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Voltage Profile Enhancement and Loss Minimization Using Incremental Analysis for Optimal Placement and Sizing of Distributed Generation in Reconfigured Network

Author
[1,2,3,4,5]Student: Yakkanti Sravani , Kondreddy Sreenivasula Reddy, Kusam Tulasinath Reddy, Devaraju Gari Varanagatheja.
Corresponding: P . Ravindra Prasad
Annamacharya Institute of Technology and Sciences, Rajampet
MTech (Assistant Professor)

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ABSTRACT: Today, power consumption is increasing further because of this distribution systems face many challenges. In order to ensure the continuity and reliability of service for customers, electricity companies are obliged to develop and operate distribution networks efficiently. When high currents pass through the distribution networks with low voltage levels, this increases power losses and voltage instability. To resolve the above issues, consider reconfiguring the network and integrating distributed generation units into the distribution network. On this detail, the optimal placement and dimensioning of DGs are crucial. Otherwise, network performance will deteriorate. The problem of distributed generator (DG units) placement for power loss reduction in distribution systems is investigated in this thesis using Incremental Analysis (IA) method and Particle Swarm Optimization (PSO) method. IA method is based on IA expressions to calculate the optimal size of four different DG types and a methodology to identify the best location for DG allocation. In PSO method, a two-stage methodology is used for placement and sizing of DG units. In both IA and PSO methods a DG injecting only Real power (P) is considered in this paper and are tested on IEEE 15 bus and IEEE 69 bus test systems. Voltage profile graphs are also plotted for both methods. Results shows that IA method is effective when compared to PSO method.

Keywords: DG, Optimal Placement, Incremental Analysis , Particle Swarm Optimization.

I. INTRODUCTION

1.1 Particle Swarm Optimization

PSO is one of the optimization techniques are used to minimize or maximize the objective function such as to solve the problem in power system. PSO algorithm is considered as one of the modern heuristic algorithms for optimization developed by Kennedy and Eberhart in 1995, based on the swarm social behaviour of birds flocking and fish schooling in nature where that's have their own viewpoint to find food and eventually move only in one direction only for move to the best food in groups. In PSO, swarm means population; particle represents each member of the population. Each particle searches through the entire space by randomly moving in different directions and remembers the previous best solutions of that particle and also positions of its neighbour particles. Particles of a swarm adjust their position and velocity dynamically by communicating best positions of all the particles with each other. In this way, finally all particles in the swarm try to move towards better positions until the swarm reaches an optimal solution. Thus, due to its easy implementation and its ability to

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obtain fast convergence, PSO technique is becoming very popular. Moreover PSO uses only basic mathematics and it does not involve any derivative or gradient information.

1.1.1Basic Model of PSO Algorithm

Consider a function of n dimension which is defined by

$$f(x1\,, x2\,, \dots \dots \dots, xn\,) = f(x) \qquad (1.1)$$

Where x_i is the optimizing variable, which represents the set of variables for a given function $f(X)$. Here, the goal is to get an optimum value x^* so that the function $f(x^*)$ can become either a maximum value or a minimum value.

The Particle Swarm Optimization (PSO) technique is parallel search technique which utilizes multi-agents (swarm of particles). Each agent in the swarm represents a solution. All agents go through entire search space and updates its position and velocity based on their own experience and on experience of other agents. Suppose x_i^t denote the agent or particle 'i' position vector search space at time step t, then each agent position is updated in the search space by
.

$$x_i^{t+1} = x_i^t + v_i^{t+1} \qquad (1.2)$$

where, v_i^t is the particle velocity vector which is used to update the own experience and other particles experience and also drives the optimization process Thus, in PSO technique, all agents are randomly initialized and fitness value is computed by updating the personal best (best value of each agent) and global best (best value of all agents in the entire swarm). The loop starts by assuming initial values of position of the particles as personal best and then updates every particle position by using the updated velocity. When the stopping criterion is met, loop will be ended. Basically, PSO algorithms are classified into two types. They are Global Best (gbest) and Local Best (pbest) PSO algorithms which differ in the size of their neighbourhood particles.

The global best PSO (or gbest PSO) is a technique in which position of each agent is influenced by best agent in the whole swarm. In this method, information is obtained from all the agents in the swarm and thus it makes use of a star network topology. Here, x^i is the current position of each agent in search space , v^i is the current velocity and a $P_{best,i}$ is personal best position of each agent in search space. If a minimization problem is considered, the personal best position $P_{best,i}$ represents the position of particle "i" in search space with smallest fitness function value. $Gbest$ is the position of particle which yields the lowest value among all personal best positions .

Personal best $P_{best,i}$ at next step, t+1, where t ϵ [0,…..N], for a minimization problem is calculated as

$$P_{best,i}^{t+1} = \begin{Bmatrix} P_{best,i}^t & if \;\; f(x_i^{t+1}) > P_{best,i}^t \\ x_i^{t+1} & if \;\; f(x_i^{t+1}) \geq P_{best,i}^t \end{Bmatrix}$$

(1.3)

Where f is the fitness function

The global best position $Gbest$ at time step for a minimization problem is calculated as

$$G_{best} = min(P_{best,i}^t), where \;\; i \in [1,2,\dots\dots,n] \; and \; n > 1 \qquad (1.4)$$

Thus we can note that personal best is best position of each agent among all time steps that each agent traversed. Global best is best position of all agents in the entire swarm.

For gbest PSO method, velocity of agent is obtained by

$$v_{ij}^{t+1} = Wv_{ij}^t + c_1 r_{1j}^t (P_{best,i}^t - x_{ij}^t) + c_2 r_{2j}^t (G_{best} - x_{ij}^t) \qquad (1.5)$$

Where

v_{ij}^t Is the velocity vector of particle i in dimension j at time t;

x_{ij}^t Is the position vector of particle i in dimension j at time t;

$P_{best,i}^t$ Is the personal best position of particle i in dimension j found from initialization through time t;

G_{best} Is the global best position of particle i in dimension j found from initialization through time t;

$c_1 \; and \; c_2$ Are positive acceleration constants which are used to level the contribution of the cognitive and social components respectively;

$r_{1j}^t \; and \; r_{2j}^t$ Are random numbers from uniform distribution U(0,1) at time t;

W Inertia parameter

The above inertia parameter has the following formulae

$$W = W_{max} - ((W_{max} - W_{min}) * t/T \qquad (1.6)$$

Where

$W_{max} \; and \; W_{min}$ are the constraints for inertia weight factor.

t = current iteration count.

T = maximum number of iterations

Constraints considered for the algorithm are as follows

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$$V_i^{min} \le V_i \le V_i^{max} \quad (1.7)$$

$$X_i^{min} \le X_i \le X_i^{max} \quad (1.8)$$

1.1.2 Algorithm of Particle Swarm Optimization Method For Placement And Sizing of Multiple DG Units

In this PSO method the Forward-Backward Load flow algorithm-based load flow program is used to solve the load flow problem. The Algorithm for optimal multiple DG placement using PSO approach to minimize the power loss and to improve the voltage profile is described in detail in the following steps:

Step 1: Get the line data and bus data as inputs and initialize popsize (population size),4 number of buses, minimum and maximum size of DG and maximum number of iterations(maxit).

Step 2: Generate initial number of velocities randomly between the limits. take iteration count as 1.

Step 3: Run the load flow to calculate the total real power loss in the system.

Step 4: Calculate the Loss function using equation 2.8 at each and every node of the considered test system.

Step 5: Now calculate the Power Loss Index using equation 2.9

Step 6: Using PSO System determine the DG suitability Index for each and every node and find out the location having more suitability index. That location could be an optimal location for DG placement.

Step 7: Perform the load flow analysis is by placing a DG at the particular location obtained by PSO and power losses PL DG are calculated. Same procedure is repeated for number of particles i.e., population size to find out the total real power loses.

Step 8: To obtain maximum loss reduction a Fitness Function is determined using the formula:

Fitness Function FA= PL- PL DG (1.9)

Where,

P_L is total real power loss before placement.

P_L^{DG} is the total real power loss after placement of DG.

Fitness with negative value is replaced with minimum and the respective particle position also assign with minimum from equation (1.8). Initially all the fitness values are copied to pbest fitness, maximum pbest fitness gives the gbest fitness.

Which is a measure of maximum loss reduction and the respective particles represents gbest particles.

Step 9: Using equations (1.4) and (1.5) new velocities for all the particles within the limits are calculated and particle positions are updated respectively.

Step 10: After updating the particles, load flow analysis is performed and new fitness value is calculated using equation (1.7). If the new fitness is greater than the pbest fitness then the respective particle is moved to the pbest particle.

Step 11: The maximum of pbest fitness gives the gbest fitness and the respective particle will be stored as gbest particle.

Step 12: By using pbest fitness the maximum fitness and average fitness are calculated. Error is calculated using the following equation.

Error = (max.fitness – avg.fitness) (1.10)

If the calculated error is less than the specified tolerance then go to step 14.

Step 13: Increment the iteration count if it not greater than or equal to maximum iteration then go to step 9.

Step 14: The gbest fitness and gbest particle gives maximum loss reduction and optimal size of DG respectively.

Step 15: Now place and fix the optimal DG size in the bus data at the bus location obtained by fuzzy of the considered test bus system.

Step 16: To place next DG repeat the same procedure from step 3 to step 15 till then the available DG units are completed.

II. INCREMENTAL ANALYSIS

2.1 IA Method:

IA method is an effective methodology to find the optimal location, size, and power factor of multiple DG units in distribution networks. This method utilizes some expressions known as Improved Analytical expressions. A brief description of the IA expressions and optimal power factors for single DG allocation is presented as follows

2.1.1 IA Expressions

The IA expressions are developed for the above mentioned four types of DG

Type 1 DG, which is capable of injecting both Real power and Reactive power and having power factor of 0<PFDG

$$P_{DGi} = \frac{\alpha_{ii}(P_{Di} + aQ_{Di}) - X_i - aY_i}{a^2\alpha_{ii} + \alpha_{ii}} \quad (2.1)$$

$$Q_{DGi} = aP_{DGi} \quad (2.2)$$

Where,

a=(sign)tan($\cos^{-1}$(PF_{DG}))

sign= +1 DG injecting reactive power

$$X_i = \sum_{\substack{j=1 \\ j\neq i}}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) \quad (2.3)$$

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$$Y_i = \sum_{\substack{j=1 \\ j\neq i}}^{N} (\alpha_{ij} Q_j - \beta_{ij} P_j) \quad (2.4)$$

The equations (1.4) & (1.5) give the optimum size of DG for each bus i, for the loss to be minimum. Any size of DG other than P_{DGi} placed at bus i will lead to a higher loss. This loss, however, is a function of loss coefficients α and β. When DG is installed in the system, the values of loss coefficients will change, as it depends on voltage and angle. Updating the values of α and β again requires another load flow calculation. However, numerical results showed that the accuracy gained in the size of DG by updating α and β is small and negligible [2]. With this assumption, the optimum size of DG for each bus, given by the above two relations, can be calculated from the base case load flow (i.e., without DG case). This methodology requires the load flow to be carried out only two times for single DG allocation, one for the base case and another at the end with DG included to obtain the final solution [2] and [5].

Type 2 DG is the one which injects Real power but consumes Reactive power. The optimal DG size can be determined from equations (1.3) & (1.4) in which sign= -1 and 0<PFDG

Type 3 DG is the one which is capable of injecting Real power only. Hence for this type 3 DG we have PFDG= 1 and a=0. The optimal size of DG at each bus i for the minimum loss is given by (1.5)

$$P_{DGi} = P_{Di} - \frac{1}{\alpha_{ii}} \sum_{\substack{j=1 \\ j\neq i}}^{N} (\alpha_{ij} P_j - \beta_{ij} Q_j) \quad (2.5)$$

Type 4 DG is capable of delivering Reactive power only the optimal DG size can be determined by using equations (2) & (3) with PFDG=0 and a=∞.

$$Q_{DGi} = Q_{Di} - \frac{1}{\alpha_{ii}} \sum_{\substack{j=1 \\ j\neq i}}^{N} (\alpha_{ij} Q_j - \beta_{ij} P_j) \quad (2.6)$$

2.1.2 Power Losses

The total real power loss in a power system is represented by an exact loss formula:

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} \left[\alpha_{ij} (P_i P_j + Q_i Q_j) + \beta_{ij} (Q_i P_j + P_i Q_j) \right]$$

(2.7)

Where,

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

(2.8)

$$\beta_{ij} = \frac{r_{ij}}{V_i V_j} \sin(\delta_i - \delta_j) \quad (2.9)$$

N Number of Buses

α and β Loss Coefficients.

$V_i \angle \delta_i$ Complex voltage at the bus ith;

$r_{ij} + j x_{ij} = Z_{ij}$ ijth element of [Z_{bus}] impedance matrix;

P_i and P_j Active power injections at the ith and jth buses, respectively;

Q_i and Q_j Reactive power injections at the ith and jth buses, respectively;

2.1.2 Optimization Algorithm

This optimization algorithm of Improved Analytical method is made on the basis of the improved analytical expressions to find the optimal buses at which the losses are the lowest and where multiple DG units are best placed. The IA expressions help to reduce the solution space. Among four types of DG units in this thesis only a type-3 DG i.e., a DG injecting only Real power is considered and the IA method Algorithm is applied for multiple DG placement in distribution system to get loss reduction and voltage profile improvement in it. Figure-2.1 illustrates the flowchart of IA method for multiple type-3 DG allocation

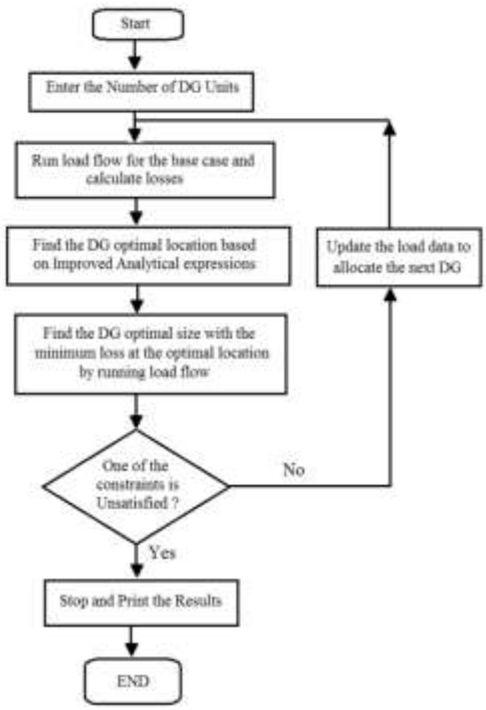

Fig 2.1 Flow Chart for a type -3 DG Placement Using IA method

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In this work, based an idea of updating the load data after each time of DG placement, the algorithm is proposed to solve optimal multiple DG placement. First, a single DG is added in the system. After that, the load data is updated with the first DG placed and then another DG is added. Similarly, the algorithm continues to allocate other DG units until it does not satisfy at least one of the constraints in step 7 as described as follows. In IA method the Newton–Raphson algorithm-based load flow program is used to solve the load flow problem. The computational step by step procedure to allocate multiple type-3 DG units on the basis of the IA expressions is described in detail as follows.

Step 1: Enter the number of DG units to be installed in the system.
Step 2: Run the load flow for the base case and determine the losses using exact loss formula as in equation (2.7).
Step 3: Calculate the optimal size of DG at each bus using equation (2.5).
Step 4: Place the DG with optimal size obtained from step 3 at each bus one at a time. Calculate the approximate loss for each case using equation (2.7) with the values of α and β of the base case.
Step 5: Locate the bus at which the power losses are minimum, and it is known to be an optimal bus and corresponding DG size will be an optimal size of DG.
Step 6: Place that optimal DG at that optimal bus and update the bus data and perform the load flows to update α and β values.
Step 7: Stop if any of the following occurs otherwise go to step 8
a. The maximum number of DG units are unavailable;
b. The new iteration loss is more than the previous iteration loss;
c. Total size of DG units is over the total load plus losses;
d. If voltage at any particular bus is above the upper limit. Step 8: To allocate next DG unit repeat the process from step 3 to step 6

III. RESULTS

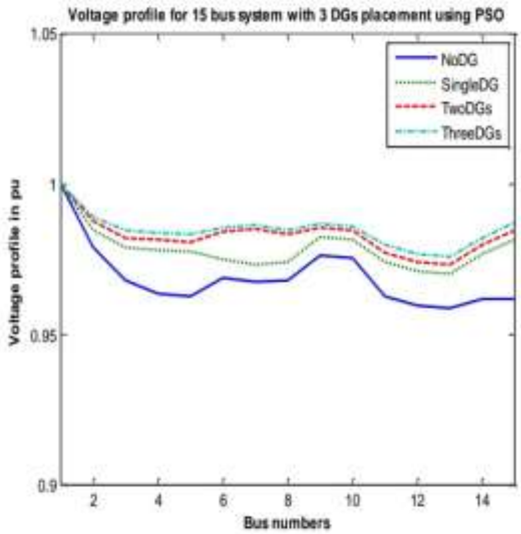

Fig3.1 Voltage Profile Plot for 15-bus System with three DG Units Placement Using PSO method

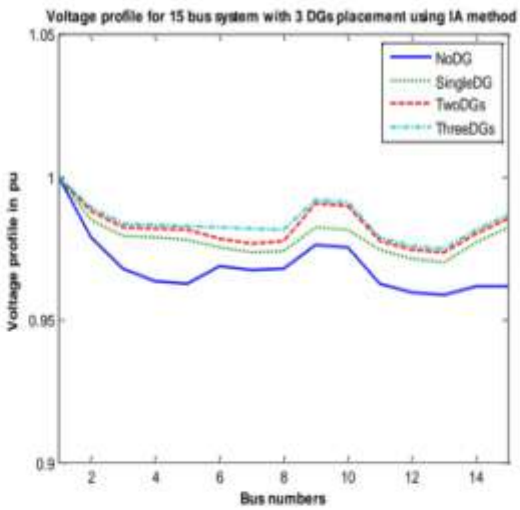

fig 3.2 Voltage Profile Plot for 15 bus System with Three DG Units Placement using IA method

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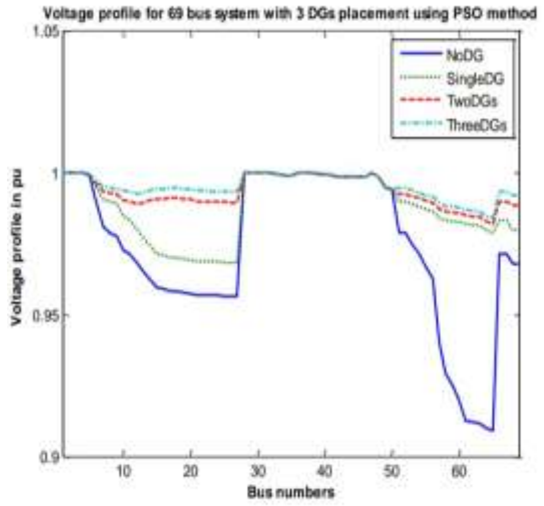

Fig .3.3 Voltage Profile Plot For 69-Bus System with Three DG Units Placement Using PSO Method

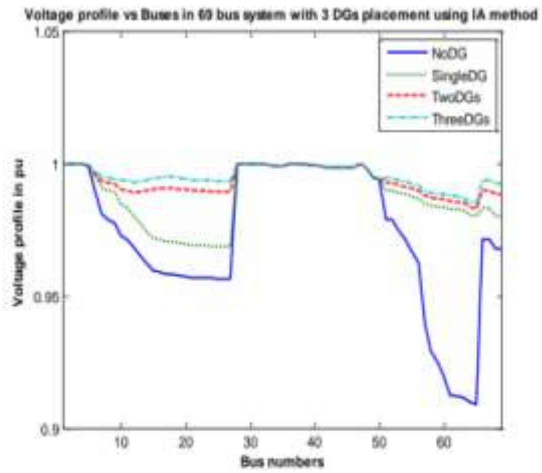

Fig .3.4 Voltage Profile Plot for 69- bus System with three DG Units Placement Using IA Method

IV. CONCLUSION

The project uses Incremental Analysis, which is a technique used to evaluate the impact of changes in a system by analysing the differences between two states of the system, to determine the optimal configuration of DG units. By implementing the optimized configuration of DG units, the voltage profile in the distribution network can be improved, and losses can be minimized, leading to a more reliable and efficient power supply. This has significant implications for the energy industry, as the use of DG units can reduce reliance on traditional power plants and lead to a more sustainable and decentralized energy system. The IA method is based on IA expressions which are used to find out the optimal location and optimal size of four types of DGs. Among four types of DG in this paper a DG injecting Active power is only considered.

The results clearly show that, loss reduction and voltage profile improvement is possible with both PSO and IA methods, but when compared to PSO method, IA method gives more accurate results and higher percentage of loss reduction. PSO method has shorter computational time when compared to IA, but for same number of DG units installed the IA method gives more percentage of loss reduction with a smaller DG size when compared to a DG size given by PSO method

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