Performance Enhancement of Electrical Distribution Systems with Multiple Distributed Generation Sources

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ABSTRACT

The recent trends in electrical power distribution system operation and management are aimed at improving system conditions in order to render good service to the customer. Reforms in the distribution sector have given major scope for employment of distributed generation (DG) resources which will boost system performance. This article proposes a heuristic technique for allocation of multiple distribution generation sources in a distribution system. The allocation is determined based on overall improvement in network performance parameters like reduction in system losses, improvement in voltage stability, improvement in voltage profile. The hybrid of Genetic Algorithm with the proposed Network Performance Enhancement Index (NPEI) along with the heuristic rules facilitates determination of feasible location for insertion of DG sources. A priority list is prepared with decreasing values of NPEI so that the designer can select most feasible locations. The developed approach is tested with different test systems to ascertain its effectiveness.

Keywords*: Distributed Generation, Network Performance, Optimal Operation, Power Loss Reduction, Voltage Stability*

INTRODUCTION

The distribution system being the nearest link to the consumers, utmost importance is to be given for its satisfactory operation. Though this sector was neglected earlier, in recent years distribution sector reforms have been implemented and it is expected to improve the

scenario in coming years. The reforms are aimed at improvement in network operation vide taking appropriate steps such as incorporation of generation sources at distribution system level and encouragement to Independent Power Producers. This will facilitate reduction in power losses of the system and the customers can be served more efficiently. There are different technologies which can be adopted for DG sources like photo voltaic cells, wind generation, combustion engines, fuel cells and other types of generation from the resources which are available in the geographical area. The concept of distributed generation helps to harness the natural resources and help the distribution system to get more strength in its operation and control. The advantages of distributed generation are reduced system losses, improvement in voltage profile, better power quality and release of burden on the existing transmission and distribution network. In this manner the overall system reliability is improved by employing distribution generation sources in distribution network.

The presence of DGs in the distribution network improves the system voltage stability [1]. The static voltage stability is evaluated on the load flow computations and impact of DGs on the network can be accessed. It is necessary to devise appropriate model in order to reflect the generation technology employed. The DG location can be arrived at so that system voltage stability can be improved. The impact indices comprising of real and reactive power losses, voltage drop estimation, voltage regulation have been computed for insertion of single DG source for the distribution network [2]. It is very much necessary to ensure that the selection of DG capacity improves the operation of the system. This aspect demands the usage of optimum DG allocation techniques considering power loss minimization. The index to estimate the voltage profile improvement with the incorporation of DG sources gives an indication of choice on placement of such sources [3]. In conjunction with voltage profile improvement, the line loss reduction is also serves as a parameter in the location and sizing issues [4]. The technical benefits can be quantified by evaluating a composite index which comprises of improvement in different parameters [5]. The placement of multiple DG sources in the network calls for application of Genetic Algorithms.

However the evaluation of multiple DG sources impact on the distribution system needs to be carried out with the help of quantifiable indices. This measure helps to place multiple DG sources at proper locations. In this regard, this article presents a heuristic approach to

address DG location and sizing issue. The proposed Network Performance Enhancement Index (NPEI) gives an indication of best location and capacity for DG source. The technique incorporates genetic algorithms combined with heuristic rules to evaluate most feasible locations based on NPEI so that all network performance parameters are improved. In certain cases the best combination of locations may not be feasible for insertion of DG sources due to geographical, social constraints. Hence it is essential to work out the other alternatives. To cater this need a priority list of bus numbers is prepared with decreasing values of NPEI. This aspect gives flexibility for the designer to select the appropriate locations satisfying technical as well as implementation constraints. The approach is applied to two test systems comprising of 33-bus and 90-bus for testing the developed approach.

POWER FLOW ANALYSIS

There are several approaches for distribution system power flow analysis [6]. The fast power flow solution algorithm for radial distribution feeders including distributed generations is employed here [7]. The main stages of the approach are given below:

a)   The system data such as real and reactive power load, line parameters like resistances and reactances are captured.

b)   The initial sending end real and reactive power is assumed as sum of corresponding load power demand and loss factors.

c)   The injected power and voltage at each bus is updated using power flow recursive equations,

d)   This procedure is done iteratively until the voltage and power mismatch is within tolerance limit.

The loss factors and power flow recursive equations used as stated by [7] helps to reach convergence quickly.

GENETIC ALGORITHM

The genetic algorithm approach helps to identify bus locations for insertion of multiple DG sources. The convergence of the GA search is

done on the basis of a fitness function as defined by the designer. The selection of GA parameters like size of population, type of crossover, mutation and termination criteria is to be decided depending on nature of application. The flow of computation through Genetic Algorithm is presented in Figure 1.
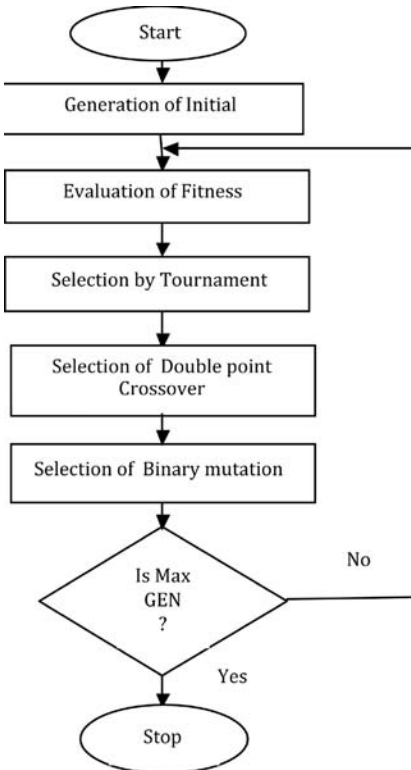

Figure 1.
Flowchart For GA Procedure

INDICES FOR NETWORK PERFORMANCE EVALUATION

The various parameters with corresponding quantifying indices used to evaluate the performance of the distribution network is given below: These indices are incorporated with attaching weightage factors in the proposed Network Performance Enhancement Index (NPEI).

Voltage Stability Index

The distributed generation source allocation can be done with the purpose of improving the voltage stability of the network. The improvement in voltage stability assumes importance because of the following factors.

1. A system with lesser voltage stability may move to uncontrollable state,

2. Since the existing networks are heavily loaded, the operator needs to have clear knowledge on system behavior to protect power quality.

The static voltage stability index (VSI) helps to estimate the health of the network [1]. The value of this index ranges from zero (No-Load) to 1 (Voltage Collapse). The VSI is computed as

$$L_j = \frac{4\left[\left(XP_j - RQ_j\right)^2 + \left(XQ_j + RP_j\right)V_i^2\right]}{V_i^4} \tag{1}$$

$$VSIn = \max\left\{L_1, L_2, ..., L_{n-1}\right\} \tag{2}$$

Where Pj, Qj are real and reactive power received at jth bus and R and X are the resistance and reactance of the branch linking jth bus. The branch corresponding to the highest index value of Voltage Stability Index (VSIn) is called the weakest branch. The voltage collapse must start from the weakest branch. If the system has lower VSI then system is considered to be more stable.

Power Loss Reduction Indices
      One of the major potential benefits offered by DG is the reduction in electrical line losses. The loss can be significant under heavy load conditions. The utility is forced to pass the cost of electrical line losses to all customers in terms of higher energy cost. With the inclusion of DGs, line loss in the distribution system can be reduced. The Power loss reduction indices cover real power loss reduction as well as reactive power loss indices and the expressions as stated in [2] are as follows:

$$PLossIn = 1 - \frac{(PLoss)dg}{PLoss_0} \tag{3}$$

$$QLossIn = 1 - \frac{(QLoss)dg}{QLoss_0} \tag{4}$$

where $(PLoss)dg$ and $(QLoss)dg$ are real and reactive power losses with DG sources, $PLoss_0$ and $QLoss_0$ are real and reactive power losses without DG sources.

Voltage Profile Improvement Index
      One of the justifications for introducing DGs is to improve the voltage profile of the system and maintain the voltage at customer terminals within an acceptable range. Hence the maximum voltage drop towards tail end node should be limited within allowable limits. Once this crite-

rion is met, then overall system voltage profile will be improved, because DGs can provide a portion of the real and reactive power to the load, thus helping to decrease current along a section of the distribution line, which, in turn, will result in a boost in the voltage magnitude at the customer site. The voltage profile index for ith node is defined as below [3]:

$$VP_i = \frac{(V_i - V_{min}) \bullet (V_{max} - V_i)}{(V_{nom} - V_{min}) \bullet (V_{max} - V_{nom})} \tag{5}$$

Where VPi is the voltage profile of the ith bus, and Vmin and Vmax are the minimum and maximum permissible voltages of the system nodes and Vnom is the nominal or desired bus voltage, typically taken as 1 pu.

The voltage profile index of the system is defined as:

$$VPIn = \frac{1}{n} \bullet \sum_{i=1}^{n} VP_i \tag{6}$$

Voltage profile Improvement Index (VPII) has been defined as the ratio of a measure of the voltage profile of the system with DGs to the same measure with no DG employed and given as:

$$VPII_i = \frac{VPIn_{dgi}}{VPIn} \tag{7}$$

Where VPIndgi is the voltage profile index of the system with DGs for ith node and VPIn is the voltage profile index of the system without DG. As the value of this index is more than 1, it is modified appropriately for incorporation in the proposed Network Performance Enhancement Index as below:

$$VPIIn_i = \frac{VPII_i - 1}{VPII_{max} - 1} \tag{8}$$

NETWORK PERFORMANCE ENHANCEMENT INDEX(NPEI)

A composite index termed as Network Performance Enhancement Index is proposed to quantify the benefits of Distributed Generator like power loss reduction, voltage stability improvement, Voltage profile Improvement and maximum reduction of power loss per unit size of DG in a combined manner. The NPEI for any node is computed as

NPEI = W1 (VSIn) + W2 (PLossIn) + W3 (QLossIn) +W4 (VPIIn)   (9)

Where W1, W2,W3 and W4 are the weithage factors such that $0 \leq$ W1$\leq$ 1, $0 \leq$ W2$\leq$ 1, $0 \leq$ W3$\leq$ 1, $0 \leq$ W4$\leq$ 1 and W1+W2+W3+W4 =1.

The weightage factors are decided by the designer of the distribution system. The parameter which has been given highest weightage factor will get largest improvement after insertion of DGs. In addition all other parameters included in NPEI also get improvement over the base case. Hence the Selection of the best combination of buses for location of DGs is made by highest value of NPEI. Such a selection will result in comprehensive improvement in network performance like reduction in system power loss, improvement in voltage stability, improvement in voltage profile. A priority list with decreasing value of NPEI is prepared so that DGs can be inserted at the most feasible locations. The top priority locations gives highest value of NPEI, improves the system performance to maximum extent.. Hence this turns out to be the best solutions. In case the first priority with highest NPEI is not feasible then the designer can select the next best locations with decreasing order of priority. This process gives flexibility for efficient planning of the network.

APPROACH FOR ALLOCATION OF MULTIPLE DGS

The designer needs to select the most feasible option for selection of DG location and its capacity. The constraints posed for decision could be from geographical, limited resources and economic domains. The geographical constraints include, right of way issues, availability of required land space, environmental issues etc. The availability of required type resources in the vicinity also plays a major role in decision making. The proposed approach incorporates these factors to facilitate the designer to choose the most feasible locations to ensure improvement in the system performance. This approach overcomes the drawback of concentrating on only one parameter, for instance reduction in power loss in deciding the location of DGs, while not giving attention to voltage stability factors or voltage profile improvement factor. Since the proposed approach includes comprehensively all the factors required for efficient operation of the distribution system, it ensures that the insertion of multiple DGs

at the most beneficial locations such that all the required parameters are better than the base system without DG. In addition the priority list obtained with decreasing value of NPEI will help the designer to select the next best feasible locations for insertion of multiple DGs to the system. The flow chart for approach for allocation of DG source is given in Figure 2.

CASE STUDIES AND RESULTS

This approach is tested on two test systems 33-bus and 90-bus systems [1] [8]. For each system the optimum location and size of the distributed generation source is determined based on NPEI and the bus with highest NPEI is assigned with highest priority and as NPEI decreases priority also decreases. The designer can select most suitable location satisfying all constraints.

The Genetic Algorithm Parameters used for optimization are as follows:

a)   Representation : Binary
b)   Population Size : 30
c)   Type of Selection : Tournament
d)   Reproduction : Two Point
     Crossover rate: 0.8
     Mutation rate: 0.05
(e)   Elitism : 5
(f)   Fitness Function : NPEI

33-Bus System

The 33-bus system has total load of 3.72 MW and 2.3 MVAR. The base system has got real power loss of 211.20 kW, reactive power loss of 137.34 kVAR and voltage stability index of
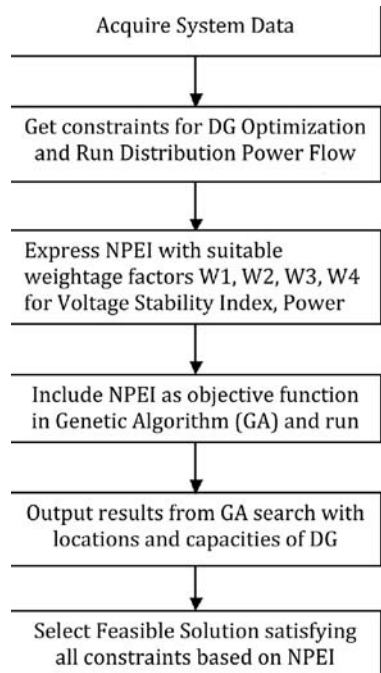


```
Acquire System Data
        ↓
Get constraints for DG Optimization
and Run Distribution Power Flow
        ↓
Express NPEI with suitable
weightage factors W1, W2, W3, W4
for Voltage Stability Index, Power
        ↓
Include NPEI as objective function
in Genetic Algorithm (GA) and run
        ↓
Output results from GA search with
locations and capacities of DG
        ↓
Select Feasible Solution satisfying
all constraints based on NPEI
```

Figure 2. Flow for optimization of multiple DG Allocation

0.0748. The market standard DG sizes like 250 kW, 500 kW, 750 kW are taken for insertion at suitable locations. As a sample case equal weightage is given to W1, W2, W3, and W4 while computing NPEI. The best combination of the bus numbers with the corresponding DG size to be inserted is obtained by maximization of NPEI as an objective function in Genetic Algorithm. The results are tabulated in Table 1. From the results it is evident that the real power loss, reactive power loss are reducing from the base case without DG. Also since the magnitude of voltage stability index is lesser than that of base case, the voltage stability has improved. However with the help of NPEI all the network performance indicators get improvement than the base system as illustrated below:

Also the voltage profile at all buses has improved as indicated in Figure 4.

In order to investigate the possibility of insertion of more DGs with smaller capacities, the case of injection of 5 DGs with capacities ranging from 200 kW to 600 kW is explored. The results as shown in Table 2
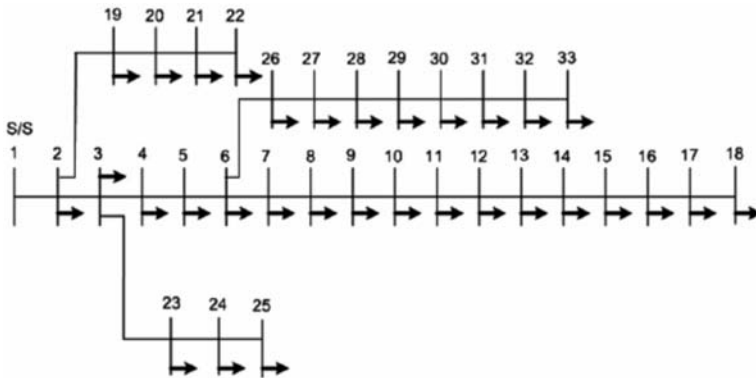

Figure 3. 33-bus Test System

Table 1. DG Capacity allocation with 3 DGs

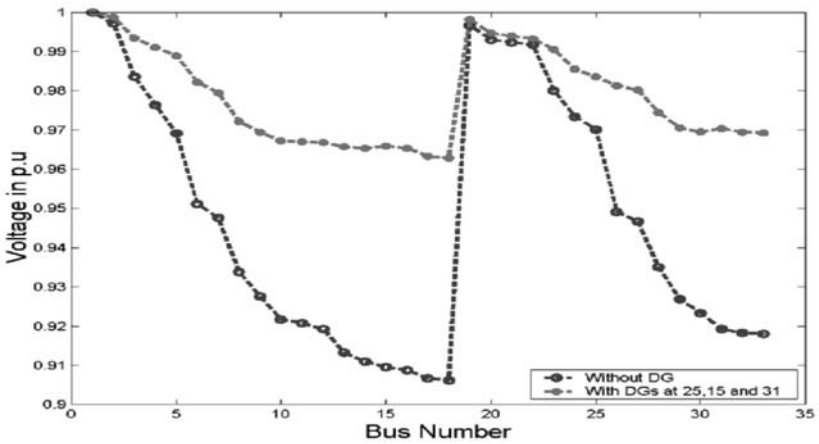| NPEI	Location of DG (Bus No.)	Size of DG (kW)	PLoss (kW)	QLoss (kVar)	VSI
0.50794	25	250	71.36	50.17	0.0279
	15	500			
	31	750			

Figure 4. Voltage Profile Improvement with 3 DGs

Table 2. DG Capacity allocation with 5 DGs

NPEI	Location of DG (Bus No.)	Size of DG (kW)	PLoss (kW)	QLoss (kVar)	VSI
0.52717	10	200	63.57	44.08	0.0275
	30	300			
	32	400			
	15	500			
	25	600			

reveal that the selection of the choice with highest value of NPEI all the system parameters have improved similar to the case of 3 DGs.

90-Bus System

The 90-bus system has total load of 19.45 MW and 29.72 MVAR. The base system has got real power loss of 0.504 MW, reactive power loss of 1.54 MVAR and voltage stability index of 0.2367. The results of the analysis for insertion of 3 DGs and 5 DGs have been tabulated in Table 3 and 4. The Voltage profile improvement is given in Figure 6 and Figure 7. As evident from the tables and plots, selection of bus locations and corresponding capacities of DGs based on highest NPEI has resulted in overall improvement of the system performance. Again range of DG size is selected appropriately from the market available DG sizes.

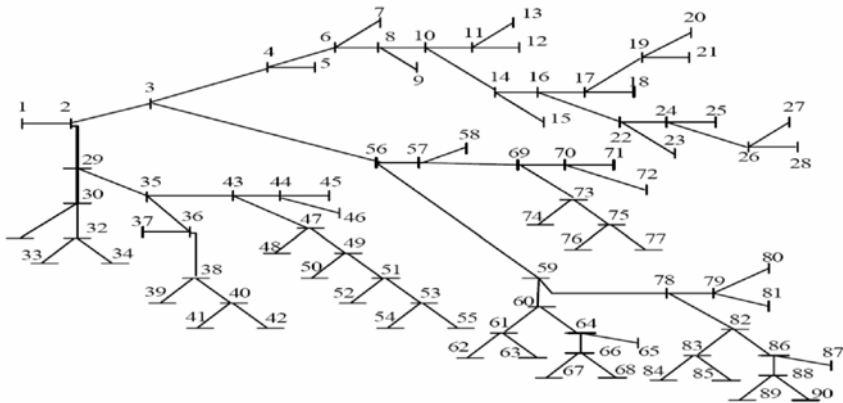Hence the studies have shown that the determination of the best

Figure 5. 90-Bus Test System

Table 3. DG Capacity allocation with 3 DGs

NPEI	Location of DG (Bus No.)	Size of DG (MW)	PLoss (MW)	QLoss (MVAR)	VSI
	27	1			
0.59553	16	2	0.173	0.913	0.0740
	9	4			

Table 4. DG Capacity allocation with 5 DGs

NPEI	Location of DG (Bus No.)	Size of DG (MW)	PLoss (MW)	QLoss (MVAR)	VSI
	14	1			
	4	1.5			
0.59871	12	2	0.160	0.845	0.0726
	23	3			
	69	0.5			

locations for insertion of multiple distributed generation sources with the help of proposed Network Performance Enhancement Index (NPEI) leads to overall system improvement.

CONCLUSION

      The distribution sector reforms have made significant impact for operation and management of utility system. The distributed generation sources are playing a key role in meeting the load demand, reducing the power losses and overall improvement in network management. This article proposes a realistic approach for determination of multiple DG locations and sizes incorporating the constraints to arrive at feasible solution. The Network Performance Enhancement Index (NPEI) serves
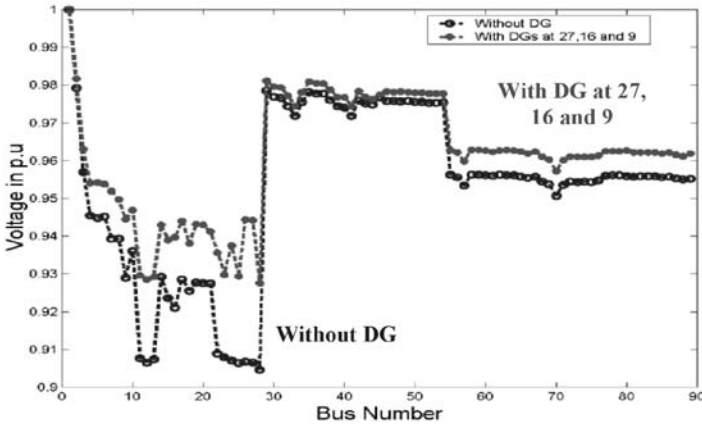

Figure 6. Voltage Profile Improvement with 3 DGs
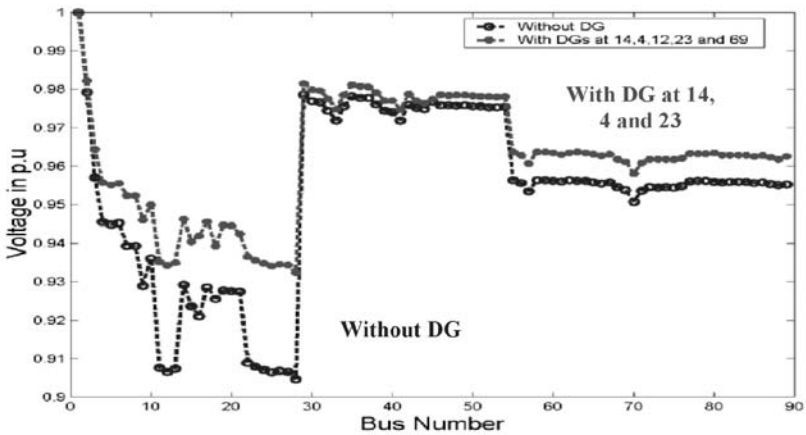

Figure 7. Voltage Profile Improvement with 5 DGs

as an indicator for best possible choice. The designer will be able to select the optimum solution satisfying all the constraints with the help of NPEI. A priority list based on NPEI is formed to select the most feasible solutions. The developed approach is tested on 33-bus and 90-bus systems and results obtained have shown that the technique gives the combination of locations with appropriate sizes of multiple DG sources which ensure overall improvement in network performance.

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