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Enhancement of Power Quality in Thirty Bus System Using ZSI Based STATCOM

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Abstract: This paper presents the modeling and simulation results of Z-Source Inverter based Static Compensator (STATCOM).The thirty bus system with and without STATCOM are modeled and simulated using the MATLAB software. The present work proposes Z-Source Inverter for the control of reactive power. Z-Source inverter would ensure a constant DC voltage across the DC link during the process of voltage. The advantages of this system are reduced ripple, shoot through capability and reduced heating. Voltages and reactive power at various buses of thirty bus distribution network, with and without STATCOM are studied.

Key Words: *FACTS*, Power quality, *Reactive power, Static Synchronous Compensator (STATCOM), Z-Source Inverter (ZSI)*.

I. Introduction

Electrical power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end user equipments. Distribution networks experience distinct change from a low to high load level everyday. With restructuring of power system and shifting trend towards distributed and dispersed generation, the issue of power quality problem is going to take newer dimensions. In developing countries like India, where the variation of power frequency and many such other determinants of power quality are themselves a serious question, it is very vital to take positive steps in this direction. The present work is to identify the prominent concern in this area and hence the measures that can enhance the quality of power are recommended.

The introduction of FACTS has given the new direction to the power system to solve the power quality problems [1]. At present, a wide range of very flexible controllers are emerging for custom power applications [2].As an important kind of FACTS devices, Static Var Compensator (SVC) is widely used in power system for shunt reactive compensation. However using Thyristor controlled reactor (TCR) and Thyristor Switched Capacitor (TSC) for reactive power generation, the thyristor controlled SVC brings harmonics and possible harmonic resonance into system. The STATCOM is a shunt connected reactive power compensation device that is capable of generating and /or absorbing reactive power. FACTS devices are routinely employed in order to enhance the power transfer capability of the otherwise under-utilized parts of the interconnected network[3,4].Out of all static FACT devices the STATCOM is the most effective device and has the potential to be exceptionally reliable with the added capability to sustain reactive current at low voltage (constant current not constant impedance), reduced land use , increased relocatability and voltage and frequency support capability(by replacing capacitors with batteries as energy storage). Although currently being applied to regulate transmission voltage to allow greater power flow in a voltage limited distribution network in the same manner as a SVC, the STATCOM has further potential. By giving an inherently faster response and greater output to a system with a depressed voltage, the STATCOM offers improved quality of supply.

II. Static Sychronous Compensator (STATCOM)

The static synchronous compensator (STATCOM) is a voltage source inverter based FACTS controller and also shunt connected reactive compensation equipment, which is capable of generating and /or absorbing reactive power. The STATCOM provides operating characteristics similar to a rotating synchronous compensator without the mechanical inertia. The STATCOM employ solid state power switching devices and provide rapid controllability of the three phase voltages, both in magnitude and phase angle.

The STATCOM mainly consists of DC voltage source behind self-commutated voltage source inverter using GTO/IGBT and coupling transformer with a leakage-reactance. The AC voltage difference across the leakage reactance produces reactive power exchange between the STATCOM and the power system, such that the AC voltage at the bus bar can be regulated to improve the voltage profile of the power system, which is the primary duty of the STATCOM. The basic objective of a VSI is to produce a sinusoidal AC voltage with minimal harmonic distortion from a DC voltage.

The principle of STATCOM operation is as follows: The AC voltage difference across the leakage reactance makes the power exchange between the STATCOM and the power system. The VSI voltage is compared with the AC bus voltage system, when the AC bus voltage magnitude is above that of the VSI magnitude; the AC system sees the STATCOM as inductance connected to its terminals. Otherwise if the VSI voltage magnitude is above that of the AC bus voltage magnitude, the AC system sees the STATCOM as capacitance connected to its terminals. If both AC system and VSI voltage magnitudes are equal, the reactive power exchange is zero. If the STATCOM has a DC source or energy storage device on its DC side, it can supply real power to the power system. This can be achieved by adjusting the phase angle of the STATCOM terminals and the phase angle of the AC power system. When phase angle of the AC power system leads the

VSI phase angle, the STATCOM absorbs the real power from the AC system, if the phase angle of the AC power system lags the VSI phase angle, the STATCOM supplies real power to AC system.

The Voltage Source Converter or Inverter (VSC or VSI) is the building block of a STATCOM and other FACTS devices. A very simple inverter produces a square voltage waveform as it switches the direct voltage source on and off. The basic objective of a VSI is to produce a sinusoidal AC voltage with minimal harmonic distortion from a DC voltage.

In the last decade commercial availability of Gate Turn Off thyristor (GTO) devices with high power handling capability, and the advancement of other types of power-semiconductor devices such as IGBT's have led to the development of controllable reactive power sources utilizing electronic switching converter technology. These technologies additionally offer considerable advantage over the existing ones in terms of space reduction and performance. The GTO thyristor enable the design of solid-state shunt reactive compensation equipment based upon switching converter technology.

This concept was used to create a flexible shunt reactive compensation device named static synchronous compensator (STATCOM) due to similar operating characteristics to that of a synchronous compensator but without the mechanical inertia. Single-line diagram of STATCOM is shown in Fig1.

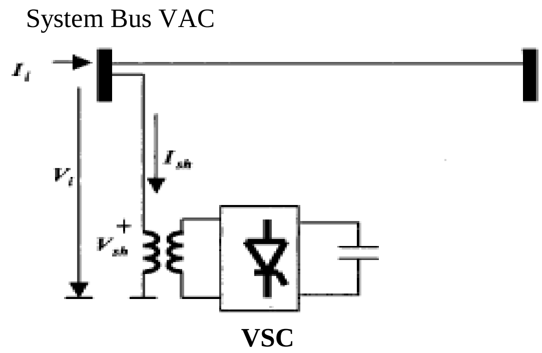

Fig.1 Single-line diagram of a STATCOM.

The advent of Flexible AC Transmission systems (FACTS) is giving rise to a new family of power electronics equipment emerging for controlling and optimizing the performance of power system, e.g. STATCOM, SSSC and UPFC. The use of voltage source inverter (VSI) has been widely accepted as the next generation of the reactive power controllers of the power system to replace the conventional VAR compensator, Such as the thyristor-switched capacitors (TSC) and thyristor controlled reactors (TCR).

III. Impedance Source Inverter (ZSI)

The main circuit of configuration of the Z-Source Inverter with load is shown in Fig2. Z-Source Inverter circuit consists of a diode rectifier, DC link circuit, and an inverter bridge. The differences are that the DC link circuit is implemented by the Z-Source network (c_1, c_2, L_1, and L_2) and small input capacitors (c_a, c_b, and c_c)are connected to the diode rectifier. Since Z-Source Inverter bridge can boost the DC capacitor (c_1, and c_2) voltage to any value above the DC value of the rectifier, a desired output voltage is always obtainable regardless of line voltage. Using the 230V load system as an example ,the DC capacitor voltage can be boosted to 350V or greater in order to produce 230 V AC output regardless of the line voltage.Theoritically ,the DC capacitor voltage can be boosted to any value above the inherent DC voltage(310-325V for a 230-V line) of the rectifier ,by using the shoot through zero switching states. When a higher voltage is needed or during voltage sags. The capacitor voltage is, however, limited by the device voltage rating in practical use.

New type of STATCOM using dynamic phasor is given by Hannan[5], Modeling and simulation of distribution STATCOM is dealt by Giroux[6].solution to power quality problem is given by Mineski[7].Analysis and implementation of thyristor based STATCOM is given by [8]&[9].Compensation of voltage sag is given by Haque[10] .Harmonics study and comparison of ZSI with traditional Inverters is given by Justus[11] and maximum boost control of Z-source is given by Peng and Shen in [12]&[13].Z-source inverter for adjustable speed drives is given by Peng[14].ZSI and Push-pull inverter based STATCOM given by Usha [15]&[16].

The authors are unaware of any literature dealing STATCOM using Z-Source Inverter based STATCOM for thirty bus distribution system. This work compares reactive power in thirty bus system at various buses with and without ZSI based STATCOM.

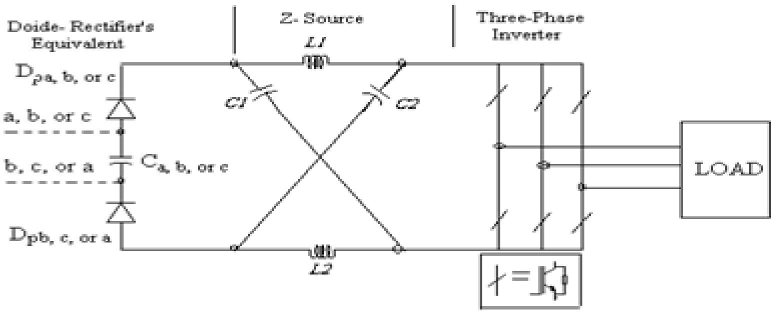

Fig.2 Main circuit configuration of Z-Source Inverter

IV. Simulation Results

A thirty bus system is considered for simulation studies. The circuit model of thirty bus system without STATCOM is shown in Fig3a. The thirty bus system is modeled and simulated using MATLAB/SIMULINK. Each line is represented by series impedance model. The shunt capacitance of the line is neglected. The voltage and reactive power at buses 11 and 25 are shown in Fig3b, 3c, 3d and Fig3e respectively.

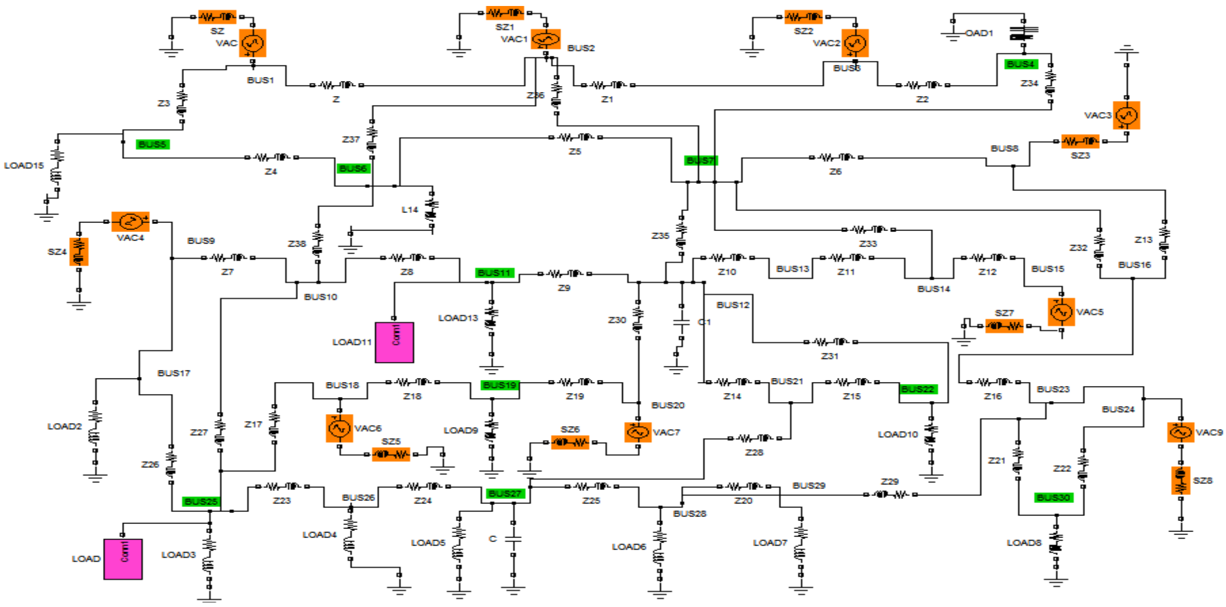

Fig3a 30 bus system without STATCOM

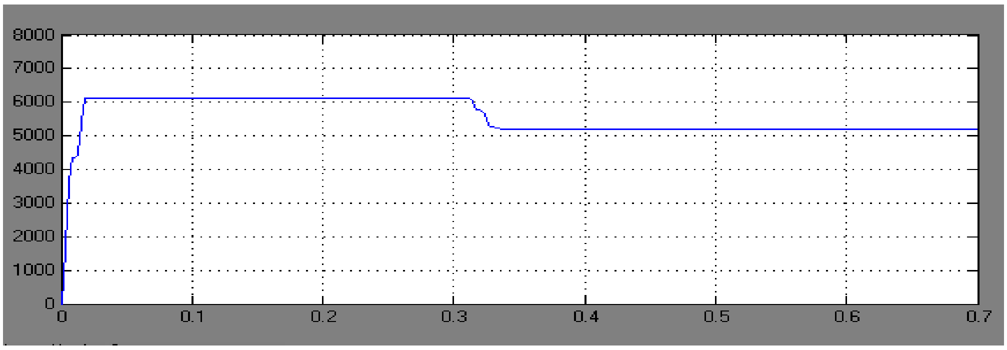

Fig 3b Voltage at bus 11

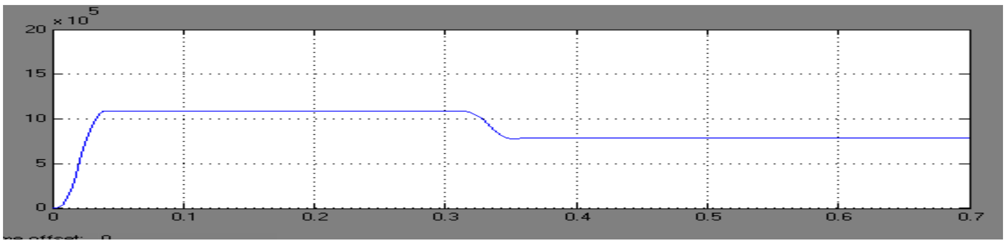

Fig3c Reactive power in bus 11

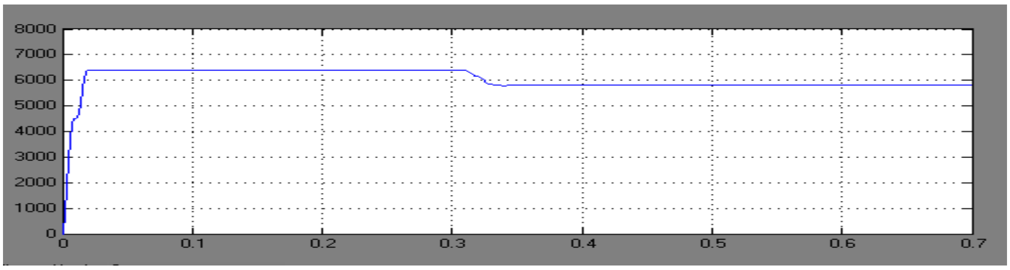

Fig3d Voltage at bus 25

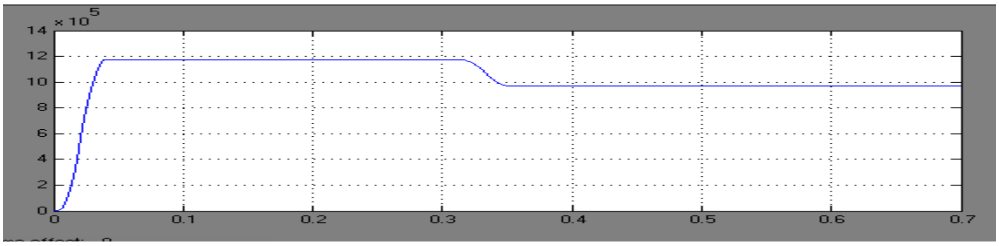

Fig3e Reactive power in bus 25

The buses 11 and 25 are identified as weak buses and STATCOMs are connected at these buses. The circuit model of thirty bus system with STATCOMs is shown in Fig4a. The voltage and reactive power at buses 11 and 25 are shown in Fig4b, 4c, 4d and Fig 4e respectively. The summary of reactive power in various buses is given in Table1.It can be seen that the reactive power increases in the buses near the STATCOMs. The increase in reactive power is due to increase in the voltage of the nearby buses. The reactive power in various buses is given in Fig4f. Hence ZSI based STATCOM gives best performance.

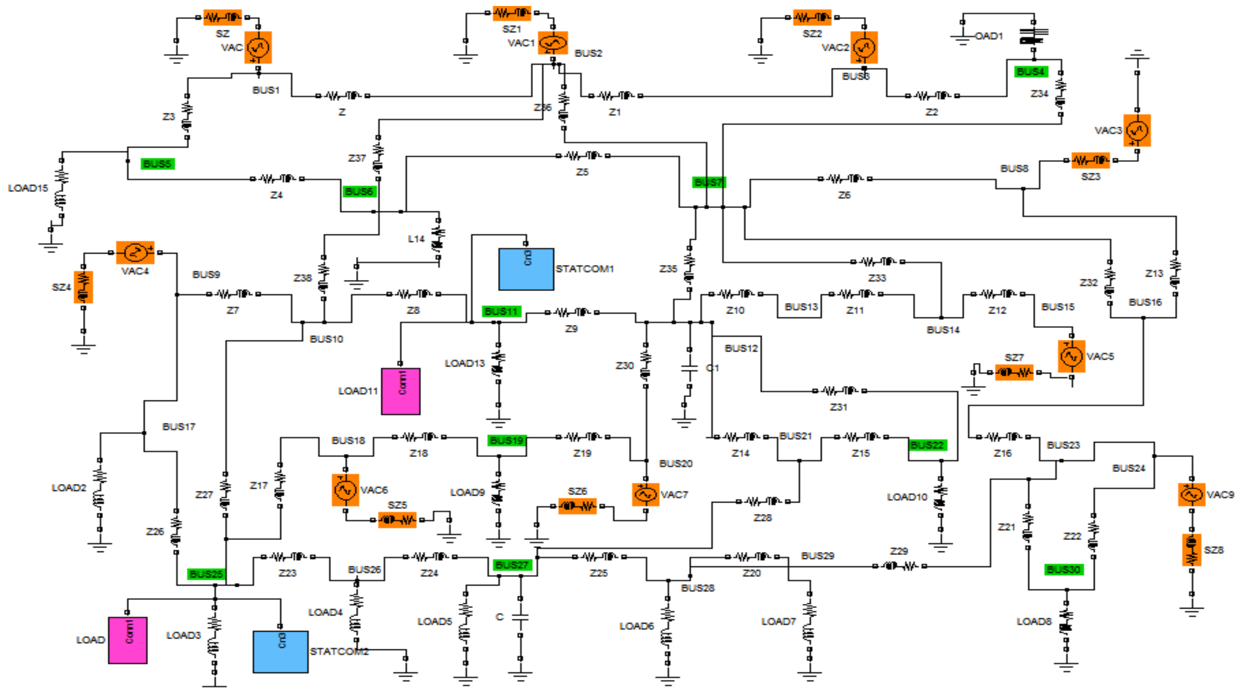

Fig4a 30 bus system with STATCOMs

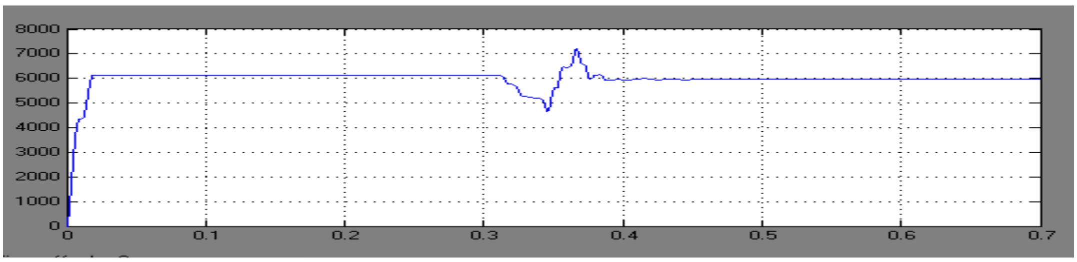

Fig4b Voltage at bus 11

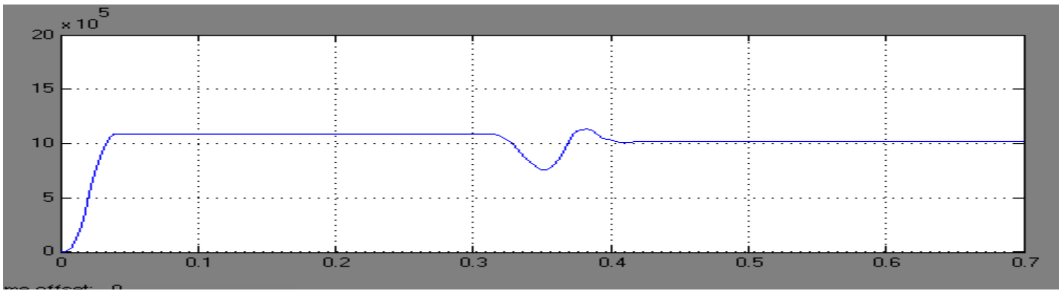

Fig4c Reactive power in bus 11

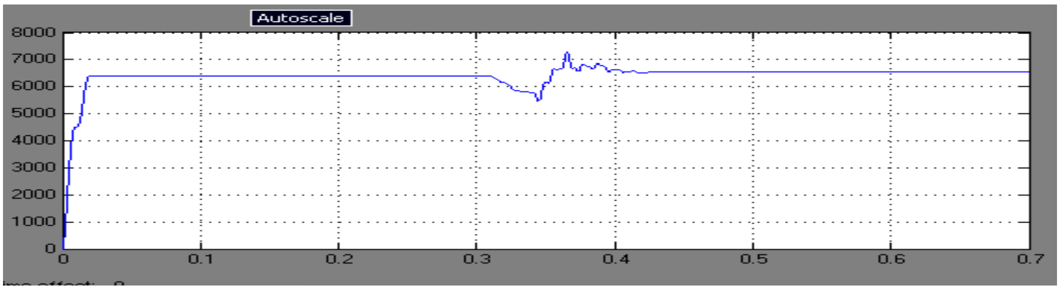

Fig 4d Voltage at bus 25

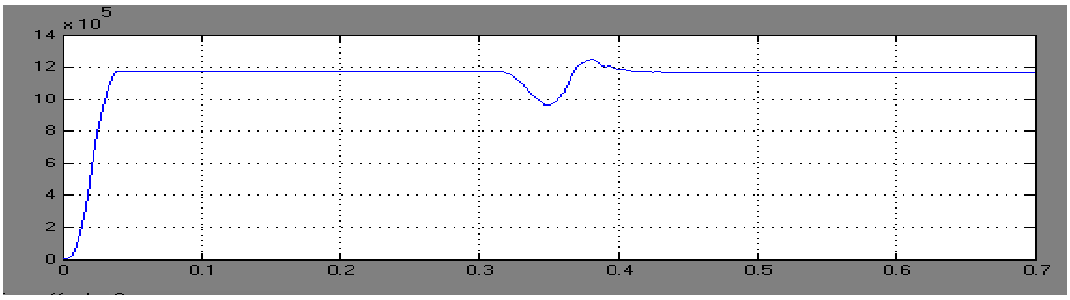

Fig 4e Reactive power in bus 25

Table-1: Summary of Reactive power with and without STATCOMs in various buses

Bus no	Reactive power without STATCOM MVAR	Reactive power with STATCOM MVAR
Bus-4	0.67	0.68
Bus-5	1.08	1.099
Bus-11	0.783	1.02
Bus-17	1.54	1.58
Bus-19	0.718	0.73
Bus-22	0.539	0.58
Bus-25	0.974	1.16
Bus-27	0.686	0.742
Bus-30	0.896	0.899

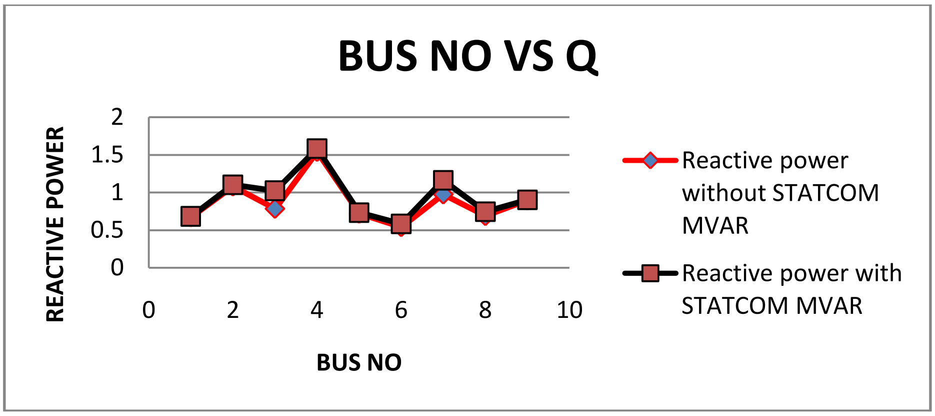

Fig 4f Reactive power in various buses

V. Conclusion

This work has explored the possibility of using Z-Source Inverter based STATCOM system. The thirty bus system is modeled and simulated using MATLAB software and results are presented. The simulation results of Thirty bus system with and without STATCOMs are presented. Simulation studies were done using single phase model of balanced three phase system. It is found that the bus voltages near the STATCOMs are improved and hence the reactive power. Overall power quality can be improved by using more STATCOMs at the load buses. The simulation results are in line with the predictions. This system has improved reliability and power quality. The scope for future work is simulation can also be done using PSCAD or PSIM. The simulation studies can be extended to 64-bus and 128-bus systems. Testing can also be done on extremely large real time power systems and also the laboratory model for STATCOM can be done using Micro-controller or DSP processor.

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