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Load Flow Analysis Methods in Electric Power Systems and Comparison of Analysis Results by Using Developed Program

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Abstract: ***In recent years, the need for electrical energy has increased in parallel with the technological developments, while the fact that raw energy resources cannot be activated at the same rate has made it necessary to make the most of the energy resources in the circuit. In order to ensure that consumers are distributed in different regions with power plants and to ensure optimum operating efficiency in energy systems, interconnected networks are formed by connecting different power systems. Nowadays, electrical energy exchanges between some countries have caused interconnection networks of these countries to be connected to each other. Thus, the problems that arise during the planning and operation of the growing networks in terms of the qualities and dimensions of the electrical engineers are increasingly complex and require the use of computers. Nowadays, in the analysis of large-scale networks, a lot of time and excessive memory requirement problems are encountered. To this end, new methods are being introduced in the formulation of networks to provide some convenience in computer calculations, and studies on this subject are still intense. In this study, load flow analysis was performed by using the program developed in MATLAB environment. Newton Rapson and Gauss Seidel methods were used in the analysis and the results for the same busbar systems were compared.***

Keywords: Load flow analysis, Newton-Raphson Method , Gauss-Seidel Method

1. Introduction

The growth and complexity of electrical energy systems has revealed the necessity of detailed studies in the planning stages. Inefficient planning and operation of a network leads to cost loss. The use of renewable resources such as wind and solar energy has been brought to the agenda as well as the resources that cannot meet the need.

The acceleration and development of the electrical industry is increasing in parallel with the development of the mathematics and computer sector. The main way to solve any problem in a mixed system is to work on an analog or mathematical model. As well as the optimal operation of existing power systems, the main information obtained in load flow analysis studies in terms of planning developments that may occur in the future is the amplitude, phase angle and active and reactive forces flowing on each line. In addition, additional information about power system operation (short circuit analysis, stability etc.) can be obtained from computer outputs.

As a result of the rapid developments in computers, the methods used in the analysis had to be replaced by computer analysis methods. The speed, reliability and high precision of the computers have quickly become the most widely used tool in the analysis of power systems and, in particular, in load flow analysis. The use of computers in the analysis of power systems as well as numerical analysis methods has come to the fore. These methods are Newton-Raphson and Gauss-Seidel.

2. Definition of Load Flow Problem

The following definition of the load flow problem is the most general definition, since it covers the most simple and practical situations. The load flow problem means finding the voltages and power flow in the network. The values that must be known in order to solve the problem are obtained from the load dispatch center of the network.

It is assumed that the busbars, loads and power plants are divided into two as load and production busbars. The active and reactive power in the load busbars is known as how the active power need of the network is distributed among the power plant and the voltage amplitudes of the power plant are centered on the load distribution center. Therefore, these values are used as the data of the problem. What is left is the complex tension in each bus, the reactive productions of the power plant and how the power is distributed to the lines. They constitute the unknowns of the problem.

It is not necessary to know the other features of the power plants and loads in the load flow study. They are shown as currents in busbars. In this way, the problem of load flow is reduced to the circuit, which consists of busbar and lines of the network, which is known and unknown to the node current and voltages. The solution must provide active and reactive powers and voltage amplitudes in some busbars. After the solution is obtained, it is determined whether the conditions and voltage of the load busbars, transformers, loading of synchronous generators, voltage level at each point of the system and phase differences between voltages are ensured. The load flow is the first step in short-circuit and stability studies other than its own benefits.

3. Load Flow Analysis Data and Oscillation Bus Concept

YBARA and ZBARA matrices can be used in load flow analysis. Because the ZBARA matrix is more suitable for short circuit analysis, YBARA matrix is used for load flow

analysis. The YBARA matrix can be obtained by taking the single line diagram of the system and considering the serial impedances and shunt admittances of the transmission lines.
For each analysis, the operating conditions must always be determined, and all other busbars, except for a bus, should be defined as the active power entering the grid. The power drawn by the load is the negative force entering the system. The other input powers are positive and negative powers coming from the generators and the system. Furthermore, the amplitude of the reactive power or voltage flowing into the system must be described in each of these busbars. The solution of the load flow problem on the computer is mathematically precise. Accurate solution can be obtained within the calculation accuracy limits. At this point, it is necessary to make an addition to the above definition of the load flow. It is impossible to know the active production of all power plants in the network, even if it can be estimated very close in practice. This is because line losses are not known. Therefore, one of the active busbar power is unknown and it is necessary to achieve this at the end of the solution. For this, a production busbar is selected and this bus is called the slack busbar. It is not necessary to choose the polling bus from the production busbars. The active power of the oscillation bus is variable and its value is equal to the active production of other plants and the difference between the active loads and the total of the active losses. While enumerating the busbars in the network, it is useful to give a number to the oscillation busbar and to take the voltage here as a phase reference of other voltages is not necessary for solution.

The choice of the oscillation bus may in some cases affect convergence considerably. As a general rule, the oscillation busbars are selected in the electrical center of the circuit or from busbars in which a plurality of lines are connected. These rules are completely empirical.

4. Load Flow Analysis Methods

4.1 Newton-Raphson Method:

In this method, the correction in the function is brought to zero by error correction for the argument associated with the function. The function x is opened to the Taylor series in order to get the error to zero. The expansion of the functions of two or more variables into the Taylor series is the basis of the Newton-Raphson method. The opening of the y-function y = f (x) to the Taylor Series is as in equation (1) [1]:

$$\mathbf{y} = \mathbf{f}(\mathbf{x}_0) + \left.\frac{\partial \mathbf{f}}{\partial \mathbf{x}}\right|_{\mathbf{x}=\mathbf{x}_0} .(\mathbf{x}-\mathbf{x}_0) + \mathrm{Y.D.T.} \quad (1)$$

Partial derivatives (Y.D.T.) which are larger than first order are ignored when opening to Taylor series and x is obtained when unknown (2) is taken.

$$\mathbf{x} = \mathbf{x}_0 + \left[\left.\frac{\partial \mathbf{f}}{\partial \mathbf{x}}\right|_{\mathbf{x}=\mathbf{x}_0}\right]^{-1} .(\mathbf{y} - \mathbf{f}(\mathbf{x}_0)) \quad (2)$$

In Equation (2), if $x(i)$ and $x(i + 1)$ are replaced by $x(i)$ instead of x_0 (3) [2].

$$\mathbf{x}(i+1) = \mathbf{x}(i) + [\mathbf{J}(i)]^{-1}.(\mathbf{y} - \mathbf{f}[\mathbf{x}(i)]) \quad (3)$$

The NxN dimensional J(i) matrix is known as the Jacobian matrix and is defined as in (4).

$$[\mathbf{J}(i)] = \left[\left.\frac{\partial \mathbf{f}}{\partial \mathbf{x}}\right|_{\mathbf{x}=\mathbf{x}(i)}\right] = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \cdots & \frac{\partial f_1}{\partial x_N} \\ \vdots & \cdots & \vdots \\ \frac{\partial f_N}{\partial x_1} & \cdots & \frac{\partial f_N}{\partial x_N} \end{bmatrix}_{\mathbf{x}=\mathbf{x}(i)} \quad (4)$$

In the solution, since the solution of the linear equation system is preferred instead of the matrix inverse, the equation obtained from (3) is converted into the following iteration relation.

$$[\mathbf{J}(i)].\Delta\mathbf{x}(i) = \Delta\mathbf{y}(i) \quad (5)$$

From this equation, Δx(i) is calculated from the unknown vector and the new value of x(i+1) is found from (6).

In the solution, the initial values x(0) are selected and iteration is continued until the stop criterion in (7).

$$|\Delta y_k(i)| < \varepsilon\,,\; k = 1,2,\ldots,N \quad (7)$$

The ε number in the equation shows a selected tolerance value.

4.2 Gauss-Seidel Method:

The Gauss-Siedel method was developed based on the Gaussian method for the solution of nonlinear algebraic equations [3]. This method is based on the termination of the calculation when the difference between the busbar voltages calculated in a n-bus power system and the busbar voltages in the previous iteration is smaller than the error value specified by the user. Using the power expression of each busbar i. The current and voltage values of the busbar shall be as in Equation (8) and Equation (9) [4].

$$I_i = \frac{P_i - JQ_i}{V_i^*}, i = 1,2,\ldots,n \quad (8)$$

$$V_i = \frac{1}{Y_{ii}}\left[I_i - \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k\right], i = 1,2,\ldots,n \quad (9)$$

Equation (8) refers to the I_i busbar current, the P_i busbar active power, the Q_i busbar reactive power, the last calculated voltage value corresponding to the V_i^* i busbar. In Equation (2), V_i stands for busbar voltage, the variability of the Y_{ii} busbars, the admintance between the Y_{ik} i and k busbars, and the last calculated voltage value for the V_k bus or the estimated voltage if no iterations are made to the busbar [5]. Equation (10) obtained when Equation (8) is replaced in Equation (9) is used for each iteration of busbar voltages.

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - JQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k\right], i = 1,2,\ldots,n \quad (10)$$

4.3 Fast-Decoupled Method

Calculations can be accelerated by making a number of omissions in the Jacobian matrix in the Newton-Raphson method. The Fast-Decoupled method is based on the fact that the dependence of the reactive power on the phase angle (J3) and the dependence on voltage (J2) of the active power in the Jacobian matrix are neglected and the load flow analyzes are performed . The systems of equations obtained in this case are given in Equations (11) and (12). In addition, the fast-decoupled method to shorten the calculation time of the Jacobian matrix is created according to the initial conditions and kept constant during the computation period is called the fixed Jacobian Fast-Decoupled method.

$$J_1(i)\Delta\delta(i) = \Delta P(i) \quad (11)$$

$$J_4(i)\Delta V(i) = \Delta Q(i) \quad (12)$$

5. Load Flow Analysis with the Help of MATLAB Program

In this study, Gauss-Seidel, Newton-Raphson methods and IEEE's 6, 14 and 30 bar test systems are used for load flow analysis at MATLAB environment. The voltages of the busbars in each busbar system, the amount of load, the load flow and losses from one busbar to another, the total loss power values in the system were calculated. When the program is run, it will ask us which bus system to choose from (Newton-Rapson or Gauss-Seidel). Then the program shows the results. As a sample application, 14 busbar system was chosen and Newton-Rapson and Gauss-Seidel methods were compared.

5.1 IEEE 14-Busbar System Selection

If Gauss-Seidel method is selected from the load flow analysis methods by selecting the 14 busbar system when the program is run, the following results are obtained:

Table 1: Load and output powers according to busbar numbers (Gauss-Seidel Method)

Bara No.	Gerilim pu	-Açı- Derece	-----Yük------- MW	Mvar	-----Üretim----- MW	Mvar
1	1.060	0.000	0.000	0.000	-206.236	93.785
2	1.045	4.974	40.000	42.400	21.700	-11.125
3	1.060	12.345	0.000	23.400	94.200	1.999
4	1.069	9.843	0.000	0.000	47.800	-3.900
5	1.063	8.507	0.000	0.000	7.600	1.600
6	1.120	13.346	0.000	12.200	11.200	-5.069
7	1.108	12.617	0.000	0.000	0.000	0.000
8	1.090	12.617	0.000	17.400	0.000	6.545
9	1.127	14.033	0.000	0.000	29.500	16.600
10	1.133	14.165	0.000	0.000	9.000	5.800
11	1.130	13.881	0.000	0.000	3.500	1.800
12	1.133	14.103	0.000	0.000	6.100	1.600
13	1.137	14.183	0.000	0.000	13.500	5.800
14	1.147	14.941	0.000	0.000	14.900	5.000
Toplam			40.000	95.400	52.764	120.435

Table 2: Line flow and line loss powers

Hat Akışı ve Hat Kayıpları					
Hat Numarası	Hattın Güç Değerleri			Hat Kayıp Güçleri	
Baradan baraya	MW	Mvar	MVA	MW	Mvar
1	-206.236	93.785	226.559		
2	-136.567	75.687	156.138	4.284	7.230
5	-69.695	18.109	72.009	2.545	4.962
2	-18.300	-53.525	56.567		
1	140.851	-68.456	156.606	4.284	7.230
3	-68.688	10.617	69.504	2.103	4.008
4	-52.040	3.396	52.151	1.456	0.618
5	-38.451	0.920	38.462	0.775	-1.478
3	94.200	-21.401	96.600		
2	70.791	-6.609	71.099	2.103	4.008
4	23.399	-14.792	27.682	0.445	-0.316
4	47.800	-3.900	47.959		
2	53.496	-2.778	53.568	1.456	0.618
3	-22.954	14.477	27.138	0.445	-0.316
5	61.541	-4.480	61.704	0.445	1.403
7	-28.008	-6.934	28.854	-0.000	1.457
9	-16.334	-4.171	16.858	0.000	1.299
5	7.600	1.600	7.767		
1	72.240	-13.148	73.427	2.545	4.962
2	39.226	-2.398	39.299	0.775	-1.478
4	-61.096	5.883	61.379	0.445	1.403
6	-42.774	11.260	44.232	0.000	3.788
6	11.200	-17.269	20.583		
5	42.774	-7.472	43.422	0.000	3.788
11	-6.929	-2.079	7.234	0.040	0.083
12	-7.530	-2.028	7.799	0.060	0.124
13	-17.163	-5.686	18.080	0.172	0.339
7	0.000	0.000	0.000		
4	28.008	8.391	29.238	0.000	1.457
8	-0.004	11.029	11.029	0.000	0.175
9	-28.054	-19.417	34.118	0.000	1.044
8	0.000	-10.855	10.855		
7	0.004	-10.855	10.855	0.000	0.175
9	29.500	16.600	33.850		
4	16.334	5.470	17.226	0.000	1.299
7	28.054	20.461	34.723	0.000	1.044
10	-5.507	-5.382	7.700	0.015	0.039
14	-9.423	-3.926	10.209	0.104	0.222
10	9.000	5.800	10.707		
9	5.522	5.421	7.738	0.015	0.039
11	3.470	0.383	3.491	0.008	0.018
11	3.500	1.800	3.936		
6	6.968	2.162	7.296	0.040	0.083
10	-3.462	-0.364	3.481	0.008	0.018
12	6.100	1.600	6.306		
6	7.590	2.152	7.889	0.060	0.124
13	-1.496	-0.544	1.592	0.004	0.004
13	13.500	5.800	14.693		
6	17.335	6.026	18.352	0.172	0.339
12	1.500	0.548	1.597	0.004	0.004
14	-5.338	-0.772	5.393	0.038	0.078
14	14.900	5.000	15.717		
9	9.528	4.148	10.391	0.104	0.222
13	5.376	0.851	5.443	0.038	0.078
Toplam kayıp güç				**12.494**	**25.098**

If Newton-Raphson method is selected from the load flow analysis methods by selecting the 14 busbar system when the program is run, the following results are obtained:

Table 3: Load and output powers according to busbar numbers (Newton-Raphson method)

Bara	Gerilim	-Açı-	------Yük-------		-----Üretim----- -	
No.	pu	Derece	MW	Mvar	MW	Mvar
1	1.060	0.000	0.000	0.000	-206.501	93.883
2	1.045	4.980	40.000	42.400	21.700	-11.143
3	1.060	12.353	0.000	23.400	94.200	1.989
4	1.069	9.854	0.000	0.000	47.800	-3.900
5	1.063	8.516	0.000	0.000	7.600	1.600
6	1.120	13.362	0.000	12.200	11.200	-5.065
7	1.108	12.633	0.000	0.000	0.000	0.000
8	1.090	12.633	0.000	17.400	0.000	6.544
9	1.127	14.051	0.000	0.000	29.500	16.600
10	1.133	14.183	0.000	0.000	9.000	5.800
11	1.130	13.897	0.000	0.000	3.500	1.800
12	1.133	14.120	0.000	0.000	6.100	1.600
13	1.137	14.199	0.000	0.000	13.500	5.800
14	1.147	14.958	0.000	0.000	14.900	5.000
Toplam			40.000	95.400	52.499	120.509

Table 4: Line flow and line loss powers

Hat Akışı ve Hat Kayıpları					
Hat Numarası	Hattın Güç Değerleri			Hat Kayıp Güçleri	
Baradan baraya	MW	Mvar	MVA	MW	Mvar
1	-206.501	93.883	226.841		
2	-136.715	75.750	156.298	4.293	7.257
5	-69.770	18.140	72.089	2.551	4.985
2	-18.300	-53.543	56.583		
1	141.007	-68.493	156.762	4.293	7.257
3	-68.719	10.629	69.536	2.105	4.016
4	-52.095	3.418	52.207	1.459	0.628
5	-38.493	0.936	38.504	0.777	-1.473
3	94.200	-21.411	96.603		
2	70.824	-6.613	71.132	2.105	4.016
4	23.376	-14.786	27.660	0.444	-0.317
4	47.800	-3.900	47.959		
2	53.554	-2.790	53.627	1.459	0.628
3	-22.932	14.469	27.115	0.444	-0.317
5	61.604	-4.492	61.768	0.446	1.406
7	-28.067	-6.922	28.908	-0.000	1.463
9	-16.360	-4.164	16.881	-0.000	1.302
5	7.600	1.600	7.767		
1	72.321	-13.155	73.507	2.551	4.985
2	39.270	-2.409	39.344	0.777	-1.473
4	-61.159	5.898	61.442	0.446	1.406
6	-42.832	11.266	44.289	0.000	3.798
6	11.200	-17.265	20.579		
5	42.832	-7.468	43.478	0.000	3.798
11	-6.930	-2.073	7.234	0.040	0.083
12	-7.535	-2.022	7.801	0.060	0.124
13	-17.167	-5.679	18.082	0.172	0.340
7	0.000	0.000	0.000		
4	28.067	8.385	29.293	-0.000	1.463
8	0.000	11.021	11.021	-0.000	0.174
9	-28.067	-19.407	34.123	0.000	1.044
8	0.000	-10.856	10.856		
7	-0.000	-10.847	10.847	-0.000	0.174
9	29.500	16.600	33.850		
4	16.360	5.467	17.249	-0.000	1.302
7	28.067	20.451	34.728	0.000	1.044
10	-5.507	-5.387	7.704	0.015	0.039
14	-9.419	-3.931	10.207	0.104	0.222
10	9.000	5.800	10.707		
9	5.522	5.426	7.742	0.015	0.039
11	3.478	0.374	3.498	0.008	0.018
11	3.500	1.800	3.936		
6	6.970	2.156	7.296	0.040	0.083
10	-3.470	-0.356	3.488	0.008	0.018
12	6.100	1.600	6.306		
6	7.594	2.146	7.892	0.060	0.124
13	-1.494	-0.546	1.591	0.004	0.004
13	13.500	5.800	14.693		
6	17.339	6.019	18.354	0.172	0.340
12	1.499	0.550	1.597	0.004	0.004
14	-5.338	-0.769	5.393	0.038	0.078
14	14.900	5.000	15.717		
9	9.524	4.153	10.390	0.104	0.222
13	5.376	0.847	5.443	0.038	0.078
Toplam Kayıp Güç				12.515	25.191

6. Result

In this study, 6, 14 and 30 bar test systems of IEEE were modeled in Matlab environment and load flow calculations were made according to Gauss-Seidel and Newton-Raphson methods and their results were compared. As a result of load flow analysis; As the tolerance values decreased, the maximum number of iterations occurred in the Gauss-Seidel method compared to the Newton-Raphson method. As the number of busbars increases, the number of iterations in the Gauss-Seidel method increases. In the Newton-Raphson method, the computation time was the highest and the Gauss-Seidel calculated lower calculation times. Due to the complexity of the Jacobian matrix for each iteration, the Newton-Raphson method has more computation time. In both of the load flow analysis methods, the forces produced by the generators according to the load demands in the busbars were calculated as close values. As a result, Gauss-Seidel method, the number of iterations is too high and the tolerance value decreases with the increase in losses due to the best results for all busbar systems were obtained by the Newton-Raphson method.

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