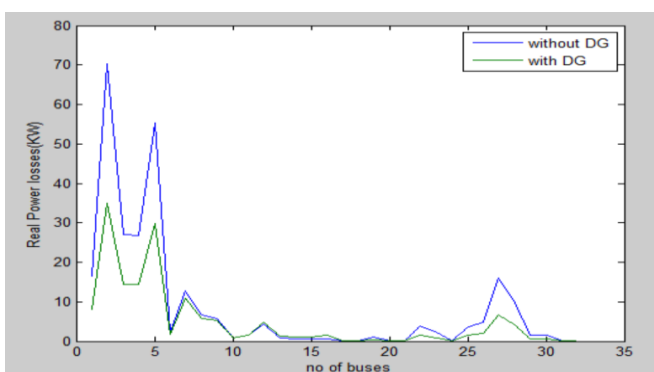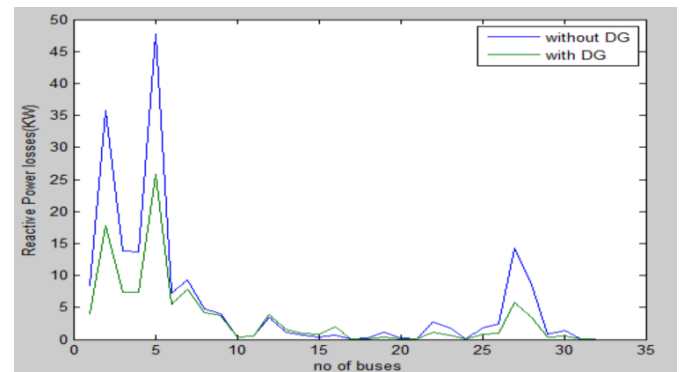Total Losses without DG=277.8841 KW
Total Losses with DG at Bus 17=156.5376 KW

Fig4.5 Real Power losses using SA for VSI

4.6 REACTIVE POWER LOSSES
Total Losses without DG=187.179 KVAR
Total Losses with DG at Bus 17=108.4409 KVAR

Fig 4.6 Reactive Power Losses using SA for VSI
Below represents various waveforms with and without DG using Firefly Algorithm with Loss Sensitivity Factor. DG is placed at bus 12.
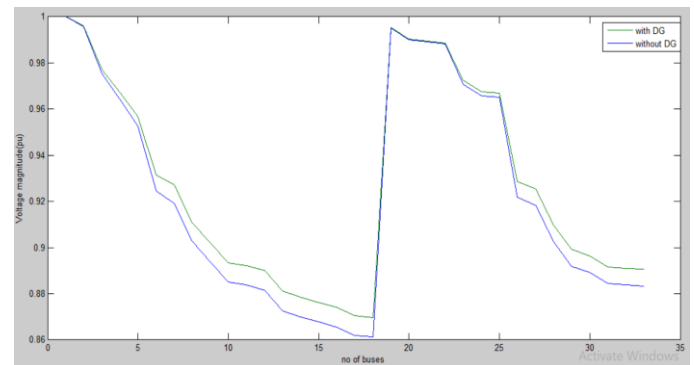
4.7 VOLTAGE MAGNITUDE

Fig 4.7 Voltage magnitude using Firefly for LSF

4.8 REAL POWER LOSSES

Total Losses without DG=277.8841 KW
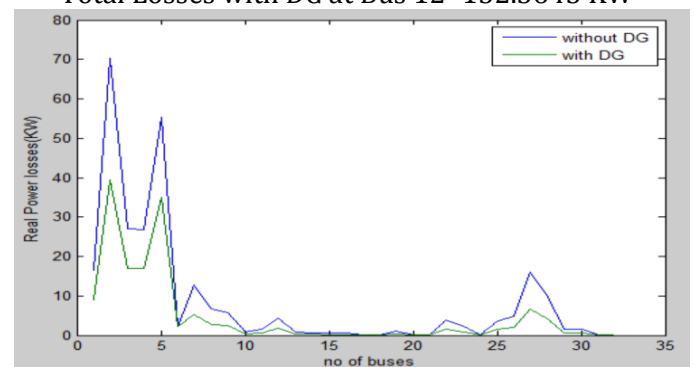Total Losses with DG at Bus 12=152.5645 KW

Fig 4.8 Real Power Losses using FF for LSF

4.9 REACTIVE POWER LOSSES

Total Losses without DG=187.179 KVAR
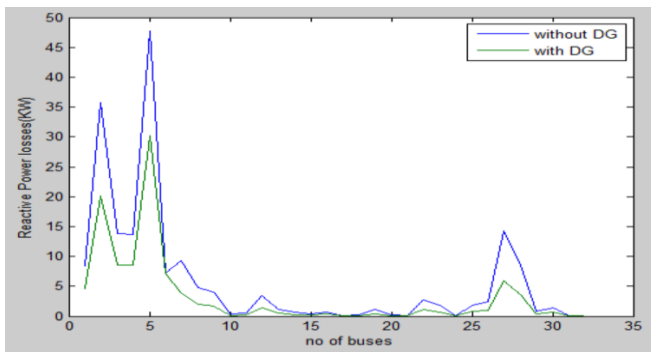Total Losses with DG at Bus 12=104.4582 KVAR
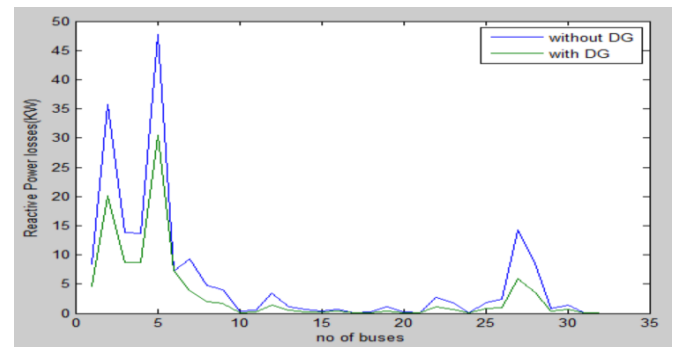
Fig 4.9 Reactive Power Losses using FF for lsf

Below represents various waveforms with and without DG using Firefly Algorithm with Voltage Stability Index. DG is placed at bus 17.
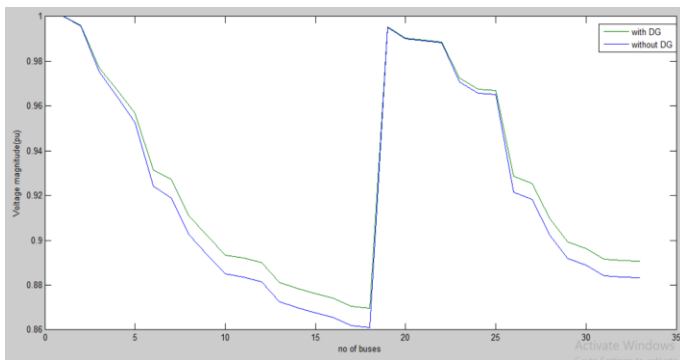
4.10 VOLTAGE MAGNITUDE

Fig 4.10 Voltage Magnitude using FF for VSI

4.11 REAL POWER LOSSES

Total Losses without DG=277.8841 KW
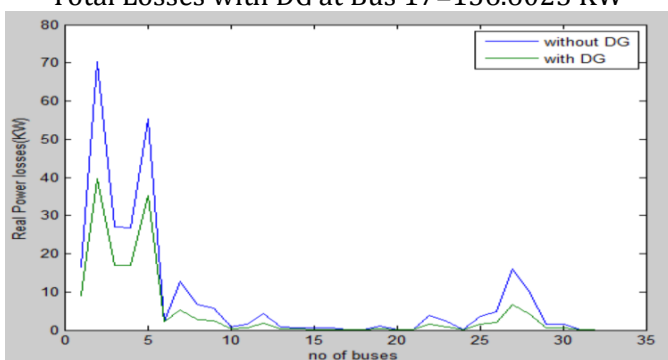Total Losses with DG at Bus 17=156.6025 KW

Fig 4.11 Real Power Losses using FF for VSI

4.12 REACTIVE POWER LOSSES

Total Losses without DG=187.179 KVAR
Total Losses with DG at Bus 17=107.393 KVAR

Fig 4.12 Reactive Power Losses using FF for VSI

Comparison of Simulated Annealing and Firefly is shown for each distribution system taken for the test, also optimal location of DG in both the optimization techniques is observed and the parameters after performing Load Flow Analysis are also observed.

6. CONCLUSION

An improvement in technological aspects in distribution system operation and management helps in improving system conditions and to provide good services to the consumer. The distribution sectors have given major scope for placement of distribution generation resources. The improper location of distribution generation may leads to deterioration of system performance like increased power losses, poor voltage profile. It is necessary to place distribution generation at optimal location. The optimal location of distribution generation is calculated by Simulated Annealing and Firefly by formulating the objective function using the Performance Indices such as Loss Sensitivity Factor and Voltage Stability Index. This method helps to allocate distribution generation in any distribution system. An algorithm is proposed for optimal location of distribution generation. The allocation of DG unit based on this method improves the voltage profile, stability.

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