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Study of Voltage Variations Quenching by Optimal Positioning of PVDG by Differential Evaluation

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ABSTRACT

A study of the voltage variations quenching is produced by PVDG units is presented. The maximum permissible penetration level of PVDG in distribution system is also considered. The general procedures of optimal planning for PVDG placement and sizing are also explained. The result of this review shows that there are different challenges for integrating PVDG in the power systems. One of these challenges is integrated system reliability whereas the amount of power produced by renewable energy source is consistent. Thus, the high penetration of PVDG into grid can decrease the reliability of the power system network. On the other hand, power quality is considered one of the challenges of PVDG whereas the high penetration of PVDGs can lead to more harmonic propagation into the power system network.

Keywords: Distribution systems, Transmission, distribution, algorithm, voltage, evaluation.

INTRODUCTION

Electrical Distribution System

Until the 1870s electricity was a matter of concern only for engineers and researchers. There was many of experiments were conducted to study more about electrical phenomena and batteries which is the main power source. The Belgian researcher Zenobe Gramme invented the generator, which could supply greater electrical currents compare to battery. Electricity feeders were then build from small and large power plants to supply light and run electricity machines for industries. The first incandescent lamp came into being around 1880, invented simultaneously by Thomas Alva Edison and the English man Joseph Swan. Electricity had finally reached its consumers providing the demand and rational for electricity power delivery systems. In other words, the electrical system between the substation fed by the transmission system and the consumer's meter is known as the "distribution system" and basic elements of a distribution system are service mains, feeders and distributors. Figure 1 depictures the single line diagram of a typical low tension distribution system.

(i) **Feeders**: A feeder is indefeasibly a conductor, connecting the localized generating station (or the sub-station) to the desired area where power has to be distributed. In order to keep the current in the feeder throughout, generally no tapping's are taken from the feeder. The current carrying capacity is the main point of focus during design of a feeder.

(ii) **Distributor**: A distributor is basically a conductor from which tapping's are taken for giving supply to theconsumers and Figure 1.1, AB, BC, CD, and DA represent the distributors. Since the tappings are taken at various places along the length of the distributor; the current through it is not constant. The voltage drop across the length of the distributor is the main point of focus during its design, as the statutory limit of voltage variations is ±10% of rated value at the consumer's terminal.

(iii) **Service mains**: The service mains are generally a small cable which connects the distributor to consumerterminals.

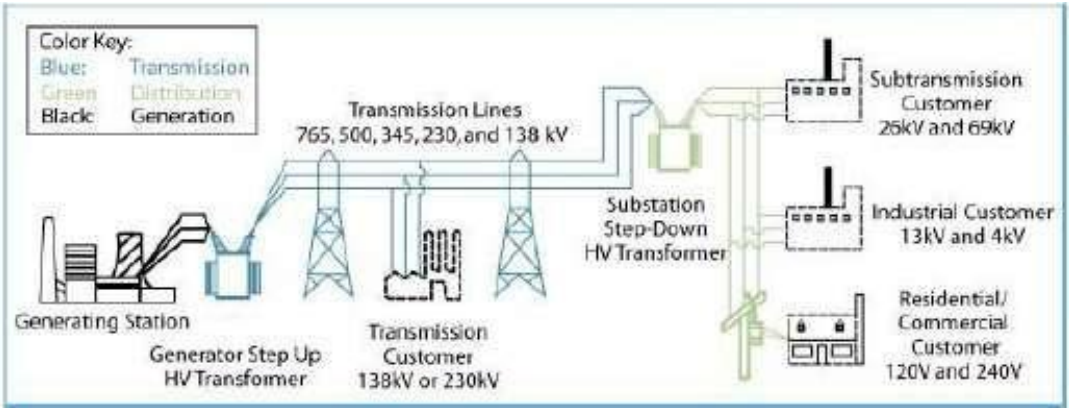

Figure 1: Diagram of a distribution system

DISTRIBUTED GENERATION

The term Distributed Generation (DG) refers to the use of small scale electric power generators dispersed within the distribution network level. The efficiency of DG technologies is high, e.g. 40 to 55% for fuel cells as compared to 28 to 35% for traditional large central power generators.

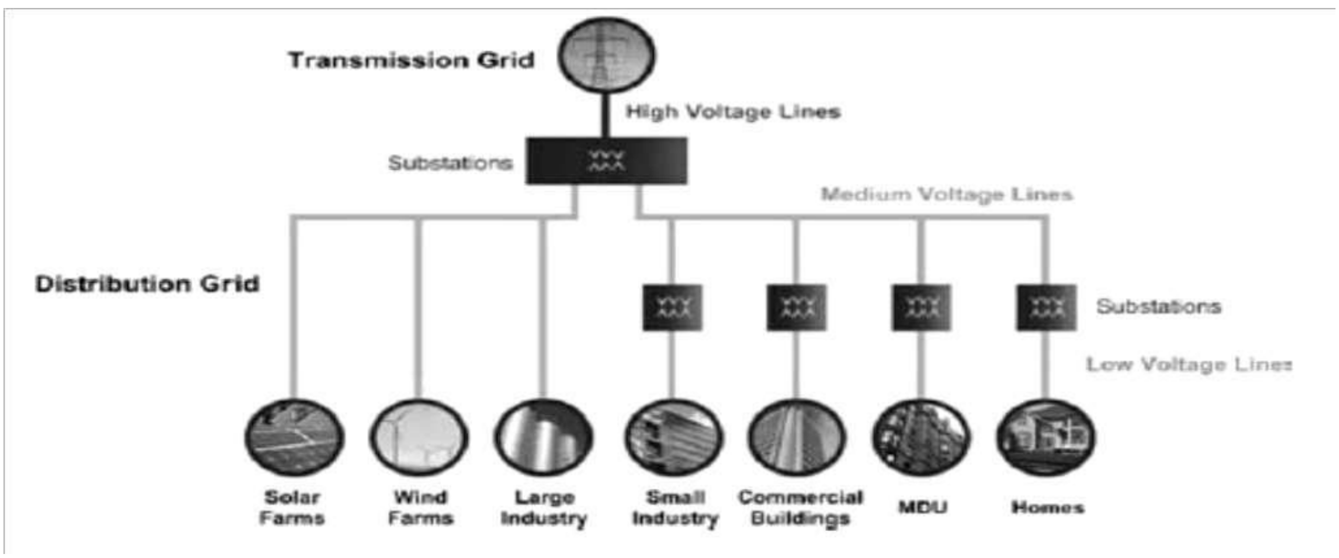

Figure 2: Interconnected Systems

Distributed Generation Technology

In Power system there are various DG technologies are used. Some of these technologies have been in use for a long time while others are newly emerging. The features of all DG technologies are common like to increase efficiency and decrease costs related to installation and operation and maintenance. DG technologies are categorized into two types: renewable technologies (e.g., photovoltaic and wind turbine) and non-renewable technologies (e.g., mini and micro-turbines, combustion turbines and fuel cells). These technologies have a significant impact on the selection of the appropriate size and place of a DG unit to be connected to a grid or customer loads.

LITERATURE REVIEW

Marko Vukobratovic (2014) presented a method for optimal Distributed Generation placement with goal of reducingvoltage level regulation and active power system losses. Active power losses in radial distribution network are determined using an Artificial Neural Network (ANN) by simultaneous formulation for the determination process based on voltage level control and injected power. By means of a genetic algorithm (GA) adequate installed power of distributed generation and the appropriate terminal for distributed generation utilization are selected and performed in a distinct manner that fits the type of decision-making assignment. For ANN the training data is obtained by means of load flow simulation performed in DIgSILENT Power factory software on a part of the Croatian distribution network. The voltage conditions and active power losses are simulated for various operation scenarios in which the back propagation ANN model has been tested to predict the power losses and voltage levels for each system terminal. Genetic algorithm (GA) is used to determine the optimal terminal for distributed generation placement.

S.P. Rajaram (2014) discussed the nonlinear aspect of power systems, with emphasis on voltage instability. In thatscenario modal analysis method make use of the power system Jacobean matrix to determine the eigen values necessary for the evaluation of the voltage stability of the power system. The least Eigen values indicate the proximity of the system to voltage instability. The voltage profile and critical loading is found by using continuation power flow method. These methods were implemented on IEEE 14 bus system result of the proposed work held on with the help of MATLAB software. Modal analysis technique, 14,10,9 buses are found to be the weakest and contributing to voltage collapse in IEEE 14 bus system. The stability margin or the distance to voltage collapse is identified based on voltage and reactive power variation. The Continuation power flow method voltage profile and critical loading is found. The weak bus is identified based on the voltage profile. In the continuation power flow method 14,10,9 buses are found to be the most critical and contributing to voltage collapse in IEEE 14 bus system

Azah Mohamed (2014) presented a method to identify optimal DG location based on maximum power stability indexwhile minimization of real power loss and also DG cost is considered in optimizing the DG size. A new evolutionary algorithm known as backtracking search algorithm (BSA) is opted in solving the optimization problem. The applicability of proposed method is verified using the IEEE 30-bus transmission network. The optimum distributed generator placement and size for improving voltage stability is determined by using the proposed voltage stability index and the backtracking search algorithm. The optimization problem has been successfully solved by considering minimization of real power loss and voltage stability improvement.

DIFFERENTIAL EVOLUTION

In evolutionary computation, differential evolution (DE) is a method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. Such methods are commonly known as meta heuristics as they make few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions. However, metaheuristics such as DE do not guarantee an optimal solution is ever found.

DE is used for multidimensional real-valued functions but does not use the gradient of the problem being optimized, which means DE does not require for the optimization problem to be differentiable as is required by classic optimization methods such as gradient descent and quasi-newton methods. DE can therefore also be used on optimization problems that are not even continuous, are noisy, change over time, etc.

DE optimizes a problem by maintaining a population of candidate solutions and creating new candidate solutions by combining existing ones according to its simple formulae, and then keeping whichever candidate solution has the best scoreor fitness on the optimization problem at hand. In this way the optimization problem is treated as a black box that merely provides a measure of quality given a candidate solution and the gradient is therefore not needed.

DE is originally due to Storn and Price. Books have been published on theoretical and practical aspects of using DE in parallel computing, multi objective optimization, constrained optimization, and the books also contain surveys of application areas.

ALGORITHM

A basic variant of the DE algorithm works by having a population of candidate solutions (called agents). These agents are moved around in the search-space by using simple mathematical formulae to combine the positions of existing agents from the population. If the new position of an agent is an improvement it is accepted and forms part of the population, otherwise the new position is simply discarded. The process is repeated and by doing so it is hoped, but not guaranteed, that a satisfactory solution will eventually be discovered.

Formally, let $f : \mathbb{R}^n \rightarrow \mathbb{R}$ be the cost function which must be minimized or fitness function which must be maximized. The function takes a candidate solution as argument in the form of a vector of real numbers and produces a real number as output which indicates the fitness of the given candidate solution. The gradient of f is not known. The goal is to find a solution m for which $f(m) \leq f(p)$ for all p in the search-space, which would mean m is the global minimum. Maximization can be performed by considering the function $h := -f$ instead.

Let $\mathbf{x} \in \mathbb{R}^n$ designate a candidate solution (agent) in the population. The basic DE algorithm can then be described as follows:

Initialize all agents $\mathbf{x}$ with random positions in the search-space.

- Until a termination criterion is met (e.g. number of iterations performed, or adequate fitness reached), repeat the following:
- For each agent $\mathbf{x}$ in the population do:
- Pick three agents $\mathbf{a}, \mathbf{b}$, and $\mathbf{c}$ from the population at random, they must be distinct from each other as well as from agent $\mathbf{x}$
- Pick a random index $R \in \{1, \ldots, n\}$ (n being the dimensionality of the problem to be optimized).
- Compute the agent's potentially new position $\mathbf{y} = [y_1, \ldots, y_n]$ as follows:
- For each i, pick a uniformly distributed number $r_i \equiv U(0,1)$
- If $r_i < \mathrm{CR}$ or $i = R$ then set $y_i = a_i + F \times (b_i - c_i)$ otherwise set $y_i = x_i$
- (In essence, the new position is outcome of binary crossover of agent $\mathbf{x}$ with intermediate agent $\mathbf{z} = \mathbf{a} + F \times (\mathbf{b} - \mathbf{c})$.)
- If $f(\mathbf{y}) < f(\mathbf{x})$ than replace the agent in the population with the improved candidate solution, that is, replace $\mathbf{x}$ with $\mathbf{y}$ in the population.
- Now pick the agent from the population that has the highest fitness or lowest cost and return it as the best found candidate solution.

Note that $F \in [0, 2]$ is called the differential weight and $\mathrm{CR} \in [0, 1]$ is called the crossover probability, both these parameters are selectable by the practitioner along with the population size. $\mathrm{NP} \geq 4$.

PROPOSED WORK

Objective Function

The goal of the optimal size and location of DG problem to minimize the total power loss and voltage profile can be expressed as:

$$Minimize\ P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} [\alpha_{i,j} (P_i P_j + Q_i Q_j)] + \beta_{i,j} (Q_i P_j - P_i Q_j)$$

Where

$$\alpha_{i,j} = \frac{r_{i,j}}{V_i V_j} \cos(\delta_i - \delta_j)$$

$$\beta_{i,j} = \frac{r_{i,j}}{V_i V_j} \sin(\delta_i - \delta_j)$$

$$z_{i,j} = r_{i,j} + j x_{i,j}$$

Where

$z_{i,j}$ is the impedance of the line between bus i and bus j;

$r_{i,j}$ is the resistance of the line between bus i and bus j;

$x_{i,j}$ is the reactance of the line between bus i and bus j is the voltage magnitude at bus I is the voltage magnitude at bus j.

4.1.1 Constraints:

The objective function in (4.1) is subjected to the following constraints.

- Bus voltage limits:

It is well known that a small change in nodal voltage, affects the flow of reactive power whereas there is no change in active powers practically. Further, the operating voltage at each node must be in safety range as given below.

$$V_{imin} \le V_i \le V_{imax}$$

Where

V_{imax} and V_{imin} = maximum and minimum voltage limits of ith node respectively.

Vi = voltage at ith node.

Nb = number of buses.

- Feeder capacity limits:
- Power flow in each branch must be less than or equal to its maximum capacity as given below.

$$|I_i| \le I_{imax}$$

Where, I_{imax} = = maximum current capacity of ith branch.
I_i = current in ith branch.

- Power flow equations:

Total active power generation must be equal to the sum of total active load and total active power losses. In same way, total reactive power generation must be equal to the sum of total reactive power losses and total reactive load as given by following equations.

$$\sum P_{iGen} = P_L + \sum P_{iLoad}$$
$$\sum Q_{iGen} = Q_L + \sum Q_{iLoad}$$

where,

$\sum P_{iGen}$ = Total active power generation.
$\sum Q_{iGen}$ = Total reactive power generation.
PL = Total active power loss.
QL = Total reactive power loss.
$\sum P_{iLoad}$ = Total active load.
$\sum Q_{iLoad}$ = Total reactive load.

Loss Sensitivity Analysis

Sensitivity factor method is based on the principle of linearization of original nonlinear equation around the initial operating point and this is helps to reduce number of solution space. For solution of capacitor allocation problem we used

Loss sensitivity factor method. Its application in DG location is new in this field and has been reported in [1]. By the exact loss formula we got the real power loss in the system. The sensitivity factor of real power loss with respect to real power injection is obtained by differentiating exact loss formula with respect to real power injection at bus Pi which is given by:

$$\alpha_i = \frac{\partial P_i}{\partial P_j} = 2\sum_{j=1}^{N}\left[\alpha_{i,j}\left(P_j\right)\right] - \beta_{i,j}\left(Q_j\right)$$

Firstly by using the value obtained at basic case load flows, Sensitivity factors are evaluated at each bus. To form a priority list, the buses are ranked in descending order of the values of sensitivity factors. At minimum losses the parabolic function is defined as the total power loss against injected power. It must be zero the rate of change of real power loss with respect to real power injection.

$$\alpha_i = \frac{\partial P_i}{\partial P_j} = 2\sum_{j=1}^{N}\left[\alpha_{i,j}\left(P_j\right)\right] - \beta_{i,j}\left(Q_j\right) = 0$$

which follows that,

$$P_i = \frac{\partial P_i}{\partial P_j} = \frac{1}{\alpha_{ii}}\left[\beta_{i,i}(Q_i) + \sum_{j=1}^{N}\left[\alpha_{i,j}\left(P_j\right)\right] - \beta_{i,j}\left(Q_j\right)\right]$$

At node I, Pi represents the real power injection, which is the difference between real power generation and real power demand at that node.

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

Where PDGI is the real power injection from DG placed at node i, PDi is the load demand at node i, combining above equations we get.

$$P_i = P_{Di} + \frac{1}{\alpha_{ii}}\left[\beta_{i,i}(Q_i) + \sum_{j=1}^{N}\left[\alpha_{i,j}\left(P_j\right)\right] - \beta_{i,j}\left(Q_j\right)\right]$$

The losses are minimum in the above equation which determines the size of the DG. By arranging the list in ascending order, the first location of DG is the bus stood in the top and further the process is repeated by placing the concerned size of DG at that particular location which generates the next location of DG. When it determines the same location than process is said to be terminated.

Bus Voltage Sensitivity Analysis

By another method that is bus voltage sensitivity analysis is used for reducing the search space. Each bus is penetrated at a time, in this case. After putting DG at each node its voltage sensitivity index can be calculated by equation. When DG is connected at bus I than voltage sensitivity index for bus i is given by

$$BVSI = \sqrt{\frac{\sum_{k=1}^{N}(1 - V_k)^2}{N}}$$

Where Vk is the voltage at kth node and N is the number of nodes. For DG placement least BVSI will be selected from the node.

Algorithm

The algorithm for DG sizing and location can be given below as:
Step 1: Run load flow for base case.
Step 2: Find the Bus voltage sensitivity indices at each node using equation described in section 4.2.1 by penetrating DG value at respective node and rank the sensitivities of all nodes in ascending order to form priority list.
Step 3: Select the bus with top 4 highest priorities.
Step 4: input them into differential evaluation function and optimize the capacity of generators at all potential buses using objective function defines in equation 4.1.
Step 4: Change the size of DG in small steps and calculate power loss for each by running load flow.
Step 5: Store the size of DG that gives minimum loss.

Step 6: Previous solution is compared with the loss. If loss is less than previous solution, store this new solution and Discard previous solution.
Step 7: Repeat Step 4 to Step 6 for all the buses in the priority list.
Step 8: Execute the load flow again for the final PVDG values and plot the comparison results.

RESULT ANALYSIS & DISCUSSION

We have considered the IEEE 14 bus system as our test system. In our work IEEE 14 bus system as been considered as a test case to evaluate the feasibility of our proposed work. We have used Newton Raphson AC load flow analysis in each bus to check out the power losses and voltage profile. Sensitivity index determines the potential buses which is suffering from higher power losses, in every case, it reduces the cost and time consumed in placing the PVDG on each bus and to analyze the losses. In our case, after locating the top four potential buses which are having higher losses. Differential evolution (DE) optimization technique is used to determine the optimal size of PVDG which reduces the losses. In previous chapter, we discussed the objective function for this. The accuracy of evolutionary algorithms depends upon the fact that the objective function must be minimized with number of iterations. In our case total of 1000 iterations are done to optimize the size of PVDG and the output of objective function for each PVDG value for each iteration is shown in below figure

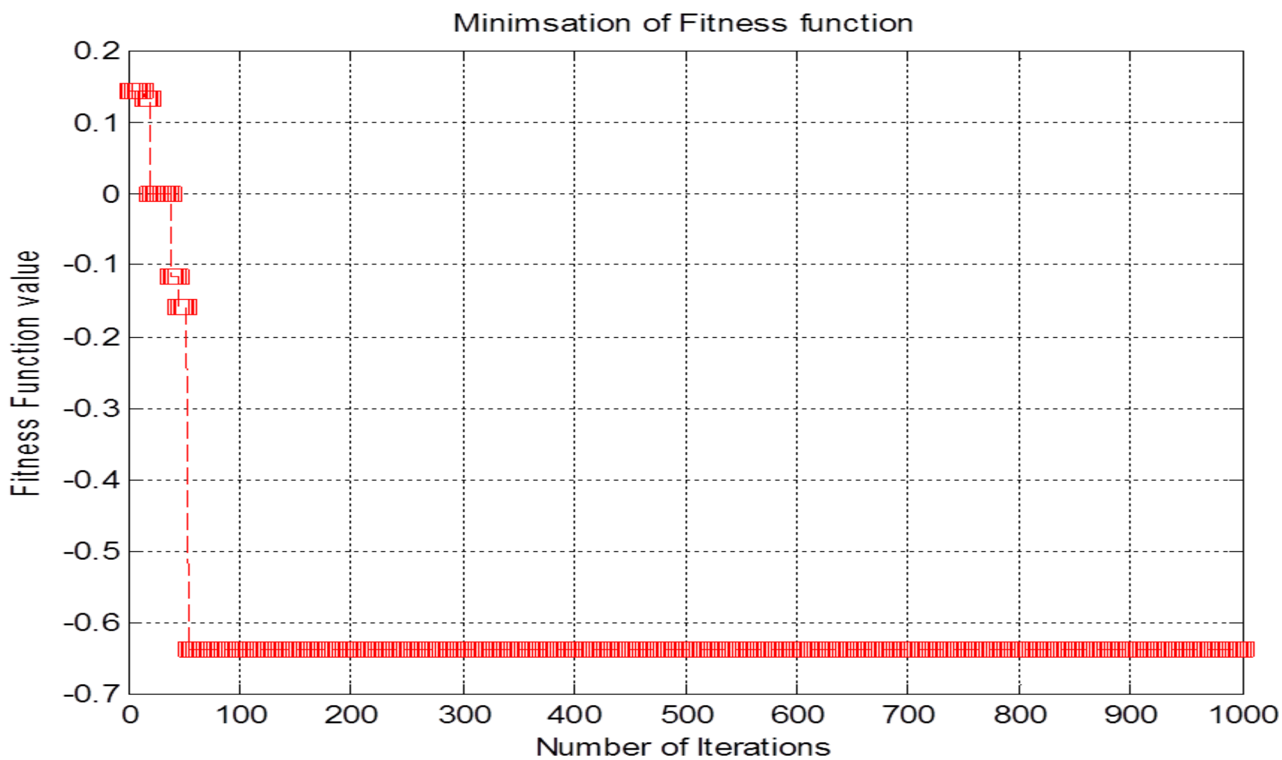

Figure 3: Fitness function output of DE for the proposed case

The objective to plot this graph is that after installation of extra generators at potential buses, voltage profile should improve, which is observed in our case. After optimal sizing calculation and placement in the IEEE 14 bus system, voltage profile almost at each bus is increased. It reduces because after installation, line losses in the whole system reduce. Since PVDG inserts the active power so a tabular format representation for the active power losses of the system. The objective to plot this graph is that after installation of extra generators at potential buses, voltage profile should improve, which is observed in our case. After optimal sizing calculation and placement in the IEEE 14 bus system, voltage profile almost at each bus is increased. It reduces because after installation, line losses in the whole system reduce. Since PVDG inserts the active power so a tabular format representation for the active power losses of the system is shown in table. Losses in lines connecting all buses are shown in that.

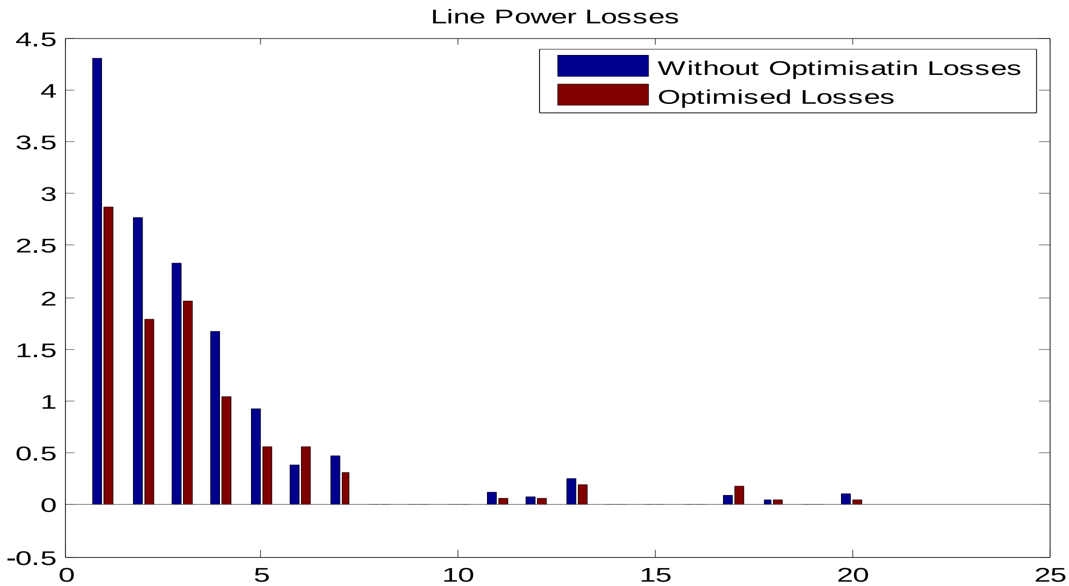

Figure 4: Comparison of line power losses

Total losses without PVDG placement is 13.5929 MW and after the insertion of generators at required buses it is 9.7368 MW. A difference of almost 4MW is visible which is a great achievement. The generator buses which are outcome of sensitivity analysis is shown in table 1 below. In actual sensitivity analysis arrange the losses in all buses in the decreasing order and we have picked the top four bus locations for that. These buses are 1, 8, 9 and10. The optimized values of PVDG on these buses are plotted. Results can be improved if in all buses generators to be placed, but it will cost of system tremendously as placement at all buses will include cost of installation, generator and maintenance cost too increases. For improvement in the losses reduction we can consider case with 6 potential bus system too, which is discussed next.

Table 1: Potential buses and PVDG values inserted in the system on that buses

PVDG Power	**Bus 1**	**Bus 8**	**Bus 9**	**Bus 10**
	17.01250001852	12.193919038663	18.763303190941	8.3371548505212

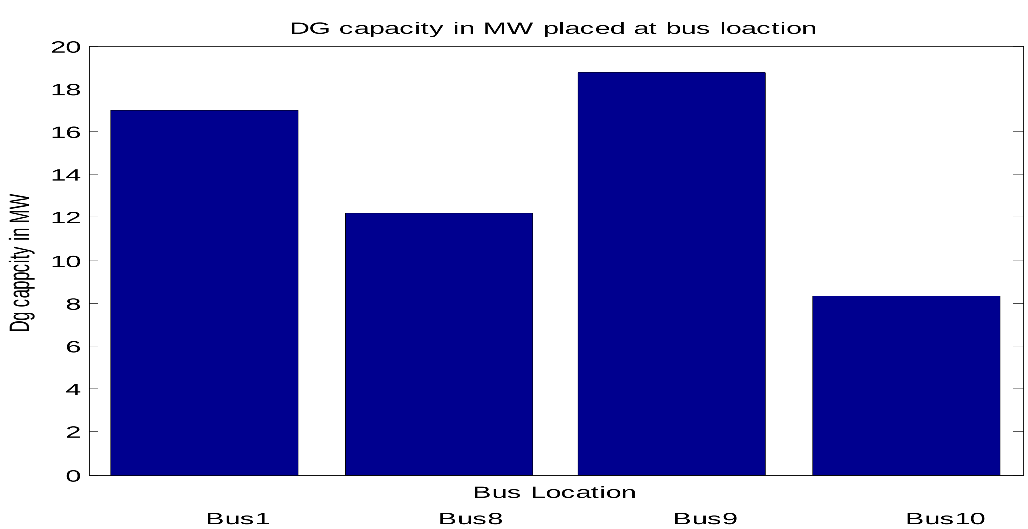

Figure 5: Bus location graph

Table 2: Losses in the lines between buses in the system

From Bus	To Bus	Active Power Losses Before Optimization	Active Power Losses After Optimization
1	2	4.30857169555884	2.87557991480894
1	5	2.77259532690289	1.79433680290452
2	3	2.33318263727529	1.96950877581078
2	4	1.66995306896197	1.03684947128808
2	5	0.919977482753033	0.560738098700384
3	4	0.391129991024268	0.564568338609188
4	5	0.479130255074836	0.317663697678633
4	7	7.10542735760100e-15	0
4	9	-3.55271367880050e-15	8.88178419700125e-16
5	6	0	7.10542735760100e-15
6	11	0.122651727128156	0.0678597662756945
6	12	0.0806454508353447	0.0686634542331976
6	13	0.251839320372849	0.191472810133229
7	8	6.93889390390723e-16	0
7	9	-3.55271367880050e-15	-3.55271367880050e-15
9	10	0.00602500299308062	0.00378975869190379
9	14	0.0894063878746927	0.181565834561955
10	11	0.0513973678251540	0.0423117968633764
12	13	0.0110150644453499	0.00726769510358705
13	14	0.105397327837949	0.0546257212625143

CONCLUSION

Results can be improved if in all buses generators to be placed, but it will cost of system tremendously as placement at all buses will include cost of installation, generator and maintenance cost too increases. For improvement in the losses reduction we can consider case with 6 potential bus system too, which is discussed next. For the case of 6 potential buses selection, process is same but total losses are improved although voltage profile improvement doesn’t show significant improvement. Total losses after installation at 6 buses are 3.6411 MW.

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