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Improvement of Voltage Profile in Distribution System by Optimal Placement and Sizing of DG

Mareesan K[1], Dr. Shunmugalatha A[2]
[1]Lecturer(Sr. Grade)/EEE, [2]Professor & Head/EEE
[1]Electrical and Electronics Engineering, VSVN Polytechnic College, Virudhunagar, Tamil Nadu, India
[2]Electrical and Electronics Engineering, Velammal College of Engineering & Technology, Tamil Nadu, India

ABSTRACT
The main objective of the power system planner is to provide dependable and cost-effective power supply to the customer. Due to the advancement in the technology, power system structure has been remodeled which in turn attracts the more number of participants to participate in the electricity market. Increase in market participant increases the utilization level in the distribution side of the power system. One among the technical challenges facing due to the increase in the load level is maintaining the power balance of the power system with respect to the load variations. In recent years, the inclusion of distributed generations (DGs) efficiently resolves the above power shortage problem. Incorporating the DG sources in the power system network helps to improve the aspects such as power quality, bus voltage profiles and voltage stability of the system. It also has the characteristics of economic and reliable power supply to customers. The extent of these benefits depends on how the DG is placed and sized in a system. Improper allocation of DG sources in power system would not only lead to increase power or energy losses, but also can endanger the system operation. In this paper, a multi-objective optimization problem for improving the voltage profile and voltage stability index has been solved by optimal placing and sizing of DG in standard 33 bus and 69 bus radial distribution systems with three tools such as Genetic Algorithm(GA), Particle Swarm Optimization(PSO) and Flower Pollination Algorithm(FPA). The comparison results are recorded.

KEY WORDS: *Distribution system, Distributed Generation (DG), Voltage profile, Voltage stability index, GA, PSO and FPA*

1. INTRODUCTION

In recent years, the inclusion of distributed generations (DGs) have taken from Ackermann et al[1] and Griffin et al[2] efficiently resolves the above power shortage problem by means of connecting directly to the distribution networks on the customer side (Load Center). Incorporating the DG sources in the power system network helps to improve the technical aspects such as power quality, bus voltage profiles and voltage stability of the system. It also has the characteristics of economic and reliable power supply to customers. Achievement of these benefits depends on how the DG is placed and sized in a system. Improper allocation of DG sources in power system can endanger the system operation, Wang et al.[3]. Hence, the optimal placement of DG source with the optimal size is indeed to achieve the above DG benefits. Optimization of the DG placement and sizing model is considered as optimization problem in maximizing the system voltages. Some of the literatures by Das et al. [4], Willis et al. [5] and Acharya et al. [6] have used analytical based optimization approach for finding the best position and sizing of DGs to solve different DG-unit problems. Many evolutionary and nature inspired algorithms such as genetic algorithm (GA) utilized by Zhu [7], and mithulanathan et al. [8]. Differential evolution (DE) by Niknam et al. [9], PSO by Reddy et al.[10]. Evolutionary Programming (EP) by De sauza et al. [11] , Fuzzy systems by Cano [12] , Ant Colony optimization (ACO) by Favuzza et al. [13], Plant growth simulation by Srinivasa rao et al. [14] , Immune algorithm based optimization (IA) Aghaebrahimi et al. [15] have been utilized as tools for solving optimal DG allocation and sizing problems. In the recent past, revolutionary hybrid process of combining the advantages of two meta-heuristic algorithms in determining the optimal solution has been practiced in many applications. The above revolutionary way of combining GA and PSO has been used in determining the optimal placement of DG by Moradi et al. [16]. In recent years, papers such as Abou et al. [17] has proposed the technical objective of minimizing the line power loss and maximizing the voltage profile. So, in order to extract the better solutions of technical aspects in the real time, multi-objective optimization problem is needed to be designed for extracting the maximum voltage stability and voltage stability Index. Based on the above proposal, two objectives such as maximizing the voltage profile and maximizing the voltage stability index of the distributed systems while satisfying the voltage profile security constraints and the power balance constraints are achieved by designing the multi-objective optimization problem as a single cost function. Here, the two objectives are converted into single objective by using weighted sum method. To demonstrate the effectiveness of the proposed optimization method, IEEE standard 33 bus and 69 bus radial distribution test system have been utilized. To extract the best solutions of the multi-objective based problem, nature inspired flower pollination algorithm (FPA) is used as an optimization tool. To demonstrate the efficiency of the FPA, standard evolutionary algorithms such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) are also used to extract the optimal solutions.

2. PROBLEM FORMULATION

Best solutions of maximizing voltage profile at the maximum voltage stability of the system are extracted by means of formulating the multi-objective problem into the single cost functions using the penalty coefficients and the weighted sum method. Therefore, the multi-objective problem has been converted into a single objective solution.

2.1 Multi-Objective Problem Formulation

The proposed multi-objective problem (F_T)is designed in such a way to fulfill the goals of objective functions such as System's voltage profile maximization(F_1), and Voltage stability index maximization (F_2) in the distributed system.

$$F_T = Min\left(F_1 * w1 + F_2 * w2 + \gamma_1 * Max\left(\left(V_{rated(min)} - Min(V_i)\right), 0\right) + \gamma_2 * Max\left(\left(Max(V_i) - V_{rated(max)}\right), 0\right)\right) \ldots (1)$$

By using weights w1 and w2 the two objectives are converted into single objective function by satisfying the power balance constraints and voltage profile constraint. $V_{rated(\min)}$ and $V_{rated(\max)}$ are the minimum and maximum bus voltage of the distribution test system. The value between 0.98 to 1 is considered as rated voltage profile of the system.

2.2 Voltage Profile Function

Maintenance of voltage at all buses in the radial distribution system (RDS) helps to provide better quality of power supply with respect to the load variations. Also the bus voltage profile of the distributed system majorly impacts the pricing value in the electricity market. Hence, it is important to maintain the voltage profile of each bus at the maximum limit to accommodate vulnerable conditions w.r.t sudden change in the load level.

So, in order to maximize the voltage profile, following function is considered

$$F_1 = \sum_{i=1}^{NB} (V_i - V_{rated})^2 \ldots(2)$$

where, V_{rated} is the rated voltage of the RDS. The value of rated voltage is unity.

2.3 Voltage Stability Function

Voltage stability of radial distributed system gets impacted by the application of DG in the distribution system. Improper placement of DG decreases voltage stability of the system. The voltage stability of the system is evaluated at each node by means of calculating the index value at each node. To improve the voltage stability index, the following function is designed

$$F_2 = \frac{1}{Min(VSI_i)} \quad \ldots(3)$$

Where, VSI_i is the Voltage stability index of the i^th^ bus in RDS. The VSI_i is calculated from the following formula

$$VSI_i = |V_{Si}|^4 - 4[P_{Li} R_i + Q_{Li} X_i] |V_{Si}|^2 - 4[P_{Li} R_i + Q_{Li} X_i]^2 \ldots(4)$$

Where, V_{Si} is the i^{th} bus voltage of the RDS, R_i and X_i are the resistance and reactance of the i^{th} bus distribution branch, P_{Li} and Q_{Li} are the real and reactive power of the load fed by the i^{th} bus. Low voltage stability index bus is the weak bus in the RDS. The above voltage stability index formula is extracted from the literature by Chakravorty et al. (2001). So, in order to improve the voltage stability index, the minimized voltage stability index of the RDS is extracted and it gets inversed.

2.4 Operating Constraints

The above single objective (F_T) converted to multi-objective focused problem needs to be attained by satisfying the following static operational limit values.

Constraint I: Voltage Limit Constraint

$$V_{i\,min} \leq V_i \leq V_{imax} \quad \dots (5)$$

Constraint II: DG Capacity Constraint

$$P_{DGmin} \leq P_{DG} \leq P_{DG\,max} \quad \dots (6)$$

$$Pf_{min} \leq Pf \leq Pf_{max} \quad \dots (7)$$

Reactive power formulation of the distributed generation from the real Power is given as below

$$Q_{DG} = (P_{DG}).\tan(\,Cos^{-1}(Pf)\,) \quad \dots (8)$$

Constraint III: Power balancing Constraints

$$P_{Gi} - P_{Di} - V_i \sum_{i=1}^{N} V_j Y_{ij}\,Cos(\,\theta_{ij} - \delta_i + \delta_j) = 0 \quad ..(9)$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{i=1}^{N} V_j Y_{ij}\,Sin\,(\,\theta_{ij} - \delta_i + \delta_j) = 0 \quad ..(10)$$

where, V_{imin} and V_{imax} are the minimum and maximum permissible voltage at i^{th}bus, P_{DGmin} and P_{DGmax} are the minimum and maximum permissible real power value of each DG capacity, P_{Gi} and Q_{Gi} are the real and reactive power from DG in p.u, Pf_{min} and Pf_{max} are the minimum and maximum permissible Power factor value of each DG capacity, P_{Di} and Q_{Gi} are the real and reactive power load demand in p.u, V_i and V_j are the voltage magnitude at the i^{th} and j^{th} bus in p.u, δ_i and δ_j are the voltage angle at the i^{th} and j^{th} bus in p.u, N is the total number of bus in distributed system, Y_{ij} is the magnitude of admittance matrix and θ_{ij} is the angle of admittance matrix between i^{th} and j^{th} bus in p.u.

3. WEIGHTED SUM METHOD

Weighted sum method helps to linearize the multi-objective problem by means of choosing the weighted coefficients W_i corresponding to the multi-objective optimization problems. The weighted sum problem formulation is provided as below

$$F_T = \sum_{i=1}^{T} W_i * F_i \quad \dots (11)$$

Where, the converted linear objective of multi-objectives (MO) problem is F_T, F_i is the i^{th} single objective and W_i is the i^{th} weighted value of the single objective. Sum of all the weighted value is equal to one.

4. PTIMIZATION ALGORITHM STRUCTURE

Stochastic algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Flower Pollination Algorithm (FPA) are used to solve the optimization problem of maximizing the voltage profile and voltage index of the DS with the optimal allocation of pre-determined number of DG's in the specified timing and also not violating the system operation limits. The structure of the optimization algorithm in implementing the multi-objective focused objective problem has been explained as follows.

4.1 Genetic Algorithm (GA) Structure

As per the objective function, the control parameters are bus position and sizing. So, based on the control parameters, the population has 'n' chromosomes that represent candidate solutions. Each chromosome is real value vector with the bus location number and the size of DG in Genetic Algorithm. Here, the chromosomes consist of six genes. First three genes indicate the position of DG and remaining three genes indicate the size of DG in each bus position.

4.2 Particle Swarm Optimization(PSO) structure

The PSO has been designed to have 'N' particles in the population that represent candidate solution. Each particle is the real value vector with the 'M' location number and size of DG for each load level.

4.3 Flower Pollination Algorithm Structure

FPA based stochastic algorithm is a highly effective and efficient to solve difficult optimization problems. FPA is the nature inspired algorithm and gaining popularity recently for solving nonlinear optimization problems. Flower pollination algorithm (FPA) proposed by Xin-She Yang in 2012, is based on flower pollination behavior. Two types of pollination occur namely self-pollination and cross-pollination. Self-pollination occurs when pollen from one flower pollinates the same flower or other flowers of the same plant. On the other hand, cross-pollination means pollination can occur from pollen of a flower of a different plant. Biotic, cross-pollination occurring at long distance may be called as the global pollination initiated by the pollinating agents such as bees, bats, birds and flies which could fly a long distance. Behaviors such as jump or fly distance of bees and birds obey a Levy distribution.

5. RESULTS AND DISCUSSION

The proposed multi objective formulation has been implemented with the help of two standard radial distribution test system. The first test system is IEEE 33 bus radial distribution test system with the total system load of 3.72 MW and 2.3 MVar with the 32 branches. While the initial system power loss of the 33 bus system is 210.908 kW and the reactive power loss is 143 kVar. The system voltage base is 12.66 kV and the base apparent power is 10 MVA. The second test system is the IEEE 69 bus radial distribution test system with the total system load of 3.80 MW and 2.69 MW. While the initial system power loss of the 69 bus system is 224.9 kW and the reactive power loss is 102.1 kVar. GA, PSO and FPA based optimization algorithms are used to extract the best optimized solution by means of finding best distributed generation site and sizing. Three best locations for DG placement have to be identified and the best sizing for each DG should be less than 2000 KW has been assumed. Weighted value (W_1 and W_2) is determined as 0.5 each using trial and error method. Similarly, the value of penalty coefficients(γ_1, γ_2) is 1000. In this chapter, DG power generation with unity power factor is optimized to achieve the better voltage stability and profile. MATLAB simulation of FPA, PSO and GA algorithm for the 33 and 69 bus RDS test systems have been conducted with the DG's unity power factor. The simulation result has been recorded and the details are provided below with the explanation.

Simulation Results of Multi-Objective Focused Problem Formulation with Unity Power Factor DGs

Table 5.1 GA, PSO and FPA based optimization results for 33 bus RDS

RDS Test system	Algorithm	Bus no	Sizing in kW	F_2 in per unit	F_1 in per unit	Fitness in per unit	Critical Voltage in per unit	Critical Voltage Bus
33 Bus system	FPA	13	1054.59	1.0388	0.000703	0.45568	0.9916	33
		29	1847.85					
		24	1314.09					
	PSO	13	1054.59	1.0391	0.000703	0.45566	0.9918	33
		29	1850.77					
		24	1319.69					
	GA	29	1865.25	1.0398	0.000691	0.45617	0.9918	33
		24	1324.73					
		14	1024.29					

Table 5.2 GA, PSO and FPA based optimization results for 69 bus RDS

RDS Test system	Algorithm	Bus no	Sizing in kW	F_2 in per unit	F_1 in per unit	Fitness in per unit	Critical Voltage in per unit	Critical Voltage Bus
69 Bus system	FPA	18	591.52	1.0235	0.00045	0.4411	0.9942	50
		55	772.90					
		61	1994.65					
	PSO	17	551.17	1.0236	0.00055	0.4411	0.9941	65
		55	842.16					
		61	1980.62					
	GA	61	1155.01	1.0251	0.001	0.4421	0.9938	65
		14	808.27					
		62	999.96					

It is inferred from the table 5.1 and table 5.2 that the FPA provides better improved voltage profile (F_1) by means of reducing the voltage difference with respect to the rated voltage and better voltage stability index (F_2) in 33 bus and 69 bus test radial distributed system. The FPA based optimization solution provides better and balanced voltage profile compared to the GA and PSO. The above is depicted with the help of voltage profile comparison graph implemented in the 33 and 69 bus RDS system shown in the figure 5.1 and figure 5.2 respectively.

Figure 5.1 33 bus RDS voltage profile for GA, PSO and FPA based optimization algorithm

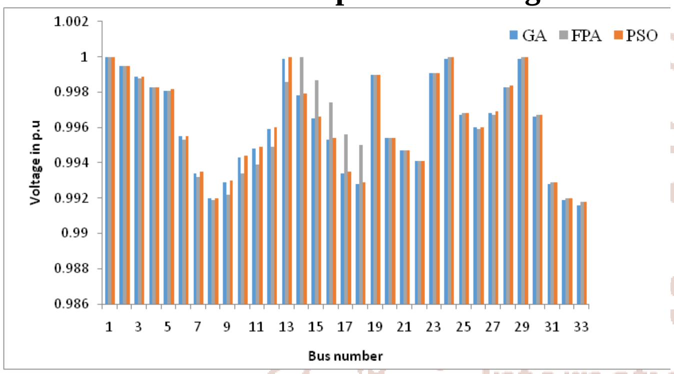
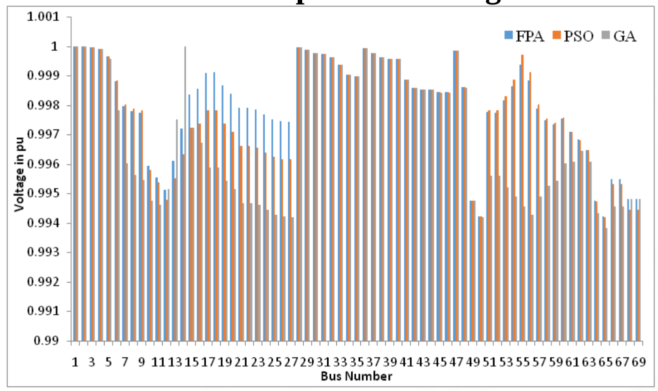


Figure 5.2 69 bus RDS voltage profile for GA, PSO and FPA based optimization algorithm



5.2 Optimization Algorithm's Performance Measure

The statistical measures such as mean, best, standard deviation and the multi-technical objective focused single objective solutions of the three algorithms for the two test systems are recorded in the table 5.3 by conducting 20 different trials.

Table 5.3 Statistical measure of GA, PSO and FPA

Test System	Algorithm	Minimum	Mean	Maximum	Standard Deviation	No of Iteration for
33 Bus	FPA	0.45568	0.4582	0.46189	0.001757	380
	PSO	0.45566	0.45945	0.46212	0.001811	500
	GA	0.45617	0.45892	0.46264	0.001973	610
69 Bus	FPA	0.4411	0.4488	0.4549	0.005109	450
	PSO	0.4411	0.4618	0.4688	0.006268	590
	GA	0.4421	0.4624	0.4709	0.006905	860

From the statistical performance table.5.3, it is inferred that the optimal solutions of FPA for the two test system is better compared to GA and PSO also the number of iterations for extracting best solution using FPA is better than compared to GA and PSO for all the test systems. The above is obvious from the three algorithm's convergence graph in figure 5.3 and figure 5.4 for the 33 bus and 69 bus respectively. It is also inferred that the best multi-objective focused solution is extracted around the low standard deviation using FPA algorithm compared to that of GA and PSO algorithm. So, it is evident that FPA provides better balance in intensification and diversification process while searching the global optimal minima.

Figure 5.3 GA, PSO and FPA based optimization convergence graph for 33 bus RDS

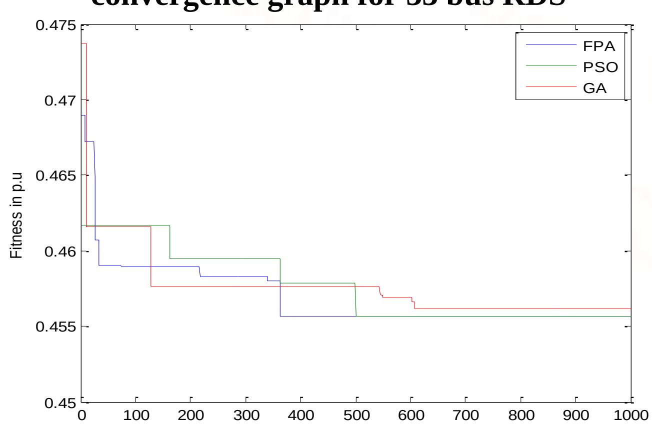
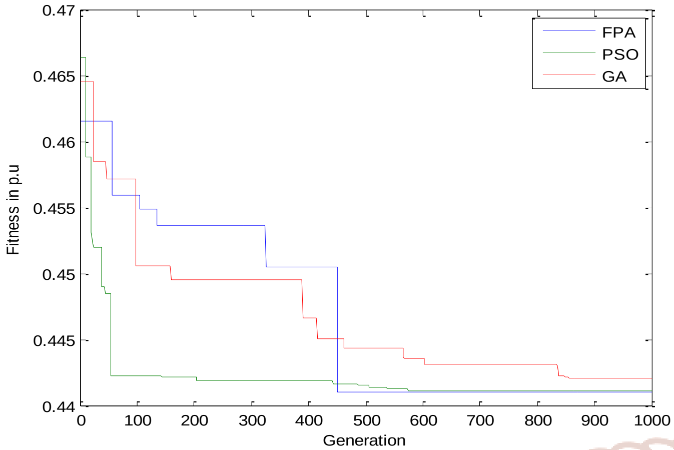


Figure 5.4 GA, PSO and FPA based optimization convergence graph for 69 bus RDS



6. CONCLUSION

This Chapter mainly presents the application of DG in extracting the technical objectives such as voltage profile improvement and voltage stability index maximization by optimally determining the placement and sizing of DG with unity power factor by considering the system security limits. From the simulation results, it is evident that the proposed optimization problem extracts the better solutions of maximum voltage profile and voltage stability index by minimizing the voltage difference with the standard bus voltage. Also it is concluded that the application of FPA in solving the proposed optimization provides the most definite solution by maintaining the good balance in exploring the global minima and exploiting the local minima. Thus the proposed multi-technical objective focussed optimization problem helps to maintain the system stability and voltage profile at higher balance.

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