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Identification of Best Load Flow Calculation Method for IEEE-30 BUS System Using MATLAB

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Abstract: **This paper presents the load flow calculation of the power system for IEEE-5 and IEEE-30 bus system. The Load flow calculation is the backbone of power system analysis and design. They are essential for planning, operation, economic scheduling and exchange of power among utilities. The primary information of load flow calculation is to determine the voltage magnitude and phase angle at each bus in the system in addition with real power and reactive power flow in each transmission lines. In this analysis, iterative schemes are used due to there no known analytical scheme 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 programming in MATLAB SOFTWARE for load flow analysis that will help the analysis become easier.**

Keywords: **Power flow, Bus Classification, Load flow calculation (LFC), Gauss Siedel (GS) method, Newton Raphson (NR) method, Voltage profile.**

I. INTRODUCTION

Load flow studies are used to make certain that electrical power transfer from generators to consumers through the power system is stable, reliable and economic [1]-[3]. Conventional techniques for solving the load flow problem are iterative, using the Gauss Seidel method and Newton Raphson method [4]-[5]. Load flow analysis forms an essential requirement for system studies. Many researchers have already been carried out in the development of computer programs for load flow calculation 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 [6].

Moreover, Load flow calculations also provide power flows and voltages for a specified power system subject to the regulating capabilities of generation, and tap changing under load transformers as well as specified net interchange between individual operating systems [7]. This information is essential for the continuous evaluation of the present performance of a power system and for the analyzing the effectiveness of alternative plans for system expansion to meet increased load demand. This analysis requires the calculation of numerous load flows for both normal and emergency operating conditions. The load flow problem consists of the calculation of power flows and voltages of a network for specified terminal or bus conditions. A single phase representation is sufficient since bus systems are usually associated with four quantities real and reactive power, voltage magnitude, and phase angles. In load flow calculation three types of buses are represented and at a bus; two of the quantities are specified. It is necessary to select one bus, called the swing bus, to provide the additional real and reactive power to supply the transmission losses, since these are unknown until the final solution is obtained. At this bus the voltage magnitude and phase angles are specified. The remaining buses of the power system are designated either as generator bus or load buses [8]-[9]. The real and reactive powers are specified at a load bus. Network connections are described by using code numbers assigned to each bus. These numbers specify the terminals of transmission lines and transformers code numbers are used also to identify the types of buses. The two primary considerations in the development of an effective engineering computer program are firstly the formulation of a mathematical description of the problem and secondly the application of a numerical method for a solution.

Thus, through the load flow studies we can obtain the voltage magnitudes and phase 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 [10]-[11]. 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. There are many solution techniques for load flow analysis. In this paper we shall discuss two of the load flow methods.

II. OBJECTIVE OF LOAD FLOW CALCULATION

The overall aim of the whole paper is to develop a program that allow user to easily solve power flow problem. However the other important objectives for the need of load flow are

1. Load flow studies have a vital role in scheduling of recent network or accumulation of existing networks by addition of innovative generators sites, meeting load demand and locating of new sites for transmission.
2. The estimation of LF provides voltage and angle, injected power in the system and power flows through the interconnecting paths.
3. For determining most favourable position in addition to optimal capacity of the generating system, lines and substation it is very beneficial.
4. The bus voltage is determined and also level of voltage at several buses kept within closed tolerances.
5. Reduction of losses in transmission system.
6. Economic operation w.r.t to cost of fuel to generate the needed power.
7. For analysing the functioning of lines in the system, transformer and generator at steady state conditions.

III. BUS CLASSIFICATION

A node at which 1 line or several lines, single or many loads and generators are linked is known as a bus. All buses in the system are related with several quantities that are Voltage (V), Phase angle (δ),Real power (P) and Reactive power (Q).In any problem from the above 4 quantities, two quantities are known and the other two remain quantities are calculated all the way through the solution of equation. The quantities which are given based upon those buses in the system are sorting into 3 categories. Whereas in load flow studies it is presumed that load are constant and defined by their power consumption. The major purpose of the LFC is to calculate buses voltage in the system and its angle while the power generated and the load are prespecified. The different buses classification in the system are given in Figure 1

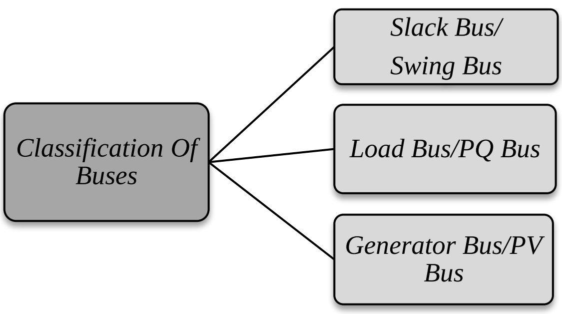

Fig.1 Classification of Buses

1. **Swing Bus/ Slack Bus / Reference Bus**: Mostly slack bus is considered as numbered one bus for load flow studies of the system. As this bus set the angular references for the buses in the system hence it’s also know reference bus. Here the angle of the reference bus set to be 0°. The voltage |V| and δ of the slack bus are known. Whereas the real (P_G) and reactive (Q_G) power are obtained by load flow solutions.

2. **Load bus / PQ bus** This bus is known as the Load bus as generator is not coupled in the bus; hence the value of power generated P_{Gi} and Q_{Gi} taken as zero. Whereas, the load taken by these type of buses are $-P_{Li}$ and $-Q_{Li}$ power, the minus sign shows that power flow outside from the bus, it can be allow to vary with in permitted values. That is why this bus is referred to PQ bus. Therefore it only needs to calculate magnitude of voltage and phase angle by load flow calculation.

3. **Generator bus / PV bus** The buses at which generator are connected are known as generator bus and power generation in such buses is managed due to prime mover. The voltage at the terminal is maintained due to excitation of the generator. By the means of turbine governor control the input power is kept constant. Similarly by using the automatic voltage regulator V is kept stable. Moreover, |V| consequent to generator voltage and P_{Gi} corresponding to its value are known at this bus. Hence the load flow solution is required to calculate phase angle of bus voltage δ and the reactive power generation Q_{Gi}.The classification of buses described brief in Table I

Table I: Variables and Bus Classification

Bus type	Defined	To Defined	Application
1.Slack bus	|V| and delta δ	P and Q	Power system has only one bus of this type and usually this is numbered as one
2.PQ bus	P and Q	|V| and Delta δ	It is pure load bus and most common bus comprising almost 80% of all of the buses in power system
3.PV bus	P and V	Q and Delta δ	Comprise about 10% of all the buses.

IV. LOAD FLOW SOLUTION METHODS

The Load Flow Study which is also known as Power Flow Study, is an important tool concerning numerical analysis applied to a power system. Contrasting traditional circuit analysis, a load flow study usually uses basic notation such as single line diagram and p.u system, and focuses on reactive, real and apparent power rather than voltage and current. . It analyses the power systems in normal steady state operation. In view point of mathematical modelling, load flow solution consist the set algebraic equation which are non linear that illustrate the system. Over the time intervals certain techniques have been recognized in favour of solving the equation of LF. There exist a number of software implementations of power flow studies. The single line representation of IEEE 5 bus system is shown in Figure 2

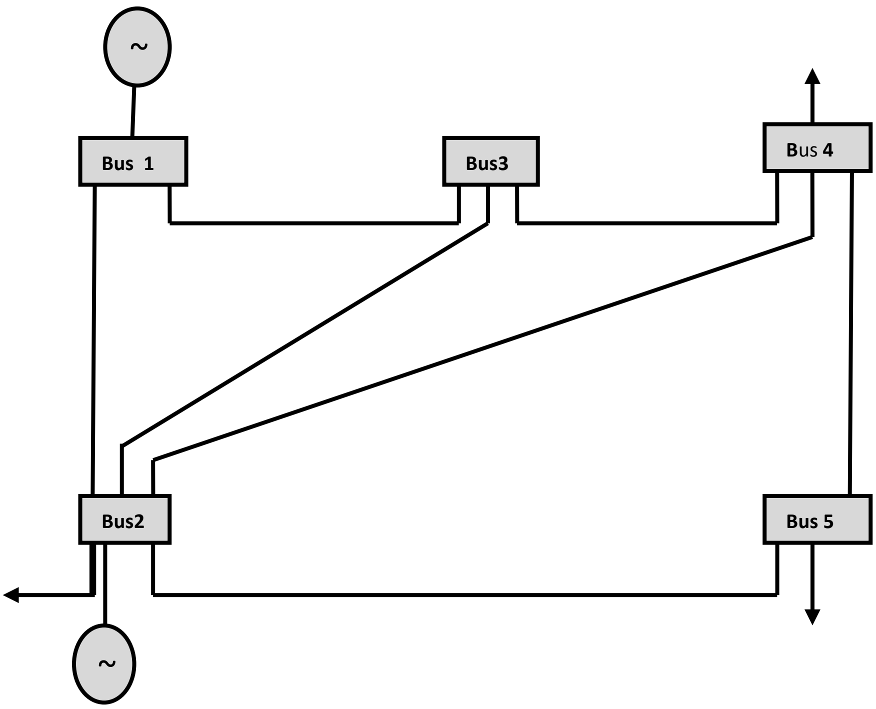

Fig. 2 Single Line Diagram of IEEE 5 Bus System

A. Gauss Seidel Method:

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

$$\mathrm{I} = \left(\frac{P-jQ}{V^*}\right) \quad (3)$$

However we also know that $I = YV$ (4)

Now the voltages of the buses are calculated from the equation summarized as below where after each iteration the voltages are replaced in the next iteration

$$VY = \left(\frac{P-jQ}{V^*}\right) \quad (5)$$

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

$$V_{new} = V_{old}.angleV_{new} \quad (6)$$

Hence the bus voltages 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.

B. Newton-Raphson Method:

The NR 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**.** In large scale load flow analysis by the NR method has proved most successful owing to its strong convergence characteristics. The Newton Raphson algorithm is expressed by

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \theta} & V\frac{\partial P}{\partial V} \\ \frac{\partial Q}{\partial \theta} & V\frac{\partial Q}{\partial V} \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \frac{\Delta V}{\mathrm{V}} \end{bmatrix} \quad (7)$$

Where ΔP is the active power and ΔQ is the reactive power mismatches, V and θ are the magnitude of bus voltage magnitude and phase angle of bus voltage respectively. The power flow equation for a generic i^{th} bus of the power system is given by equation (2) and (3). Considered the first element connected between busses i and j in Figure 3, for which self and mutual jacobian terms are calculated by taking the derivates of equation (8) and (9)

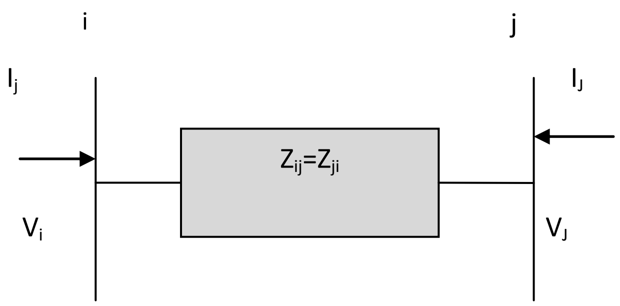

Fig.3 Equivalent Impedance

$$P_i^{cal} = \sum_{j=1}^{N} V_i V_j \left(G_{ij} \cos(\theta_i - \theta_j) + B_{ij} \sin(\theta_i - \theta_j)\right) \quad (8)$$

$$Q_i^{cal} = \sum_{j=1}^{N} V_i V_j \left(G_{ij} \sin(\theta_i - \theta_j) - B_{ij} \cos(\theta_i - \theta_j)\right) \quad (9)$$

The NR method 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 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.

Table II: Comparison of Load Flow Calculation Techniques

	Parameters Of Comparison	*Gauss Siedel Method*	*Newton Raphson Method*
1.	*Coordinate*	Works well with rectangular coordinates	Polar coordinates preferred as rectangular coordinate occupies more memory
2.	*Arithmetic operation*	Less in no. to complete one iteration	Elements of jocobian to be calculated in each iteration
3.	*Time*	Less time per iteration but increases with the number of buses	Time per iteration is 7 times of GS and increases with number of buses
4.	*Convergence*	Linear convergence	Quadratic convergence
5.	*Number of iteration*	Large number, increases with the number of buses	Very less for large system and is practically constant
6.	*Accuracy*	Less accurate	More accurate
7.	*Memory*	Less memory because of sparsity of matrix	Large memory even with compact storage scheme
8.	*Usage*	Small size system	Large system, ill conditioned problem, optimal load flow studies
9.	*Programming*	Easy	Very complex
10.	*Reliability*	Reliable only for small system	Reliable for huge system

V. RESULT

Load flow calculation is taken out for IEEE 5 and IEEE 30 bus system. The magnitude of bus voltage and its phase angle from Gauss-Seidel method and Newton Raphson method for IEEE 5 bus system are shown in Table III and for IEEE 30 bus system are shown in Table IV. All data's are in per unit (p.u) and the angle is given in degree.

Table III: Bus Voltage and Angle for IEEE 5 Bus System

Bus No.	*Gauss Seidel Method*		*Newton Raphson Method*	
	Voltage V (p.u)	*Angle (Degree)*	*Voltage V (p.u)*	*Angle (Degree)*
1	1.06000	0.00000	1.06000	0.0000
2	1.05233	-0.52926	1.05000	-0.48981
3	1.02910	-3.19543	1.02730	-3.17776
4	1.02881	-3.38108	1.02688	-3.36193
5	1.02602	-3.52255	1.02377	-3.49859

Table IV: Bus Voltage and angle for IEEE 30 Bus System

Bus No.	*Gauss Seidel Method*		*Newton Raphson Method*	
	Voltage V (p.u)	*Angle (Degree)*	*Voltage V (p.u)*	*Angle (Degree)*
1	1.0600	0	1.0600	0
2	1.0400	-5.6141	1.0400	-5.6363
3	1.0191	-8.0036	1.0173	-8.0043
4	1.0101	-9.8810	1.0079	-9.8834
5	1.0100	-14.6667	1.0100	-14.7134
6	1.0090	-11.7311	1.0075	-11.7643
7	1.0015	-13.4651	1.0006	-13.5046
8	1.0100	-12.5222	1.0100	-12.5837
9	1.0424	-15.0666	1.0363	-15.1598
10	1.0252	-16.8436	1.0180	-16.9761
11	1.0883	-15.0665	1.0800	-15.1598
12	1.0596	-16.1519	1.0477	-16.1874
13	1.0904	-16.1519	1.0700	-16.1874
14	1.0409	-17.0761	1.0298	-17.1391
15	1.0324	-17.1187	1.0220	-17.2091
16	1.0377	-16.7031	1.0277	-16.7893
17	1.0236	-17.0100	1.0155	-17.1333
18	1.0175	-17.7272	1.0082	-17.8501
19	1.0119	-17.8953	1.0032	-18.0318
20	1.0144	-17.6896	1.0061	-17.8264
21	1.0112	-17.5168	1.0034	-17.6540
22	1.0134	-17.4188	1.0063	-17.5571
23	1.0116	-17.5433	1.0036	-17.6771
24	0.9969	-18.0677	0.9900	-18.2121
25	1.0001	-17.8125	0.9952	-17.9551
26	0.9821	-18.2476	0.9772	-18.3945
27	1.0120	-17.2624	1.0084	-17.3959
28	1.0065	-12.4912	1.0050	-12.5356
29	0.9882	-18.8828	0.9845	-19.0289
30	0.9760	-19.8506	0.9723	-20.0036

VI. CONCLUSION

Load flow calculation is important for planning future expansion of power systems as well as in determining the best operation of existing systems. The major information obtained from the LFC is the bus voltage magnitude and phase angle at different buses also real and reactive power flow in each line. We have formulated the programming in MATLAB software for Y bus matrix, converting polar form to rectangular form, GS method and NR method for analyzing the load flow of the IEEE 5 and IEEE 30 bus systems. The magnitude and phase angles of IEEE 5 and IEEE 30 bus system were observed, it is concluded though GS has simple calculations and is easy to execute, but as the number of buses increase, number of iterations increases. On the other hand, in NR method, the calculations are complex, but the number of iterations is low even when the number of buses is high.

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