

OPTIMAL ARRANGEMENT OF DIFFERENT TYPES OF DISTRIBUTION GENERATION RESOURCES IN DISTRIBUTION NETWORKS

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Abstract - *This paper proposes the application of Particle Swarm Optimization (PSO) technique to find the optimal size and optimum location for the placement of DG in the radial distribution networks for active power compensation by reduction in real power losses and enhancement in voltage profile. In the first segment, the optimal size of DG is calculated at each bus using the exact loss formula and in the second segment the optimal location of DG is found by using the loss sensitivity factor. The analytical expression is based on exact loss formula. The optimal size of DG is calculated at each bus using the exact loss formula and the optimal location of DG is found by using the loss sensitivity factor. The results obtained from the PSO technique have also been compared with the analytical approach results. The proposed technique is tested on 15-bus and 69-bus test systems.*

Index Terms—*Analytical expressions, distributed generation (DG), loss reduction, optimal location, optimal power factor, optimal size.*

I. INTRODUCTION

The delivery of power from source to the consumer is always accompanied with power losses. It has been reported that power losses occurring in distribution networks account for as much as 13% of the generated energy. Such non-negligible amount of power losses has a direct impact on the financial results and the overall efficiency of distribution utilities is reduced.

The aim of our project is to examine the effect of optimal size and location of Distributed Generation to reduce the Real power loss on the distribution networks. Distributed Generation resources serve as a well-known solution in most of the power system problems. DG has lot of features which makes it attractive and offer good solution to the growing power demand[1-3].

The analysis of distribution system is an important area of activity as distribution systems provide the link between the bulk power system and customers. The power flow is an important tool for power system analysis. The efficiency of such power flow algorithm is utmost importance as each optimization study requires numerous power flow runs.

The effect of active power loss has become a major problem because it reduces the efficiency of power transfer and deteriorates the voltage profile. The minimization of real power loss in the distribution network is gaining much significance when compared to the transmission system. The optimal placement and sizing of DG units in the existing grid system attempt to reduce the real power loss to a considerable extent.

DG sources in the real power distribution system could achieve many technical and economical benefits. In order to optimize these benefits, it becomes essential to determine optimal size of DG units for any specified power network.

II. LOSS REDUCTION TECHNIQUES

There have been many studies on the reconfiguration of distribution systems for loss reduction. A switch exchange algorithm was proposed in [4]. In [5], an approximate power-flow technique was developed for analyzing loss reduction from network reconfiguration. In [6], Fan *et al.* formulated the reconfiguration problem as a linear programming problem and applied angle-loop optimization method to solve network reconfiguration. Other techniques such as the genetic algorithm (GA) [7], simulated annealing (SA) [8], improved Tabu Search (TS) [9], and ant colony search (ACS) algorithm [10] have been used for the purpose of network reconfiguration for reducing losses. For optimal capacitor placement for loss reduction, a well known “Golden Rule,” or “2/3 rule” is presented in [11]. This method would yield good solutions in system where the loads are uniformly distributed. Many researchers have applied other techniques such as dynamic programming [12], fuzzy expert system [13], TS [14], and GA [15] for finding best locations for capacitors to reduce losses.

In distribution systems, DG can deliver a portion of real and/or reactive power so that the feeder current is reduced and voltage profile can be improved with reduction in losses. However, studies indicate that poor selection of location and size would lead to higher losses than the losses without DGs [16], [17]. A technique for DG placement using “2/3 rule” has been presented in [17]. Although the 2/3 rule is simple and easy to apply, this technique may not be effective in distribution with not uniformly distributed loads. Besides, if a DG is capable of delivering real and reactive power, applying the method that was developed for capacitor placement may not work. In [18], an analytical approach has been presented to identify appropriate location to place single DG in radial as well as loop systems to minimize losses. But, in this approach, optimal sizing is not considered.

GA was applied to determine the size and location of DG in [19] and [20]. Though GA is suitable for multiobjective problems and can lead to a near optimal solution, they demand computational time. Recently, an analytical approach based on exact loss formula was presented to find the optimal size and location DG [16]. In this method, the load flow is required to be conducted only twice. The first load-flow calculation is needed to calculate the loss of base case. The second load-flow solution is required to find the minimum total loss after DG placement. The technique requires less computation. However, the analytical approach can be applied to DG capable of delivering only real power. Most of the approaches presented so far model DG as a machine that is capable of delivering only real power. However, there are other types of DG being integrated into distribution systems. This paper develops a comprehensive formula by improving the analytical (IA) method proposed in [16] to find the optimal sizes, optimal locations of various types of DG. The paper also presents the importance of operating DGs that are capable of delivering both real and reactive power at the proper power factor to achieve minimum losses.

III. PROPOSED METHODOLOGY

A. Problem Formulation

The optimal sizing and placement of DG results in minimum loss in the distribution system [11]. The total real Loss in a distribution system is given by:

$$P_{losses} = \sum_{i=1}^N |I_i|^2 R_i \quad (4.1)$$

where I_i is the current magnitude of each branch and R_i is the resistance of i th branch. considering N bus distribution systems, the loss minimization may be formulated as given below:

$$\text{Minimize } P_l = \sum_i^N \sum_j^N [\alpha_{ij} (P_i P_j + Q_i Q_j) + \beta_{ij} (Q_i P_j - P_i Q_j)] \quad (4.2)$$

$$\text{where } \alpha_{ij} = \frac{R_{ij}}{V_i V_j} \cos(\delta_i - \delta_j) \quad (4.3)$$

$$\beta_{ij} = \frac{R_{ij}}{V_i V_j} \sin(\delta_i - \delta_j) \quad (4.4)$$

and

$$Z_{ij} = R_{ij} + jX_{ij} \quad (4.5)$$

where

Z_{ij} is the impedance of the line between bus i and bus j ;

R_{ij} is the resistance of the line between bus i and bus j ;

V_i is the voltage magnitude at bus i ;

V_j is the voltage magnitude at bus j ;

δ_i is the voltage angle at bus i ;

δ_j is the voltage angle at bus j ;

P_i and Q_i is the active and reactive power injection at bus i ;

P_j and Q_j is the active and reactive power injection at bus j ;

SUBJECT TO THE CONSTRAINTS:

Another significant part of the optimization model that needs to be defined is the constraints. There are two types of constraints they are

1. Equality Constraints

2. Inequality Constraints

1). Equality Constraints:

These constraints are related to the nonlinear power flow equations.

$$P_i = P_{DG_i} - P_{D_i} \quad (4.6)$$

$$Q_i = Q_{DG_i} - Q_{D_i} \quad (4.7)$$

where

P_{DG_i} and Q_{DG_i} are real and reactive power injection from DG is placed at node i .

P_{D_i} and Q_{D_i} are the load demand at node i .

2). Inequality constraints

The Inequality constraints are those associated with bus voltages and DG to be installed.

(a) Bus Voltage Limit:

The bus voltage magnitudes are to be kept within acceptable operating limits throughout the optimization process.

$$V_{min} \leq V_i \leq V_{max} \quad (4.8)$$

where

V_{min} is Lower bound of bus voltage limits.

V_i is RMS value of the bus voltage.

V_{max} is Upper bound of bus voltage limits.

(b) Number and sizes of DGs:

These are constraints related with the DG and themselves. DGs that are commercially available come in discrete sizes. The total real power losses of the system is minimum with respect to injected power is zero with partial derivative of Equation (4.1).

It follows that

$$P_{DG_i} = P_{Di} - \frac{1}{\alpha_{ii}} \left[\sum_{j=1}^N \sum_{j \neq i} (\alpha_{ij} P_j - \beta_{ij} Q_j) \right] \quad (4.9)$$

$$Q_{DG_i} = Q_{Di} - \frac{1}{\alpha_{ii}} \left[\sum_{j=1}^N \sum_{j \neq i} (\alpha_{ij} Q_j + \beta_{ij} P_j) \right] \quad (4.10)$$

Equations (4.9) and (4.10) can be combined to determine the size of DG. The bus which has an lowest real power loss is considered as the optimal placement for DG followed by satisfactions of constraint.

The power factor may be considered as optimal and represented as:

$$OPF = \frac{P_{DG_i}}{\sqrt{P_{DG_i}^2 + Q_{DG_i}^2}} \quad (4.11)$$

B. Types of DG

DG can be classified into four major types based on their terminal characteristics in terms of real and reactive power delivering capability as follows:

- 1) Type 1: DG capable of injecting P only.
- 2) Type 2: DG capable of injecting Q only.
- 3) Type 3: DG capable of injecting both P and Q .
- 4) Type 4: DG capable of injecting P but consuming Q .

Photovoltaic, micro turbines, fuel cells, which are integrated to the main grid with the help of converters/inverters are good examples of Type 1. Type 2 could be synchronous compensators such as gas turbines. DG units that are based on synchronous machine (cogeneration, gas turbine, etc.) fall in Type 3. Type 4 is mainly induction generators that are used in wind farms.

C. Sizing at Various Locations

Assuming $a = (\text{sign})\tan(\cos^{-1}(\text{PFDG}))$, the reactive power output of DG is expressed by (2) $Q_{DG_i} = aP_{DG_i}$ (2) in which

sign = +1: DG injecting reactive power;
sign = -1: DG consuming reactive power;
PFDG is the power factor of DG.

The active and reactive power injected at bus i , where the DG located, are given by (3) and (4), respectively,

$$P_i = PDG_i - PDi \quad (3)$$

$$Q_i = QDG - QDi = aPDG_i - QDi \quad (4)$$

From (1), (3), and (4), the active power loss can be rewritten as

$$\text{Minimize } P_l = \sum_i^N \sum_j^N [\alpha_{ij} (P_i P_j + Q_i Q_j) + \beta_{ij} (Q_i P_j - P_i Q_j)]$$

The power factor of DG depends on operating conditions and type of DG. When the power factor of DG is given, the optimal size of DG at each bus i for minimizing losses can be found in the following way.

- 1) *Type 1 DG*: For Type 1 DG, power factor is at unity, i.e., $FDG = 1$, $a = 0$. From (10), the optimal size of DG at each bus i for minimizing losses.
- 2) *Type 2 DG*: Assuming $PFDG = 0$ and $a = \infty$, from (2) to (10), the optimal size of DG at each bus i for minimizing Losses.
- 3) *Type 3 DG*: Assuming $0 < PFDG < 1$, $\text{sign} = +1$ and “ a ” is a constant, the optimal size of DG at each bus i for the minimum loss is given by (10) and (4), respectively.
- 4) *Type 4 DG*: Assuming $0 < PFDG < 1$, $\text{sign} = -1$ and “ a ” is a constant, the optimal size of DG at each bus i for the minimum loss is given by (10) and (4), respectively.

D. Optimal Location

For optimal location, the method proposed in [16] is used. Based on this method, first the optimal sizes at various locations have been calculated for different types of DG and the losses were calculated with optimal sizes for each case. The case with minimum losses is selected as the optimal location for each type of DG.

Based on this method proposed in [16], one can avoid exhaustive computation and save time, especially for large-scale distribution systems as trend of loss reduction can be captured with α and β coefficients from the bases case. *E.*

In practice, a complex distribution system includes a few sources, many buses, many lines and loads. The power factors of loads are different. If each load is supplied by each local DG, at which the power factor of each DG is equal to that of each load, there is no current in the lines. The total line power loss is zero. The transmission lines are also unnecessary. However, that is unrealistic since the capital investment cost for DG is too high. Therefore, the number of installed DGs should be limited. To find the optimal power factor of DG for a radial complex distribution system, fast and repeated methods are proposed. It is interesting to note that in all the three test systems the optimal power factor of DG (Type 3) placed for loss reduction found to be closer to the power factor of combined load of respective system.

Fast Approach: Power factor of combined total load of the system (PFD) can be expressed by (13). In this condition, the total active and reactive power of the load demand. The “possible minimum” total loss can be achieved if the power factor of DG (PFDG) is quickly selected to be equal to that of the total load (PFD). That can be expressed by (17)

$$PFDG = PFD . \quad (17)$$

F. Computational Procedure

When power factor of DG is set to be equal to that of combined total loads, computational procedure to find optimal size and location of one of four types of DG's is described in the following.

Step 1: Run base case load flow without DG.

Step 2: Find base case loss by using equation (4.1)

Step3: Except reference bus find the optimal sizes of DG by using equations (4.9) and (4.10) for minimum distribution loss.

Step 4: Check constraint violation after the placement of DG.

Step 5: Locate optimal bus at which the total loss is minimum corresponding with optimal size at that DG.

Step 6: Calculate power factor using equation (4.11).

Step 7: Run load flow with the optimal size of DG placed at optimal bus.

Step 8: Then calculate exact real power loss after the placement of DG.

IV. NUMERICAL RESULTS

The proposed methodology was tested on a distribution system consisting of 15 bus and 69 bus test systems is shown in figure 5.1 and 5.2. By this method the real power loss can be minimized and optimal sizes of DG units are calculated at each and every buses. In this study two different test systems are used and legalize the result for optimal sizing, placement and power factor. The first test system is 15 bus system with total load of 1.23 MW and 1.25 MVAR. The second of the test system is 69 bus system with load demand of 3.80 MW and 2.69 MVAR[12].

The proposed methods have been developed and simulated in MATLAB environment and to calculate the optimum sizes of DG at various buses and real power losses with DG at different locations to identify the best locations. Thus real power loss is get minimized by the optimal placement of DG. To solve the load flow problem a Newton-Raphson method is used [13].

C. Simulation Results

Sizing Allocation: The optimal sizes and total losses with the optimal sizes of DG one at a time at respective

location for 16, 33, and 69 bus test systems, respectively. In all the figures, lower half shows the optimal sizes obtained using proposed method (IA) and ELF method using exact loss formula. Notice in all the cases, optimal sizes of DG obtained from the proposed method is closer to actual optimal size obtained from exhaustive load flow solutions. Similarly, total losses obtained from the method without updating α and β for the purpose of identifying best location and exhaustive methods give a comparable result.

Observe that when DG with a large size is placed at any locations near a swing bus, the loss reduction of each system is quite low. In contrast, only a small size of DG is added at the other locations, a higher loss reduction can be achieved. As a result, finding a location at which the total loss at minimum is important.

V. CONCLUSION

This paper presents analytical expressions to identify the optimal sizing and placement of DG at various locations for different bus systems. The system performance improvement on the system depends largely on where the DG is located. The effect of active power loss has become a major problem because it reduces the efficiency of power transfer and deteriorates the voltage profile. The minimization of real power loss in the distribution network is gaining much significance when compared to the transmission system. The optimal placement and sizing of DG units in the existing grid system attempt to reduce the real power loss to a considerable extent. The methodology was tested on 15 and 69 bus test system for minimizing the real power losses. Adding DG to critical bus will improve the system performance most effectively. Analytical approach method is used for the DG installation at the optimal locations and reducing the real power losses of the network. Results shows that the locations, size, of distributed generators are decisive factors in reducing losses.

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