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Evaluation of IEEE 57 Bus System for Optimal Power Flow Analysis

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ABSTRACT

The analysis of load flow in a network under steady state operation is challenging task especially subjected to inequality constraints in which the system operates. No doubt, that the load flow system analysis is an important aspect for power system analysis and design. The basic analysis technique for power flow is to find different parameters including magnitude and phase angle of voltage at each bus with active and reactive power flows in each transmission lines. Thus, load flow analysis is important numerical analysis for any power system. In this regard, this experiment is studied to evaluate IEEE 57 bus system for optimal flow analysis.

***Keywords* -** IEEE 57 bus system, active and reactive power, power losses, optimal load flow, Newton Raphson method.

I. INTRODUCTION

Optimal Power flow (OPF) is one of the most significant problems for power system planners and operators [1]. The main aim of OPF is to discover new techniques for the optimal settings of a given power system network that improve a selected objective function such as total generation cost, system loss, bus voltage deviation while fulfilling its load flow equations, system protection, and equipment operating limits [2-5]. The basic objective of OPF problem is to meet the required load demand at minimum production cost, satisfying units' and system's operating constraints, by adjustment of power system control variables. In other words, optimal power flow (OPF) problem deals with finding an optimal operating point of a power system that minimizes an appropriate cost function such as generation cost or transmission loss subject to certain constraints on power and voltage variables. Optimal power flow is a nonlinear programming problem, which is used extensively to determine optimal outputs of generators, bus voltage and transformer tap, setting in power system, with a predetermined objective of minimizing total production cost [6]. In any power system, the whole network must be capable of withstanding the loss of some or several transmission lines, transformers or generators, guaranteeing its security; such outage or loss events are often termed probable or credible contingencies [7] [8]. These contingencies can be very well handled using optimal load flow analysis. In its most general formulation, the OPF problem is a nonlinear, non-convex, large scale, static optimization problem with both continuous and discrete control variables [9]. Even in the absence of non-convex unit operating cost functions, unit prohibited operating zones, and discrete control variables, the non-convex nature of OPF problem is due to the existence of the nonlinear (AC) power flow equality constraints [10]. It has a significant influence on the economic dispatch and secured operation of power systems. The active power loss, voltage profile and voltage security in a power system are important parameters in optimal load flow studies [11-13]. Some additional constraints like reactive power capability of generators, voltage magnitude limits of load bus etc should also be observed to obtain an optimal solution. Voltage stability margin is another factor which needs to be considered while optimizing a power system network. In case the power generation capacity of a system is very close to its power demand then installation of few extra power sources at some suitable points in the system may improve the voltage profile, voltage stability margin along with reduction of active power loss of the system [14] [15].

II. OPTIMAL POWER FLOW ANALYSIS

The basic objectives of optimal power flow can be stated as below:

a) *To minimize total generation cost:*

Generation cost of any power system network can be represented in terms of fuel cost , labour cost and maintenance cost but for simplicity fuel cost is considered only to be variable one. Hence the generation cost minimization involves minimizing the fuel cost. Fuel cost can be defined as;

$$f_c = \sum_{i=1}^{n} (a_i P_{Gi}{}^2 + b_i P_{Gi} + c_i) \ \$/\text{h} \qquad (1)$$

where a_i, b_i and c_i are generator cost curve coefficient. n is the total number of generators. P_{Gi} is the active power of the ith generator. To minimize fuel cost, its derivative is obtained, denoted by lambda (λ).

b) To minimize transmission losses:

Total transmission losses in a power system network are represented as;

$$P_L = \sum_{K=1}^{N} \frac{r_K}{r_K^2 + x_K^2}(V_i^2 + V_j^2 - 2V_iV_j \cos(\delta_i - \delta_j)) \quad (2)$$

where *N* is the number of transmission lines, r_i and x_i are respectively the resistance and reactance of the transmission line k connecting bus *i* and bus *j*. V_i and V_j are the voltage magnitudes at bus *i* and bus *j*, respectively; δ_i and δ_j are the voltage angles at bus *i* and bus *j*, respectively.

c) Equality and inequality constraints consideration:

Equality constraints include power balance constraints given as;

$$\sum_{i=1}^{N} P_{Gi} = \sum_{j=1}^{M} P_{load_i} + P_{loss} \quad (3)$$

where *M*= total no. of load buses, *N*= total no. of generation buses.

Inequality constraints deals with tolerable limits on generation power, shunt capacitors, transformer taps, voltage magnitudes, etc. Various inequality constraints involved in optimal power flow studies are;

$$P_{G\min} < P_{Gi} < P_{G\max} \quad (4)$$

$$Q_{G\min} < Q_{Gi} < Q_{G\max} \quad (5)$$

$$V_{\min} < V_i < V_{\max} \quad (6)$$

$$Q_{c\min} < Q_c < Q_{c\max} \quad (7)$$

$$Tap_{\min} < Tap_i < Tap_{\max} \quad (8)$$

To solve optimal power flow problem, no. of methods have been developed. These include Linear Programming (LP) method, Newton- Raphson (NR) method, Quadratic Programming (QP) method, Nonlinear Programming (NLP) method, Interior Point (IP) method and Artificial Intelligence (AI) methods. In this paper Newton Raphson method is being used to carry out optimal power flow study of a power system network.

III. NEWTON RAPHSON METHOD

Newton Raphson method is the best opted method for solving non-linear optimal load flow equations as it gives better convergence speed as compare to Gauss-siedel load flow method. The number of iterations involved in Newton Raphson method is independent of number of buses considered, hence power flow equations can be solved just in few iterations. Keeping in view all these advantages, Newton Raphson method is popularly used for load flow studies in a power system. In using Newton Raphson method, a direct solver is used to solve the linear systems. Basically an iterative technique is used in this method for obtaining optimal power flow solution.

IV. IEEE 57 BUS SYSTEM

The standard IEEE 57-bus system consists of 80 transmission lines; seven generators at buses 1, 2, 3, 6, 8, 9, 12; and 15 OLTC transformers.

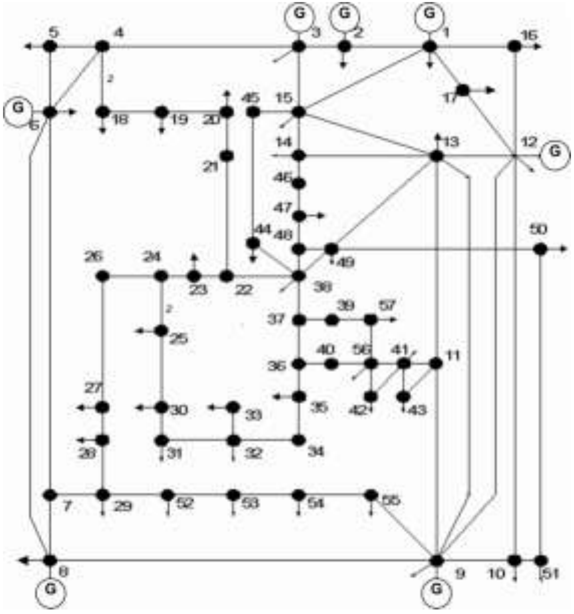

Fig. 1. One-line diagram of the IEEE 57 bus test system.

V. METHODOLOGY

In present study, optimal power flow study of IEEE 57 bus system has been done using Newton Raphson power flow algorithm. The MATPOWER software has been used to run the algorithm. To perform optimal load flow analysis using Newton Raphson method, the algorithm developed is as follows:

Step 1: Form the nodal admittance matrix (Y_{ij}).

Step 2: Assume an initial set of bus voltage and set bus n as the reference bus as:

$V_i = V_{i,\,spec.} \angle 0^0$ (at all PV buses)

$V_i = 1\angle 0^0$ (at all PQ buses)

Step 3: Calculate the real Power P_i using the load flow equation;

$$P_i = G_{ii}|V_i|^2 + \sum_{j=1}^{n} |V_i||V_j|\left(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right) \quad (9)$$

Step 4: Calculate the reactive Power Q_i using the load flow equation;

$$Q_i = -B_{ii}|V_i|^2 + \sum_{j=1}^{n} |V_i||V_j|\left(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right) \quad (10)$$

Step 5: Form the Jacobian matrix using sub-matrices H, N, K and L.
Step 6: Find the power differences ΔP_i and ΔQ_i for all $i=1, 2, 3 \dots (n-1)$;

$$\begin{aligned}\Delta P_i &= P_{i,spec.} - P_{i,cal.} \\ \Delta Q_i &= Q_{i,spec.} - Q_{i,cal.}\end{aligned} \qquad (11)$$

Step 7: Choose the tolerance values.
Step 8: Stop the iteration if all ΔP_i and ΔQ_i are within the tolerance values.
Step 9: Update the values of V_i and δ_i using the equation $x^{k+1}=x^k+\Delta x^k$.
Step 10: Calculate generation cost λ by using derivative of fuel cost.

VI. RESULTS AND DISCUSSIONS

Optimal power flow results of IEEE 57 bus system includes voltage magnitudes, active and reactive powers and generation and load costs so that optimal operation of the system can be guaranteed. Various results obtained using MATPOWER are shown in tables below.

Table 1: IEEE 57 bus system optimal bus data

	Voltage		**Generation**		**Load**		**Lambda($/MVA-hr)**	
Bus	**Mag(p.u)**	**Ang(deg)**	**P (MW)**	**Q (Mvar)**	**P (MW)**	**Q (Mvar)**	**P**	**Q**
1	1.009	0.000*	142.63	44.6	55	17	42.13	-
2	1.008	0.821	87.81	50	3	88	41.756	0.158
3	1.003	-1.169	45.07	28.77	41	21	42.536	-
4	1.006	-1.066	-	-	-	-	42.499	0.011
5	1.016	-0.035	-	-	13	4	42.007	0.046
6	1.026	0.881	72.89	7.77	75	2	41.458	-
7	1.024	1.666	-	-	-	-	41.233	0.17
8	1.044	4.724	459.82	87.17	150	22	40.437	-
9	1.004	-0.091	97.55	9	121	26	41.954	0.247
10	0.984	-3.579	-	-	5	2	43.207	0.238
11	0.984	-2.244	-	-	-	-	43.011	0.394
12	0.992	-3.488	361.54	43.26	377	24	43.325	-
13	0.978	-3.157	-	-	18	2.3	43.419	0.232
14	0.97	-3.517	-	-	10.5	5.3	43.522	0.098
15	0.988	-2.545	-	-	22	5	43.065	0.096
16	0.991	-3.949	-	-	43	3	43.471	0.019
17	0.993	-2.891	-	-	42	8	43.118	0.088
18	1.026	-5.297	-	-	27.2	9.8	42.533	-0.017
19	0.988	-6.664	-	-	3.3	0.6	44.557	0.669
20	0.977	-6.837	-	-	2.3	1	44.995	0.916
21	1.015	-6.524	-	-	-	-	45.109	0.719
22	1.015	-6.461	-	-	-	-	45.064	0.711
23	1.014	-6.468	-	-	6.3	2.1	45.134	0.742
24	1.017	-5.848	-	-	-	-	45.365	1.008
25	1.001	-10.772	-	-	6.3	3.2	45.629	1.227
26	0.976	-5.334	-	-	-	-	45.44	1.073
27	1.013	-2.856	-	-	9.3	0.5	43.325	0.708
28	1.033	-1.508	-	-	4.6	2.3	42.1	0.491
29	1.05	-0.625	-	-	17	2.6	41.148	0.237
30	0.98	-11.36	-	-	3.6	1.8	46.75	1.856

31	0.951	-12.158	-	-	5.8	2.9	48.383	2.781
32	0.96	-11.551	-	-	1.6	0.8	47.608	2.51
33	0.958	-11.589	-	-	3.8	1.9	47.77	2.591
34	0.967	-7.624	-	-	-	-	47.403	2.24
35	0.973	-7.405	-	-	6	3	47.023	2.032
36	0.982	-7.15	-	-	-	-	46.449	1.739
37	0.991	-6.996	-	-	-	-	46.032	1.44
38	1.016	-6.431	-	-	14	7	44.917	0.65
39	0.989	-7.022	-	-	-	-	46.114	1.491
40	0.98	-7.142	-	-	-	-	46.488	1.843
41	1.007	-6.414	-	-	6.3	3	43.053	0.857
42	0.975	-8.037	-	-	7.1	4.4	45.335	1.54
43	1.02	-3.479	-	-	2	1	43.018	0.519
44	1.019	-5.911	-	-	12	1.8	44.515	0.59
45	1.035	-4.065	-	-	-	-	43.021	0.33
46	1.06	-5.091	-	-	-	-	43.468	-0.652
47	1.034	-6.298	-	-	29.7	11.6	44.235	-0.064
48	1.029	-6.329	-	-	-	-	44.441	0.179
49	1.038	-6.339	-	-	18	8.5	44.126	0.108
50	1.024	-6.4	-	-	21	10.5	44.674	0.619
51	1.052	-4.817	-	-	18	5.3	43.153	0.213
52	1.019	-2.162	-	-	4.9	2.2	43.444	0.847
53	1.009	-2.829	-	-	20	10	44.393	0.991
54	1.029	-2.193	-	-	4.1	1.4	43.391	0.676
55	1.059	-1.225	-	-	6.8	3.4	41.945	0.177
56	0.975	-8.764	-	-	7.6	2.2	46.242	1.237
57	0.97	-9.421	-	-	6.7	2	46.83	1.262
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		Total:	1267.31	270.56	1250.8	336.4		

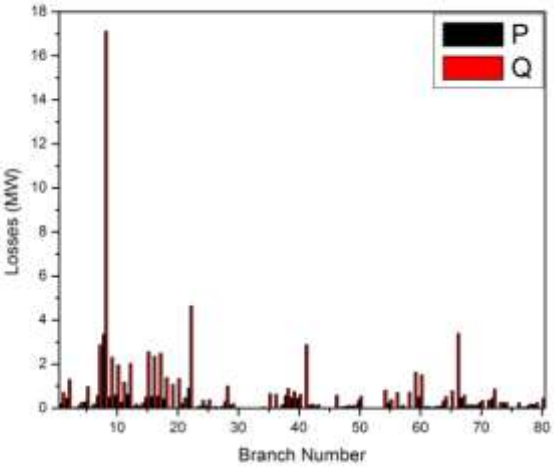

Fig. 2: Graph showing losses as per active and reactive powers due to branches in IEEE 57 bus system

VII. CONCLUSION

In this paper, an IEEE 57 based bus system for optimal power flow is being discussed. In this experiment, Newton Raphson method is studied and discussed to evaluate the optimal conditions including power losses for this bus system. Moreover, load flow data is also evaluated. This technique is studied using MATPOWER simulation software and the results showed faster convergence with reliable results.

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