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Research Article

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Modified Particle Swarm Optimization Based Optimal Sizing and Placement of Distributed Generation in Power Distribution System

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Abstract Distributed Generation (DG) installation has been growing rapidly in deregulated power systems due to their potential solutions to meeting localized demands at distribution level and for mitigating otherwise limited transmission capacities from centralized power stations. However, incorrect sizing and siting of DG sources in power system would not only lead to increase in power losses, but can also jeopardize reliable system operation. The primary objective is to reduce the total power loss and improve voltage profile. Consequently, there is need to identify the optimal location and size of the DG to be installed in distribution network infrastructure. This paper presents the application of Modified particle swarm optimization (MPSO) to accomplish the aforementioned objective. Herein, hybrid combination of backward/forward sweep method and Newton Raphson technique has been developed for the power flow analysis. To validate the effectiveness of the developed tool, it was applied to 71 Bus University feeder in Maiduguri. The algorithm gives faster and accurate results.

Keywords Distributed Generation, Modified particle swarm optimization, Power loss, Voltage profile

1. Introduction

Integrating DG sources within the network can improve both the reliability and efficiency of the power supply; release the available capacity of the distribution substation as well as reducing thermal stresses caused by loaded substations, feeders, and ancillary equipment; improve the system voltage profiles as well as the load factor; and delay the imminent upgrade of the present system or the need to build newer infrastructure [5]. The extent of these benefits depends on how the DG is placed and sized in a system. In addition to supplying the system with the power needed to meet certain demands as an installation incentive, the real power losses could be minimal if the DG is optimally sited and sized. DG optimal allocation and sizing is an ongoing research area [3]. The exact solution of the DG allocation can be obtained by a complete enumeration of all feasible combinations of sites and sizes of DGs in the network [7].

Several methods have been proposed in determining the optimal location of DG. The majority of DG placement objectives were power or energy losses in the network. In addition, other technical parameters like voltage profile, reliability of distribution network, line loadings, reactive power requirement, maximizing DG capacity, investment cost, operating cost, and etc. have also been considered to form single or multi objective problem formulation in different studies.

2. Problem Formulation

The objective of the placement technique is to minimize the total real power loss and improved voltage profile. Mathematically, the objective function can be written as

$$\sum_{i=1}^{N}|I_i|^2 R_i \qquad (1)$$

Subject to power balance constraints.

$\sum_{i=1}^{N} P_{DGi} = \sum_{i=1}^{N} P_{Di} + P_L$ (2)

Voltage constrains

$V_i^{min} \leq V_i \leq V_i^{max}$ (3)

Where i is the number of bus, N is the total number of Buses,P_L is the real power loss in the system, P_{DGi} is the real power generation of DG at bus i, P_{Di} is the power demand at bus i , I_{ij} is the current between buses i and j and R_i is the resistance. The current I_i is determined from the load flow using Hybrid load flow studies Method called Backward – Forward and Newton Raphson. For single source network all the power is supplied by the source but with DG that are optimally placed there is going to be reduction in power loss. This reduction in power loss is determined as the difference of the power loss with DG and without DG. Thus, the new power loss in the network with DG is:

$P_{L-new} = \sum_{i=1}^{N} |I_i^{new}|^2 R_i$ (4)

$P_{L-new} = \sum_{i=1}^{N} I_i^2 R_i - 2JI_i I_{DG} R_i - JI_i I_{DG}^2 R_i$ (5)

Where $j=1$for a feeder with DG or else $j = 0$ Hence, the power loss reduction value for bus i with DG is obtained by subtracting (5) from (6) as

$PLR = P_{L-new} - P_L$ (6)

$PLR = -\sum_i^N (2JI_i I_{DG} R_i + JI_i I_{DG}^2) R_i$ (7)

The bus that gives the highest value of PLR is selected as the optimal location of DG. The emphasis is to place the DG at a location that will give maximum loss reduction. To obtain the DG current that will give maximum loss reduction, equation (8) is differentiated with respect to I_{DG} and equated to zero, hence the current is given by equation (9) below.

$I_{DGI} = -\frac{\sum_{i=1}^{n} I_{ai} R_i}{\sum_{i=1}^{n} R_i}$ (8)

The procedure is repeated for all the buses in order to obtain the highest power loss reduction value as the DG units are singly and doubly located. Assuming there is no significant changes in the voltage as DG units are connected, the power that can be generated is;

$P_{DGi} = I_{DG} V_i$ (9)

Where V is the voltage magnitude of the bus i and the optimum DG size is obtained from equation (9). The optimal location of the DG is bus i for maximum power loss reduction.

3. Modified Particle swarm optimization

The proposed MPSO considers the worst position also along with the best positions, so we keep track of particle's worst and global worst positions as we do for the best positions in normal PSO. As the name suggests, worst particle here, will be the particle having maximum function value. This modification can be applied to any of the PSO variants, which will be named here after as "base PSO". In this paper we are using inertia weight PSO as base PSO. Here, in each iteration, s1 particles are selected and named as "bad particles"; others are "good particles". There can be many methods for selecting "bad particles". For these "bad particles", velocity is updated using particle's worst and global worst positions. Other particles will follow the base PSO's velocity update rules. Here particles, going towards worst positions can explore the region nearby the bad function values during the run. There is possibility that these "bad particles" find good positions during their search. Then they will transform into the "good particles" and attract the other particles also towards them as they are ruled by the best ones.

In this paper we are choosing particles already performing worse than others as "bad particles" in each iteration and get velocity update by worst positions. As the particles which are already performing bad, do not participate much into the velocity update of whole swarm. Thus we still contain the essence of "base PSO".

Firstly, the modified algorithm chooses the particle with maximum fitness when it is iterating and initializes its position randomly for increasing the searching ability of particles. By this means, the particle can search more domains. Secondly, by referring to ideas of using neighborhoods to achieve the guaranteed convergence, the fitness of the particle which has the best value in present iteration would be smaller than previous time, and it is acceptable the fitness is worse in a limited extent sayα. We calculate the change of fitness value of two positions Δf, and accept the new position if Δf is smaller thanα. Otherwise, a new position is assigned to the particle randomly from its neighborhood with radius r [9]. The velocity and positions are updated using equations (10) & (11)

$$V_{m,n}^{new} = W \times V_{m,n}^{old} + G_1 \times r_1 \times K_1(P_{m,n}^{local\ best} - P_{m,n}^{old}) + G_2 \times r_2 \times K_2(P_{m,n}^{global\ best} - P_{m,n}^{old}) + G_3 \times r_3 \times K_3(P_{m,n}^{local\ worst} - P_{m,n}^{old}) + G_4 \times r_4 \times K_4(P_{m,n}^{global\ worst} - P_{m,n}^{old}) \quad (10)$$

$$P_{m,n}^{new} = P_{m,n}^{old} + V_{m,n}^{new} \quad (11)$$

Where,

K = [K_1, K_2, K_3, K_4] is a switch matrix. For particles affected by best ones, K = [1, 1, 0, 0] which will switch for bad particles to K = [0, 0, 1, 1]

$V_{m,n}^{old}$ = Particle velocity

$P_{m,n}^{old}$ = Particle position

r_1, r_2, r_3, r_4 are n- dimensional column vectors whose elements are random number selected from uniform distribution U (0, 1)

W = Inertia weight choosing between [0, 1]

$G_1 = G_3$ are the cognitive acceleration coefficient

$G_2 = G_4$ are the social acceleration coefficient

4. Reliability Index

The reliability index used in this research work was System Average Voltage Index (SAVI) [1]. This is a new reliability index which is used to calculate the customers affected due to deviation in voltage.

The acceptable voltage level deviation in PU is ± 5% *i.e.* 1.05 to 0.95 PU. The number of customers affected due to voltage variations are calculated with this index. The SAVI is defined as,

$$SAVI = \frac{Number\ of\ customers\ below\ the\ specified\ limit\ PU}{Number\ of\ customers\ served} \quad (12)$$

Without placement of DG this index was calculated to know the customers affected, and with DG placement by re-evaluating the same index shows the decrement in the customers affected.

The sum of square of voltage errors was calculated using equations (13)

$$SSVE = \sum_{i=1}^{n}(1 - V_i)^2 \quad (13)$$

5. The procedure of modified PSO is as follows:

Step 1. Initialize the position and velocity of each particle;

Step 2. Calculate the fitness of each particle;

Step 3. Calculate the particle with the biggest fitness value, reinitialize its position; and evaluate the particle with the smallest fitness value whether its new position is acceptable, if the answer is yes, update its position, otherwise, a new position is assigned to the particle randomly in its neighborhood with radius r; then renew the position and velocity of other particles using equation (10) & (11)

Step 4. For each particle, compare its current fitness value with the fitness of its p best, if the current value is better, then update p best and its fitness value;

Step 5. Determine the best particle of group with the best fitness value, if the current fitness value is better than the fitness value of g best, then update the g best and its fitness value with the position;

Step 6. Is the stopping criterion satisfied, otherwise, go to step 3.

6. University Feeder

University feeder in Maiduguri has 71 bus and 70 sections with the total load of 4.715 MW and 27.8 MVAR. Base MVA 100, conductor type is 100 mm^2, All Aluminum Alloy Conductor (AAAC), Base voltage 11kV, Resistance of 0.55 ohm per km and reactance of 0.35 ohm per km. The single line diagram of the system is shown in Fig 1 below.

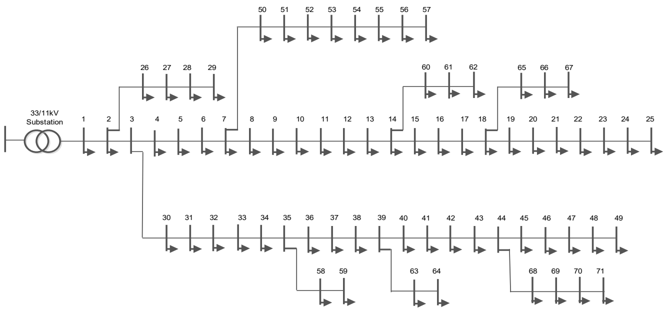

Figure 1: 71 Bus, 11kV University Feeder, Maiduguri (YEDC)

7. Results and Discussions

To validate the developed optimization technique, it was applied to a Feeder called University feeder in Maiduguri considering two scenario cases. Scenario case one was placement of one DG and scenario case two was placement of two DGs.

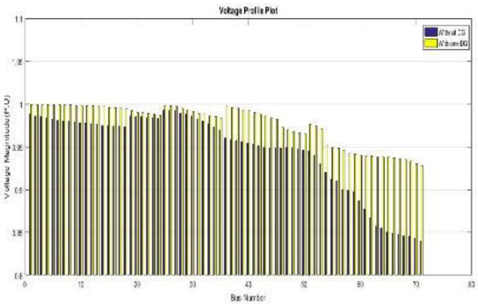

Figure 2: Voltage Profile for Scenario one

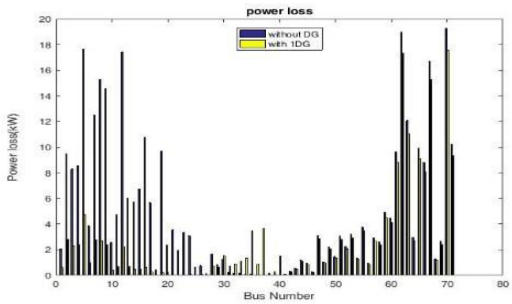

Figure 3: Power loss for Scenario one

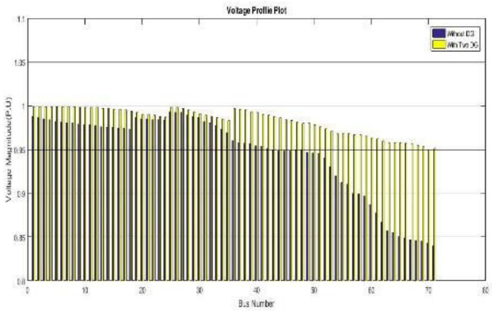

Figure 4: Voltage Profile for Scenario Two

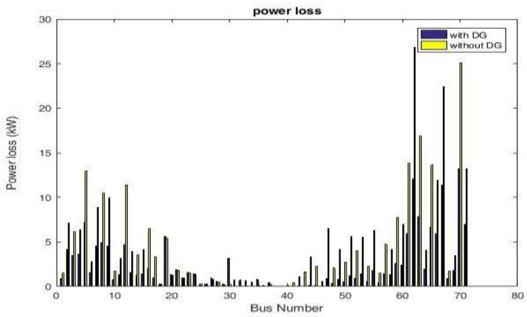

Figure 5: Power loss for Scenario two

Table 1: Best Location, Size and Power losses

S/No	Feeder Parameters	University feeder with 1DG	University feeder with 2 DG
1	Best Location	Node 45	Node 20 and 32
2	DG Size (MW)	1.352	1.022 and 0.482
3	DG Type	Solar	Solar
4	Initial power loss (kW)	335.59	335.9
5	Final power loss (kW)	184.91	100.68
6	% power loss reduction	55.05	73.21

Table 2: Bus affected and its corresponding Customer for University Feeder

Constraint	Bus affected	Total number of customer affected	SAVI
Without DG	28	2200	0.6197
With one DG	18	900	0.2535
With two DG	0	0	0

Table 3: Bus violating voltage limit and Sum of Square of Voltage Error (SSVE) for University Feeder

Constraint	Bus Violating Limit	SSVE
Without DG	28	0.15488
With one DG	18	0.03542
With two DG	0	0

8. Conclusions

In this paper, Modified Particle swarm optimization has been presented for finding the optimal sizes and locations of DGs. The Methodology was tested on 71 bus University feeder in Maiduguri. The result showed that optimal sizing and location of DG in a Power distribution system can improve the voltage profile and reduces the power losses. The proposed algorithm gives better result compared to conventional Particle swarm optimization.

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