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LOAD FLOW ANALYSIS OF AN EHT NETWORK USING ETAP®

Muhammad Naveed Malik, Ateeb Iftikhar Toor and Muhammad Asim Siddiqui
Electrical Engineering
PNEC-NUST
Karachi Pakistan

Nusrat Husain and Akif Nadeem
Electrical Engineering, Faculty Members
PNEC-NUST
Karachi Pakistan

***Abstract*—Load flow analysis is one of the major tools of power system analysis. It can be used for the modeling & designing of extra high tension (EHT) network. Load flow analysis is vastly used for making the highly controllable power balance among the utilities and loads. It is also essentially used by the engineers in designing, running, maintaining and economic scheduling of electrical power systems. Through this analysis very important parameters of bus & transmission line are determined i.e. phase angle & magnitude of voltage and flow of active/reactive power respectively. In this paper, a work is presented based on simulation and analysis of a 132 kV EHT network with the help of ETAP® software. At the end, conclusions are drawn on the basis of performed analysis.**

***Keywords*—Power Systems; EHT Network; Load Flow Analysis; ETAP; Under Voltage; Capacitor banks.**

I. INTRODUCTION

When a power network goes through a non steady state condition or when it subjects to some sort of inequality power balance condition, there is a need for a complete electrical solution in which the this analysis is the key tool.

In the load flow solution of an electrical network, first we must know the constraints that can produce problems for an electrical network such as the nodal voltages, their phase angles, reactive power generation/absorption and tap arrangements of transformers under varying load etc. [1]

Due to increase in the load demand the designing of new power system and sometimes extension in the existing power network is required, for that electrical engineers go through the detail process of numerical calculations of the network both under normal and abnormal operating conditions. An abnormal condition in the network can be an outage of any transmission line, a particular load or an outage of a generating source. The initial transient behavior of the system is also studied under such load flow analysis.

There could be two possible ways for solving the operating condition of the power system (*i*) balanced, or (*ii*) unbalanced condition. For that load flow problem is solved by these two steps

(*i*) System equations formulation.

(*ii*) Mathematical techniques for solving these equations. [2]

II. BUS CLASSIFICATION

Magnitude & phase angle of voltage and real & the reactive power are the main quantities that are associated with the bus or the node in the power system. On the basis of these four quantities, buses are classified into three categories two of which are specified and the remaining two can be found out by the solution of the equations.

The categories are following: [3]

A. LOAD BUS:

Active & reactive power of Load bus is specified but phase angle & magnitude of the bus voltage is determined. The load bus that can be allowed to vary the voltage by a permissible value such as 5% would only to specify the active power (*PD*) and reactive power (*QD*) while the voltage phase angle is not that much important. [3]

B. GENERATOR OR VOLTAGE COTROLLED BUS:

The rated real power (*PG*) and rated magnitude of voltage is specified for this bus. The remaining two quantities that are the voltage phase angle and the reactive power generation (*QG*) of the bus is determined. [3]

C. SLACK, REFERENCE OR SWING BUS:

In Swing Bus magnitude & phase angle of the voltage is known whereas the real power (*PG*) and reactive power (*QG*) is determined by the load flow solution.

This is the type of the generator bus that contributes to the transmission losses to make additional real and reactive power supply. For this reason this bus is also known as the swing or slack bus. [3]

TABLE 1: Summary of all three types of buses [1]

Bus classification	**Specified parameters**	**Obtained parameters**
Generator bus	*Voltage magnitude, Active Power*	*Voltage angle, Reactive power*

TABLE 1 **(Contd.)**

Swing bus	*Voltage magnitude, Voltage angle*	*Active Power, Reactive power*
Load bus	*Active Power, Reactive power*	*Voltage magnitude, Voltage angle*

III. COMPARISON OF LOAD FLOW METHODS

TABLE 2: Comparison Of Various Load Flow Methods

S. No	PARAMETER OF COMPARISION	NEWTON RAPHSON	GAUSS SIEDEL	FAST DECOUPLED
1	Coordinates	Rectangular coordinates	Polar coordinates	Polar coordinates
2	Arithmetic operations	Less in number to complete one iteration	Jacobian elements will be evaluated in each iteration	Less in number while comparing Newton Raphson
3	Time	Less time involved in each iteration, but increases with high number of buses	Seven times of Gauss Seidel	Less time compared to both
4	Convergence	Linear	Quadratic	Geometric
5	No. of iterations	Large number depends upon no of buses	Very less (3 to 5) And is practically constant	Only 2 to 5 iterations for practical accuracies
6	Slack bus selection	Affects convergence adversely	Minimum sensitivity	Modest
7	Accuracy	Less	High	Modest
8	Memory	Less	Large	Less than Newton Raphson
9	Application	For smaller systems	For larger systems	Optimization and multiple load flow studies
10	Programming logic	Easy	Less Easy	Modest
11	Reliability	Better for smaller systems	Better for larger systems	Better than Newton Raphson

I. ABOUT ETAP

ETAP is the abbreviation of the 'Electrical Transient Analyzer Program'. Its model-driven architecture provides the faster and real time data to its users, engineers, operators, and managers. It also provides the data and analysis which helps the operator to estimate the forecasting behavior, preventive action, and situational aptitude. One of its best features is that it provides the environment for the continuous functionality from designing to processing.
ETAP is the complete guide for electrical engineers and it offers a complete solution to all the electrical problems such as the power flow, arc flash & short circuit analysis, transient stability, relay coordination, cable selection, and best possible power flow.
It provides a customize solution for any company consists of a small or large power system. Here we are focusing on an extra high tension (EHT) line having rating of 132 kV. [4]

II. DETAILS OF THE EHT NETWORK COMPONENTS

Table 3 below is showing various components of the selected EHT network in which three phase power transformers, current transformers and three phase feeders are present.

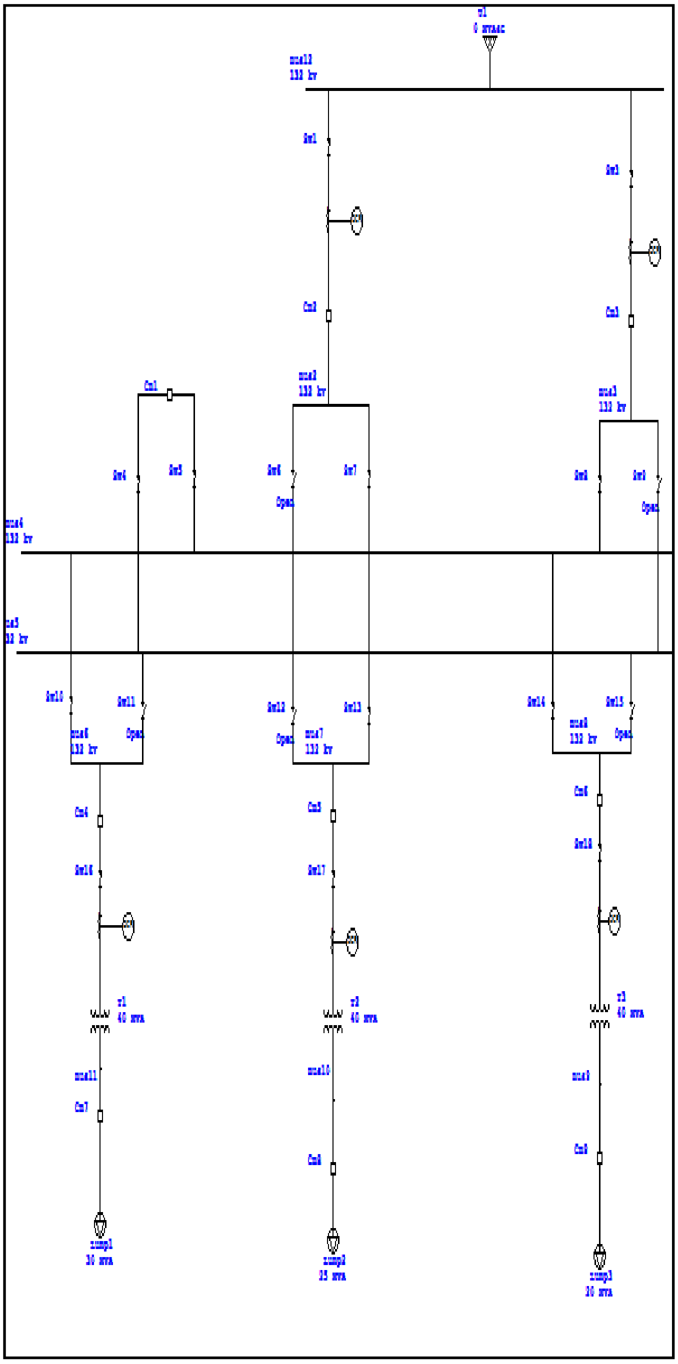
TABLE 3: The Components Used For The Modeling Of The EHT Network

Component	Label	Ratings	
Power Transformer	T 1	40 MVA	
	T 2	40 MVA	
	T 3	40 MVA	
Current Transformer		PRIM	SEC
	CT 1	200 A	1 A
	CT 2	200 A	1 A
	CT 3	200 A	1 A
	CT 4	200 A	1 A
	CT 5	200 A	1 A
Feeders	Lump Load 1	30 MVA, 1443 A	
	Lump Load 2	25 MVA, 1203 A	
	Lump Load 3	20 MVA, 962.3 A	

III. SIMULATION OF A 132 kV SUBSTATION BY USING ETAP:

The network consists of a power grid that supplies the 132 kV supply to the bus 2 and bus 3 with the help of the swing bus 12. Bus 6, bus 7 and bus 8 supply, 132 kV to the primaries of the three phase transformers T1, T2 and T3, respectively. These transformers step down the 132 kV supply to 12 kV and supply this voltage to bus 9, bus 10 and bus 11. Then these buses are connected to three phase feeders having lumped loads; load1, load2 and load3, respectively. [7]

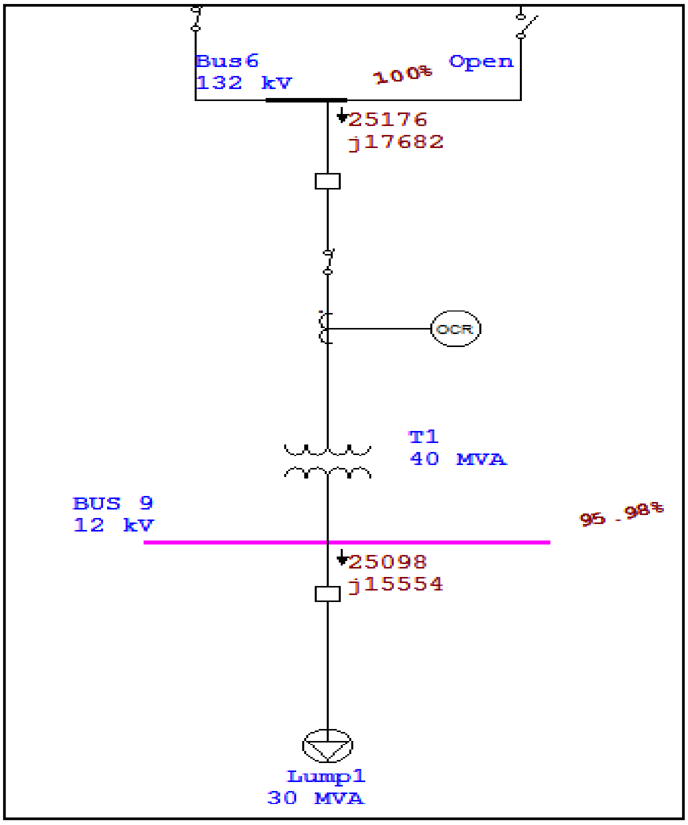
Figure 1: Simulated substation in ETAP



IV. POWER FLOW ANALYSIS

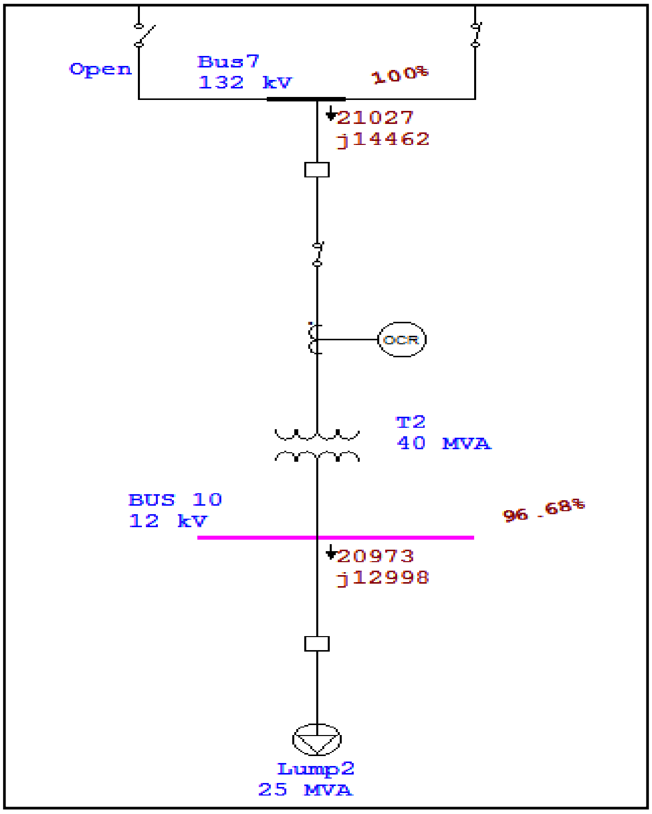
The power/load flow analysis of the substation starts by clicking the load flow analyzer button. By analyzing the substation, the ETAP gives prompt of the under voltage bus 9 with the voltage level of 95.98% of the rated voltage as shown in the figure 2(A). [1][5]

Figure 2(A): Bus 9 facing under voltage



The bus 10 is also facing under voltage with the voltage level of 96.98% of the rated voltage as shown in Figure 2(B).

Figure 2(B): Bus 10 facing under voltage



Bus 11 is also facing under voltage with the voltage level of 97.38% of the rated voltage as shown in Figure 2(C).

Figure 2(C): Bus 11 facing under voltage

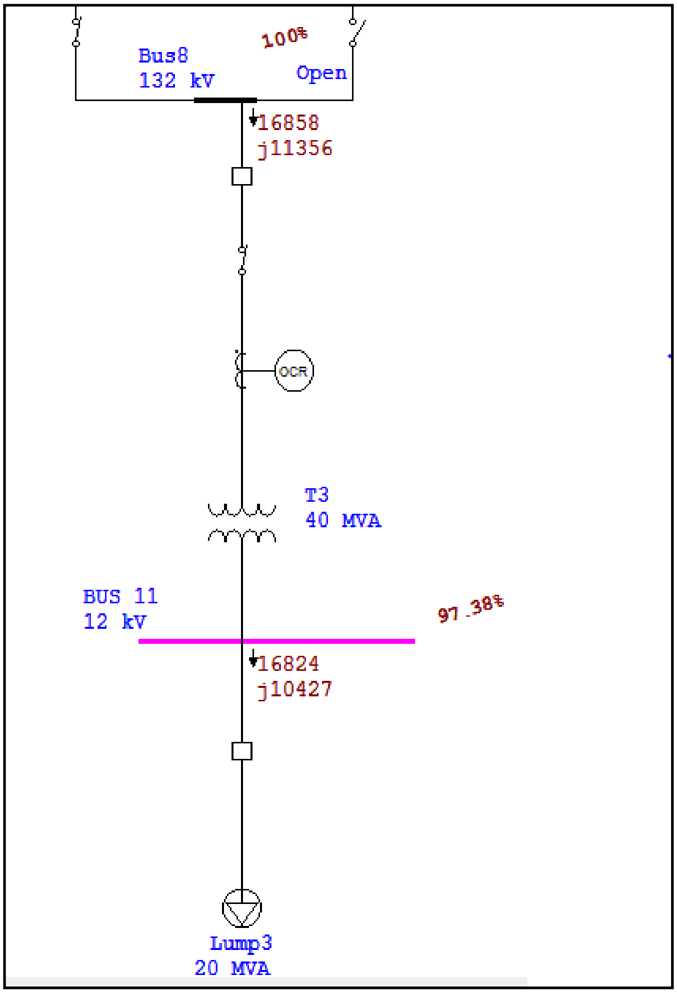


TABLE 4: Real/Reactive Power And Power Factor (%PF) Of The Under Voltage Buses

Monitoring Points	**Rated kV**	**MW**	**MVAr**	**%PF**
Bus 9	12	25.500	15.803	85.2
Bus 10	12	21.250	13.170	85.7
Bus 11	12	17.000	10.536	85.5

Here the monitoring points show clearly that the reactive power of all the three buses is high with a low power factor.

V. ETAP ALERT VIEW

During the load flow analysis the ETAP gives the different alerts for the condition to be solved on urgent basis. It shows the operating condition of device and shows whether the condition is marginal or critical.

TABLE 5: Alert View Of The ETAP

Device Id	**Condition**	**Rated Voltage**	**Operating Voltage**	**%Kv**
Bus 9	Under Voltage	12 KV	11.517	96
Bus 10	Under Voltage	12 KV	11.602	96.7
Bus 11	Under Voltage	12 KV	11.685	97.4

VI. SOLUTION FOR THE UNDER VOLTAGE PROBLEM BY PERFORMING LOAD FLOW ANALYSIS

The problem of the under voltage for bus 9, bus 10 and bus 11 can be solved by placing the capacitor banks in parallel with the three phase feeders. These capacitor banks produce the leading current and absorb the reactive power of the bus.

HOW TO FIND THE CAPACITOR BANK RATING?

Rating of capacitor bank is calculated by using the following formula

Rating of Capacitor Bank
MVAr = MW * (Tan ф1 – Tan ф2)

Where ф1 and ф2 can be calculated as:

Cos ф1 = Existing Power Factor
Cos ф2 = Required Power Factor [3]

Figure 3(A) shows the solution for the Bus 9. Here we can see the shunt capacitor bank with value of 12.151 MVAr which improves the voltage level from 96% to 98.74%.

Figure 3(B) shows the solution for the Bus 10 here you can see the shunt capacitor bank with value of 10.126 MVAr which improves the voltage level from 96.7% to 98.98%.

Figure 3(C) shows the solution for Bus 10 here you can see the shunt capacitor bank in parallel with value of 8.1 MVAr which improves the voltage level from 97.4% to 99.21%.

Figure 3(A): Solution for bus 9

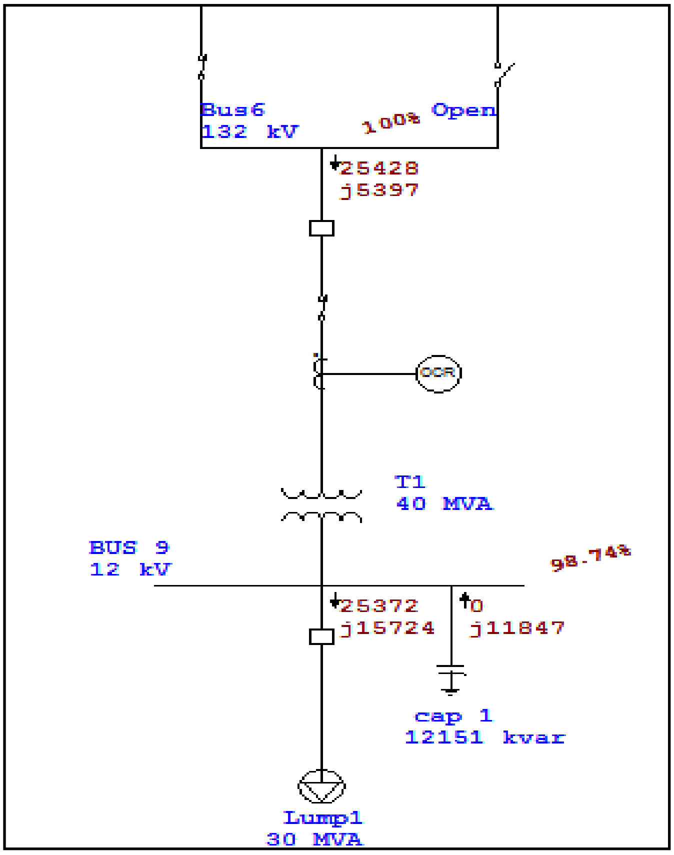


Figure 3(B): Solution for the bus 10

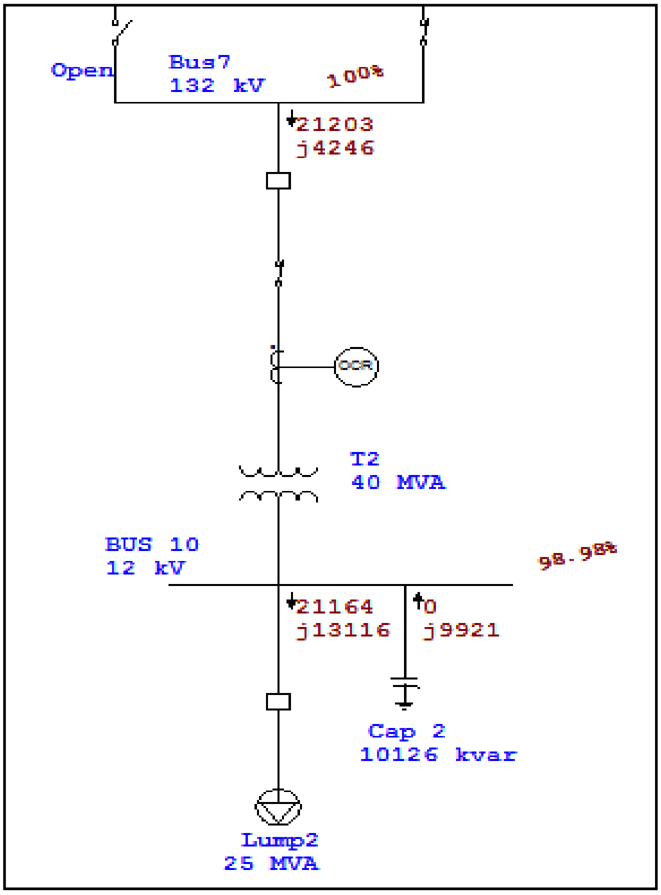


Figure 3(C): Solution for the bus 11

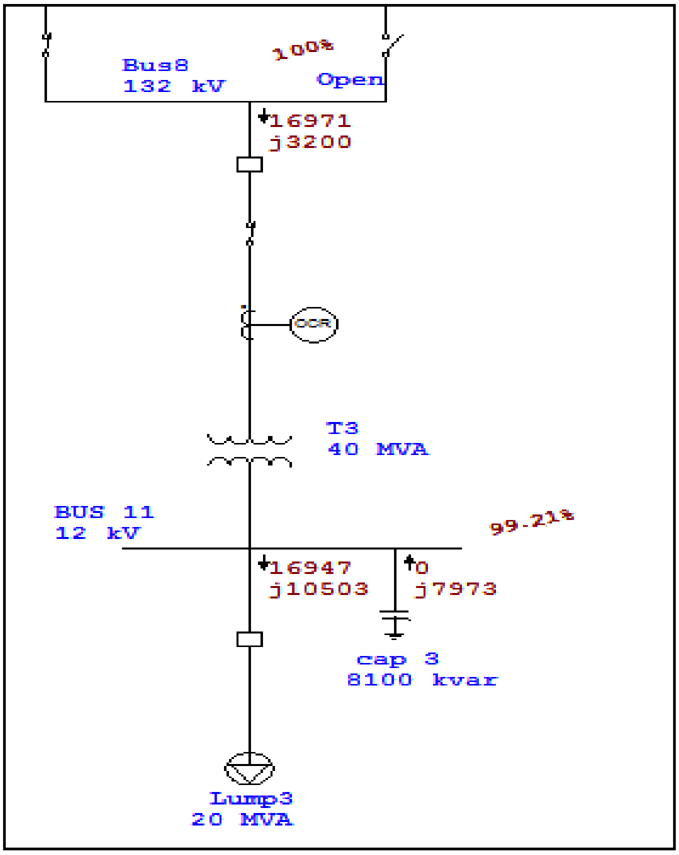


TABLE 6: Results Of Buses After The Installation Of Capacitors

Monitoring Point	kV	MW	MVAr	%PF
Bus 9	12	25.50	3.652	99.15
Bus 10	12	21.250	3.044	99.07
Bus 11	12	17	2.436	99.03

Table 6 shows the improvement in the buses' power factor and reduction in the buses' reactive power. The reactive power is actually responsible for producing losses and thus leading to the under voltage condition.

VII. ETAP REPORT AFTER THE SOLUTION

Hence after observing the ETAP report (see Table 7), it is clear that the under voltage problem is now solved. The three feeder buses now show the normal operating condition and normal voltage. The reactive power of all the selected buses reduces and gives an improved power factor.

TABLE 7: Results Of Buses After The Complete Solution

Device Id	**Condition**	**Voltage Rating**	**Operating**	**%Pf**
Bus 9	Normal Voltage	12 KV	11.849	98.74
Bus 10	Normal Voltage	12 KV	11.878	98.98
Bus 11	Normal Voltage	12 KV	11.906	99.21

VIII. CONCLUSIONS

Load/power flow study is the backbone of the power network. With the help of this study engineers could assume the requirement of active and reactive powers and also help for the future expansions of the power system network. It also provides solutions to different problems like voltage stability, transient stability, harmonics minimization and system reliability. In this paper the simulation of a 132 kV EHT substation has been done with the help of the ETAP software. ETAP is an outstanding tool for the engineers that can provide the solution for the loss of the transmission line, load, transformer or the generator. As an example for load flow analysis, a problem of under voltage has occurred on different buses that have been solved with the addition of the shunt capacitor banks connected in parallel with each feeder. The capacitor bank produces the leading current and hence absorbing the reactive power which increases the power factor of each bus.

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