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Voltage Improvement Using Shunt Capacitive Compensation Technique

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ABSTRACT: Correct capacitor bank configuration in electrical circuit has become very essential for the improvement of system voltage to avert the risk of voltage sag or voltage swell. Either of these will always dangerously adjust the voltage outside the statutory value. Relevant data used for the analysis of the power system were collected from AfamPower Station, Port Harcourt Mains Transmission Station and Port Harcourt Electricity Distribution Company. The data formed the input in ETAP 12.6 software for the load flow analysis on the network without capacitor in the first case. A second case of load flow analysis was conducted in conjunction with capacitor banks modelled using shunt capacitive compensation method and optimally placed on the transmission section load buses. The load flow analysis showed that after optimal capacitor placement, voltage improvement occurred on all the buses, especially buses 4, 5 and 6. The voltage improved from 123.93kV to 132.04kV, 123.92kV to 132.03kV and 123.92kV to 132.03kV for buses 4, 5 and 6. Shunt capacitive compensation technique utilization has brought the transmission line voltage to the nominal value of 132kV which is in agreement with IEEE regulation on voltage stability and efficient power system.

KEY WORDS: Voltage, Transmission line, Shunt capacitive compensation, Load bus, Capacitor bank.

I. INTRODUCTION

It has obviously become so pertinent to assert that building of new generators and transmission facilities to accommodate the regionally increasing load demands is costly and technically cumbersome. Voltage instability may occur because of over utilization of the existing facilities or any contingency. One major problem bedeviling the electric utilities is voltage instability which is generally because of load congestion in the power system [1]. Modern power system is generally complex and therefore, it is pertinent to fulfill the demand with better power [2]. Very important contributory factors to voltage instability are power system configuration, generation pattern, and load pattern [3]. In furtherance of this, Kamdaret *al.* [4] maintained that power system security depends on detailed stability studies of system.

Voltage stability plays a major role in keeping the system operational. Because of its importance an impressive amount of work has been devoted to it in view of recent blackouts that have been attributed to it. Voltage stability is mainly concerned with maintaining acceptable voltage profile under all operating conditions [5]. Voltage instability has been seen as the reason for system voltage collapse, which usually subjects the system voltage to decay to a level from which it becomes impossible to recover. The consequence of voltage collapse may give rise to a partial or full power interruption in the system. The only option to keep and save the system from voltage collapse is to reduce the reactive power load or add additional reactive power prior to reaching the point of voltage collapse.

The power system network can be redesigned or modified to ease voltage instability by adding shunt capacitors and/or flexible ac transmission system (FACTS) controllers at the weakest bus of the system [3]. According to Kumar [6], compensation means the modification of the electrical characteristics of a transmission line to increase its power transmission capacity while satisfying the fundamental requirements for transmission namely, stability and flat voltage profile. Optimal placement of the capacitor matters much in correcting voltage instability problem.

II. RELATED WORKS

Power quality problems have always been a serious challenge in power transmission and distribution networks. Due to unplanned expansion of the networks and installation of different kinds of loads in the present-day power system



management, power distribution and transmission system is faced with very serious power quality problems [7]. These power quality problems include harmonics, excessive reactive power burden, load unbalancing, voltage instability etc [7]. The FACTS device is meant to address the power quality issues by enhancing controllability as well as increasing power transfer capability of the network [8]. In the same vein, Shakil *et al.*[7] maintained that voltage instability is one of the major problems increasing on daily basis. Voltage instability problems arise mainly due to the increase in demand of load and inability of the power system to fulfill that demand of reactive power and consequence upon this, technical advancements have been made and are still in progress. These technical advancements reside in Power Electronics with regards to high performance and rapid response capable of providing high end power and voltage stability and other essential benefits to both the electric utilities and the end users.

The generation pattern is much easier to control by system operators compared to load pattern and customarily, the generation of each participating generator is raised at the same rate, at a predefined rate, or according to their spinning reserves [3]. Secure operation of a power system requires appropriate planning and control actions to avert the occurrence of voltage collapse as it is undesirable. Voltage collapse may lead to partial or even full power failure in the power system. Voltage collapse which is closely tied to instability of heavily loaded electric power systems characterized by monotonically decreasing voltages and blackout becomes imminent when power system is unable to provide the required reactive power.

The voltage can be controlled by providing reactive power control margin to modulate the supply needs using the following compensations:

- i. Shunt compensation.
- ii. Series compensation.
- iii. Dynamic compensator.

Volt-ampere reactive (VAR) compensation can be said to mean the management of reactive power capable of improving the performance of AC power systems. The concept of VAR compensation embraces a wide and diverse field of both system and customer problems with regards to power quality (stability and efficiency) issues. Most of the power quality problems can be attenuated or solved with adequate control of reactive power and hence voltage profile improvement [9]. Reactive power compensation in transmission systems also improves the stability of the AC system by increasing the active power that can be transmitted. It also helps to maintain a substantially good voltage profile at all buses of power transmission, and increases transmission efficiency, control steady-state conditions and avoid disastrous blackouts [9]. Modern transmission systems of today demand that amount of reactive power support in the system should be increased to mitigate attendant consequences of inadequate reactive power supply on the system [10]. Reactive power is the most important factor to voltage stability. From the expectation of the impact level on voltage stability from load increase, the signals on which buses the reactive power compensation is necessary for maintaining enough system loading margin can be obtained.

III. MATERIALS AND METHOD

The rating of capacitor can be calculated with the simplified equation as:

$$C = \frac{q_c}{\omega V^2} \quad (1)$$

Equation (1) shows that the capacitance required to improve the system efficiency is inversely proportional to V^2 . Note that at high voltages power capacitors or capacitor bank values are rated in Kilo Volt-Ampere Reactive (KVar or MVar). For three phase system, the equation for the capacitor in delta connection where ($V_p = V_L$) is given by Equation

$$C_{\Delta} = \frac{q_c}{\omega V_p^2} = \frac{q_c}{\omega V_L^2} \quad (2)$$

Compensation added to the network is given by Equation

$$Q_c = \frac{P}{P_{f_1}} X \sin(\cos^{-1}(P_{f_1})) - \frac{P}{P_{f_2}} X \sin(\cos^{-1}(P_{f_2})) \quad (3)$$

Where P = real power specified at the buses, $P_{f_1} = 0.85$ power factor, $P_{f_2} = 0.95$ power factor, Q_c = value of shunt capacitance to be added to the network to boost the system voltage. Hence the capacitor required per three phases in star connection is equal to three times the capacitance required per phase when the capacitors are connected in delta. Also, the capacitors for the star-connected bank have a working voltage equal to $\frac{1}{\sqrt{3}}$ times that for the delta-connected bank.



Considering that

$$Q_c = \frac{P}{P_{f1}} \times \sin(\cos^{-1}(P_{f1})) - \frac{P}{P_{f2}} \times \sin(\cos^{-1}(P_{f2}))$$

Where

$$P_{f1} = 0.85$$

$$P_{f2} = \text{Unity}$$

P = Total load in KVA taken as 400KVA

Q_c = Rating of capacitor bank realized as 0.25MVAR

Optimal capacitor placement technique is very essential for the successful compensation of the network. In order to select appropriate bus for placement of capacitor in contingency analysis, risk index analysis method can be used. In order to maintain system operating at static voltage stability under each outage, transmission systems need sufficient loading margin to avert the problem of voltage instability while accommodating more power transfer since it was observed that the generator injected 0.165MVAR. Since contingency events inevitably give birth to decrease in loading margin, those contingencies with higher failure probability and resulting in more loading margin decrease will have higher values, namely requiring reactive power compensation. Under normal state devoid of capacitor installation, the system loading margin represented as a loading factor is assumed to be λ^*_{nor} . For a contingency (E_i), the loading margin becomes $\lambda^*_{E_i}$, resulting in a decreased loading margin expressed as:

$$\Delta_{E_i} = \lambda^*_{nor} - \lambda^*_{E_i} \tag{4}$$

The RI value under contingency is calculated from

$$\text{Risk}(E_i) = P_r(E_i) \times \Delta_{E_i} \tag{5}$$

Where

$P_r(E_i)$ = 1 representing the failure probability of contingency (E_i)

The failure rate of the contingency is expressed as which can be given in data. It is assumed that the contingency events are independent, and under a contingency, during the period of voltage instability resulted from demand increase, the component is assumed not to be repairable. The failure rate is converted to the failure probability by a Poisson distribution. Here $P_r(E_i)$ is the average outage probability of contingency (E_i) in a defined time interval T_r (one year). Using the highest risk index value as base, the line outages with percentages of RI values higher than 30% are considered for reactive power compensation by injecting 0.25MVAR on each of the transmission section load buses.

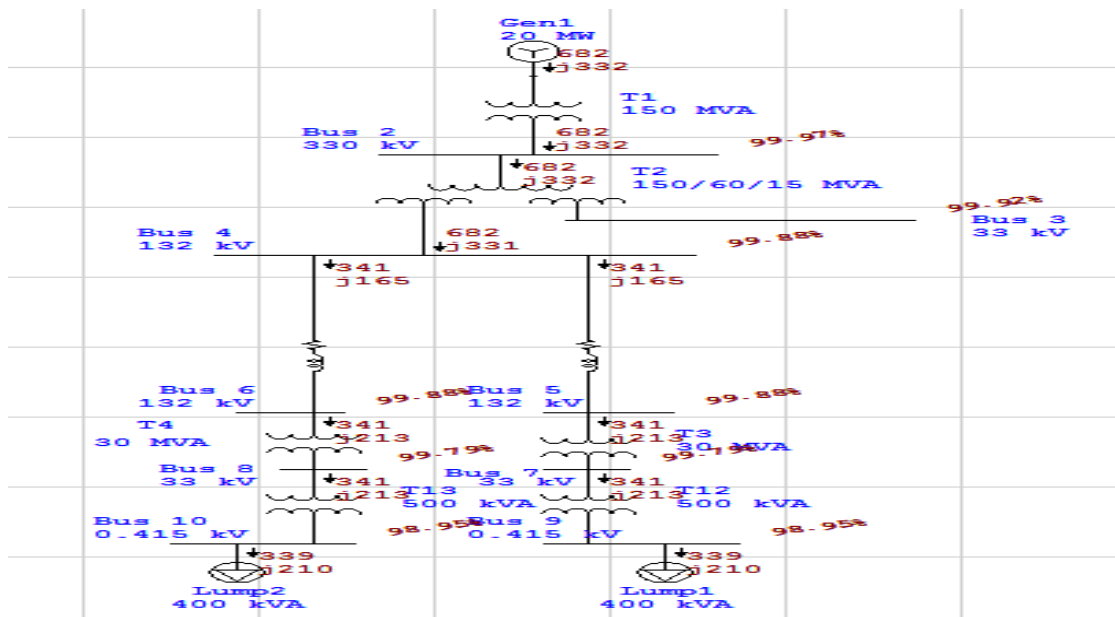


Fig. 1 Network Simulation without Capacitor Placement

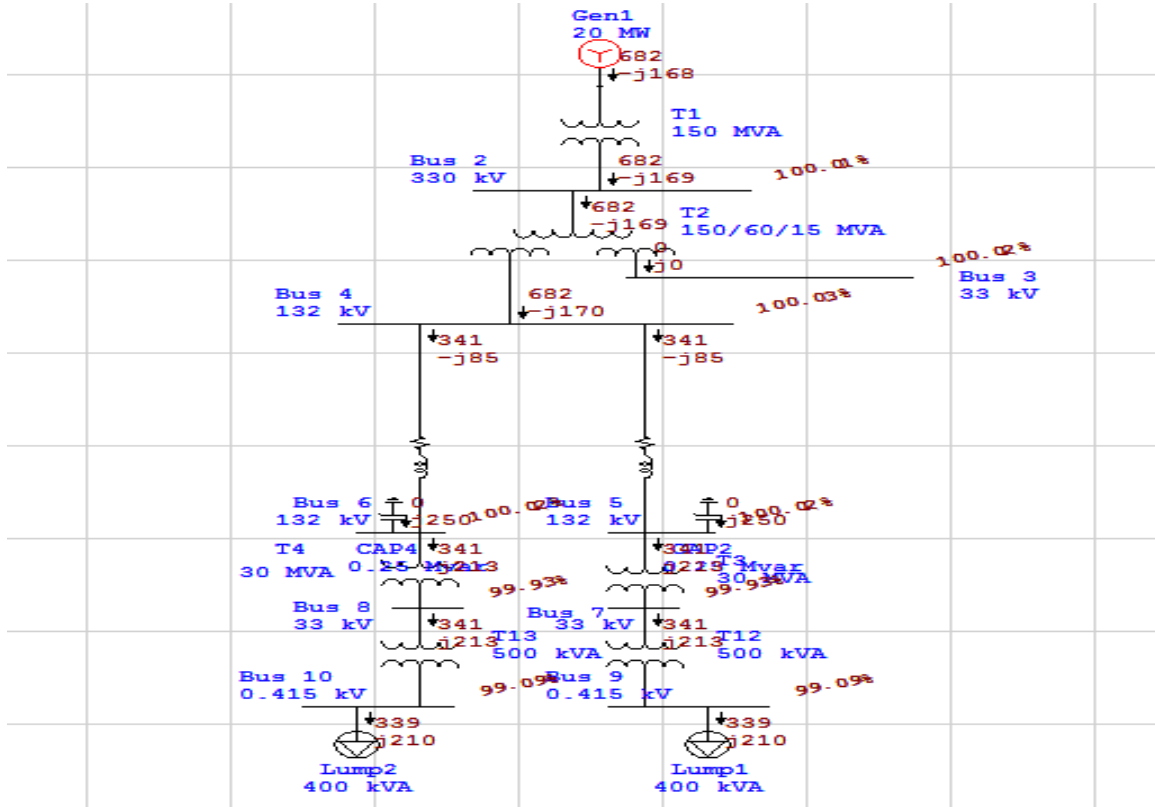


Fig. 2 Network Simulation with Capacitor Placement

IV. RESULTS AND DISCUSSION

The results obtained from the power flow without capacitor for compensation and power flow with capacitor for compensation are shown in tables 1 to 3 and figs.3 to 5 respectively.

Table 1 Summary of Voltage Magnitude without Capacitor for Compensation

Buses	Voltage Magnitude (%)
1	100
2	93.971
3	93.915
4	93.884
5	93.878
6	93.878
7	93.787
8	93.787
9	92.947
10	92.947

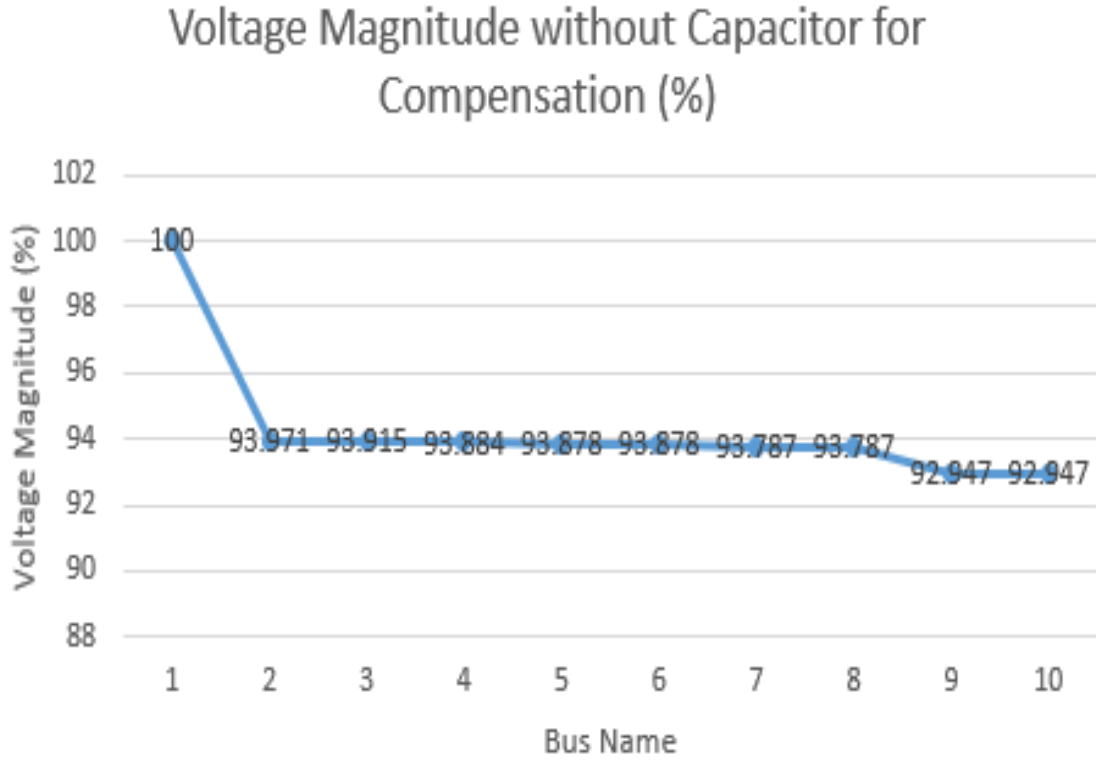


Fig. 3 Graph of Voltage Magnitude without Capacitor for Compensation

Table 2 Summary of Voltage Magnitude with Capacitor for Compensation

Buses	Voltage Magnitude (%)
1	100
2	100.008
3	100.024
4	100.03
5	100.025
6	100.025
7	99.935
8	99.935
9	99.095
10	99.095

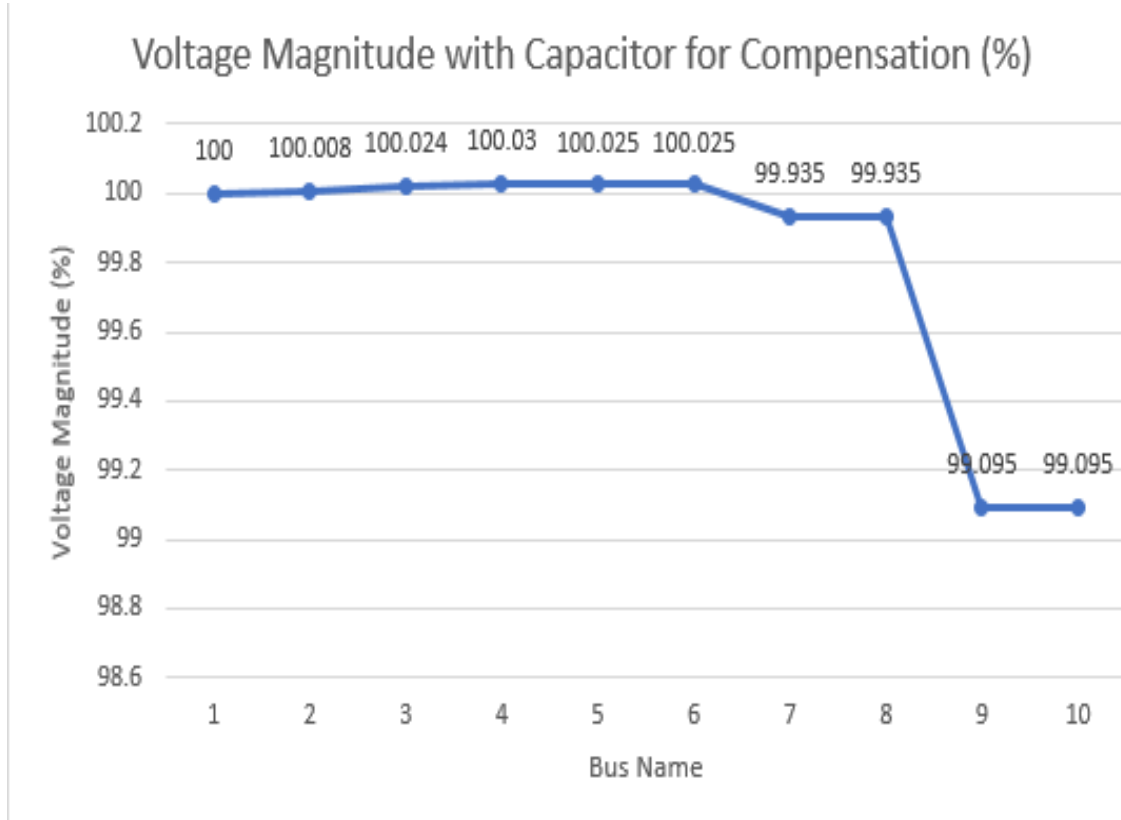


Fig. 4 Graph of Voltage Magnitude with Capacitor for Compensation

Table 3 Voltage Magnitude, with and without Capacitor for Compensation

Buses	Voltage Magnitude without Capacitor for Compensation (%)	Voltage Magnitude with Capacitor for Compensation (%)
1	100	100
2	93.971	100.008
3	93.915	100.024
4	93.884	100.03
5	93.878	100.025
6	93.878	100.025
7	93.787	99.935
8	93.787	99.935
9	92.947	99.095
10	92.947	99.095

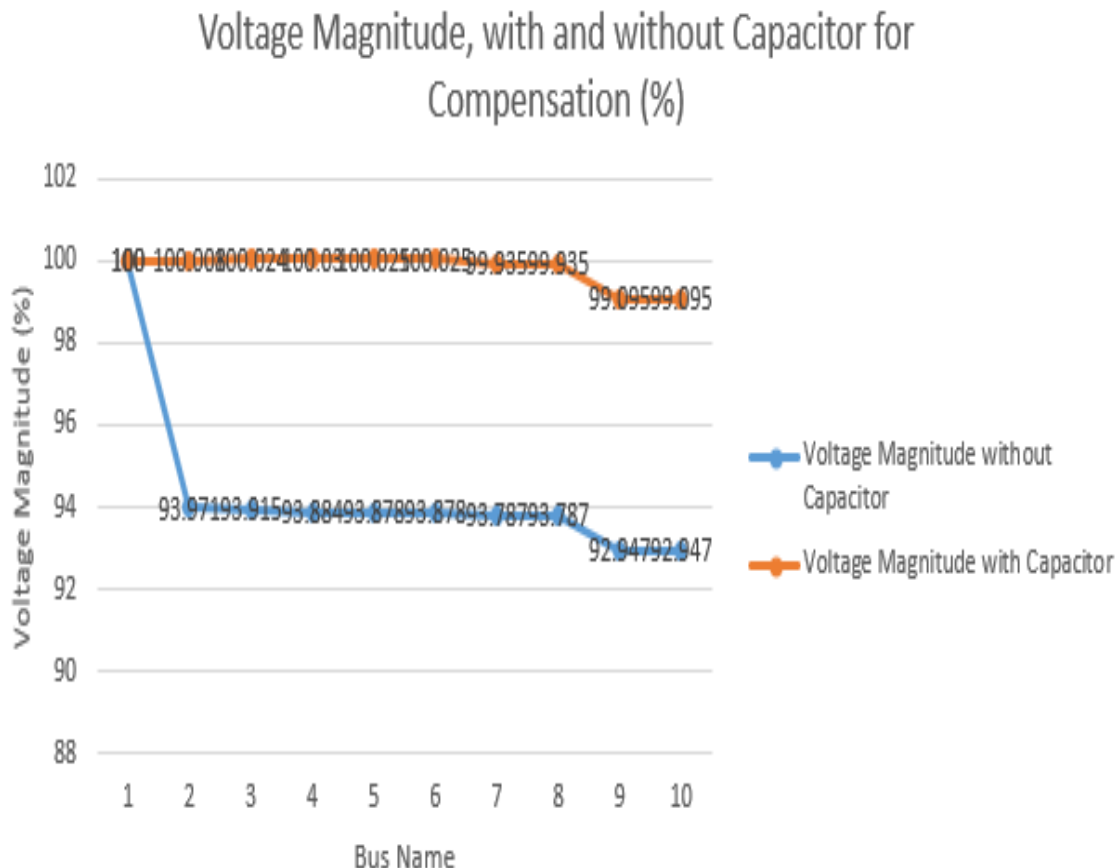


Fig. 5 Graph of Voltage Magnitude, with and without Capacitor for Compensation

V. CONCLUSION

A 3-bus 132kV transmission network having lines 1 and 2 was modelled in ETAP 12.6 software to ascertain the bus voltages all the way from generation through transmission to distribution points respectively. This was performed to analyze the performance of the transmission lines with and without compensation. The transmission lines were subjected to load flow analysis with static load of 400KVA for each of buses 9 and 10. The load flow analysis showed that without capacitor provided for compensation, buses 1,2,3,4, 5,6,7,8, 9 and 10 have voltage magnitudes of 100, 93.971, 93.915, 93.884, 93.878, 93.878, 93.787, 93.787, 92.947, and 92.947. These voltage magnitudes represent 11kV, 329.9kV, 32.97kV, 123.93kV, 123.92kV, 123.92kV, 32.93kV, 32.93kV, 0.4106kV, and 0.4106kV as against 11kV for bus 1, 330kV for bus 2, 33kV for bus 3, 132kV for buses 4, 5, and 6, 33kV for buses 7 and 8, and 0.415kV for buses 9 and 10.

With the use of shunt capacitive compensation, capacitor bank was modelled and placed on the two transmission load buses. This modelling was to provide compensation on the transmission network. The 3-bus 132kV transmission network was subjected to a second case of load flow analysis with capacitor bank modelled and placed on the two transmission load buses. The load flow analysis showed that buses 1,2,3,4, 5,6,7,8, 9 and 10 have voltage magnitudes of 100, 100.008, 100.024, 100.030, 100.025, 100.025, 99.935, 99.935, 99.095, and 99.095. These voltage magnitudes represent 11kV, 330.03kV, 33kV, 132.04kV, 132.03kV, 132.03kV, 32.98kV, 32.98kV, 0.4112kV, and 0.4112kV as against 11Kv for bus 1, 330kV for bus 2, 33kV for bus 3, 132kV for buses 4, 5, and 6, 33kV for buses 7 and 8, and 0.415kV for buses 9 and 10.



Comparatively, the 3-bus 132kV transmission network having lines 1 and 2 voltage proved to be more stable when compensated as the voltage magnitudes in % improved from 93.884 to 100.030 for bus 4 and 93.878 to 100.025 for each of buses 5 and 6 representing voltage improvement from 123.93kV to 132.04kV, 123.92kV to 132.03kV and 123.92kV to 132.03kV for buses 4, 5 and 6 respectively. This enhancement in voltage magnitude has grown the working voltage closer to the nominal voltage of 132kV by 8.11kV for each transmission section bus than when not compensated.

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