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Load Flow Analysis on IEEE 30 bus System

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Abstract- Power flow analysis is the backbone of power system analysis and design. They are necessary for planning, operation, economic scheduling and exchange of power between utilities. The principal information of power flow analysis is to find the magnitude and phase angle of voltage at each bus and the real and reactive power flowing in each transmission lines. Power flow analysis is an importance tool involving numerical analysis applied to a power system. In this analysis, iterative techniques are used due to there no known analytical method to solve the problem. To finish this analysis there are methods of mathematical calculations which consist plenty of step depend on the size of system. This process is difficult and takes a lot of times to perform by hand. The objective of this project is to develop a toolbox for power flow analysis that will help the analysis become easier. Power flow analysis software package develops by the author use MATLAB programming

The economic load dispatch plays an important role in the operation of power system, and several models by using different techniques have been used to solve these problems. Several traditional approaches, like lambda-iteration and gradient method are utilized to find out the optimal solution of non-linear problem. More recently, the soft computing techniques have received more attention and were used in a number of successful and practical applications.

Index Terms- Power flow, Gauss-Seidal method, Newton Raphson method, Voltage profile.

I. Introduction

Load flow studies [1]-[2] are used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic. Conventional techniques for solving the load flow problem are iterative, using the Newton-Raphson or the Gauss-Seidel methods [3]-[4]. Load flow analysis forms an essential prerequisite for power system studies. Considerable research has already been carried out in the development of computer programs for load flow analysis of large power systems. However, these general purpose programs may encounter convergence difficulties when a radial distribution system with a large number of buses is to be solved and, hence, development of a special program for radial distribution studies becomes necessary [5]. There are many solution techniques for load flow analysis. The solution procedures and formulations can be precise or approximate, with values adjusted or unadjusted, intended for either on-line or off-line application, and designed for either single-case or multiple-case applications. Since an engineer is always concerned with the cost of products and services, the efficient optimum economic operation and planning of electric power generation system have always occupied an important position in the electric power industry. With large interconnection of the electric networks, the energy crisis in the world and continuous rise in prices, it is very essential to reduce the running charges of the electric energy [6]-[7]. A saving in the operation of the system of a small percent represents a significant reduction in operating cost as well as in the quantities of fuel consumed. The classic problem is the economic load dispatch of generating systems to achieve minimum operating cost.

This problem area has taken a subtle twist as the public has become increasingly concerned with environmental matters, so that economic dispatch now includes the dispatch of systems to minimize pollutants and conserve various forms of fuel, as well as achieve minimum cost [8]. In addition there is a need to expand the limited economic optimization problem to incorporate constraints on system operation to ensure the security of the system, thereby preventing the collapse of the system due to unforeseen conditions [9]. However closely associated with this economic dispatch problem is the problem of the proper commitment of any array of units out of a total array of units to serve the expected load demands in an ‘optimal’ manner [10]. For the purpose of optimum economic operation of this large scale system, modern system theory and optimization techniques are being applied with the expectation of considerable cost savings.

Through the load flow studies we can obtain the voltage magnitudes and angles at each bus in the steady state. This is rather important as the magnitudes of the bus voltages are required to be held within a specified limit. Once the bus voltage magnitudes and their angles are computed using the load flow, the real and reactive power flow through each line can be computed [11]-[12]. Also based on the difference between power flow in the sending and receiving ends, the losses in a particular line can also be computed. Furthermore, from the line flow we can also determine the over and under load conditions. The steady state power and reactive power supplied by a bus in a power network are expressed in terms of nonlinear algebraic equations. We therefore would require iterative methods for solving these equations. In this paper we shall discuss two of the load flow methods.

II. Power Flow Overview

The overall aim of the whole paper is to develop a program that allow user to solve power flow problem. However the other objective that needed to complete are:

- Power flow analysis is very important in planning stages of new networks or addition to existing ones like adding new generator sites, meeting increase load demand and locating new transmission sites.

- The load flow solution gives the nodal voltages and phase angles and hence the power injection at all the buses and power flows through interconnecting power channels.
- It determines the voltage of the buses. The voltage level at the certain buses must be kept within the closed tolerances.
- The line flows can be known. The line should not be overloaded, it means, we should not operate the close to their stability or thermal limits.
- To study the performance of the transmission lines, transformer and generator at steady state condition.
- To write a program for power flow analysis for education and training purposes
- To obtain the simulation of power flow analysis by MATLAB.

III. Power Flow Analysis

The power flow analysis (also known as load-flow study) is an importance tool involving numerical analysis applied to a power system. Unlike traditional circuit analysis, a power flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various form of AC power (i.e: reactive, real and apparent) rather than voltage and current. The advantage in studying power flow analysis is in planning the future expansion of power systems as well as in determining the best operation of existing systems. Power flow analysis is being used for solving power flow problem by Newton-Raphson method and Gauss Seidel method. This sub-chapter will discuss all two methods generally on formula or mathematical step in order to solve power flow problem.

3.1 Bus Classification

A bus is a node at which one or many lines, one or many loads and generators are connected. In a power system each node or bus is associated with 4 quantities, such as magnitude of voltage, phage angle of voltage, active or true power and reactive power in load flow problem two out of these 4 quantities are specified and remaining 2 are required to be determined through the solution of equation. Depending on the quantities that have been specified, the buses are classified into 3 categories. For load flow studies it is assumed that the loads are constant and they are defined by their real and reactive power consumption. The main objective of the load flow is to find the voltage magnitude of each bus and its angle when the powers generated and loads are pre-specified. To facilitate this we classify the different buses of the power system shown in the chart below.

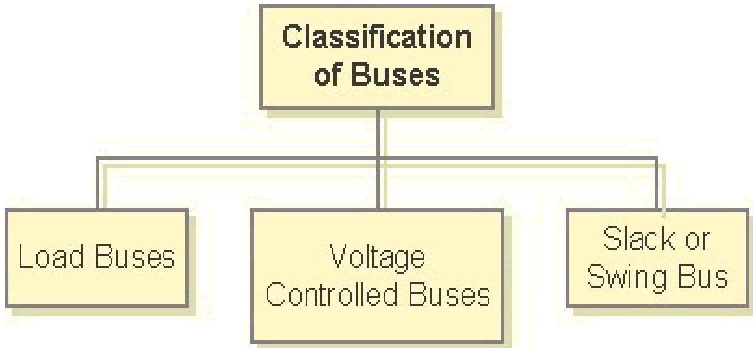

Fig. 1 Classification of buses.

Load Buses: In these buses no generators are connected and hence the generated real power P_{Gi} and reactive power Q_{Gi} are taken as zero. The load drawn by these buses are defined by real power $-P_{Li}$ and reactive power $-Q_{Li}$ in which the negative sign accommodates for the power flowing out of the bus. This is why these buses are sometimes referred to as P-Q bus. The objective of the load flow is to find the bus voltage magnitude $|V_i|$ and its angle δ_i.

Voltage Controlled Buses: These are the buses where generators are connected. Therefore the power generation in such buses is controlled through a prime mover while the terminal voltage is controlled through the generator excitation. Keeping the input power constant through turbine-governor control and keeping the bus voltage constant using automatic voltage regulator, we can specify constant P_{Gi} and $| V_i |$ for these buses.

Slack or Swing Bus: Usually this bus is numbered 1 for the load flow studies. This bus sets the angular reference for all the other buses. Since it is the angle difference between two voltage sources that dictates the real and reactive power flow between them, the particular angle of the slack bus is not important. However it sets the reference against which angles of all the other bus voltages are measured. For this reason the angle of this bus is usually chosen as 0°. Furthermore it is assumed that the magnitude of the voltage of this bus is known.

3.2 Bus Admittance Matrix

1. The first step is to number all the nodes of the system from 0 to n . Node 0 is the reference node (or ground node).

2.Rreplace all generators by equivalent current sources in parallel with an admittance.

3. Replace all lines, transformers, loads to equivalent admittances whenever possible.

4. The bus admittance matrix Y is then formed by inspection as follows (this is similar to what we learned in circuit theory): sum of admittances connected to node $iiy = i$ and $yij = y$ ji = -sum of admittances connected from node i to node j

5. The current vector is next found from the sources connected to nodes 0 to n . If no source is connected, the injected current would be 0.

6. The equations which result are called the node-voltage equations and are given the "bus" subscript in power studies thus: bus bus bus I = Y V.

IV. LOAD FLOW SOLUTION

In Power System Engineering, the load flow study (also known as power flow study) is an important tool involving numerical analysis applied to a power system. Unlike traditional circuit analysis , a power flow study uses simplified notation such as a one line diagram and per unit system , and focuses on various forms of AC power (i.e. reactive ,real and apparent) rather than voltage and current. It analyses the power systems in normal steady state operation. There exist a number of software implementations of power flow studies.

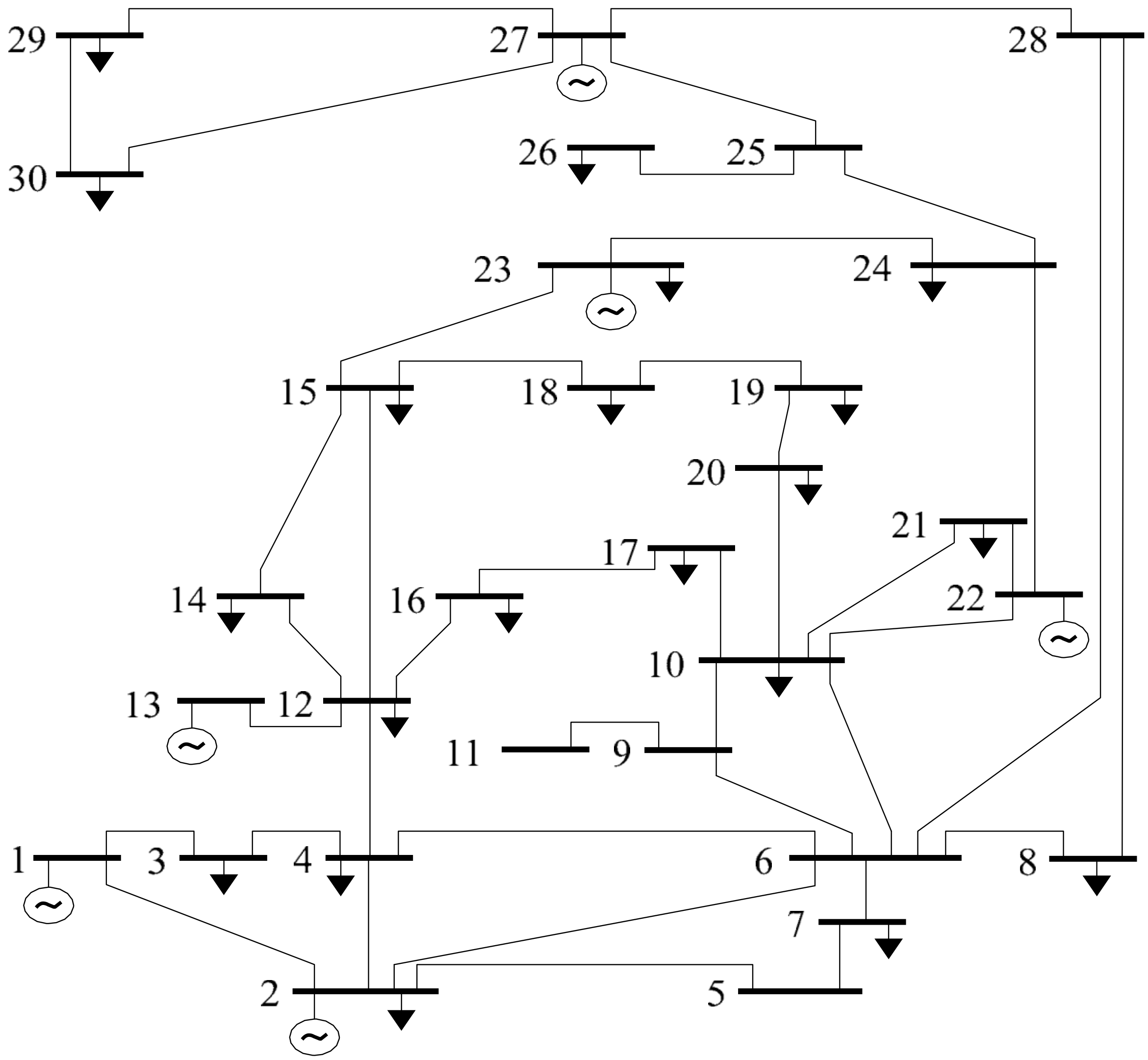

Fig. 4.1 One line diagram of IEEE 30 bus system

4.1 Gauss- Seidel method

In this method of solving for power system analysis, the equation S=VI* is used where S=P+jQ and hence the equation becomes

P + jQ = VI* **(1)**

P – jQ =V*I **(2)**

From the above equation we can deduce that the current I is given by

I=(P-jQ)/V* **(3)**

But we also know that

I=YV **(4)**

Now the voltages of the buses are calculated from the equation summarized as

VY=(P-jQ)/V* **(5)**

where after each iteration the voltages are replaced in the next iteration.

The slack bus where V is known the voltage equation for that bus is not formulated. For the P-Q buses the voltage magnitudes and angles are obtained directly from the power flow equations. But for the P-V buses where we know the magnitude of the voltage of those buses, the voltages are calculated in the following way

$$\mathbf{V_{new}=V_{old}\,.angle(V_{new})} \qquad \textbf{(6)}$$

Hence, the voltages of the buses are calculated and the error of their values with the old values are calculated and checked with the tolerance value to decide whether iteration would be needed or not.

4.2 Newton-Raphson Method

The Newton-Raphson method is widely used for solving non-linear equations. It transforms the original non-linear problem into a sequence of linear problems whose solutions approach the solutions of the original problem.

Let G=F(x,y) be an equation where the variables x and y are the function of arguments of F. G is a specified quantity. If F is non-linear in nature there may not be a direct solution to get the values of x and y for a particular value of G. in such cases, we take an initial estimate of x and y and iteratively solve for the real values of x and y until the difference is the specified value of G and the calculated value of F(using the estimates of x and y) i.e. ΔF is less than a tolerance value. The procedure is as follows Let the initial estimate of x and y be x^0 and y^0 respectively

Using Taylor series

$$G = F(x^0, y^0) + \left|\frac{\partial F}{\partial x}\right|_{x0,y0} . \Delta x + \frac{\partial F}{\partial y}_{x0,y0} . \Delta y \qquad \textbf{(7)}$$

Where $\frac{\partial F}{\partial x}$ and $\frac{\delta F}{\delta y}$ are calculated at x^0 and y^0

$$G - F(x^0, y^0) = \Delta F = \frac{\partial F}{\partial x} . \Delta x + \frac{\delta F}{\delta y} . \Delta y \qquad (8)$$

In the matrix form it can be written as

$$(\Delta F) = \begin{pmatrix} \frac{\partial F}{\partial x} & \frac{\partial F}{\partial y} \end{pmatrix} \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix} \qquad (9)$$

Or

$$\begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix} = inv\left(\begin{pmatrix} \frac{\partial F}{\partial x} & \frac{\partial F}{\partial y} \end{pmatrix}\right) (\Delta F) \qquad (10)$$

After the first iteration x is updated to $x^1 = x^0 + \Delta x$ and y to $y^1 = y^0 + \Delta y$. The procedure is continued till after some iteration both ΔF is less than some tolerance value ε. The values of x and y after the final update at the last iteration is considered as the solution of the function F.

For the load flow solution , the non-linear equations are given by equation (9). There will be 2n – 2 – p such equations, with n being the total number of buses and p the number of PV and generator buses.

Equation (11) can be replaced as

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = \begin{pmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial |V|} \end{pmatrix} \begin{pmatrix} \Delta \delta \\ \Delta |V| \end{pmatrix} \qquad (11)$$

or

$$\begin{pmatrix} \Delta \delta \\ \Delta |V| \end{pmatrix} = inv \begin{pmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial |V|} \end{pmatrix} \begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} \qquad (12)$$

The matrix of equation (14) consisting of the partial differentials, is known as the Jacobian matrix and is very often denoted as J.ΔP is the difference between the specifies value of $P(P^{sp})$ and the calculated value of P using the estimates of δ and |V| in a previous iteration. We calculate ΔQ similarly.

The Newton power flow is the most robust power flow algorithm used in practice. However, one drawback to its use is the fact that the terms in the Jacobian matrix must be recalculated each iteration, and then the entire set of linear equations in equation (14) must also be resolved each iteration. Since thousands of complete power flow are often run for planning or operations study, ways to speed up this process were devised.

4.3 Compare G-S method and N-R methods of load flow solutions.

G-S method	N-R method
1. The variables are expressed in rectangular co-ordinates.	1. The variables are expressed in polar coordinates.
2. Computation time per iteration is less.	2. Computation time per iteration is more
3. It has linear convergence characteristics.	3. It has quadratic convergence characteristics.
4. The number of iterations required for convergence increase with size of the system.	4.The number of iterations are independent of the size of the system.
5.The choice of slack bus is critical.	5. The choice of slack bus is arbitrary.

5

V. Test Result

Load flow analysis is carried out in IEEE 30 bus test system. Output Voltage magnitude and Voltage Angle values from Gauss-Seidal method for IEEE 30 bus system. All datas are in per unit. Angle is given in radian

Voltage:
abs(V)=

Columns 1 through 10
1.0000 1.0038 1.0001 1.0039 1.0018 1.0088 0.9942 1.0031 1.0195 1.0048
Columns 11 through 20
1.0647 1.0182 1.0532 0.9926 0.9966 0.9967 0.9945 0.9980 0.9964 0.9991
Columns 21 through 30
0.9965 1.0000 0.9963 0.9937 1.0000 0.9824 1.0102 1.0011 0.9953 0.9809

Angle:
d=
Columns 1 through 10
0 0.0124 -0.0004 -0.0009 -0.0502 -0.0001 -0.0089 0.0015 0 0.0007
Columns 11 through 20
0.0350 0.0024 0.0225 -0.0060 -0.0031 -0.0026 -0.0040 -0.0022 -0.0035 -0.0010
Columns 21 through 30
-0.0022 0.0000 -0.0028 -0.0021 0.0000 -0.0076 0.0039 -0.0012 -0.0042 -0.0253

Output Voltage magnitude and Voltage Angle values from Newton-Raphson method for IEEE 30 bus system. Angle is given in radian.

Voltage:
abs(V)
Columns 1 through 10
1.0500 1.0438 1.0483 1.0468 1.0232 1.0446 1.0283 1.0470 1.0768 1.0736
Columns 11 through 20
1.1328 1.0782 1.1251 1.0648 1.0614 1.0692 1.0671 1.0539 1.0525 1.0570
Columns 21 through 30
1.0618 1.0624 1.0537 1.0517 1.0534 1.0364 1.0628 1.0411 1.0438 1.0328

Angle:
d=
Columns 1 through 10
0 -0.0502 -0.0850 -0.1019 -0.1578 -0.1174 -0.1429 -0.1177 -0.1450 -0.1761
Columns 11 through 20
-0.1144 -0.1626 -0.1431 -0.1776 -0.1797 -0.1729 -0.1786 -0.1900 -0.1929 -0.1896
Columns 21 through 30
-0.1838 -0.1837 -0.1872 -0.1915 -0.1898 -0.1966 -0.1844 -0.1243 -0.2043 -0.2185

VI. Conclusion

Power flow or load-flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing systems. The principal information obtained from the power flow study is the magnitude and phase angle of the voltage at each bus, and the real and reactive power flowing in each line.

We have formulated the algorithm and designed the MATLAB programs for bus admittance matrix, converting polar form to rectangular form, Gauss-Siedel method and Newton Raphson method for analyzing the load flow of the IEEE-30 bus systems. The Voltage magnitude and angles of a 30 bus system were observed for different values of Reactance loading and the findings have been presented. From the findings, it is concluded that increasing the reactance loading resulted in an increased voltage regulation. Gauss-Siedel has simple calculations and is easy to execute, but as the number of buses increase, number of iterations increases. On the other hand, in Newton-Rahpson method, the calculations are complex, but the number of iterations is low even when the number of buses is high.

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