

# Optimal Load Flow Analysis in Interconnected Network using MATLAB

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**Abstract-** Load flow analysis is the basis of power system planning design and operation. The main objective of this paper is to present an optimal load flow method to solve the Interconnected Distribution System... The load flow test case problem has been successfully solved for interconnected distribution systems with different methods like Newton-Raphson, Gauss-Seidel and Fast-Decoupled. The comparison of results for the test case of IEEE 30 bus network clearly shows that the Newton-Raphson method is indeed capable of obtaining optimum solution efficiently for Load flow problems. The power loss has also been reduced on getting the solution and implementation of remedial actions through MATLAB programming.

**Keywords-** Load flow, Newton-Raphson, Gauss-Seidel, Fast-decoupled method, MATLAB, Interconnected system

## I. INTRODUCTION

The history of civilization shows a close relationship between the consumption of energy and progress of mankind. The per capita electricity consumption shows a measure of prosperity and progress of any country. Energy consciousness in the people has created an interest in them to tap new sources of energy from time to time.

Amongst the various forms of energy, electricity has played a very vital role for a devolved country. To fetch the electricity as per the requirement of various categories of users a huge interconnected network is required. Therefore a number of studies need to be conducted on the system for its operation control. Power system network is the biggest man made system in the world. This network is very vast and it is very difficult to understand its behavior. For getting values of system parameters, a deep study of this system network is required. A system may be under steady state or transient state. When a power system is in operation, it frequently switches over from one state to another. Therefore the system conditions need to be analyzed under both the conditions for better operation and control.

The study can be covered in to three stages:

Network modeling, Mathematical modeling and Solution

In the network modeling stage, the equipments are represented as an equivalent electrical circuit component.

In mathematical modeling stage, with the help of applicable laws, the network model is converted in to mathematical model as algebraic equations in study state and differential equations are developed in dynamical studies. Solution of the equations is obtained through Matlab programming.

Depending upon the type of algebraic equations developed in the study, numerical methods are selected to solve them. The solution of mathematical expressions gives the parametric values which are helpful to decide whether the system is stable or unstable, controllable or uncontrollable.

The energy is produced at the locations where necessary raw material is available economically and safely i.e. pithead power station. This resulted in evolution of large central energy generating station with elaborate transmission and distribution systems. Due to large energy requirements an interconnected power systems are preferred over isolated power system.

An interconnected system gives better handling of load and operation is economical as compared to the isolated system with given security and reliability constraints.

## II. LOAD FLOW ANALYSIS

One of the most common computational procedures used in power system analysis is the load flow calculation.

Load flow studies determine the voltage, current, active, and reactive power, power factor and power loss in the system. Load flow studies are an excellent tool for system planning. A number of operating stages can be analyzed, including contingency conditions, such as the loss of a generator, a transmission line, a transformer, or a load and also to determine the size and location of capacitors for power factor improvement.

Following three methods are mostly used for the solution of a Load Flow Problem.

- Newton-Raphson method (N-R)
- Fast-decoupled Power Flow method and
- Gauss-Seidel method (G-S)

## III. LOAD FLOW EQUATION

For the formulation of the active and reactive power entering a bus, we need to define the following quantities. Let the voltage at the  $i^{\text{th}}$  bus be denoted by

$$V_i = |V_i| \angle \delta_i = |V_i| (\cos \delta_i + j \sin \delta_i) \quad \dots (1)$$

Self admittance at bus-i as

$$Y_{ii} = |Y_{ii}| \angle \theta_{ii} = |Y_{ii}| (\cos \theta_{ii} + j \sin \theta_{ii}) = G_{ii} + jB_{ii} \quad \dots (2)$$

Mutual admittance between the buses i and j can be written as

$$Y_{ij} = |Y_{ij}| \angle \theta_{ij} = |Y_{ij}| (\cos \theta_{ij} + j \sin \theta_{ij}) = G_{ij} + jB_{ij}$$

..(3)

Let the power system contains a total number of n buses. The injected current at bus-i is given as

$$I_i = Y_{i1}V_1 + Y_{i2}V_2 + \dots + Y_{in}V_n$$

$$= \sum_{k=1}^n Y_{ik}V_k \quad .. (4)$$

The complex power at bus-i

$$P_i - jQ_i = V_i^* I_i = V_i^* \sum_{k=1}^n Y_{ik}V_k$$

$$= |V_i| \left[ (\cos \delta_i - j \sin \delta_i) \sum_{k=1}^n [Y_{ik}V_k] (\cos \theta_{ik} + j \sin \theta_{ik}) (\cos \delta_k + j \sin \delta_k) \right]$$

$$= \sum_{k=1}^n [Y_{ik}V_iV_k] (\cos \delta_i - j \sin \delta_i) (\cos \theta_{ik} + j \sin \theta_{ik}) (\cos \delta_k + j \sin \delta_k) \quad (5)$$

Note that

$$(\cos \delta_i - j \sin \delta_i) (\cos \theta_{ik} + j \sin \theta_{ik}) (\cos \delta_k + j \sin \delta_k)$$

$$= (\cos \delta_i - j \sin \delta_i) [\cos(\theta_{ik} + \delta_k) + j \sin(\theta_{ik} + \delta_k)]$$

$$= \cos(\theta_{ik} + \delta_k - \delta_i) + j \sin(\theta_{ik} + \delta_k - \delta_i)$$

Therefore substituting in (5) we get,

$$P_i = \sum_{k=1}^n |Y_{ik}V_iV_k| \cos(\theta_{ik} + \delta_k - \delta_i) \quad (6)$$

$$Q_i = - \sum_{k=1}^n |Y_{ik}V_iV_k| \sin(\theta_{ik} + \delta_k - \delta_i) \quad (7)$$

This is load flow equation.

Then the total real power injected in bus-i is

$$P_{i,inj} = P_{Gi} - P_{Li} \quad (8)$$

Let the injected power calculated by the load flow program be  $P_{i,calc}$ . Then the mismatch

$$\Delta P_i = P_{i,inj} - P_{i,calc} = P_{Gi} - P_{Li} - P_{i,calc} \quad (9)$$

Similarly, the mismatch between the reactive power and calculated values is given by

$$\Delta Q_i = Q_{i,inj} - Q_{i,calc} = Q_{Gi} - Q_{Li} - Q_{i,calc} \quad (10)$$

The purpose of the load flow is to minimize the above two mismatches. It is to be noted that (6) and (7) are used for the calculation of real and reactive power in (9 to 10).

#### IV TECHNICAL SOLUTION

Because of the nonlinearity and the difficulty involved in the analytical expressions for the above power flow equations, numerical iterative techniques are applied such as:

##### A Gauss-Seidel Method

The Gauss-Seidel Method is another iterative technique for solving the load flow problem, by successive estimation of the node voltages.

The steps of a computational algorithm are given below:

Step-1: With the load profile known at each bus i.e.  $P_D$ ,  $Q_D$  are known, allocate  $P_{ca}$  and  $Q_{ca}$  to all generating stations.

Step-2: Assembly of bus admittance matrix  $Y_{BUS}$  with the line and shunt admittance data stored in the computer,  $Y_{BUS}$  is assembled by using the rule for self and mutual admittances.

Step-3: Iterative computation of bus voltages ( $V_{ij} = 2, 3, \dots, n$ ): to start the iterations a set of initial voltage values is assumed.

Step-4: Computation of slack bus power: substitution of all bus voltages computed in step 3 along with  $V_i$  yields  $S^* = P - jQ$ .

Step-5: Computation of line flows and line losses: this is the last step in the load flow analysis wherein the power flows on the various lines of the network are computed. Consider the lines connecting buses i and k.

##### B Newton-Raphson Method

The first method (G-S) is simpler but the second (NR) is reported to have better convergence characteristics and is faster than (G-S) method.

The Newton-Raphson procedure is as follows:

Step1: Choose the initial values of the voltage magnitudes  $|V|^{(0)}$  of all  $n_p$  load buses and  $n - 1$  angles  $\delta^{(k)}$  of the voltages of all the buses except the slack bus.

Step-2: Use the estimated  $|V|^{(k)}$  and  $\delta^{(k)}$  to calculate a total  $n - 1$  number of injected real power  $P_{calc}^{(k)}$  and equal number of real power mismatch  $\Delta P^{(k)}$ .

Step-3: Use the estimated  $|V|^{(k)}$  and  $\delta^{(k)}$  to calculate a total  $n_p$  number of injected reactive power  $Q_{calc}^{(k)}$  and equal number of reactive power mismatch  $\Delta Q^{(k)}$ .

Step-3: Use the estimated  $|V|^{(k)}$  and  $\delta^{(k)}$  to formulate the Jacobian matrix  $J^{(k)}$ .

$$\text{Step-4: Solve } J \begin{bmatrix} \Delta \delta_2 \\ \vdots \\ \Delta \delta_n \\ \frac{\Delta |V_2|}{|V_2|} \\ \vdots \\ \frac{\Delta |V_{1+n_p}|}{|V_{1+n_p}|} \end{bmatrix} = \begin{bmatrix} \Delta P_2 \\ \vdots \\ \Delta P_n \\ \Delta Q_2 \\ \vdots \\ \Delta Q_{1+n_p} \end{bmatrix} \text{ for } \Delta \delta^{(k)} \text{ and}$$

$\Delta |V|^{(k)} \pm |V|^{(k)}$ .

Step-5: Obtain the updates from

$$\delta^{(1)} = \delta^{(0)} + \Delta \delta^{(0)} \quad (11)$$

$$|V|^{(k+1)} = |V|^{(k)} \left[ 1 + \frac{\Delta |V|^{(k)}}{|V|^{(k)}} \right] \quad (12)$$

Step-6: Check if all the mismatches are below a small number. Terminate the process if yes. Otherwise go back to step-1 to start the next iteration with the updates given by (11) and (12).

### C. Fast-Decoupled Load Flow method:

#### Power-flow Programming Steps

Step 1: Input raw data: Input the electrical grid data in the standard data structure and estimate start points of the remaining undefined bus magnitude and phase angle.

Step 2: Data regeneration: Line data and bus data are specified to change along with bus numbers simultaneously.

Step 3: Evaluate  $Y_{bus}$ : Evaluate bus admittance matrix.

Step 4: Evaluate power mismatch: Evaluate  $\Delta P_i$  and  $\Delta Q_i$  respectively from real power mismatch equation (9) and (10).

Step 5: Evaluate Jacobian elements.

Step 6: Evaluate increments. Evaluate increments of bus voltage magnitude  $\Delta V$  and increments of bus angle degree  $\Delta \delta$  by power flow matrix with Gauss Elimination method.

Step 7: Update variables. Update new bus voltage magnitude and new bus phase angle by using equations as follows. And then returns to Step5 with new values to replace the precious values.

$$V^{(k+1)} = V^k + \Delta V^k \quad (13)$$

$$\theta^{(k+1)} = \theta^{(k)} + \Delta \theta^{(k)} \quad (14)$$

Step 8: Examine reactive power of each PV Bus.

Step 9: Termination conditions. The process is continued until the residuals  $\Delta P^{(k)}$  and  $\Delta Q^{(k)}$  are less than tolerance accuracy as follows.

$$\begin{aligned} \text{Max}|\Delta P^{(k)}| &< \epsilon \\ \text{Max}|\Delta Q^{(k)}| &< \epsilon \end{aligned}$$

Note the  $\epsilon$  are the small positive constant, such as 0.001, 0.00001, and the smaller numbers are pretty more accurate.

Step 10: Evaluate power of the swing bus and each PV bus: Evaluate reactive power of each PV bus and evaluate active power and reactive power of the swing bus eq.

Step 11: Reconfigure bus numbers: Return each bus number to the original bus number in the bus data matrix and the line data matrix.

Step 12: Evaluate line flow and loss: Evaluate real and reactive power flows in transmission lines and transformers, as well as equipment losses.

## V. OPTIMAL POWER FLOW PROBLEMS-SOLUTION TECHNIQUES:

### A. Problem – I (IEEE – 30 bus system)

One case is to make use of it to gives the optimal solution of load flow techniques on the IEEE- 30 bus test system. The case study is evaluating various analytical methods and computer program for the solution by Gauss-seidel, Newton-Raphson and Fast Decouple load flow method. Bus 1 is taken as a slack bus with its voltage adjusted to  $1.06 \angle 0^\circ$  pu. The data for the voltage controlled buses are given in Appendix-I and II.

### B. Test Results

Load flow analysis is carried out in IEEE 30 bus test system. Output Voltage magnitude and Voltage Angle Load Bus active and reactive power, generation bus active and reactive bus and line losses values from N-R, G-S and FDLF.

TABLE-1  
IEEE-30 Bus Data comparison of different load flow methods

Bus Status				
S. No.	Data	N-R	G-S	Fast Decoupled
1	Iteration	4	83	15
2	Error	1.2e-005	0.000951	0.0009195
3	Total Load Bus active power in MW	283.400	283.400	283.400
4	Total Load Bus Reactive power in MVar	126.200	126.200	126.200
5	Total Generation Bus active power in MW	300.998	300.727	300.998
6	Total Generation Bus Reactive power in MVar	125.144	125.098	125.145
Line Losses				
1	Total MW Line Losses	17.599	17.573	17.598
2	Total MVar Line losses	22.244	22.139	22.245

The rate of convergence of the GS method is slow as compare to other two methods. In GS method no of iteration are in increases trend in proportion to the no of buses in network whereas in NR and FDLF method no of iteration are lower side despite increase of no of buses in network.

The chief advantage in GS method is the easy programming and most efficient utilization of core memory. In FDLF, storage requirements are around 60% to that of the NR method, but slightly more than the GS method. The programming of NR method is complex and it has the disadvantage of requiring a large computer memory. But Because of high accuracy and lowest no of iterations, the NR method is preferable for load flow and stability studies. The method can be extended for transformer tap-changing operations, variable constraints on bus voltage, optimal real and reactive power scheduling. The GS method is useful only for smaller bus system. NR method is reliable small and large system also. The FDLF method is comparatively more reliable than GS method and of course the NR method is most reliable for any system whether small or larger one.

## VI. CONTROL TECHNIQUES

### A. Load sharing

In the given data, the active load on bus no.-5 is 94.2 MW and line losses is 17.599 MW/22.244MVar as shown in table 1. Corrective step:-

From the highly loaded bus no 5, the 10% load is shared by bus no 7 with the modified loading condition of bus no 5 as 84.8MW and on bus no 7 as 32.2MW.

Now the results simulation process is obtained by way of reduced line losses to the extent of 17.536MW/21.976 MVar as show in table2

TABLE-2

IEEE-30 Bus Data comparison after 10% load sharing from bus no 5 to 7

Bus Status				
S. No.	Data	N-R	G-S	Fast Decoupled
1	Iteration	4	83	15
2	Error	7.75e-007	0.0009625	0.0009271
3	Total Load Bus active power in MW	283.400	283.400	283.400
4	Total Load Bus Reactive power in MVar	126.200	126.200	126.200
5	Total Generation Bus active power in MW	300.936	300.661	300.936
6	Total Generation Bus Reactive power in MVar	124.876	124.829	125.877
Line Losses				
1	Total MW Line Losses	17.536	17.510	17.536
2	Total MVar Line losses	21.976	21.869	21.977

### B. Control by VAR generators

The control the voltage profiles of an interconnected system using positive VAR power injects the load buses. Load flow solution gives the voltage levels at the load buses. In bus no 30 voltage is less as compare to other buses voltages, it is indicate of the fact that the reactive power flow capacity of the transmission lines for specifies voltage limits cannot meet the reactive load demand. This situation can be remedied by installing VAR generators at the load bus no 30. After the positive VAR inject.

Reduction in line losses by injecting 10% MVar power in the system:-

In the given data, PU voltage magnitude is less than the rated to the extend of 0.995 and the line losses are to the extend of 17.599MW/22.244MVar as shown in table 1.

Corrective step:-

From the given data table 1, bus no 30 is identifies as the weak bus in terms of the rated voltage and therefore additional 10% reactive power 1.0MVar is injected in bus no 30.

Now the results are obtained through simulation process by way of reduced line losses to the extent of 17.578 MW/22.1415MVar as shown in table 3.

TABLE-3

IEEE-30 Bus Data comparison after 10% MVar power injected at bus no 30

Bus Status				
S. No.	Data	N-R	G-S	Fast Decoupled
1	Iteration	4	83	15
2	Error	7.69e-007	0.0009300	0.0009720
3	Total Load Bus active power in MW	283.400	283.400	283.400
4	Total Load Bus Reactive power in MVar	126.200	126.200	126.200
5	Total Generation Bus active power in MW	300.978	300.693	300.962
6	Total Generation Bus Reactive power in MVar	124.040	114.650	124.041
Line Losses				
1	Total MW Line Losses	17.578	17.536	17.578
2	Total MVar Line losses	21.141	21.69	22.141

### C. Changing the tap position of the transformer

In the given data, the transformer tap position feeding bus no 4 is 0.932 as shown in table 1. And the line losses are to the extent of 17.599MW/22.244MVar.

Corrective step:-The transformer tap position is put on 1 instead of 0.932 and the results are obtained through the simulation process by way of reduced line losses to the extent of 17.542MW/22.625MVar as shown in table-4.

TABLE-4

IEEE-30 Bus Data comparison after changing the tap position 0.932 to 1.0 at bus no 4.

Bus Status				
S. No.	Data	N-R	G-S	Fast Decoupled
1	Iteration	4	83	15
2	Error	0.0004082	0.0009567	0.0009871
3	Total Load Bus active power in MW	283.400	283.400	283.400
4	Total Load Bus Reactive power in MVar	126.200	126.200	126.200
5	Total Generation Bus active power in MW	300.939	300.686	300.928
6	Total Generation Bus Reactive power in MVar	125.482	125.476	125.547
Line Losses				
1	Total MW Line Losses	17.542	17.531	17.528
2	Total MVar Line losses	22.625	22.517	22.644

## VII. CONCLUSION

The load flow case problem has been successfully solved for interconnected systems with different load flow methods and obtained results have been compared for all the three methods like Newton-Raphson, Gauss-Seidel and Fast-Decouple.

The Newton-Raphson, Gauss-Seidel and Fast-Decoupled load flow method were successfully designed and implemented to solve the Load flow problem. The comparison of results for the test case of IEEE 30 bus network clearly shows that the Newton-Raphson method is indeed capable of obtaining optimum solution efficiently for Load flow problems. After getting the solution, the line losses have also been reduced by taking the remedial actions like reactive power injection, changing the transformer tap position and shifting of load and after formulation of the programmed results obtained through running on mat lab software as shown in table 2 and 4. This indicates the significance of the Newton Raphson method to solve load flow problems interconnected power system network.

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Appendix-I  
30 Bus system Line Data

From Bus	To Bus	R (pu)	X (pu)	B/2 (pu)	X'mer Tap
1	2	0.0192	0.0575	0.0264	1
1	3	0.0452	0.1652	0.0204	1
2	4	0.057	0.1737	0.0184	1
3	4	0.0132	0.0379	0.0042	1
2	5	0.0472	0.1983	0.0209	1
2	6	0.0581	0.1763	0.0187	1
4	6	0.0119	0.0414	0.0045	1
5	7	0.046	0.116	0.0102	1
6	7	0.0267	0.082	0.0085	1
6	8	0.012	0.042	0.0045	1
6	9	0	0.208	0	0.978
6	10	0	0.556	0	0.969
9	11	0	0.208	0	1
9	10	0	0.11	0	1
4	12	0	0.256	0	0.932
12	13	0	0.14	0	1
12	14	0.1231	0.2559	0	1
12	15	0.0662	0.1304	0	1
12	16	0.0945	0.1987	0	1
14	15	0.221	0.1997	0	1
16	17	0.0824	0.1923	0	1
15	18	0.1073	0.2185	0	1
18	19	0.0639	0.1292	0	1
19	20	0.034	0.068	0	1
10	20	0.0936	0.209	0	1
10	17	0.0324	0.0845	0	1
10	21	0.0348	0.0749	0	1
10	22	0.0727	0.1499	0	1
21	23	0.0116	0.0236	0	1
15	23	0.1	0.202	0	1
22	24	0.115	0.179	0	1
23	24	0.132	0.27	0	1
24	25	0.1885	0.3292	0	1
25	26	0.2544	0.38	0	1
25	27	0.1093	0.2087	0	1
28	27	0	0.396	0	0.968
27	29	0.2198	0.4153	0	1
27	30	0.3202	0.6027	0	1
29	30	0.2399	0.4533	0	1
8	28	0.0636	0.2	0.0214	1
6	28	0.0169	0.0599	0.065	1

Appendix-II  
30 Bus System Bus Data

Bus	Type	V	the ta	P g	Qg	Pi	QI	Qmin	Qmax
1	1	1.06	0	0	0	0	0	0	0
2	2	1.04 3	0	4 0	50	21. 7	12.7	-40	50
3	3	1	0	0	0	2.4	1.2	0	0
4	3	1.06	0	0	0	7.6	1.6	0	0
5	2	1.01	0	0	37	94. 2	19	-40	40
6	3	1	0	0	0	0	0	0	0
7	3	1	0	0	0	22. 8	10.9	0	0
8	2	1.01	0	0	37. 3	30	30	-10	40
9	3	1	0	0	0	0	0	0	0
10	3	1	0	0	19	5.8	2	0	0
11	2	1.08 2	0	0	16. 2	0	0	-6	24
12	3	1	0	0	0	11. 2	7.5	0	0
13	2	1.07 1	0	0	10. 6	0	0	-6	24
14	3	1	0	0	0	6.2	1.6	0	0
15	3	1	0	0	0	8.2	2.5	0	0
16	3	1	0	0	0	3.5	1.8	0	0
17	3	1	0	0	0	9	5.8	0	0
18	3	1	0	0	0	3.2	0.9	0	0
19	3	1	0	0	0	9.5	3.4	0	0
20	3	1	0	0	0	2.2	0.7	0	0
21	3	1	0	0	0	17. 5	11.2	0	0
22	3	1	0	0	0	0	0	0	0
23	3	1	0	0	0	3.2	1.6	0	0
24	3	1	0	0	4.3	8.7	6.7	0	0
25	3	1	0	0	0	0	0	0	0
26	3	1	0	0	0	3.5	2.3	0	0
27	3	1	0	0	0	0	0	0	0
28	3	1	0	0	0	0	0	0	0
29	3	1	0	0	0	2.4	0.9	0	0
30	3	1	0	0	0	10. 6	1.9	0	0