Energy and Power Engineering, 2019, 11, 186-199
http://www.scirp.org/journal/epe
ISSN Online: 1947-3818
ISSN Print: 1949-243X

Design and Power Flow Analysis of Electrical System Using Electrical Transient and Program Software

Raheel Muzzammel*, **Ibrahim Khail, Muhammad Huzaifa Tariq, Abubakar Muhammad Asghar, Ali Hassan**

Department of Electrical Engineering, University of Lahore, Lahore, Pakistan
Email: *raheelmuzzammel@gmail.com

How to cite this paper: Muzzammel, R., Khail, I., Tariq, M.H., Asghar, A.M. and Hassan, A. (2019) Design and Power Flow Analysis of Electrical System Using Electrical Transient and Program Software. *Energy and Power Engineering*, **11**, 186-199.
https://doi.org/10.4236/epe.2019.114011

Received: March 17, 2019
Accepted: April 21, 2019
Published: April 24, 2019

Abstract

Power flow analysis is a numerical way of study of behavior of flow of electric power in an interconnected system. In order to meet the growing demands of electrical energy in an optimum way, there is a need to upgrade existing systems or to install new systems. Therefore, planning of new installations and determination of best operating conditions of existing systems need power flow analysis. In this way, cost/benefit ratio for both suppliers and customers is maintained. This research involves the design and power flow analysis of IEEE-14 bus system. Newton Raphson method is applied for better efficiency and reduced computational time. Simulation analysis is conducted in ETAP software because of its excessive used in real life systems.

Keywords

Power Flow Analysis, IEEE-14 Bus System, Newton Raphson Method, ETAP Software

1. Introduction

Behavior of flow of electric power in an interconnected system is studied numerically by power flow analysis. Single line diagram and per unit system are the fundamental components of this analysis. Voltage (V), voltage angles (δ), active power (P) and reactive power (Q) are the variables involved in this study. Active power and voltage are known at supply side and reactive power and voltage angles are determined through numerical analysis of power flow. Active power and reactive power are known at consumer side and voltage and voltage angles are evaluated through power flow analysis [1] [2] [3].

There is a requirement to improve current power system or to add new systems to existing systems for meeting energy demands. Therefore, power flow analysis is an essential study for future expansion of power system and for finding the ideal operating conditions of existing electric power systems. Moreover, economic dispatch, unit commitment, contingency analysis, transient and steady state analysis and short circuit analysis require power flow analysis [2] [3].

In power flow analysis, there are three types of buses *i.e.*, swing bus, generator bus and load bus. Swing bus and generator bus are source buses. For swing bus, V and δ are known and P and Q are unknown values. The source bus with larger size of generator is normally taken as swing bus. For generator bus (PV bus), P and V are known values and Q and δ are unknown. For load bus (PQ bus), P and Q are known and V and δ are unknown values. The unknown parameters of buses (*i.e.*, P and Q for swing bus, Q and δ for generator bus and V and δ for load bus) are determined from known values of buses (*i.e.*, V and δ for swing bus, P and V for generator bus and P and Q for load bus) and impedance between these buses (Z_{ij}) using power flow calculations. After performing power flow analysis, all the four parameters (V, δ, P and Q) are available for swing bus, generator bus and load bus. The other electrical parameters such as current, power factor, apparent power for the whole electrical system can be determined from these four parameters (V, δ, P and Q) and impedance between the buses (Z_{ij}) [2] [3].

Commercial power systems are complicated. It is not possible to analyze power flow through hand calculations. Physical models of power systems were analyzed through network analyzers in laboratories between 1929 and early 1960. Afterwards, invention of digital computers replaced the analog methods with numerical methods [1]-[7].

Initially, linear methods were proposed to analyze power flow analysis. Among these, Cramer's method, Gauss elimination and LU factorization are notable. However, these methods cannot handle complex, nonlinear and big power systems. Therefore, iterative techniques *i.e.*, Gauss Seidel method, Newton Raphson method are developed to solve complex power systems [4] [5] [6] [7] [8].

In this research paper, Newton Raphson method is implemented because of its accuracy and reduced computational time due to less iteration as compared to Gauss Seidel method. Iterative methods are techniques for solving the n equations of the linear system $Ax = b$ one at a time in sequence, and use previously computed results as soon as they are available, In Gauss Seidel method, the computations appear to be serial. Further, each component of new iteration depends upon all previously computed components. Updates cannot be done simultaneously. In addition to this, new iteration depends on the order in which equations are examined. If this ordering is changed, the components of new iteration (and not just their order) also change. These limitations persuade engineers and researchers to go for Newton Raphson method. Gauss Seidel method is easy to program. Newton Raphson method is complex to program and it acquires more memory space then Gauss Seidel method. Time required for per iteration in Newton Raphson method is larger than Gauss Seidel method but the overall time for iterative process is less because of less number of iterations for convergence [1] [2] [3] [4] [7] [8] [9].

ETAP software is used for simulation because of its extension of real time intelligent power management systems for monitoring, controlling, automating and optimizing power systems. It is a high impact software used for power flow analysis is generation, transmission and distribution systems of electric power engineering [10] [11] [12] [13].

This research paper consists of following sections: Section II covers the mathematical background and proposed flow chart for Newton Raphson method. Section III contains the details of IEEE-14 bus system as a test model for depicting accuracy of power flow analysis method. Simulation analysis in tabular form is presented in Section IV. Section V concludes the research.

2. Newton Raphson Method

Newton Raphson method is named after Isaac Newton and Joseph Raphson. Successively better approximations for the roots of a real-valued function are determined from this method. Newton-Raphson load flow analysis is based on Newton Raphson method for evaluation of a system of nonlinear equations. It is an iterative method which approximates a set of non-linear simultaneous equations is approximated to a set of linear simultaneous equations using Taylor's series expansion by this iterative method [2] [3].

Referring to **Figure 1**, polar form of power flow equations are formulated for n bus system in terms of bus admittance matrix Y as

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \tag{1}$$

$$I_i = \sum_{j=1}^{n} \left|Y_{ij}\right|\left|V_j\right| < \left(\theta_{ij} + \delta_j\right) \tag{2}$$

where i and j represent i^{th} and j^{th} bus respectively. The current in terms of the active and the reactive power at bus i is:

$$I_i = \frac{P_i - JQ_i}{V_i} \tag{3}$$

Using Equation (3) into Equation (2) gives:

$$P_i - jQ_i = \left|V_i\right| < -\delta_i \sum_{i=1}^{n} \left|V_j\right|\left|Y_{ij}\right| < \theta_{ij} + \delta_j \tag{4}$$

$$P_i - jQ_i = \sum_{i=1}^{n} \left|V_i V_j Y_{ij}\right| < \theta_{ij} + \delta_j - \delta_i \tag{5}$$

Real and imaginary parts are separated as:

$$P_i = \sum_{i=1}^{n} \left|V_i V_j Y_{ij}\right| \cos\left(\theta_{ij} + \delta_j - \delta_i\right) \tag{6}$$

$$Q_i = -\sum_{i=1}^{n} \left|V_i V_j Y_{ij}\right| \sin\left(\theta_{ij} + \delta_j - \delta_i\right) \tag{7}$$

Taylor series expansion of Equation (6) and Equation (7) and neglecting higher order term result:

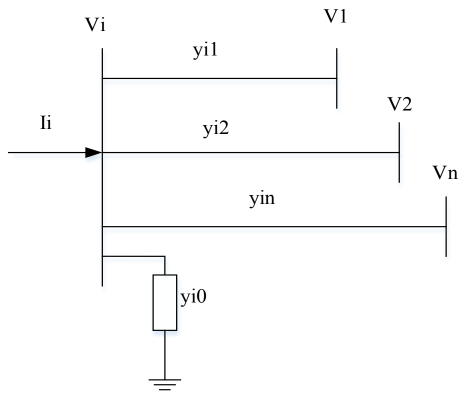

Figure 1. Typical power system bus bar model.

$$\begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \cdots & \frac{\partial P_2}{\partial \delta_n} & \frac{\partial P_2}{\partial |V_2|} & \cdots & \frac{\partial P_2}{\partial |V_n|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_n}{\partial \delta_2} & \cdots & \frac{\partial P_n}{\partial \delta_n} & \frac{\partial P_2}{\partial |V_2|} & \cdots & \frac{\partial P_2}{\partial |V_2|} \\ \frac{\partial Q_2}{\partial \delta_2} & \cdots & \frac{\partial Q_2}{\partial \delta_n} & \frac{\partial Q_2}{\partial |V_2|} & \cdots & \frac{\partial Q_2}{\partial |V_n|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial Q_n}{\partial \delta_2} & \cdots & \frac{\partial Q_n}{\partial \delta_n} & \frac{\partial Q_n}{\partial |V_2|} & \cdots & \frac{\partial Q_n}{\partial |V_n|} \end{bmatrix} \begin{bmatrix} \Delta\delta_2 \\ \vdots \\ \vdots \\ \Delta\delta_n \\ \Delta|V_2| \\ \vdots \\ \vdots \\ \Delta|V_n| \end{bmatrix} = \begin{bmatrix} \Delta P_2 \\ \vdots \\ \vdots \\ \Delta P_n \\ \Delta Q_n \\ \vdots \\ \vdots \\ \Delta Q_n \end{bmatrix} \tag{8}$$

Linearized relationship is obtained by this Jacobian matrix between small changes in voltage angles $\Delta\delta_i$ and voltage magnitude $\Delta|V_i|$ with the small changes in real and reactive power ΔP_i and ΔQ_i. (8) can be modified as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{9}$$

The diagonal and the off diagonal elements of J_1 are:

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j\neq i} |V_i||V_j||Y_{ij}|\sin\left(\theta_{ij} + \delta_j - \delta_i\right) \tag{10}$$

$$\frac{\partial P_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}|\sin\left(\theta_{ij} + \delta_j - \delta_i\right) \tag{11}$$

where $j \neq i$.

$$\frac{\partial Q_i}{\partial \delta_j} = \sum_{j=1}^{n} |V_i V_j Y_{ij}|\sin\left(\theta_{ij} + \delta_j - \delta_i\right) \tag{11}$$

Similarly, diagonal and off diagonal elements of J_2, J_3, J_4 are:

$$\frac{\partial P_i}{\partial |V_i|} = 2|V_i||Y_{ii}|\cos\theta_{ii} + \sum_{j\neq i} |V_j||Y_{ij}|\cos\left(\theta_{ij} + \delta_j - \delta_i\right) \tag{12}$$

$$\frac{\partial P_i}{\partial |V_j|} = |V_i||Y_{ij}|\cos\left(\theta_{ij} + \delta_j - \delta_i\right) \tag{13}$$

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{j \neq i} |V_i||V_j||Y_{ij}|\cos\left(\theta_{ij} + \delta_j - \delta_i\right) \quad (14)$$

$$\frac{\partial P_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}|\cos\left(\theta_{ij} + \delta_j - \delta_i\right) \quad (15)$$

$$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ij}|\sin\theta_{ii} + \sum_{j \neq i} |V_i||Y_{ij}|\sin\left(\theta_{ij} + \delta_j - \delta_i\right) \quad (16)$$

$$\frac{\partial Q_i}{\partial |V_j|} = -|V_i||Y_{ij}|\sin\left(\theta_{ij} + \delta_j - \delta_i\right) \quad (17)$$

The terms ΔP_i and ΔQ_i in Equation (8) are the differences between the scheduled and calculated values of power called power residuals given as:

$$\Delta P_i = P_i^{sch} - P_i \quad (18)$$

$$\Delta Q_i = Q_i^{sch} - Q_i \quad (19)$$

Using Equation (8), Equation (18) and Equation (19), $\Delta\delta_i$ and $\Delta|V_i|$ are calculated to complete the particular iteration. The new values calculated as shown below are used for the next iteration $(k+1)$

$$\delta_i^{k+1} = \delta_i^k - \Delta\delta_i^k \quad (20)$$

$$\left|V_i^{k+1}\right| = \left|V_i^k\right| - \left|\Delta V_i^k\right| \quad (21)$$

Flow chart of Newton Raphson method is given in Figure 2. Test system *i.e.*, IEEE 14 bus system is analyzed in Figure 3.

3. Test System—IEEE 14 BUS System

IEEE 14 bus system is used to validate the performance of Newton Raphson method. Table 1 and Table 2 provide the details of buses data and branches data for power system. In Table 1, *Bus Type (1) represents swing bus, (2) represents generator bus (PV bus) and (3) represents load bus (PQ bus).

4. Simulation Analysis

ETAP software is used for simulation analysis and simulation circuit is given in Figure 4. Power flow analysis for IEEE-14 bus system is carried out by Newton Raphson method. Table 3 provides the results of power flow analysis on branches of electric power system.

Table 4 gives the detail of load and losses in electric power system after power flow analysis via Newton Raphson method. IEEE-14 bus system after power flow analysis is given in Figure 5.

Power flow analysis results in generation of alerts at generators. The alerts contain the conditions of operation of generator as shown in Table 5. Conditions of operation of generators are overload, overexcited, under excited and normal. After taking into consideration the capability curve and load values, the generation values are readjusted to bring operation of generators under normal conditions and it is shown in Table 6.

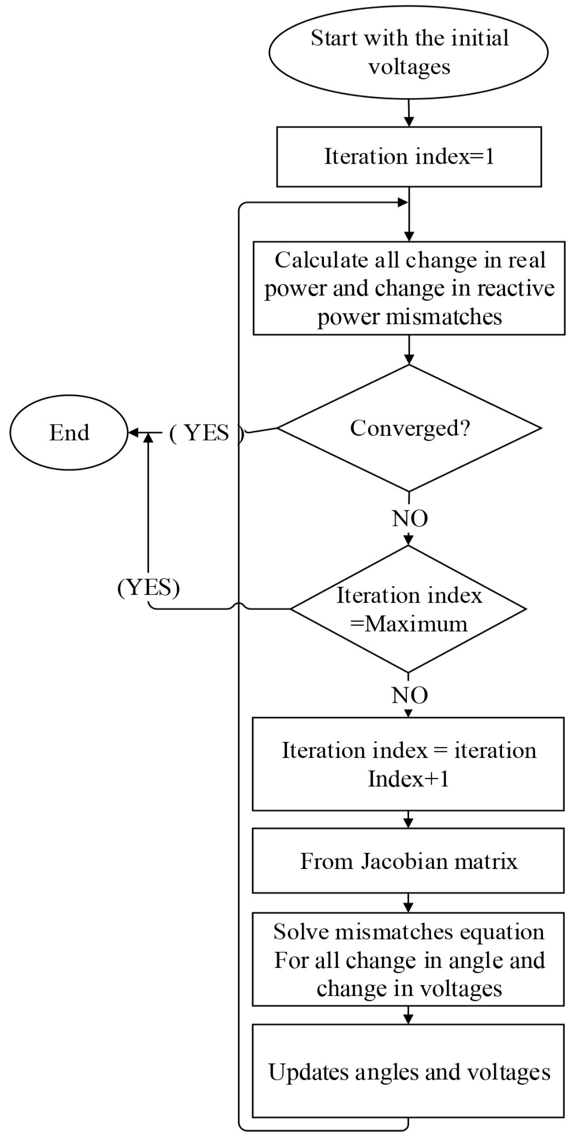

Figure 2. Flow chart of Newton Raphson method.

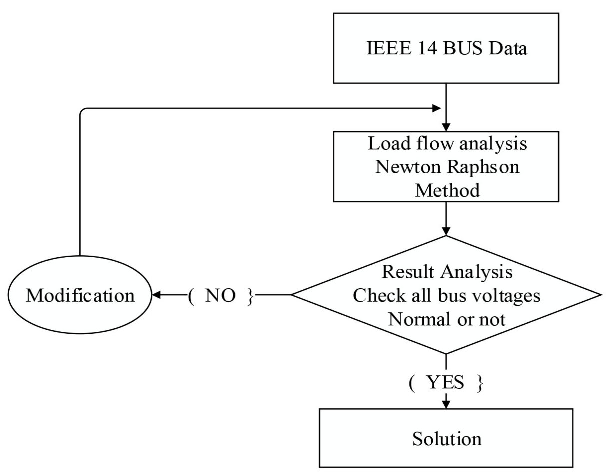

Figure 3. IEEE-14 bus system and Newton Raphson method.

Table 1. This table shows the bus data of IEEE-14 bus system.

Bus No.	P Generated (p.u)	Q Generated (p.u)	P load (p.u)	Q Load (p.u)	Bus Type*	Q Generated Max. (p.u)	Q Generated Min. (p.u)
1	2.32	0.00	0.00	0.00	2	10.0	-10.0
2	0.4	−0.424	0.2170	0.1270	1	0.5	-0.4
3	0.00	0.00	0.9420	0.1900	2	0.4	0.00
4	0.00	0.00	0.4780	0.00	3	0.00	0.00
5	0.00	0.00	0.0760	0.0160	3	0.00	0.00
6	0.00	0.00	0.1120	0.0750	2	0.24	-0.06
7	0.00	0.00	0.00	0.00	3	0.00	0.00
8	0.00	0.00	0.00	0.00	2	0.24	-0.06
9	0.00	0.00	0.2950	0.1660	3	0.00	0.00
10	0.00	0.00	0.0900	0.0580	3	0.00	0.00
11	0.00	0.00	0.0350	0.0180	3	0.00	0.00
12	0.00	0.00	0.0610	0.0160	3	0.00	0.00
13	0.00	0.00	0.1350	0.0580	3	0.00	0.00
14	0.00	0.00	0.1490	0.0500	3	0.00	0.00

Table 2. This table shows the branch data of IEEE-14 bus system.

From Bus	To Bus	Resistance (p.u.)	Reactance (p.u)	Line charging (p.u.)
1	2	0.01938	0.05917	0.0528
1	5	0.05403	0.22304	0.0492
2	3	0.04699	0.19797	0.0438
2	4	0.05811	0.17632	0.0374
2	5	0.05695	0.17388	0.034
3	4	0.06701	0.17103	0.0346
4	5	0.01335	0.04211	0.0128
4	7	0.00	0.20912	0.00
4	9	0.00	0.55618	0.00
5	6	0.00	0.25202	0.00
6	11	0.09498	0.1989	0.00
6	12	0.12291	0.25581	0.00
6	13	0.06615	0.13027	0.00
7	8	0.00	0.17615	0.00
7	9	0.00	0.11001	0.00
9	10	0.03181	0.08450	0.00
9	14	0.12711	0.27038	0.00
10	11	0.08205	0.19207	0.00
12	13	0.22092	0.19988	0.00
13	14	0.17093	0.34802	0.00

Table 3. This table provides the result of power flow analysis of on branches of IEEE-14 bus system.

ID	Type	From Bus	To Bus	R	X	Z
T1	2W XFMR	Bus5	Bus6	554.70	832.05	1000
T2	2W XFMR	Bus9	Bus6	554.70	832.05	1000.
T5	2W XFMR	Bus9	Bus4	69.43	3124.23	3125
Z1	Impedance	Bus1	Bus2	0.00	0.01	0.01
Z2	Impedance	Bus1	Bus5	0.01	0.04	0.04
Z3	Impedance	Bus3	Bus4	0.01	0.03	0.03
Z4	Impedance	Bus2	Bus3	0.01	0.04	0.04
Z5	Impedance	Bus2	Bus4	0.01	0.03	0.04
Z6	Impedance	Bus5	Bus4	0.00	0.01	0.01
Z7	Impedance	Bus9	Bus15		0.02	0.02
Z8	Impedance	Bus4	Bus15		0.04	0.04
Z9	Impedance	Bus8	Bus15		0.03	0.03
Z10	Impedance	Bus10	Bus9	0.01	0.02	0.02
Z11	Impedance	Bus11	Bus10	0.02	0.04	0.04
Z12	Impedance	Bus11	Bus6	0.02	0.04	0.04
Z13	Impedance	Bus12	Bus6	0.02	0.05	0.05
Z14	Impedance	Bus13	Bus12	0.04	0.04	0.06
Z15	Impedance	Bus13	Bus14	0.03	0.07	0.07
Z16	Impedance	Bus14	Bus9	0.02	0.05	0.06
Z17	Impedance	Bus5	Bus2	0.01	0.03	0.03
Z18	Impedance	Bus4	Bus9		0.11	0.11
Z19	Impedance	Bus13	Bus6	0.13	0.02	0.13

Table 4. This table shows the result of load and losses after load flow analysis at 230 kv and at 100 percent magnitude.

ID	Load		Losses	
	MW	MVAR	MW	MVAR
Bus1	-	-	-	-
Bus2	27.880	17.278	6.970	4.320
Bus3	336.600	208.606	84.150	52.151
Bus4	169.320	104.935	42.330	26.234
Bus5	26.520	16.436	6.630	4.109
Bus6	42.840	26.550	10.710	6.637
Bus8	-	-	-	-
Bus9	110.840	68.692	27.710	17.173
Bus10	34.000	21.071	8.500	5.268
Bus11	104.720	64.900	26.180	16.225
Bus12	135.320	83.864	33.830	20.966
Bus13	48.960	30.343	12.240	7.586
Bus14	53.720	33.293	13.430	8.323
Bus15	-	-	-	-
Total Number of Buses: 14	1090.720	675.968	272.680	168.992

Table 5. This table gives the condition of three phase generators after power flow analysis via Newton Raphson method.

Device ID	Condition	Rating/limit	Operating	%Operating
Gen1	Overload	60 MW	60	100
Gen1	Over Excited	37.5 Mvar	37.185	100
Gen2	Overload	25 MW	25	100
Gen2	Under Excited	0	0	-
Gen3	Overload	25 MW	25	100
Gen3	Under Excited		0	-
Gen4	Overload	60 MW	60	100
Gen4	Under Excited		0	-
Swing Gen	Overload	615 MW	1193.143	194

Table 6. This table gives the values of generation under normal operating conditions of generators.

Device ID	Condition	Rating/limit	Operating	%Operating
Gen1	Normal	70 MW	60 MW	87
Gen1	Normal	37 Mvar	37 Mvar	100
Gen2	Normal	40 MW	30 MW	70
Gen2	Normal	15 Mvar	15 Mvar	100
Gen3	Normal	40 MW	30 MW	70
Gen3	Normal	16 Mvar	16 Mvar	100
Gen4	Normal	80 MW	70 MW	87.5
Gen4	Normal	36.5 Mvar	36.5 Mvar	100
Swing Gen	Normal	1300 MW	1173.151	90

ETAP report is generated and is given in Table 7 to depict the generation and load in electric power system test model.

Voltage and current of test system are measured before and after load flow analysis to depict the state of the system and are shown in Figure 6 and Figure 7. Change in the values of voltage and angles are observed. It is the requirement of power system to have good voltage regulation for ensuring acceptable power factor value.

5. Conclusion

In this research paper, IEEE-14 bus system is developed and analysed. Power flow analysis is conducted through Newton Raphson method. Further, operating conditions of generators are determined. Generation values are readjusted by

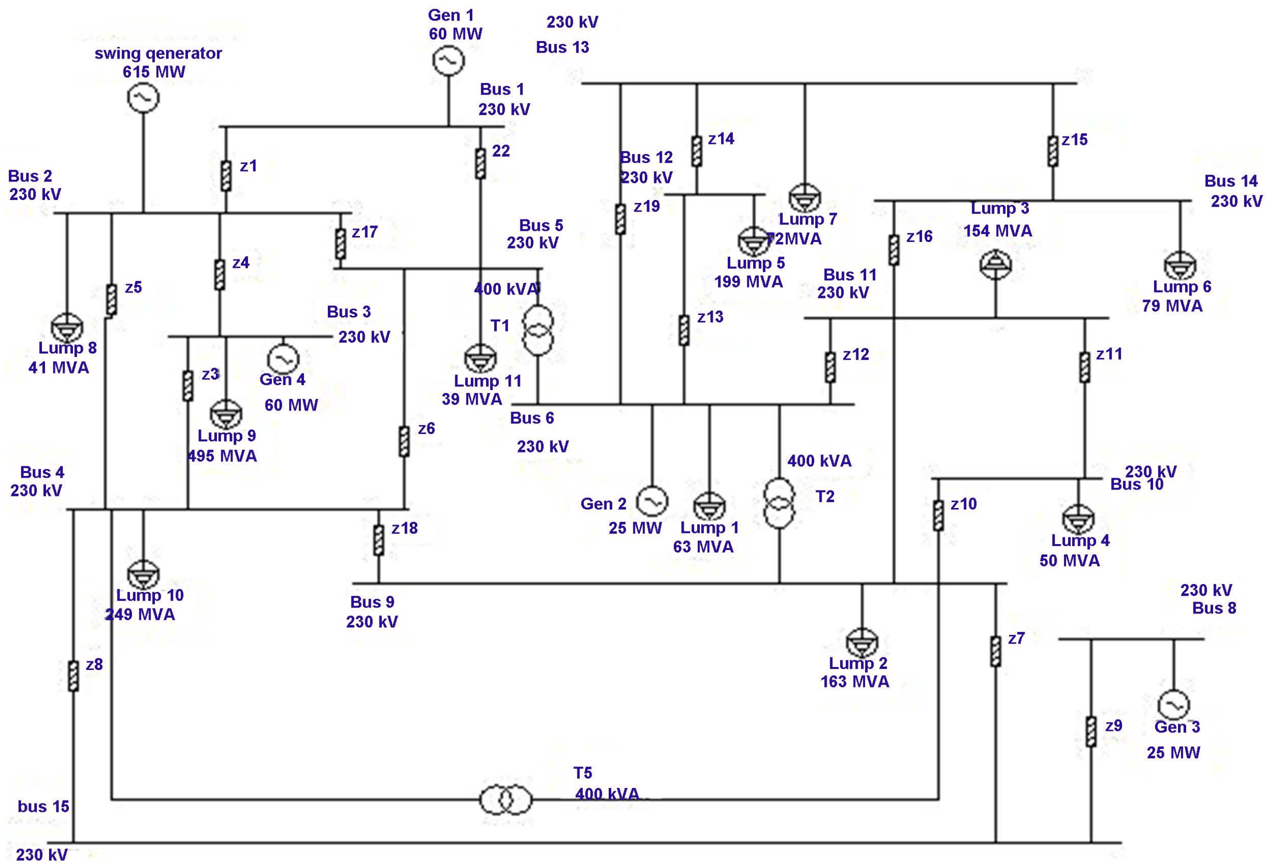

Figure 4. This figure shows the simulation circuit of IEEE-14 bus system on ETAP software.

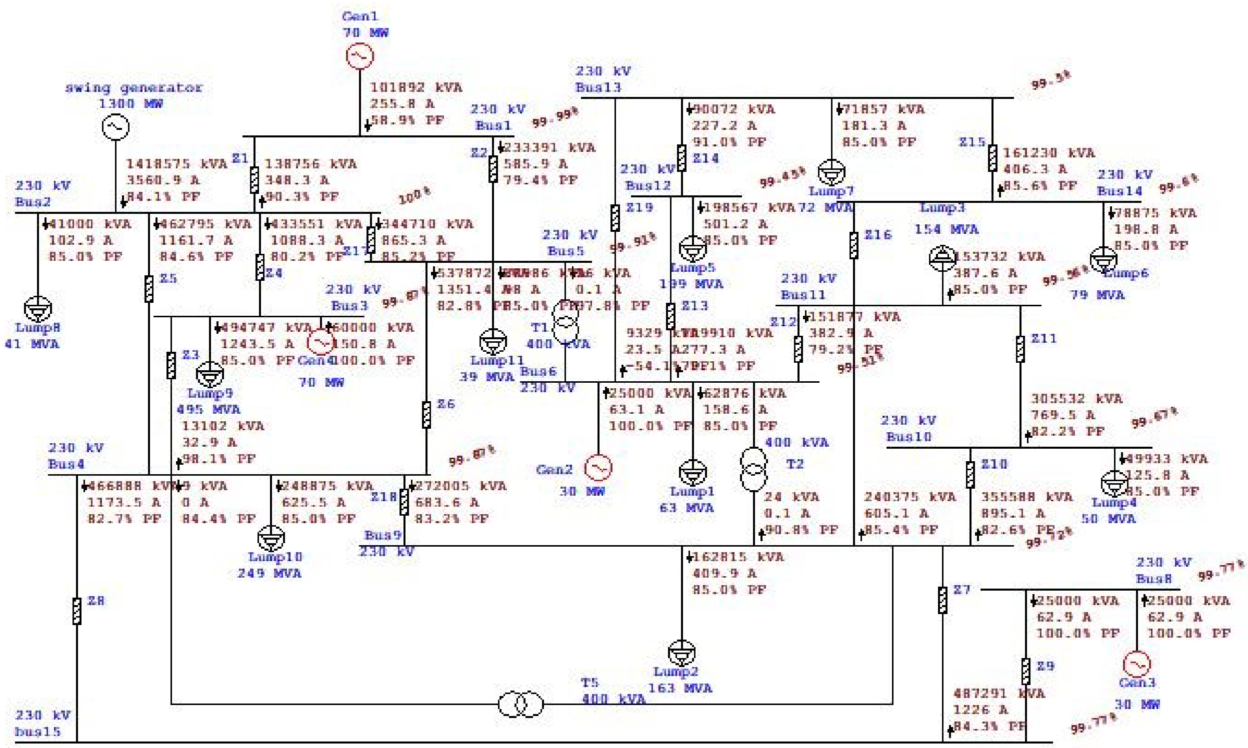

Figure 5. IEEE-14 bus system after power flow analysis.

Table 7. This table shows the load flow ETAP software report via Newton Rahson method.

LBUS		VOLTAGEES		Generation		Load		Load flow				
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF
Bus1	230.000	99.986	0.0	60.000	37.000	0	0	Bus2	−123.282	−−88.741	381.4	81.2
								Bus5	183.282	125.741	558.0	82.5
*Bus2	230.000	100.000	0.0	1173.151	744.880	34.850	21.598	Bus1	123.291	88.767	381.4	81.2
								Bus3	341.401	233.300	1038.0	82.6
								Bus4	384.927	230.797	1126.6	85.8
								Bus5	288.683	170.419	841.5	86.1
Bus3	230.000	99.882	−0.1	70.000	36.500	420.552	260.635	Bus4	−9.303	8.525	31.7	−73.7
								Bus2	−341.249	−232.660	1038.0	82.6
Bus4	230.000	99.881	−0.1	0	0	211.549	131.106	Bus3	9.303	−8.525	31.7	−73.7
								Bus2	−384.705	−230.125	1126.6	85.8
								Bus5	−438.534	−274.827	1300.7	84.7
								Bus15	378.986	240.940	1128.7	84.4
								Bus9	223.393	141.425	664.5	84.5
								Bus9	0.008	0.005	0.0	85.7
Bus5	230.000	99.914	0.0	0	0	33.139	20.537	Bus1	−183.232	−125.532	558.0	82.5
								Bus4	438.601	275.040	1300.7	84.7
								Bus2	−288.562	−170.055	841.5	86.2
								Bus6	0.054	0.010	0.1	98.3
Bus6	230.000	99.533	−0.3	30.000	15.000	53.450	33.126	Bus11	−117.751	−82.473	362.6	81.9
								Bus12	87.306	70.447	282.9	77.8
								Bus13	7.070	−6.081	23.5	−75.8
								Bus5	−0.054	−0.010	0.1	98.4
								Bus9	−0.022	−0.009	0.1	92.0
Bus8	230.000	99.791	−0.1	30.000	16.000	0	0	Bus15	30.000	16.000	85.5	88.2
Bus9	230.000	99.732	−0.2	0	0	138.402	85.774	Bus15	−408.986	−255.651	1214.0	84.8
								Bus10	291.130	190.366	875.5	83.7
								Bus14	202.833	120.195	593.4	86.0
								Bus4	−223.393	−140.688	664.5	84.6
								Bus6	0.022	0.009	0.1	91.9
								Bus4	−0.008	−0.005	0.0	85.8
Bus10	230.000	99.684	−0.2	0	0	42.446	26.306	Bus9	−291.057	−190.172	875.5	83.7
								Bus11	248.610	163.866	749.8	83.5
Bus11	230.000	99.586	−0.3	0	0	130.684	80.990	Bus10	−248.472	−163.542	749.8	83.5
								Bus6	117.788	82.551	362.6	81.9
Bus12	230.000	99.479	−0.3	0	0	168.798	104.612	Bus6	−87.276	−70.385	282.9	77.8
								Bus13	−81.522	−34.226	223.1	92.2
Bus13	230.00	99.986	−0.3	0	0	61.08	37.85	Bus12	81.5	34.256	223.1	92.2
								Bus14	−135.57	−78.194	394.7	86.5
								Bus6	−7.0650	6.081	23.5	−75.8
Bus14	230.0	99.622	−0.2	0	0	67.04	41.553	Bus13	135.6	78.3	394.7	86.6
								Bus9	−202.69	−119.90	593.4	86.6
								Bus9	408.9	256.1	1214	84
Bus15	230.000	99.7	−0.1	0	0	0	0	Bus4	−378.9	−240.1	1128.7	84.5
								Bus8	−30.0	−15.996	85.5	88.2

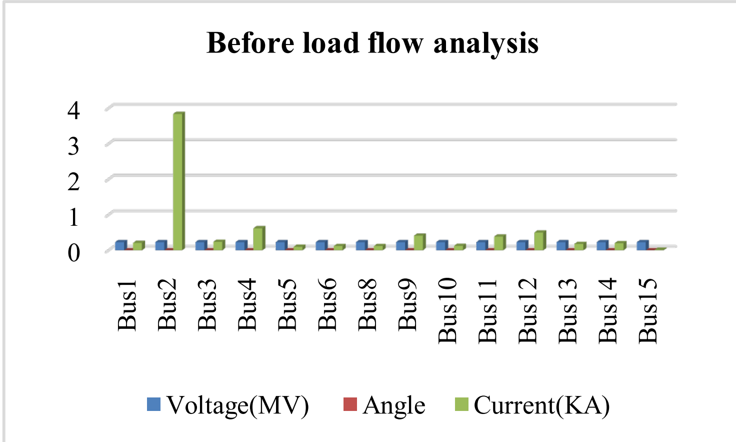

Figure 6. Graphical representation of voltage and current of IEEE-14 bus system before power flow analysis.

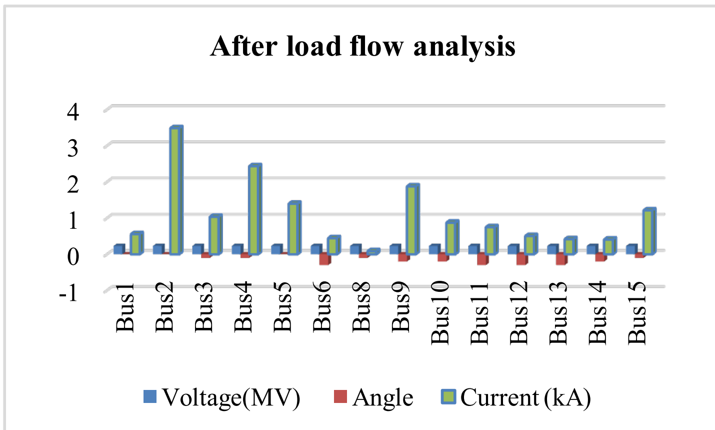

Figure 7. Graphical representation of voltage and current of IEEE-14 bus system after power flow analysis.

taking into consideration capability curve and load values to bring operation of generators under normal conditions. It is found that power flow analysis is comprehensively conducted through Newton Raphson method via ETAP software. This research depicts the importance of implementing Newton Raphson and using ETAP software at industrial and commercial levels. With a little change in voltage values at buses of power system, generators are brought to normal operating conditions. Power factor is not much compromised. Load is meeting in economic operating conditions. Weak branches are identified. Capacitor banks and static volt Ampere reactive compensator (SVC) would be the ultimate solution to make them strong. This load flow study would lead to the installation of flexible alternating current transmission system (FACTS) devices for reactive power compensation. This research led to the development of optimization algorithms for finding the location of FACTS devices. Transient and economic dispatch for circuit breaker placements and economics of generations will be the future work of this power flow analysis.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Muzzammel, R., Ahsan, M. and Ahmad, W. (2015) Non-Linear Analytic Approaches of Power Flow Analysis and Voltage Profile Improvement. 2015 *Power Generation System and Renewable Energy Technologies (PGSRET)*, Islamabad, June 2015, 1-7.

[2] Saadat, H. (1999) Power System Analysis. Mc Graw-hill, Inc., 2 Pennsylvania Plaza New York City.

[3] Stevenson, W.D. (1982) Elements of Paver System Analysis. McGraw-Hill, 2 Pennsylvania Plaza New York City.

[4] Athay, T. (1983) An Overview of Power Flow Analysis. 1983 *American Control Conference*, San Francisco, CA, USA, 22-24 June 1983, 404-410. https://doi.org/10.23919/ACC.1983.4788145

[5] Mešanović, A., Münz, U. and Ebenbauer, C. (2018) Robust Optimal Power Flow for Mixed AC/DC Transmission Systems with Volatile Renewables. *IEEE Transactions on Power Systems*, **33**, 5171-5182. https://doi.org/10.1109/TPWRS.2018.2804358

[6] Levron, Y., Guerrero, J.M. and Beck, Y. (2013) Optimal Power Flow in Microgrids with Energy Storage. *IEEE Transactions on Power Systems*, **28**, 3226-3234. https://doi.org/10.1109/TPWRS.2013.2245925

[7] Stott, B. (1974) Review of Load-Flow Calculation Methods. *Proceedings of the IEEE*, **62**, 916-929. https://doi.org/10.1109/PROC.1974.9544

[8] Fikri, M., Cheddadi, B., Sabri, O., Haidi, T., Abdelaziz, B. and Majdoub, M. (2018) Power Flow Analysis by Numerical Techniques and Artificial Neural Networks. 2018 *Renewable Energies*, *Power Systems & Green Inclusive Economy* (*REPS-GIE*), Casablanca, 23-24 April 2018, 1-5. https://doi.org/10.1109/REPSGIE.2018.8488870

[9] Montoya, O.D., Garrido, V.M., Gil-González, W. and Grisales-Noreña, L. (2019) Power Flow Analysis in DC Grids: Two Alternative Numerical Methods. *IEEE Transactions on Circuits and Systems II*: *Express Briefs*, 1-1. https://doi.org/10.1109/TCSII.2019.2891640

[10] Asrari, A. and Ramos, B. (2018) Power System Protection Upgrade at Anclote Plant a Case Study in Florida State. 2018 *IEEE Texas Power and Energy Conference* (*TPEC*), College Station, TX, 8-9 February 2018, 1-6. https://doi.org/10.1109/TPEC.2018.8312091

[11] Chandraratne, C., Woo, W.L., Logenthiran, T. and Naayagi, R.T. (2018) Adaptive Overcurrent Protection for Power Systems with Distributed Generators. 2018 8*th International Conference on Power and Energy Systems* (*ICPES*), Colombo, Sri Lanka, 21-22 December 2018, 98-103. https://doi.org/10.1109/ICPESYS.2018.8626908

[12] Soni, C.J., Gandhi, P.R. and Takalkar, S.M. (2015) Design and Analysis of 11 KV Distribution System Using ETAP Software. 2015 *International Conference on Computation of Power*, *Energy*, *Information and Communication* (*ICCPEIC*), Chennai, Chennai, 22-23 April 2015, 0451-0456. https://doi.org/10.1109/ICCPEIC.2015.7259526

[13] Alinejad-Beromi, Y., Sedighizadeh, M., Bayat, M.R. and Khodayar, M.E. (2007) Using Genetic Alghoritm for Distributed Generation Allocation to Reduce Losses and Improve Voltage Profile. 2007 42*nd International Universities Power Engineering Conference*, Brighton, 4-6 September 2007, 954-959. https://doi.org/10.1109/UPEC.2007.4469077