CHAPTER 2
PROBLEM FORMULATION

2.1 INTRODUCTION

The need for reliable, uninterruptable, improved quality of power creates a favorable situation for the penetration of renewable and non-renewable distributed generation system into the power system grid. Due to this penetration at the distribution level, the distribution system becomes active with the flow of power. In order to obtain the required performance of Distributed Generation (DG) systems such as power loss reduction, voltage profile improvement, reliability increase and better power quality, the suitable placement and size of DG are necessary.

There are normally more methods are available for the optimal allocation of DG in the distribution network. They are traditional based optimal power flow; sensitivity factor ranking based optimum power flow and evolutionary computation algorithms. Here, the optimum allocation of DG means the optimum location and size at which the fitness function i.e. the objective of the network is satisfied.

In this thesis, the objective of optimal allocation of DG in the distribution system is to recognize the control parameters which reduce the system real power loss while supporting the operating constraints.

2.2 OBJECTIVE FUNCTION AND CONSTRAINTS

The optimal allocation of DG is formulated as a nonlinear optimization problem subjected to nonlinear equality and inequality constraints.
The goal of the optimization problem in the RDN is framed so as to reduce the real power losses occurred in the system.

\[ f = \text{Min} \sum P_{\text{LOSS}} \]  

(2.1)

In equation (2.1) the PLOSS is given as

\[ P_{\text{LOSS}} = \sum_{i=1}^{n} \sum_{j=1}^{n} A_{ij} (P_iP_j + Q_iQ_j) + B_{ij} (Q_iP_j - P_iQ_j) \]  

(2.2)

The reactive power loss is given as

\[ Q_{\text{LOSS}} = \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} (P_iP_j + Q_iQ_j) + B_{ij} (Q_iP_j + P_iQ_j) \]  

(2.3)

In the above equation(2.2) and (2.3)

\[ A_{ij} = \frac{R_{ij}\cos(\delta_i - \delta_j)}{V_iV_j} \]  

(2.4)

\[ B_{ij} = \frac{R_{ij}\sin(\delta_i - \delta_j)}{V_iV_j} \]  

(2.5)

\[ C_{ij} = \frac{X_{ij}\cos(\delta_i - \delta_j)}{V_iV_j} \]  

(2.6)

\[ D_{ij} = \frac{X_{ij}\sin(\delta_i - \delta_j)}{V_iV_j} \]  

(2.7)

\[ P_i \] and \[ P_j \] are the real power insertion in bus \( i \) and bus \( j \), respectively.

\[ Q_i \] and \[ Q_j \] are the reactive power insertion in bus \( i \) and \( j \), respectively.

\[ V_i \] and \( V_j \) are the per unit voltage at \( i^{th} \) bus and \( j^{th} \) bus, respectively.

\( \delta_i \) and \( \delta_j \) are the voltage angle of \( i^{th} \) bus and \( j^{th} \) bus, respectively.

\( R_{ij} \) is the resistance between \( i^{th} \) and \( j^{th} \) buses.

\( X_{ij} \) is the reactance between \( i^{th} \) and \( j^{th} \) buses.

When the DG is installed in the RDN

\[ P_i = P_{DGi} - P_{Di} \]  

(2.8)

\[ Q_i = Q_{DGi} - Q_{Di} \]  

(2.9)
Equality constraints

The successive load balance equation should be satisfied in the distribution system for each bus.

\[ P_{\text{slack}} + \sum_{i=1}^{N} P_{\text{DG}_i} = P_L + \sum_{i=1}^{N} P_{\text{Di}} \] \hspace{1cm} (2.10)

Inequality constraints

The inequality constraints of voltage limits, real and reactive power limits of DG are considered in this problem.

Voltage constraints

The voltage limits of each bus should be bounded by upper and lower magnitude values.

\[ |V_i|_{\text{min}} \leq |V_i| \leq |V_i|_{\text{max}} \] \hspace{1cm} (2.11)

The corresponding lower and higher voltage magnitude values are given as

\[ |V_i|_{\text{min}} = 0.9 \text{ and } |V_i|_{\text{max}} = 1.05 \]

Generation constraints

For each DG system, there should be an upper and lower MVA ratings for the DG size.

\[ S_{\text{DG}_i}^{\text{min}} \leq S_{\text{DG}_i} \leq S_{\text{DG}_i}^{\text{max}} \] \hspace{1cm} (2.12)

The limits of DGs are according to their MVA ratings.

\[ S_{\text{DG}_i}^{\text{min}} = 0.25 \text{ MVA and } S_{\text{DG}_i}^{\text{max}} = 4 \text{ MVA} \]

Current transfer Capacity constraints

For each feeder the current transfer should be within its maximum transfer capacity.

\[ I_l = I_l^{\text{max}} \] \hspace{1cm} (2.13)

where \( l \in \{1,2,3 \ldots N\} \)
DG Position Constraints

Bus $2 \leq \text{position of DG} \leq \text{bus n}$ \hspace{1cm} (2.14)

Multiple DGs constraints

In case of multiple DGs placement, the following inequality constraints are also included.

No of DGs $\leq 3$ \hspace{1cm} (2.15)

$P_1 \neq P_2 \neq P_3$ \hspace{1cm} (2.16)

where $P_1, P_2$ and $P_3$ are the bus location of DGs at position 1, position 2 and position 3 respectively.

2.3 LOAD FLOW

To determine the objective function value i.e. the real power loss and bus voltage, the load flow solution is used in the distribution system. The load flow solution based on Gauss Seidal method and Newton Rapson method are inefficient to analyze the distribution system. The distribution system has radial structure, unbalanced load and high R/X ratio. Hence, it is difficult to make the power flow computation using the above algorithms for the distribution system. They are capable of producing best results in the transmission system. The backward-forward sweep algorithm is selected to perform the load flow analysis in the Radial Distribution Network (RDN) due to its low memory requirement, fast convergence, increased computational efficiency and accuracy. (Haque 1996)

2.4 BACKWARD AND FORWARD SWEEP METHOD

The backward and forward sweep based power flow is generally applied for the radial network topology. It consists of two processes i.e. forward and backward sweep processes. To determine the node voltage from the near end to the far end, the forward sweep is used. To calculate the branch current or
28

power summation from the far end to the near end, the backward sweep is applied. (Sunisith & Meena 2014) Kirchhoff’s Voltage law (KVL) and Kirchhoff’s Current Law (KCL) are employed in this algorithm to calculate the nodal voltages. In the RDN, the branch currents are initially computed and then the bus voltages are determined using these branch current values. This process is an iterative procedure to solve the equations involved in the load flow problem.

2.4.1 Backward Sweep

According to this procedure, the current injection at each branch is calculated as a function of the end node voltages. The bus voltages at the end nodes are initialized at first. From the end bus to the source bus, the voltage is updated and the current injected at each bus is calculated. The node current is given as

\[ I_i = \left( \frac{S_i}{V_i} \right)^* \]  

(2.17)

where, \( S_i \) is the load power at ith bus.

\[ S_i = P_L(i) + Q_L(i) \]  

(2.18)

The branch current between \( j \) and \( i \) node can be specified as,

\[ I(j, i) = I_i(i) + \sum_{k=1}^{n} I(i, k) \]  

(2.19)

The voltage at any node \( i \) is derived as

\[ V_i = V_j + I(i, j) * Z(i, j) \]  

(2.20)

where, \( Z(i, j) \) is the impedance of the branch between \( i \) and \( j \).

2.4.2 Forward Sweep

The current determined using backward sweep are kept and used in the succeeding Forward Sweep. The Forward Sweep estimates the node voltages which are a function of the current inserted into each bus. The Forward Sweep calculates the voltage drop with the constraint that the source voltage applied is
the specific nominal voltage at the beginning of each forward sweep. The voltage is calculated at each bus, from the source bus and traversing towards the end buses by means of the current determined in preceding the Backward Sweep.

The voltage at node ‘i’ is calculated as

\[ V_i = V_j - I(j,i) \times Z(j,i) \]  

(2.21)

If the difference between calculated source voltage and specific source voltage is equal or less than a specific tolerance, then the convergence of load flow is achieved. The currents determined in all branches at the final iteration are used for calculation of voltages and losses at each bus.

2.5 CONCLUSION

This thesis applies the backward-forward sweep algorithm to determine the load flow solution. In order to achieve better convergence, accuracy and minimum computational time period the backward-forward sweep method is applied to find the real and reactive power losses in the RDN. With the presence of DG, additional consideration is given to the load flow according to the type of DG. For the Type I DG, only the real power is injected into the system at the point where the DG is integrated and there is no change in reactive power. Both the real and reactive power is injected for the Type II DG. In case of Type III DG, the real power is injected and the reactive power is absorbed from the system at the point of connection considered. The Type IV DG injects only reactive power and there is no change in real power of the distribution system. The load flow is done in the RDN according to the mentioned terminal characteristics of DG.