



OPTIMAL PLACEMENT OF DISTRIBUTED GENERATION IN DISTRIBUTION SYSTEMS BY USING SHUFFLED FROG LEAPING ALGORITHM

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ABSTRACT

In this paper Shuffled Frog Leaping Algorithm (SFLA) algorithm is used for optimal DG placement in distribution system. DG placement plays an important role in radial distribution network in filling the demands of consumers. DG is a small generating plant which generates electrical power to minimize the power losses, improving the voltage profile of the network. The locations found from PLR method and sizes are found by SFLA algorithm. The main objective is to attain ample improvement in the voltage profile and substantial reduction in network power losses and economic benefit. The main idea behind SFLA algorithm is the interacting virtual population of frogs partitioned into different memplexes. IEEE 33 bus and 69 bus test systems are used for the analysis and the results were compared with other techniques.

Keywords: distributed generation, shuffled frog leaping algorithm, economic analysis, distributed networks.

INTRODUCTION

Interconnection of generating, transmitting and distribution systems usually called as electric power system. Usually, distribution systems are radial in nature and power flow is unidirectional. Due to ever growing demand modern distribution networks are facing several problems. With the installation of different distributed power sources like distributed generations, capacitor banks etc. Several techniques have been proposed in literature for the placement of DGs.

DGs are small generating plants which are connected to consumers in distribution systems to improve the voltage profile, voltage regulation, stability, reduction in power losses and economic benefits [1]. These benefits can be elevated, by finding the optimal points and optimal size of DG.

For the past two decades distributed generation placement is a best research topic. A good proportion of study is carried out in this area by Dugan, R.C. and McDermott, T.E. [1]. The authors in [2], [4] proposed an analytical method to find the optimal DG location and sizes to reduce the losses. Rajesh Kumar Singh [3] presents a new technique based on nodal pricing for optimally allocating the distributed generation to achieve profit, loss reduction, and voltage improvement.

Multiple DG units were used by Naveen Jain [5] to minimize the power losses and evaluating the network capacity. The authors in [6] proposed a hybrid method i.e. Combined particle swarm optimization (PSOGA) to improve the voltage stability. SFLA was proposed by Eusuff [7] for solving continuous non-linear optimization problems. Optimal DG Placement and sizing by using index vector method and Flower pollination algorithm [8] to reduce the power loss is proposed by dinakara Prasad reddy *et al.* teaching learning based optimization method to determine the optimal placement of capacitors in distribution system is used by sneha [10].

A new approach was discussed for the integration of dispatchable and non dispatchable DG units for minimizing annual energy losses [18]. The authors [19] presented a new multi-stage model, based on the mixed integer nonlinear programming (MINLP) approach.

Sensitivity [17] based simultaneous optimal placement of capacitors and DG. In this paper analytical approach is used for sizing. The authors [22] in this paper uses particle swarm optimization algorithm is used for DG allocation. A new MLPSO was used in [23] for power loss reduction. The authors [15] proposed a generalized optimization formulation is introduced to determine the optimal location of distributed generators to offer reactive power capability. The authors [21] proposed a dynamic model of distributed generation in the smart grid. GSS algorithm [16] is used for optimal DG placement. A novel combined GA/PSO is presented in [24] for optimal DG placement on distribution systems. An analytical approach based on exact loss formula has been presented in [14] to find the optimal size and location of DG however voltage constraint has not been considered.

A memetic meta-heuristic called the shuffled frog-leaping algorithm (SFLA) has been used in this paper. The SFLA is a population-based cooperative search metaphor inspired by natural memetics. The algorithm contains elements of local search and global information exchange. The SFLA consists of a set of interacting virtual population of frogs partitioned into different memplexes. The virtual frogs act as hosts or carriers of memes where a meme is a unit of cultural evolution. The algorithm performs simultaneously an independent local search in each memplex. SFLA algorithm is used in this paper for finding optimal sizes of DG units.



PROBLEM FORMULATION

Objective function

The problem of DG allocation and sizing should be approached with caution. If DG units are connected at non-optimal locations, the system losses may increase. Studies have indicated that inappropriate locations or sizes of DG may lead to greater system losses than the ones in the existing network.

In this paper different methodologies to determine optimal locations and sizes of DG units to minimize the system real power loss are used. In achieving this objective some system constraints have to be satisfied. The distribution system considered is a balanced radial distribution system. The problem statement can be defined as

$$\text{Objective Function} = \text{Min (TLP)} \quad (1)$$

Where $\text{TLP} = \sum_{i=1}^n I_i^2 R_i$ is the total real power loss of the radial distribution system? Subject to voltage constraint $|V_{i\min}| \leq |V_i| \leq |V_{i\max}|$. Where I_i is the current flowing through the i th branch which is a function of the locations and sizes of DG. R_i is the resistance of the i th branch and n is the number of branches in the system. V_{\max} and V_{\min} are the upper and lower limits on i th bus voltage.

OPTIMAL LOCATIONS USING POWER LOSS REDUCTION (PLR) METHOD

DG locations are obtained based on the power losses and their loss reductions in the system in this method and do not involve any artificial intelligence technique. First load flows are calculated and then real power losses are calculated using equation (3). Then the loss reductions at all the buses are calculated by compensating the total reactive power at each bus. The obtained loss reduction values are normalized into the range [0, 1] for simplification and minimum and maximum loss reductions are noted.

Power loss Index (PLI) represent the loss reduction of that particular bus with respect to the maximum and minimum loss reductions in the system so that when the capacitors are placed on the buses with high power loss index, maximum loss reduction can be anticipated. This index can be represented by the following equation.

$$\text{PLI}(b) = (\text{LR}(b) - \text{LR}(\min)) / (\text{LR}(\max) - \text{LR}(\min)) \quad (2)$$

$$\text{PL}[j] = \frac{(P^2[j] + Q^2[j]) * R_k}{(V[j])^2} \quad (3)$$

$$\text{QL}[j] = \frac{(P^2[j] + Q^2[j]) * X_k}{(V[j])^2} \quad (4)$$

Where b is the number of the bus

$\text{LR}(b)$ is the loss reduction at bus b

$\text{LR}(\min)$ and $\text{LR}(\max)$ are the minimum and maximum loss reduction values.

Best locations for 33-bus system are 30 and 61 for the 69-bus system.

OPTIMAL SIZING OF DG UNITS BY USING SHUFFLED FROG LEAPING ALGORITHM

A memetic meta-heuristic called the shuffled frog-leaping algorithm (SFLA) has been developed for solving combinatorial optimization problems [7]. The SFLA is a population-based cooperative search metaphor inspired by natural memetics. The algorithm contains elements of local search and global information exchange. The SFLA consists of a set of interacting virtual population of frogs partitioned into different memeplexes. The virtual frogs act as hosts or carriers of memes where a meme is a unit of cultural evolution. The algorithm performs simultaneously an independent local search in each memeplex.

The local search is completed using a particle swarm optimization like method adapted for discrete problems but emphasizing a local search. To ensure global exploration, the virtual frogs are periodically shuffled and reorganized into new memeplexes in a technique similar to that used in the shuffled complex evolution algorithm. In addition, to provide the opportunity for random generation of improved information, random virtual frogs are generated and substituted in the population.

Compared with a genetic algorithm, the experimental results in terms of the likelihood of convergence to a global optimal solution and the solution speed suggest that the SFLA can be an effective tool for solving combinatorial optimization problems.

The SFL algorithm combines the benefits of the genetic based and the social behavior-based PSO algorithms. In this algorithm the population consists of a set of frogs (solutions) that is partitioned into subsets referred to as memeplexes. The different memeplexes are considered as different cultures of frogs, each performing a local search. Within each memeplex, the individual frogs, and evolve through a process of memetic evolution. After a defined number of memetic evolution steps, ideas are passed among memeplexes in a shuffling process. The local search and the shuffling processes continue until defined convergence criteria are satisfied. For S -dimensional problems (S variables), a frog i is represented as

$$X_i = (x_{i1}, x_{i2}, \dots, x_{is}). \quad (5)$$

Afterwards, the frogs are sorted in a descending order according to their fitness. Then the entire population is divided into m memeplexes, each containing n frogs ($p = m \times n$). In this process the first frog goes to the first memeplex, the second frog goes to the second memeplex, frog m goes to the m memeplex and frog $m+1$ goes back to the first memeplex, etc. within each memeplex, the frogs with the best and the worst fitness is identified as x_g .



Then, a process similar to PSO is applied to improve only the frog with the worst fitness in each cycle. Accordingly, the position of the frog with the worst fitness is adjusted as follows:

$$\text{Change in frog position } (D_i) = \text{rand}() \times (x_b - x_w) \quad (6)$$

$$\text{New position } X_w = \text{current position } X_w + D_i \quad (7)$$

$$D_{\max} \geq D_i \geq -D_{\max}$$

Where $\text{rand}()$ is a random number between 0 and 1 and D_{\max} is the maximum allowed change in a frog's position.

If this process produces a better result, it replaces the worst frog, otherwise the calculations in (6) and (7) are repeated but with respect to the global best frog (x_g replaces x_b). If no improvement becomes possible in this case, then new solution is randomly generated to replace that frog. The calculations then continue for a specific number of iterations. Accordingly, the main parameters of SFL are: number of frog's p, number of memeplexes, number of generation for each memeplex before shuffling, number of shuffling iterations, and maximum step size.

RESULTS

The SFLA method has been tested on IEEE-33 and 69-bus test systems. The base MVA and base kV have been taken as: 100 MVA, 12.66 kV. The power factors taken under study are unity and 0.9 pf (lag).

Results for 33 bus test system using SFLA method

Without installation of DG, real and reactive power losses are 211 kW and 143 kVAR respectively. With installation of DG at unity pf, real, reactive power losses are 125.1650 kW and 89.2868 kVAR respectively. With DG at 0.9 pf lag, real, reactive power losses are 78.4356 kW and 58.9711 kVAR respectively.

The losses obtained are lower when lagging power factor DG is used when compared to unity power factor DG. This is due to reactive power available in lagging power factor DG. The results obtained are also given in Tables 1, 2 using SFLA method. Better results are obtained while considering reactive power of DG when comparison with unity pf.

Results for 69 bus test system using SFLA method

Without DG real, reactive power losses are 225 kW and 102.1091 kVAR respectively. With the installation of DG at unity pf, the real and reactive power losses are 83.2261 kW and 40.5754 kVAR respectively. With DG at 0.9 pf lag real, reactive power losses are 27.9636 kW and 16.4979 kVAR.

The losses obtained are lower when lagging power factor DG is used when compared to unity power

factor DG. This is due to reactive power available in lagging power factor DG. The results obtained are given in Tables 3, 4. Better results are obtained while considering reactive power of DG when comparison with unity pf.

Cost of energy losses

The cost of energy losses and cost component of DG power has been calculated based on the mathematical model represented as:

a) Cost of energy losses (CL): The annual cost of energy loss is given by [13]

$$CL = (TRPL) * (K_p + K_e * L_{sf} * 8760) \$ \quad (8)$$

Where

TRPL: Total Real Power Losses

K_p : annual demand cost of power loss (\$/kW)

K_e : annual cost of energy loss (\$/kW h)

L_{sf} : loss factor

Loss factor is expressed in terms of load factor (L_f) as below:

$$L_{sf} = k * L_f + (1 - k) * L_f^2 \quad (9)$$

The values taken for the coefficients in the loss factor calculation are:

$k = 0.2$, $L_f = 0.47$, $K_p = 57.6923$ \$/kW, $K_e = 0.00961538$ \$/kW h.

b) Cost component of DG for real and reactive power

$$C(P_{dg}) = a * P_{dg}^2 + b * P_{dg} + c \text{ \$/MWh} \quad (10)$$

Cost coefficients are taken as:

$a=0$, $b=20$, $c=0.25$

Cost of reactive power supplied by DG is calculated based on maximum complex power supplied by DG as

$$C(Q_{dg}) = \left[\text{Cost}(S_{g \max}) - \text{Cost}(\sqrt{S_{g \max}^2 - Q_{g \max}^2}) \right] * k \quad (11)$$

$$S_{g \max} = \frac{P_{g \max}}{\cos \phi} \quad (12)$$

$P_{g \max} = 1.1 * p_g$, the power factor, $\cos \phi$ has been taken 1 at unity power factor and 0.9(lag) at lagging power factor to carry out the analysis. $k=0.05-0.1$. In this paper, the value of factor k is taken as 0.1.

**Table-1.** Results for 33 bus system with DG at unity power factor.

	Without With DG	Voltage sensitivity index method[13]	Proposed method
DG location	--	16	30
DG size(kW)	--	1000	1542.7
Total real power loss(kW)	211	136.7533	125.1650
Total reactive powerloss (kVAR)	143	92.6599	89.2868
Minimum bus voltage(p.u.)	0.9040	0.9318	0.9412
Cost of energy losses(\$)	16982.5724	11007.9901	10067.59
Cost of Pdg (\$/MWh)	--	20.2500	31.104

Table-2. Results for 33 bus system with DG at 0.9 power factor.

	With DG	
	Voltage sensitivity index method[13]	Proposed method
DGlocation	16	30
DG size(kVA)	1200	1940.4
Total real power loss(kW)	112.7864	78.4356
Total reactive power loss(kVAR)	77.449	58.9711
Minimum bus voltage(p.u.)	0.9378	0.9566
Cost of Energy losses(\$)	9078.7686	6308.935
Cost of PDG (\$/MWh)	21.8500	35.172
Cost of QDG (\$/MVARh)	2.1207	3.886

Table-3. Results for 69 bus system with DG at unity power factor.

	Before DG	Voltage sensitivity index method [13]	Proposed method
DGlocation	--	65	61
DG size(kW)	--	1450	1872.7
Total real power loss(kW)	225	112.0217	83.2261
Total reactive powerloss (kVAR)	102.109	55.1172	40.5754
Minimum bus voltage(p.u.)	0.9092	0.9660621	0.9685
Cost of energy losses(\$)	18101.7	9017.2139	6694.25
Cost of Pdg (\$/MWh)	-	29.2500	37.69

**Table-4.** Results for 69 bus system with DG at 0.9 power factor.

	With DG	
	Voltage sensitivity index method [13]	Proposed method
DGlocation	65	61
DG size(kVA)	1750	2217.3
Total real power loss(kW)	65.4502	27.9636
Total reactive power loss(kVAR)	35.6250	16.4979
Minimum bus voltage(p.u.)	0.969302	0.9728
Cost of Energy losses(\$)	5268.4297	2249.2
Cost of PDG (\$/MWh)	31.7500	40.16
Cost of QDG (\$/MVARh)	3.0830	4

CONCLUSIONS

In this paper SFLA has been used for DG sizes and locations are obtaining from PLI method to improve the voltage profile improvement, reduction in real power losses and economic benefit. In this paper the analysis of results is carried out with unity and 0.9 pf lagging operated DGs. The real and reactive power losses, voltage profile, cost component for real power and reactive power obtained from DGs, and their sizes. This paper accomplish that the better results are obtained i.e. real power loss reduction and voltage profile improvement with DG at 0.9 pf lag because DG operating at 0.9 pf supplies reactive power supply to the system. The DG operating at 0.9 pf gives the better results. From the results, it can be concluded that the proposed method is giving overall better results.

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