CHAPTER 4

4. OPTIMAL POWER FLOW ANALYSIS

4.1 OPTIMAL POWER FLOW

The **Optimal Power Flow**(OPF) model represents the problem of determining the best operating levels for electric **power** plants in order to meet demands given throughout a transmission network, usually with the objective of minimizing operating cost.The basic objectives of optimal power flow can be stated as below:

A) To minimize total generation cost:

B) To minimize transmission losses

4.2 LOAD FLOW STUDIES:

LOAD flow studies are performed on Power Systems to understand the nature of the installed network. **Load flow** studies determine if system voltages remain within specified limits under normal or emergency operating conditions, and whether equipment such as transformers and conductors are overloaded. **Load flow** studies are commonly used to: Optimize component or circuit loading. Develop practical bus voltage profiles. A power-flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various forms of AC power (i.e.: voltages, voltage angles, real power and reactive power). It analyzes the power systems in normal steady-state operation. The distribution networks because of the some of the following special features fall in the category of ill-condition.

• Radial or weakly meshed networks

• High R/X ratios

• Multi phase, unbalanced operation

• Unbalanced distributed load

• Distributed generation

Due to the above factors the NR and other transmission system algorithms are failed with transmission network. So the backward forward sweeping method is introduced NRmethods. However, conventional backward forward sweep method is not useful for modern active distribution networks.

4.2.1 BACKWARD/ FORWARD SWEEP METHOD:

A. Forward Sweep

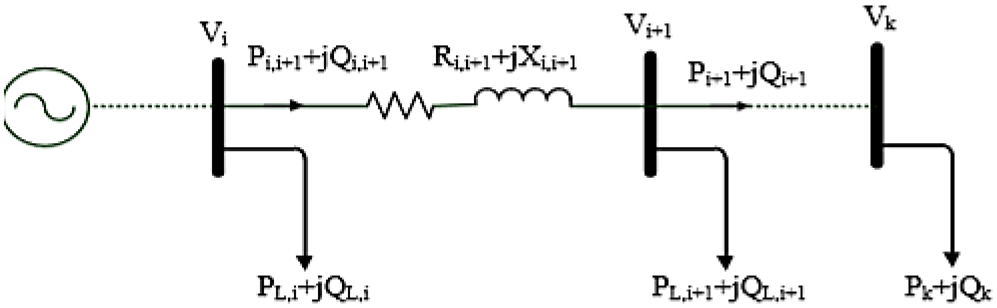
The forward sweep is basically a voltage drop calculation with possible cur-rent or power flow updates. Nodal voltages are updated in a forward sweep starting from branches in the first layer toward those in the last. The purpose of the forward propagation is to calculate the voltages at each node starting from the feeder source node. The feeder substation voltage is set at its actual value. During the forward propagation the effective power in each branch is held constant to the value obtained in backward walk.

B. Backward Sweep

The backward sweep is basically a current or power flow solution with possible voltage updates. It starting from the branches in the last layer and moving towards the branches connected to the root node .The updated effective power flows in each branch are obtained in the backward propagation computation by considering the node voltages of previous iteration. It means the voltage values obtained in the forward path are held constant during the backward propagation and updated power flows in each branch are transmitted backward along the feeder using backward path. This indicates that the backward propagation starts at the extreme end node and proceeds towards source node.

By comparing the calculated voltages in previous and present iterations, the successive iteration is obtained. The convergence can be achieved if the voltage mismatch is less than the specified tolerance i.e., 0.0001. Otherwise new effective power flows in each branch are calculated through backward walk with the present computed voltages and then the procedure is repeated until the solution is converged.

4.3 LOAD FLOW:



2.1 SIMPLE RADIAL DISTRUBUTION SYSTEM

The active and reactive power is given by

$$P_{i,i+1} - P_{L,i+1} - R_{i,i+1}\left(\frac{P_{i,i+1}^2 + Q_{i,i+1}^2}{|V_i|^2}\right)$$
$$Q_{i+1} = Q_{i,i+1} - Q_{L,i+1} - X_{i,i+1}\left(\frac{P_{i,i+1}^2 + Q_{i,i+1}^2}{|V_i|^2}\right)$$

——— **(1)**

Where $P_{i,i+1}$ and $Q_{i,i+1}$ are real and reactive power flows into branch connecting between buses i and i+1. $P_{L,I+1}$ and $Q_{L,i+1}$ are real and reactive power loads feeding from bus i+1.

The bus voltage magnitude at bus I is given by

$$V_{i+1}^2 = V_i^2 - 2\left(R_{i,i+1}P_{i,i+1} + X_{i,i+1}Q_{i,i+1}\right)$$
$$+\left(R_{i,i+1}^2 + X_{i,i+1}^2\right)\left(\frac{P_{i,i+1}^2 + Q_{i,i+1}^2}{|V_i|^2}\right)$$

——— **(2)**

$R_{i,i+1}$ and $X_{i,i+1}$ are resistance and reactance of the line section between buses i and i+1,V_i is the bus voltage magnitude at bus i.

The active and reactive power losses of n^{th}line between line n and n+1 are given as follows:

$$P_{loss(i,i+1)} = R_{i,i+1}\left(\frac{P_{i,i+1}^2 + Q_{i,i+1}^2}{|V_i|^2}\right)$$
$$Q_{loss(i,i+1)} = X_{i,i+1}\left(\frac{P_{i,i+1}^2 + Q_{i,i+1}^2}{|V_i|^2}\right)$$

———**(3)**

The total system active loss is computed by taking the summation of all system branches which provided as:

$$P_{T\ loss} = \sum_{i=1}^{n-1} P_{loss(i,i+1)}$$

Where n is number of buses (4)

4.4 OBJECTIVE FUNCTION

4.4.1 Objective Function:

The objective function is to minimize the overall cost of power generation subject to the constraints. Objective function takes various forms such as fuel cost, transmission losses and reactive source allocation.

4.4.2 Multi Objective Function:

In practice, problems with multiple objectives are reformulated as single-objective problems by either forming a weighted combination of the different objectives or by treating some of the objectives by constraints. The choice of optimal capacitor capacity and placement problem can be determined for minimization of the total real power loss and the total system cost (system energy loss cost and capacitors cost). This can be modeled using the proposed mathematical equations of the objective function (OF):

$$OF = Min(f_1, f_2)$$

$$f_1 = \min(P_{T\ loss})$$

$$f_2 = \min(Cost) \qquad (5)$$

The total cost function is offered as:

$$Cost = K_p\, P_{T\ loss} + \sum_{k=1}^{n} K_{fc}\, Q_{fc} \qquad (6)$$

where coefficient Kp is the per KW cost of total energy loss cost which is appreciated as (168$/KW)

K_{fc} = per KVAR cost of total capacitor capacity cost ($/KVAR)

Q_{fc} = the size of the shunt capacitor and

n = number of capacitors for the selected buses.

4.5 Constrains

The previous equations are tied to the given constrains:

a) **Voltage bounds**

The bus voltage magnitude is allowed to be between the given well-known limits: $V_{min} \leq V_i \leq V_{max}$

Where Vmin and Vmax are the minimum and maximum allowable voltage limit of system buses.

b) **Injected reactive power**

The total generated reactive power must be less or equal the total reactive power of loads.

$$Q_{fc} \leq \sum_{i=1}^{n} Q_{Li}$$

where Q_{Li} ,is reactive power loads feeding from bus i. Q_{fc} is total injected reactive power by capacitor banks.

c) **Capacitor size**

$$Q_{min} \leq Q_i \leq Q_{max}$$

d) Line capacity limits

The current flow through network branches must be within their allowable limits as follows:

$$i_{n,i} \leq i_{max,i},\ i = 1,2, 3\ldots, NL$$

4.6 FLOWCHART FOR BACKWARD/FORWARD SWEEP BASED DISTRIBUTION LOAD FLOW METHOD