INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD ISSN: 2455-0620 Volume - 5, Issue - 4, Apr – 2019
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value: 86.87 Impact Factor: 6.497 Publication Date: 30/04/2019

Load Flow Analysis of 8-Bus Power System using ETAP

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Abstract: *Load flow analysis is used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic. The solution of load flow problem is so complicated and takes a long time to solve for simple bus power system, where for large bus power system computer program must be used to solve power flow problem. ETAP (Electrical Transient Analyzer Program) is the most powerful program to study load flow analysis comparing with other program because it's easy in use and faster solution. In this paper, load flow analysis is a steady state analysis based on the Newton-Raphson method whose objective is to determine various bus voltages and phase angle, active and reactive power flows through different branches, generators and loads of 8- bus power system by using ETAP. Furthermore, this paper also presents the application of shunt capacitor bank in load flow analysis of 8-bus power system is carried out with an approach to overcome the problem of an under voltage.*

Key Words: *load flow analysis, under voltage, bus voltage profile improvement, shunt capacitor bank, ETAP*

1. INTRODUCTION:

Load flow analysis in power system is the steady state solution of the power system network. The main information obtained from this analysis comprises the phase angles and magnitudes of load bus voltages, real and reactive power flow on transmission lines, reactive powers at generator buses, other variables being specified. This information is required for the continuous monitoring of the currents state of the system and for analyzing the effectiveness of alternative plans for future system expansion to meet increased the load demand. Newton-Raphson method, Gauss-Seidel method and Fast Decoupled method are commonly used to get the load flow solution. These three Numerical methods are techniques by which mathematical problems are formulated so that they can be solved with arithmetic operations and they usually provide only approximate solution. The most reliable and effective among the these load flow methods is the Newton-Raphson method because it is more accurate and converges fast.

Successful power system operation under normal balanced three-phase steady-state conditions requires; (a) generation supplies the demand (load) plus losses, (b) bus voltage magnitudes remain close to rated values, (c) generators operate within specified real and reactive power limits, (d) transmission lines and transformers are not overloaded. Therefore, reactive power control and voltage control in an electrical power system is important for proper operation for electrical power equipment to prevent damage such as overheating of motors and generators , to reduce transmission losses and to maintain the ability of the system to withstand and prevent voltage collapse. In this paper, the equipment used for voltage control and reactive power control is shunt capacitor injection. Capacitor banks are static equipment without any rotating parts and require less maintenance. They are installed as a single unit or as a bank to regulate the voltage and reactive power flows at the point where they are installed.

Before the advent of digital computers, the load flow studies were tedious and time consuming. With the availability of large size and very fast digital computers, all kinds of power system studies, including load flow, can be carried out conveniently. ETAP is a fully graphical Enterprise package that runs on Microsoft Windows operating systems and the most powerful program to study load flow analysis comparing with other program because it's easy in use and faster solution. The program operation imitates real electrical system operation as closely as possible. In this paper, load flow analysis is considered without shunt capacitor bank and with shunt capacitor bank by using the ETAP. The comparisons are on based of normal, load flow results with shunt capacitor bank described the voltage of loaded buses are increased within the specified range.

2. LOAD FLOW ANALYSIS:

The starting point for a load flow analysis is a single line diagram of the power system, from which the input data for computer solutions can be obtained. Input data consist of bus data, transformer data and transmission line data. As shown in Fig. 1, the following four variables are associated with each buses: voltage magnitude V, phase angle δ, net real power P, and reactive power Q supplied to the bus. At each bus, two of these variables are known as input data, and the other two are unknowns to be computed by the power flow program. Each bus is categorized into one of the following three bus types;

(1) Slack bus or swing bus: In a network as power flow from the generators to loads through transmission lines power losses occur due to the losses in the line conductors. These losses when included, the power balance relations are: Pg-Pd-PL = 0 and Qg-Qd-QL = 0, where Pg and Qg are the total real and reactive generations, Pd and Qd are the total real ancf reactive power demands and PL and QL are the power losses in the transmission network. The values of Pg, Qg, Pd and Qd are either estimated or known. Since the flow of cements in the various lines in the transmission lines are not known in advance, PL and QL remains unknown before the analysis of the network. However, the losses have to be supplied by the generators in the system. For this purpose, one of the generator buses is specified as swing bus or slack bus. At this bus the generation Pg and Qg are not specified. The voltage magnitude is specified at this bus. Further, the voltage phase angle δ is also fixed at this bus. Generally it is specified as 0° so that all voltage phase angles are measured with respect to voltage at this bus. For this reason swing bus is also known as reference bus. All the system losses are supplied by the generation at this swing bus. Further the system voltage profile is also influenced by the voltage specified at this slack bus. The three types of buses are illustrated in Fig. 1.

(2) Voltage controlled bus or generator bus: A voltage controlled bus is any bus in the system where the voltage magnitude can be controlled. The real power developed by a synchronous generator can be varied by changing the input of prime mover. This in turn changes the machine rotor axis position with respect to a synchronously rotating or reference axis or a reference bus. In other words, the phase angle of the rotor δ is directly related to the real power generated by the machine. The magnitude of voltage on the other hand, is mainly, influenced by the excitation current in the field winding. Thus at a generator bus the real power generation Pg and the voltage magnitude IVgI can be specified. It is also possible to produce Vars by using capacitor banks or reactor banks too. They compensate the leading or lagging Vars consumed and then contribute to voltage control. At a generator bus or voltage controlled bus, also called a PV bus the reactive power Qg and δg are the values that are not known and are to be computed.

(3) Load bus: A bus where there is only load connected and no generation exists is called a load bus. At this load bus, real and reactive load demand Pd and Qd are drawn from the supply. The demand is generally estimated or predicted as in load forecast or metered and measured from instruments. The reactive powers are calculated from real power demands with an assumed power factor. A load bus is also called a PQ bus. Since the load demands Pd and Qd are known values at this PQ bus. The other two unknown quantities at a load bus are voltage magnitude and its phase angle at the bus. In a power balance equation, the load demands Pd and Qd are treated as negative quantities since generated powers Pg and Qg are assumed positive.

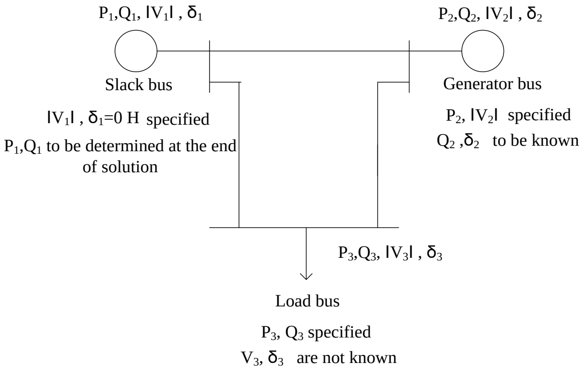


Fig. 1 Types of bus and bus variables

TABLE I
BUS CLASSIFICATION

Types of Bus	Specified Variables	Computed Variables
Slack bus	Voltage magnitude and its phase angle	Real and reactive power
Generator bus (PV)	Magnitudes of bus voltage and real power	Voltage phase angle and reactive power
Load bus (PQ)	Real and reactive power	Magnitude and phase angle of bus voltage

A. Newton-Raphson Method of Load Flow Solution

Newton- Raphson method is more efficient and practical for large power systems. Main advantage of this method is that the number of iterations required to obtain a solution is independent of the size of the problem and computationally it is very fast. Here, load flow solution is formulated in polar form;

$$P_i = \sum_{k=1}^{n} \mathrm{IV}_i\mathrm{I}\ \mathrm{IV}_k\mathrm{IIY}_{ik}\mathrm{I} \cos(\theta_{ik} - \delta_i + \delta_k) \tag{1}$$

$$Q_i = -\sum_{k=1}^{n} \mathrm{IV}_i\mathrm{I}\ \mathrm{IV}_k\mathrm{IIY}_{ik}\mathrm{I} \sin(\theta_{ik} - \delta_i + \delta_k) \tag{2}$$

The above Equation (1) and (2) constitute a set of non-linear algebraic equations in terms of $|V|$ in per unit and δ in radians. Equation (1) and (2) are expanded in Taylor's series about the initial estimate and neglecting all higher order terms, the following set of linear equations are obtained.

$$\left[\begin{array}{c} \Delta P_2^{(p)} \\ \vdots \\ \Delta P_n^{(p)} \\ \hline \Delta Q_2^{(p)} \\ \vdots \\ \Delta Q_n^{(p)} \end{array}\right] = \left[\begin{array}{ccc|ccc} \frac{\partial P_2^{(p)}}{\partial \delta_2^{(p)}} & \cdots & \frac{\partial P_2^{(p)}}{\partial \delta_n^{(p)}} & \frac{\partial P_2^{(p)}}{\partial \mathrm{IV}_2\mathrm{I}^{(p)}} & \cdots & \frac{\partial P_2^{(p)}}{\partial \mathrm{IV}_n\mathrm{I}^{(p)}} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(p)}}{\partial \delta_2^{(p)}} & \cdots & \frac{\partial P_n^{(p)}}{\partial \delta_n^{(p)}} & \frac{\partial P_n^{(p)}}{\partial \mathrm{IV}_2\mathrm{I}^{(p)}} & \cdots & \frac{\partial P_n^{(p)}}{\partial \mathrm{IV}_n\mathrm{I}^{(p)}} \\ \hline \frac{\partial Q_2^{(p)}}{\partial \delta_2^{(p)}} & \cdots & \frac{\partial Q_2^{(p)}}{\partial \delta_n^{(p)}} & \frac{\partial Q_2^{(p)}}{\partial \mathrm{IV}_2\mathrm{I}^{(p)}} & \cdots & \frac{\partial Q_2^{(p)}}{\partial \mathrm{IV}_n\mathrm{I}^{(p)}} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(p)}}{\partial \delta_2^{(p)}} & \cdots & \frac{\partial Q_n^{(p)}}{\partial \delta_n^{(p)}} & \frac{\partial Q_n^{(p)}}{\partial \mathrm{IV}_2\mathrm{I}^{(p)}} & \cdots & \frac{\partial Q_n^{(p)}}{\partial \mathrm{IV}_n\mathrm{I}^{(p)}} \end{array}\right] \left[\begin{array}{c} \Delta\delta_2^{(p)} \\ \vdots \\ \Delta\delta_n^{(p)} \\ \hline \Delta\ \mathrm{IV}_2\mathrm{I}^{(p)} \\ \vdots \\ \Delta\ \mathrm{IV}_n\mathrm{I}^{(p)} \end{array}\right]$$

In the above equation, the element of the swing bus variable voltage magnitude and angle are omitted because they are already specified. The element of Jocobian matrix are obtained after partial derivatives of equations (1) and (2) are expressed which gives linearized relationship between small changes in voltage magnitude and voltage angle. The equation can be presented in matrix form as;

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_3 \\ J_2 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta \mathrm{IVI} \end{bmatrix} \tag{3}$$

J_1, J_2, J_3, J_4 are the elements of the Jocobian matrix.

The difference between the schedule and calculated values known as power residuals for the terms $\Delta P_i^{(p)}$ and $\Delta Q_i^{(p)}$ is represented as;

$$\Delta P_i^{(p)} = P_i^{sch} - P_i^{(p)} \tag{4}$$

$$\Delta Q_i^{(p)} = Q_i^{sch} - Q_i^{(p)} \tag{5}$$

The new estimates for bus voltage are;

$$\delta^{(p+1)} = \delta_i^{(p)} + \Delta\ \delta_i^{(p)} \tag{6}$$

$$\mathrm{I\ VI}^{(p+1)} = \mathrm{IV}_i\ \mathrm{I}^{(p)} + \Delta\ \mathrm{IV}_i\mathrm{I}^{(p)} \tag{7}$$

B. Voltage Profile Improvement with Shunt Capacitor Bank

The shunt capacitors reduce the amount of inductive current in an electric circuit. The reduction in the line current decreases the IR and IX voltage drops, thereby improving the voltage level of the system from the capacitor location back to the source. In both the distribution and transmission systems, there is a need to maintain a voltage within the specified limit.

A lower system voltage will cause inductive loads to operate with a larger than nominal current. With lower voltages, the recovery voltages after fault clearing will be slow. Therefore, maintaining acceptable voltage levels in the power system is an important objective. A one-line diagram of a power system for the voltage drop analysis is shown in Fig. 2(a). The phasor diagram of the system without shunt capacitors is shown in Fig. 2(b). The corresponding voltage relations are:

$$V_R = V_S - I(\cos\theta \pm j\sin\theta)(R + jX) \tag{8}$$

where V_S = Sending end voltage/phase,
V_R = Receiving end voltage/phase,
I = Current, A,
R = Resistance,_/phase,
X= Reactance,_/phase and
θ = Power factor angle, degrees

The phasor diagram of the system with shunt capacitors is shown in Fig. 2 (c). The corresponding current relations are:

$$I' = I\,(\cos\theta \pm j\,\sin\theta\,) - j\,I_C \tag{9}$$

where the capacitor current is

$$I_C = \frac{V}{X_C} \tag{10}$$

The improved voltage profile at the load is due to the decrease in the line current and reduced voltage drop.

The addition of a shunt capacitor bank raises the voltage at the point of installation. The voltage drop equations without shunt capacitors (VD_1) and with shunt capacitors (VD_2) are:

$$VD_1 = \frac{kVA1}{(10)(kV)^2}\,(R\cos\theta_1 - j\sin\theta_1) \tag{11}$$

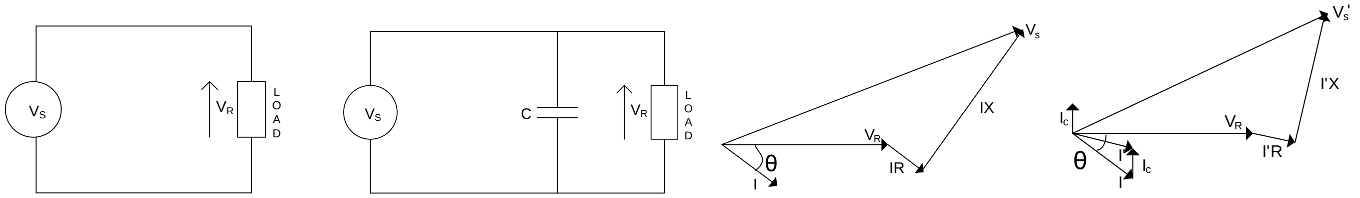
$$VD_2 = \frac{kVA2}{(10)(kV)^2}\,(R\cos\theta_2 - j\sin\theta_2) \tag{12}$$

$$VD1 - VD2 = \frac{1}{(10)(kV)^2}\,\{[R(kVA1\cos\theta_1 - kVA2\cos\theta_2)] + j\;X(kVA1\sin\theta_1 - kVA2\sin\theta_2)]\} \tag{13}$$

.

$$VD1 - VD2 = \frac{kVAc}{(10)(kV)^2}\,X \tag{14}$$

Where ($kVA1\cos\theta_1 - kVA2\cos\theta_2$) is the change in the real power, which is equal to zero. The other component, ($kVA1\sin\theta_1 - kVA2\sin\theta_2$), is the change in the reactive power due to the addition of reactive power supplied through shunt capacitors.



(a) (b) (c) (d)

Fig. 2 A one-line diagram of a power system for the voltage analysis: (a) and (c) without, (b) and (d) with shunt capacitor

C. Description of ETAP to Study Load Flow

ETAP is the most comprehensive solution for the simulation, design and analysis of generation, transmission, distribution, and industrial power systems. In ETAP, each research project makes available a set of users, user access controls, and a separate database in which its elements and connectivity data are stored. All interface views are fully graphical and the engineering properties of each circuit element can be edited directly from these views. The results are displayed on the interface views. Generally, ETAP has three modes of operation under Network Systems; Edit, AC and DC Study. The AC Study mode consists of analysis such as load flow, motor acceleration, transient stability, short circuit, and protective device coordination.

To work in load flow mode after creating the research project, follow these instructions: (a) Firstly, go to load flow mode by clicking the load flow analysis button on the mode toolbar. The load flow toolbar is now displayed and the top toolbar becomes the study case toolbar. (b) Click the run load flow button on the load flow toolbar. The study results will be displayed on the one-line diagram. (c) Review the results and familiarize with the type of information displayed on one-line diagram. (d) Click the display options button and explore the variety of options available for the results. (e) Click the alert button to display critical and marginal limit violations for the output report. (f) Click the report manager button to view any part of the output report. (g) Click the edit button and study the solution parameters and alert settings available for load flow analysis.

3. CASE STUDY: LOAD FLOW ANALYSIS USING ETAP:

A. Input Data of 8- Bus Power System Model

Fig. 3 shows single line diagram of 8- bus power system model. The input data of 8-bus power system model are shown in Tables II, III, IV, V, and VI. According to these Tables, the 8 bus system model was created in Edit model of ETAP, Generator 1 is set up to be the slack generator at bus 1. Generator 2 is set up to be 200 MW output at bus 7. The connected loads are 70 MW, 25 Mvar (inductive) at bus 2, 60 MW , 30 Mvar (inductive) at bus 3, 70 MW, 30

Mvar (inductive) at bus 4, 50 MW, 25 Mvar (inductive) at bus 5, 50 MW, 40 Mvar (inductive) at bus 6, and 80 MW, 30 Mvar (inductive) at bus 8.

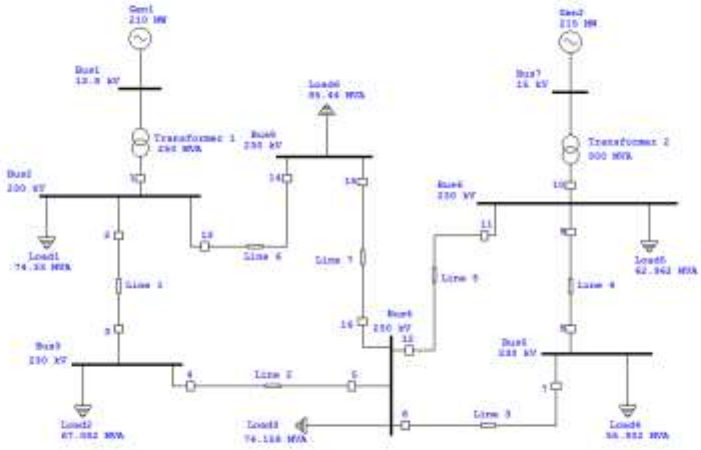


Fig. 3 One line diagram of 8-bus power system model using ETAP

Table II
Load (PV) bus input data of 8-bus power system model

Bus		Initial Voltage		Load	
ID	kV	% Mag.	Ang.	MW	Mvar
2	230.000	100	0	70	25
3	230.000	100	0	60	30
4	230.000	100	0	70	30
5	230.000	100	0	50	25
6	230.000	100	0	50	40
8	230.000	100	0	80	30

Total Number of Load Buses: 6 380 180

Table III
Generation (PQ) bus input data of 8-bus power system model

Generation Bus			Voltage		Generation		Mvar Limts	
ID	kV	Type	% Mag.	Ang.	MW	Mvar	Max	Min
1	13.800	Swing	100	0				
7	15.00	Voltage Control	100	0	200		125	-125

Table IV
2 -Winding transformer input data of 8-bus power system model

Transformer		Rating					Z Variations		% Tap Setting		Adjusted	Phase Shift	
ID	Phase	MVA	Pri kV	Sec kV	%Z1	X1/R1	+5%	-5%	Pri	Sec	%Z	Type	Angle
Tr-1	3-Phase	250	13.8	230	0.1	99999.000	0	0	0	0	0.1	YNd	0
Tr- 2	3-Phase	300	15.0	230	0.1	99999.000	0	0	0	0	0.1	YNd	0

Table V
Line/Cable input data of 8-bus power system model

Line/Cable	Length		Ohms or Siemens/1000 m per Conductor (Cable) or Phase (Line)		
ID	Adj (m)	Phase	T(℃)	R	X
Line 1	60000	1	75	0.08	0.5

Line 2	60000	1	75	0.08	0.5
Line 3	50000	1	75	0.08	0.5
Line 4	60000	1	75	0.08	0.5
Line 5	60000	1	75	0.08	0.5
Line 6	60000	1	75	0.08	0.5
Line 7	50000	1	75	0.08	0.5

Line/Cable resistance are listed at the specified temperatures.

Table VI
Branch connection of 8-bus power system model

CKT/Branch		Connected Bus		% Impedance, Pos. Seq., 100 MVA Base		
ID	**Type**	**From Bus**	**To Bus**	**R**	**X**	**Y**
Tr-1	2W XFMR	Bus 1	Bus 2	0.00	0.04	0.04
Tr-2	2W XFMR	Bus 7	Bus 6	0.00	0.03	0.03
Line 1	Cable	Bus 2	Bus 3	0.91	5.67	5.74
Line 2	Cable	Bus 4	Bus 3	0.91	5.67	5.74
Line 3	Cable	Bus 5	Bus 4	0.76	4.73	4.79
Line 4	Cable	Bus 6	Bus 5	0.91	5.67	5.74
Line 5	Cable	Bus 6	Bus 4	0.91	5.67	5.74
Line 6	Cable	Bus 8	Bus 2	0.91	5.67	5.74
Line 7	Cable	Bus 8	Bus 4	0.76	4.73	4.79

Table VII
Bus input data and unknown data of 8- bus power system model

Bus	Input Data	Unknowns
1	$V_1 =$ 13.8 kV, $\delta_1 = 0$ H	P_{G1}, Q_{G1}
2	$P_{L1} = 70$ MW, $Q_{L1} = 25$ Mvar	V_2, δ_2
3	$P_{L2} = 60$ MW, $Q_{L2} = 30$ Mvar	V_3, δ_3
4	$P_{L3} = 70$ MW, $Q_{L3} = 30$ Mvar	V_4, δ_4
5	$P_{L4} = 50$ MW, $Q_{L4} = 25$ Mvar	V_5, δ_5
6	$P_{L5} = 50$ MW, $Q_{L5} = 40$ Mvar	V_6, δ_6
7	$P_{G2} = 200$ MW, $V_7 = 15$ kV	Q_{G2}, δ_7
8	$P_{L6} = 80$ MW, $Q_{L6} = 30$ Mvar	V_8, δ_8

B. Load Flow Results of 8- Bus Power System Model without Shunt Capacitor Bank (Case Study I)

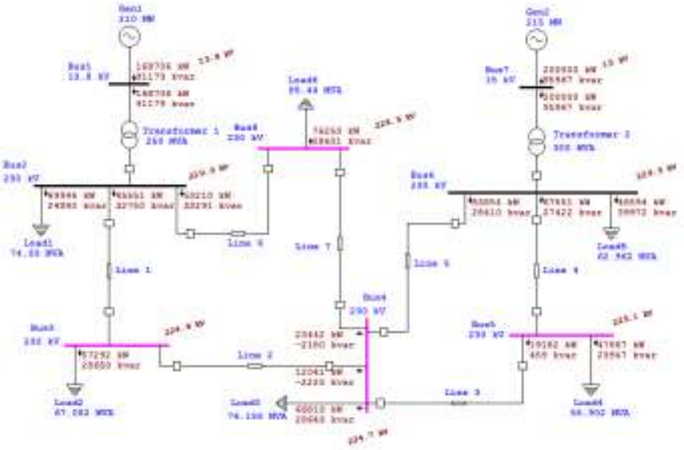


Fig. 3 Illustrates load flow results of 8-bus power system model using ETAP

The load flow results are shown in Fig. 4. The detail load flow report from the report manager after running the Newton-Raphson load flow analysis are shown in Tables VIII, IX, X, XI, XII and XIII.

Table VIII
Load flow report of 8- bus power system model

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	**kV**	**% Mag**	**Ang**	**MW**	**Mvar**	**MW**	**Mvar**	**ID**	**MW**	**Mvar**	**Amp**	**% PF**	**% Tap**
*Bus 1	13.8	100	0	168.706	91.179	0	0	Bus 2	168.706	91.179	8023.0	88.0	
Bus 2	230	99.964	0	0	0	69.946	24.99	Bus 3	45.551	32.750	140.9	81.2	
								Bus 8	53.210	33.291	157.6	84.8	
								Bus 1	-168.706	-91.032	481.4	88.0	
Bus 3	230	97.719	-1.4	0	0	57.292	28.650	Bus 2	-45.265	-30.964	140.9	82.5	
								Bus 4	-12.027	2.314	31.5	-98.2	
Bus 4	230	97.699	-1.0	0	0	66.813	28.643	Bus 3	12.041	-2.225	31.5	-98.3	
								Bus 5	-19.153	-0.277	49.2	100.0	
								Bus 6	-83.143	-23.961	222.3	96.1	
								Bus 8	23.442	-2.180	60.5	-99.6	
Bus 5	230	97.865	-0.4	0	0	47.887	23.947	Bus 4	19.182	0.459	49.2	100.0	
								Bus 6	-67.069	-24.406	183.1	94.0	
Bus 6	230	99.968	1.7	0	0	48.594	39.972	Bus 5	67.551	27.442	183.1	92.7	
								Bus 4	83.854	28.410	222.3	94.7	
								Bus 7	-200.0	-95.803	556.8	90.2	
*Bus 7	15	100.000	1.7	200.0	95.967	0	0	Bus 6	200.0	95.967	8538.3	90.2	
Bus 8	230	97.630	-1.6	0	0	76.250	28.601	Bus 2	-52.852	-31.055	157.6	86.2	
								Bus 4	-23.398	2.454	60.5	-99.5	

* Indicates a voltage regulated bus (voltage controlled or swing type machine connected to it)
# Indicates a bus with a load mismatch of more than 0.1 MVA

Table IX
Bus loading summary report of 8- bus power system model

Bus		Directly Connected Load		Total Bus Load			
ID	**kV**	**MW**	**Mvar**	**MVA**	**% PF**	**Amp**	**% Loading**
Bus 1	13.8	0	0	191.769	88.0	8023.0	
Bus 2	230	69.946	24.99	191.699	88.0	481.4	
Bus 3	230	57.292	28.650	65.124	88.0	167.3	
Bus 4	230	66.813	28.643	106.230	96.3	272.9	
Bus 5	230	47.887	23.947	71.371	94.0	183.1	
Bus 6	230	48.594	39.972	221.762	90.2	556.8	
Bus 7	15	0	0	221.833	90.2	8538.3	
Bus 8	230	76.250	28.601	82.332	92.6	211.7	

* Indicates operating load of a bus exceeds the bus critical limit (100 % of the continuous Ampere rating)
# Indicates operating load of a bus exceeds the bus marginal limit (95 % of the continuous Ampere rating)

Table X
Branch loading summary report of 8- bus power system model

CKT/Branch			Loading Input		Loading Output	
ID	**Type**	**Capability (MVA)**	**MVA**	**%**	**MVA**	**%**
Tr-1	Transformer	250	191.769	76.7	191.699	76.7
Tr-2	Transformer	300	221.833	73.9	221.762	73.9

* Indicates a branch with operating load exceeding the branch capability.

Table XI
Branch losses summary report of 8- bus power system model

CKT/Branch	From -To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		% drop in V_{mag}
ID	**MW**	**Mvar**	**MW**	**Mvar**	**kW**	**kvar**	**From**	**To**	**V_d %**
Tr - 1	168.706	91.179	-168.706	-91.032	0.0	147.1	100.0	100.0	0.04
Line 1	45.551	32.750	-45.265	-30.964	285.8	1786.2	100.0	97.7	2.24
Line 6	53.210	33.291	-52.852	-31.055	357.7	2235.8	100.0	97.6	2.33
Line 2	-12.027	2.314	12.041	-2.225	14.3	89.1	97.7	97.7	0.02
Line 3	-19.153	-0.277	19.182	0.459	29.1	181.7	97.7	97.9	0.17
Line 5	-83.143	-23.961	83.854	28.410	711.7	4448.2	97.7	100.0	2.27
Line 7	23.442	-2.180	-23.398	2.454	43.9	274.4	97.7	97.6	0.07
Line 4	-67.069	-24.406	67.551	27.422	482.6	3016.2	97.9	100.0	2.10
Tr-2	-200.0	-95.803	200.0	95.967	0.0	164.0	100.0	100.0	0.03
					1925.1	12342.7			

Table XII (A)
Alert setting of 8- bus power system model

	% Alert Setting	
Loading	Critical	Marginal
Bus	100.0	95.0
Cable	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Bus voltage (Over)	105.0	102.0
Bus voltage (Under)	95.0	98.0
Generator (OverExcited Q Max)	100.0	95.0
Generator (UnderExcited Q Min)	100.0	

Table XII (B)
Marginal report of 8- bus power system model

Device ID	**Type**	**Condition**	**Rating/Limit**	**Unit**	**Operating**	**% Operating**	**Phase Type**
Bus 3	Bus	Under Voltage	230.0	kV	224.75	97.7	3-Phase
Bus 4	Bus	Under Voltage	230.0	kV	224.71	97.7	3-Phase
Bus 5	Bus	Under Voltage	230.0	kV	225.09	97.9	3-Phase
Bus 8	Bus	Under Voltage	230.0	kV	224.55	97.6	3-Phase

Table XIII
Total summary of generation, loading and demand

Type	**MW**	**Mvar**	**MVA**	**% PF**
Swing Buses	168.706	91.179	191.769	87.97 Lagging
Non-Swing Bus	200.0	95.967	221.833	90.16 Lagging
Total Demand	368.706	187.146	413.483	89.17 Lagging
Total Static Load	366.781	174.803	406.306	90.27 Lagging
Apparent Losses	1.925	12.343		

Number of Iterations :3

C. Load Flow Results of 8- Bus Power System Model with Shunt Capacitor Bank (Case Study II)

According to the alert view of case study I, the voltage of buses 3, 4, 5 and 8 are under voltage which is shown in Fig. 3 and Table XII (B). To overcome the problem of these under voltage, shunt capacitor banks rated at 35 Mvar (capacitive) were connected to the load bus 3, 4, 5 and 8. After adding the shunt capacitor banks, the voltage at the load buses 3, 4, 5 and 8 are increased within the specified limit which is shown in Fig. 4. Therefore, there is no alert view in this case study II. The detail load flow report from the report manager after running the Newton-Raphson load flow analysis are shown in Tables XIV, XV, XVI, XVII, XVIII, and XIX.

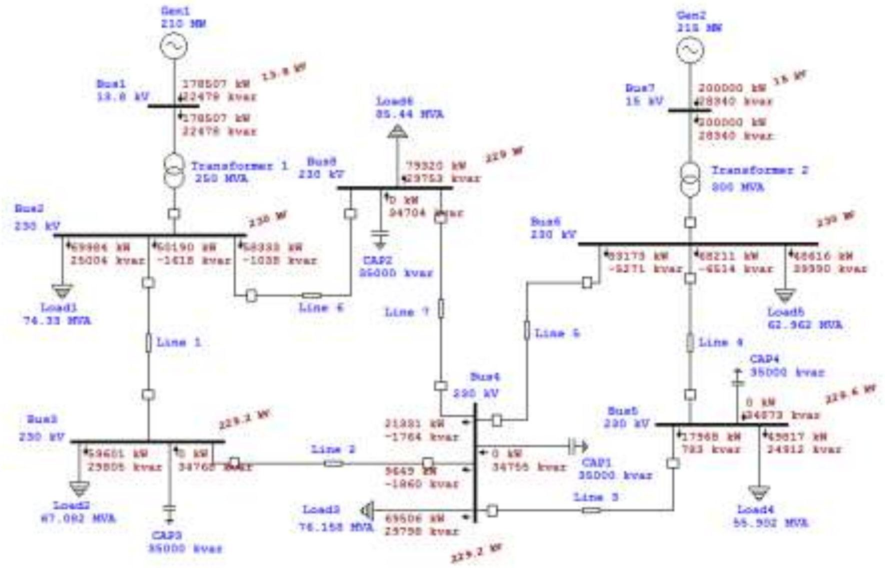


Fig. 4 Illustrates load flow results of 8-bus power system model using ETAP

Table XIV
Load flow report of 8- bus power system model

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	**kV**	**% Mag**	**Ang**	**MW**	**Mvar**	**MW**	**Mvar**	**ID**	**MW**	**Mvar**	**Amp**	**% PF**	**% Tap**
*Bus 1	13.8	100	0	178.507	22.478	0	0	Bus 2	178.507	22.478	7527.2	99.2	
Bus 2	230	99.991	0	0	0	69.984	25.004	Bus 3	50.190	-1.618	126.1	-99.9	
								Bus 8	58.33	-1.038	146.5	-100.0	
								Bus 1	-178.507	-22.348	451.6	99.2	
Bus 3	230	99.668	-1.7	0	0	59.601	-4.963	Bus 2	-49.961	3.048	126.1	-99.8	
								Bus 4	-9.640	1.915	24.8	-98.1	
Bus 4	230	99.649	-1.4	0	0	69.506	-4.957	Bus 3	9.649	-1.860	24.8	-98.2	
								Bus 5	-17.943	-0.629	45.2	99.9	
								Bus 6	-82.542	9.211	209.2	-99.4	
								Bus 8	21.331	-1.764	53.9	-99.7	
Bus 5	230	99.818	-0.9	0	0	49.817	-9.961	Bus 4	17.968	0.783	45.2	99.9	
								Bus 6	-67.785	9.178	172.0	-99.1	
Bus 6	230	99.991	1.4	0	0	48.616	39.990	Bus 5	68.211	-6.514	172.0	-99.5	
								Bus 4	83.173	-5.271	209.2	-99.8	
								Bus 7	-200.0	-28.204	507.1	99.0	
*Bus 7	15	100.000	1.4	200.0	28.340	0	0	Bus 6	200.0	28.340	7774.9	99.0	
Bus 8	230	99.576	-2.0	0	0	79.320	-4.951	Bus 2	-58.025	2.969	146.5	-99.9	
								Bus 4	-21.296	1.982	53.9	-99.6	

* Indicates a voltage regulated bus (voltage controlled or swing type machine connected to it)
\# Indicates a bus with a load mismatch of more than 0.1 MVA

Table XV
Bus loading summary report of 8- bus power system model

Bus		Directly Connected Load		Total Bus Load			
ID	**kV**	**MW**	**Mvar**	**MVA**	**% PF**	**Amp**	**% Loading**
Bus 1	13.8	0	0	179.917	99.2	7527.2	
Bus 2	230	69.984	25.004	180.250	99.0	452.5	
Bus 3	230	59.601	-4.963	69.001	86.4	173.8	
Bus 4	230	69.506	-4.957	107.791	93.2	271.5	
Bus 5	230	49.817	-9.961	76.229	88.9	191.7	
Bus 6	230	48.616	39.990	203.959	98.1	512.0	
Bus 7	15	0	0	201.998	99.0	7774.9	
Bus 8	230	79.320	-4.951	86.580	91.6	218.3	

* Indicates operating load of a bus exceeds the bus critical limit (100 % of the continuous Ampere rating)
# Indicates operating load of a bus exceeds the bus marginal limit (95 % of the continuous Ampere rating)

Table XVI
Branch loading summary report of 8- bus power system model

CKT/Branch			Loading Input		Loading Output	
ID	**Type**	**Capability (MVA)**	**MVA**	**%**	**MVA**	**%**
Tr-1	Transformer	250	179.917	72.0	179.901	72.0
Tr-2	Transformer	300	201.998	67.3	201.979	67.3

* Indicates a branch with operating load exceeding the branch capability.

Table XVII
Branch losses summary report of 8- bus power system model

CKT/Branch	From -To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		% drop in V_{mag}
ID	**MW**	**Mvar**	**MW**	**Mvar**	**kW**	**kvar**	**From**	**To**	**V_d %**
Tr - 1	178.507	22.478	-178.507	-22.348	0.0	129.5	100.0	100.0	0.01
Line 1	50.190	-1.618	-49.961	3.048	228.8	1430.3	100.0	99.7	0.32
Line 6	58.333	-1.038	-58.025	2.969	308.9	1930.7	100.0	99.6	0.42
Line 2	-9.640	1.915	9.649	-1.860	8.8	55.1	99.7	99.6	0.02
Line 3	-17.943	-0.629	17.968	0.783	24.5	153.4	99.6	99.8	0.17
Line 5	-82.542	9.211	83.173	-5.271	630.3	3939.6	99.6	100.0	0.34
Line 7	21.331	-1.764	-21.296	1.982	34.9	218.0	99.6	99.6	0.07
Line 4	-67.785	9.178	68.211	-6.514	426.1	2663.2	99.8	100.0	0.17
Tr-2	-200.0	-28.204	200.0	28.340	0.0	136.0	100.0	100.0	0.01
					1662.5	10655.8			

Table XVIII (A)
Alert setting of 8- bus power system model

	% Alert Setting	
Loading	Critical	Marginal
Bus	100.0	95.0
Cable	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Bus voltage (Over)	105.0	102.0

Bus voltage (Under)	95.0	98.0
Generator (OverExcited Q Max)	100.0	95.0
Generator (UnderExcited Q Min)	100.0	

Table XVIII (B)
Alert view (Critical & Marginal) of 8- bus power system model

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type

Table XIX
Total summary of generation, loading and demand

Type	MW	Mvar	MVA	% PF
Swing Buses	178.507	22.478	179.917	99.22 Lagging
Non-Swing Bus	200.0	28.340	201.998	99.01 Lagging
Total Demand	378.507	50.818	381.903	99.11 Lagging
Total Static Load	376.845	40.162	378.979	99.44 Lagging
Apparent Losses	1.622	10.656		

Number of Iterations: 3

4. CONCLUSION:

In this paper, load flow analysis of 8-bus power system model was tested both case study I and II by using ETAP 12.6. Through these studies, the active and reactive power losses, the voltage drop in the lines were identified. In case study I, there is some bus voltage less than the specified limit (marginal alert setting) that voltage levels outside of a specified limit can affect the operation of the customer's loads. In case study II, shunt capacitor banks were used to maintain the voltage magnitude of the system within the controllable voltage limit at all system load buses. The results of load flow analysis after adding shunt capacitor bank described all the bus voltage could be set within the specified limit (98 % to 102 % of rated voltage). Furthermore, not only the power factors of the total system were improved but also the real power losses of the system were reduced significantly.

REFERENCES:

1. P.Kundur, (1994), Power System Stability and Control, First Edition, McGraw-Hill, Inc., New York.
2. P.S.R Murty, (2007), Power System Analysis , BS Publications, Hyderabad, India.
3. D P Kothari, I J Nagrath, (2003), Modern Power System Analysis, Third Edition, Ta Ta McGraw-Hill, New Delhi, India.
4. B.M Weddy, B.J Cory, N. Jenkins, J. B. Ekanayake, G. Strbac, (2012), Electric Power System, Fifth Edition, John Wiley and Sons Ltd, United kingdom
5. Ramasamy Natarajan, (2005), Power System Capacitors, CRC Press, Taylor and Francis Group, USA.
6. DEBAPRIYA DAS, (2006), Electrical Power Systems, New Age International Ltd, New Delhi, India.