CHAPTER 2

LOAD FLOW STUDY

2.1 Introduction

Load flow is the solution of the static operating condition of an electric power transmission system. The results from load flow calculation are needed for network planning purposes as well as optimization of operation with regard to network losses and also as a start of stability calculation.

Load flow calculations provide power flows and voltages for a specified power system subject to the regulating capability of generators, condensers and tap changing under load transformers as well as specified net interchange between individualy operating power systems. This information is essential for the continuous evaluation of the current performance of a power system and for analyzing the effectiveness of alternative plans for system expansion to meet an increased load demand. These analyses require the calculation of numerous load flows for both normal and emergency operating conditions.

2.2 Load flow equations

Load flow equations are used a lot by both network planning and operations people for a variety of purposes.

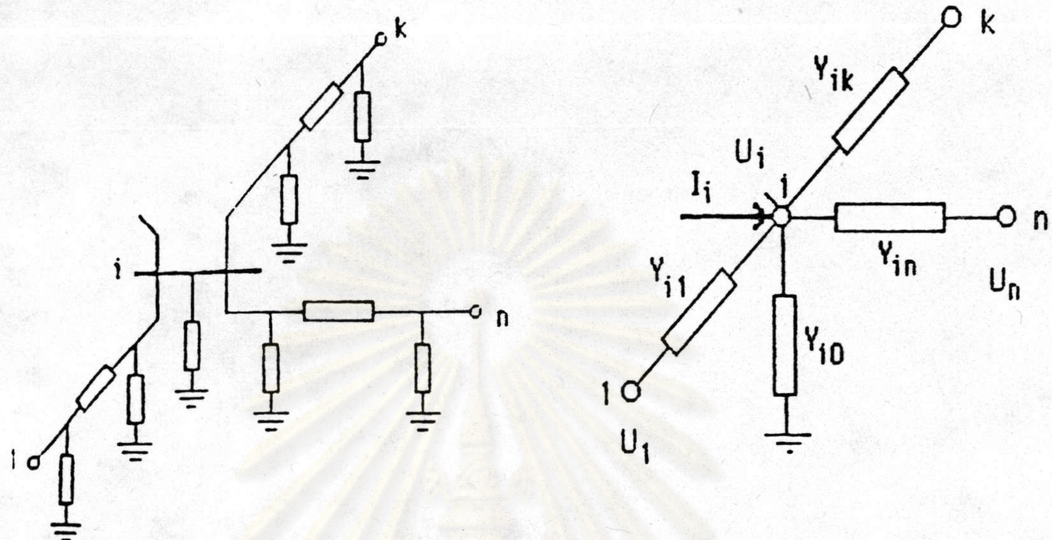


Figure 2.1 A network the injected current.

For each node in a network the injected current is given by the equation.

$$I_i = U_i \cdot Y_{i0} + (U_i - U_1) \cdot Y_{i1} + \cdots + (U_i - U_k) \cdot Y_{ik} + \cdots + (U_i - U_n) \cdot Y_{in}$$

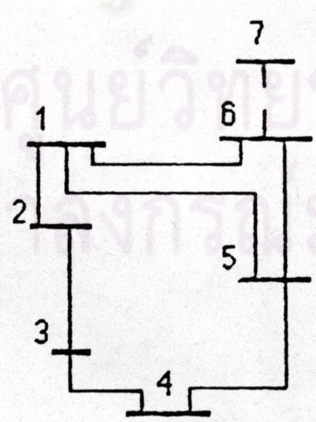
$$I_i = \left[Y_{10} + \sum_{\substack{1 \\ k \neq i}}^{n} {}_k Y_{1k}\right] U_1 + \sum_{\substack{1 \\ k \neq i}}^{n} {}_k (-Y_{1k})\, U_k = Y_{11}\, U_1 + \sum_{\substack{1 \\ k \neq i}}^{n} {}_k Y_{1k} \cdot U_k$$

where Yii is the sum of all admittances connected to the node i and Yik is the negative of the admittance between node "i" and "k" which also means Yik = Yki. This can be written as a matrix equation.

$$\begin{vmatrix} I_1 \\ \vdots \\ I_i \\ \vdots \\ I_k \\ \vdots \\ I_n \end{vmatrix} \quad \begin{vmatrix} y_{11} & y_{1i} & \cdots & y_{1k} & \cdots & y_{1n} \\ \vdots & \vdots & & \vdots & & \vdots \\ y_{i1} & y_{ii} & \cdots & y_{ik} & \cdots & y_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ y_{k1} & y_{ki} & \cdots & y_{kk} & \cdots & y_{kn} \\ \vdots & \vdots & & \vdots & & \vdots \\ y_{n1} & y_{ni} & \cdots & y_{nk} & \cdots & y_{nn} \end{vmatrix} \quad \begin{vmatrix} U_1 \\ \vdots \\ U_i \\ \vdots \\ U_k \\ \vdots \\ U_n \end{vmatrix}$$

or $I_{bus} = Y_{bus} \cdot U_{bus}$ a set of complex, linear simultaneous equations I_{bus} and U_{bus} are the bus current and bus voltage vectors. Y_{bus} is the bus admittance matrix and a model of the studied passive network.

The structure of Y_{bus} is symmetrical around the main diagonal. It is sparsely filled in. Each pair of off diagonal positions corresponds to a branch. If there is no branch the matrix elements are zero.



	1	2	3	4	5	6	7
1	1	1			1	1	
2	1	1	1				
3		1	1	1			
4			1	1	1		
5	1			1	1	1	
6	1				1	1	+
7						+	+

Figure 2.2 The structure of Y_{bus} is symmetrical around the main diagonal.

Unfortunately neither the voltage nor the currents are normally known. At least not both magnitudes and phase angles. More commonly is the knowledge about power at the nodes both active and reactive.

At node "i" power injected into the network is like this :

$$S_i^* = U_i^* \cdot I_i = U_i^* \cdot y_{ii} \cdot U_i + U_i^* \cdot \sum_{\substack{k=1 \\ k \neq i}}^{n} y_{ik} \cdot U_k$$

$$S_i^* = P_i - jQ_i = U_i^* \cdot \sum_{k=1}^{n} y_{ik} \cdot U_k$$

a complex equation which can be divied into two real equation in this manner :

$$P_i = \sum_{k=1}^{n} |y_{ik}| \cdot |U_i| \cdot |U_k| \cos(\varphi_k - \varphi_i + \delta_{ik})$$

$$Q_i = -\sum_{k=1}^{n} |y_{ik}| \cdot |U_i| \cdot |U_k| \sin(\varphi_k - \varphi_i + \delta_{ik})$$

Where $|U_i|$, φ_i are voltage magnitude and phase angle and P_i, Q_i are active and reactive power.

If we know the magnitude of all n voltages and the n-1 phase angle towards a referance all currents and the entire power flow in the network.

As we have 2n equations we must know 2n of the state variables to be able to solve the problem. These known variables can be chosen like this.

Referance bus $\left| U_{ref} \right| , \varphi_{ref}$

The voltage magnitude and phase angle is given. active and reactive power are calculated. This bus is called "swing bus" or "slack bus" where the differance between power production and load including system losses is accumulated.

Load bus P , Q

Active and reactive power is given and voltage magnitude and angle towards the referance are calculated.

Voltage control bus $\left| U \right|$, P

Voltage magnitude is given together with active power. Voltage phase angle and reactive power are calculated.

The principle of the power flow model is established and the solution is obtained by some mathematical method.

The oldest method is the Gauss-Seidel iterative method. When large computer memories became available the Newton-Raphson method became popular. The well-known polar-mismatch Newton-Raphson load flow (NRLF) in matrix form is :

$$\begin{vmatrix} \Delta P \\ \Delta Q \end{vmatrix} = \begin{vmatrix} H & N \\ J & L \end{vmatrix} \begin{vmatrix} \Delta \varphi \\ \Delta V \end{vmatrix} \qquad \text{------(2.1)}$$

Where ΔP is the real power mismatch vector

ΔQ is the reactive power mismatch vector

$$\begin{vmatrix} H & N \\ \hline J & L \end{vmatrix}$$ is the jacobian matrix

$\Delta \varphi$ is the phase angle correction vector

ΔV is the voltage correction vector.

There are two equations present in eq.2.1 for every PQ-bus and one equation ΔP, $\Delta \varphi$ for PV-bus. No equation for swing bus is required. The jacobian matrix is not symmetric but similar to [Y-bus] sparse.

The standard technique for accelerating Newton's method is to re-use the jacobian matrix from one iteration for several sucessive cycles without recomputation. The normal procedure is like this : a) computing mismatch in node power injections, the residuals, b) which are multiplied by the inverse of the jacobian matrix to obtain the node voltage corrections, c) applying the corrections, d) computing new residuals. The process is continued until the problem is solved or the decrease in rate of improvement indicates that jacobian matrix should be re-evaluated at a new operating point.

This thesis uses the SIMPOW program package for load flow analysis of MEA's distribution system 400 V. The SIMPOW program package offers two mathematical methods for load flow calculations one of which is the Newton-Raphson technique. The other one is a predictor-corrector method called Gear's method primarily chosen for the dynamic calculations where the algebraic power flow equations are solved simultaneously with the differential equations of the dynamic simulation.