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Comparison of Push-Pull and Z-Source Inverter Based Statcom Systems

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Abstract

This paper presents the comparison of Push-Pull Inverter and Z-Source Inverter based Static Compensators (STATCOM).The closed loop system with STATCOM is modeled and simulated using the blocks of MATLAB/SIMULINK.Voltage sag mitigation using Push-Pull Inverter and Z-Source Inverter are presented. The present work proposes Z-Source Inverter and Push-Pull Inverter based STATCOM for the control of reactive power and hence the voltage. The advantages of these systems are reduced ripple, shoot through capability and reduced heating. The results of Push-Pull Inverter based STATCOM are compared with those of Z-Source Inverter based STATCOM system.

Index Terms - FACTS, Static Synchronous Compensator (STATCOM), Z-Source Inverter (ZSI), Push-pull Inverter ,Voltage sag.

I Introduction
Today world wide transmission and distribution systems are undergoing continuous changes and restructuring. They are being heavily loaded and operated in, was not originally envisioned. Transmission and distribution systems must be flexible to react to more diverse generation and load patterns. In addition, the economical utilization of system of assets is of vital importance to enable utilities in industrialized countries to remain competitive and to survive. But increasingly complex power system can become less secure because of inadequate power control, excessive reactive power and large dynamic swings and bottlenecks of full utilization of the potential of transmission interconnections. The Flexible AC Transmission System (FACTS) is a

concept promoting the use of power electronic based and other static controllers to enhance controllability and increased power transfer capability. The basic idea behind the FACTS concept is to enable active elements, playing active roles in increasing the flexibility of power transfer requirement. 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 generation and /or absorbing reactive power. Out of all static FACT devices the STATCOM has the potential to be exceptionally reliable but with the added capability to sustain reactive current at low voltage (constant current not constant impedance), reduced land use and increased relocatability (footprint 40% of SVC) and be developed as a voltage and frequency support (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 transmission 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.

One of the most important voltage related problems is voltage sag. Voltage sag is an RMS reduction in the AC voltage at the power frequency, for duration from half-cycle to few seconds [2]. A solution to the voltage sag can be introduced at several levels between the utility and customer. Since the cost of solution increases as the mitigation equipment drifts apart from customer, often it is more efficient to install the equipment closer to the customer.

The major applications of STATCOM are: voltage stability enhancement, damping of torsional oscillations, power system voltage control, and power system stability improvement.

These applications can be implemented with a suitable control (voltage magnitude and phase angle control) [3-4].

II. Static Synchronous Compensator

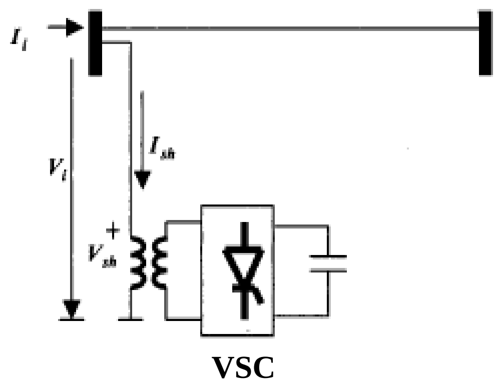
The static synchronous compensator (STATCOM) is shunt connected reactive compensation equipment, which is capable of generating and /or absorbing reactive power whose output can be varied so as to maintain control of specific parameters of the electric power system. The STATCOM provides operating characteristics 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 basically consists of a step-down transformer with a leakage-reactance, a three phase GTO/IGBT voltage source inverter (VSI), and a DC capacitor. 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. However a secondary damping function can be added into the STATCOM for enhancing power system oscillation stability. 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 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 to its terminals. If the 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 real and reactive powers are given by the following equations.

$$P_{12} = (V_1 V_2 / X_{12}) \sin(\delta_1 - \delta_2) \quad \text{-----(1)}$$

$$Q_{12} = (V_2 / X)(V_1 - V_2) \quad \text{-----(2)}$$



VSC

Fig1. Single-line diagram of a STATCOM.

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.
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 capacitors (TCR).

II. Push-Pull Inverter

The present work uses a push-pull inverter circuit comprising a transformer with a power output end coupled to a load and two power input ends, and a power driver unit is connected between the two power output ends. A power supply unit, and the power driver unit receives a power signal and outputs two sets of drive signals having same frequency.

Circuit diagram of Push-Pull inverter is shown in Fig2.This circuit is also called parallel inverter since the capacitor appears in parallel with the transformer. The devices $T_1$and T_2 conduct alternatively to produce the AC output.

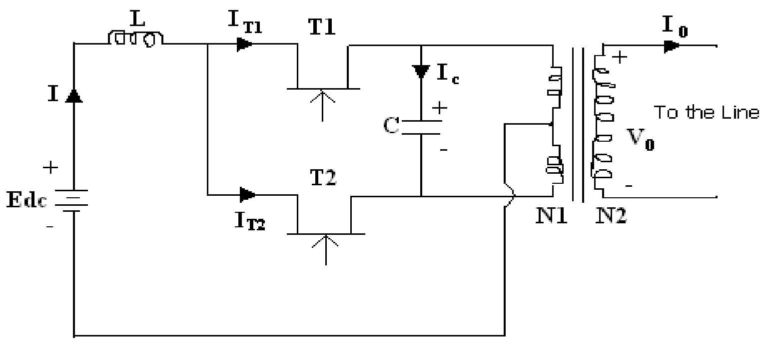


Fig2. Push-Pull Inverter system

III. Z-Source Inverter

The main circuit configuration of the Z-Source Inverter with load is shown in Fig3. 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. Theoretically, the DC capacitor voltage can be boosted to any value above the inherent DC voltage (310-325 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.

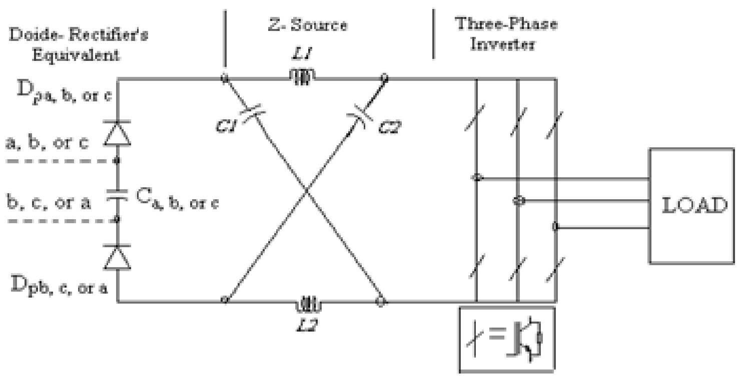


Fig.3 Main circuit configuration of Z-Source Inverter

ZSI has many advantages which are very desirable for many applications. It can produce any desirable output AC voltage even greater than the line voltage. It provides ride through during voltage sags without any additional circuits and energy storage. It reduces inrush and harmonic currents. Unique buck-boost inversion by single power conversion stage. The impedance source technology can be applied to the entire spectrum of power conversion.

New type of STATCOM based on VSI with phase shifted SPWM is given by Liang[4], Modeling and simulation of DSTATCOM is dealt by Giroux[5].Introduction to multilevel inverter is given by [6]&[7].The solution to power quality problem is given by [8],[9]&[10].Voltage sag by using ZSI is given by[11]&[12].Analysis and implementation of thyristor based STATCOM is given by Wang[13].Analysis and control of design of STATCOM for power system voltage regulation is given in[14].Compensation of voltage sag by [15] & maximum boost control of Z-source is given in[16]. Maximum boost control of the Z-source inverter is given by [17].Analysis of thyristor based STATCOM is given by Song[18].Z-source inverter for adjustable speed drives is given by Peng[19].Transfer capability improvement using FACTS is given by Arun[20].Multipulse-inverter based STATCOM is presented by Dananjayan[21].ZSI and Push-pull inverter based STATCOM given by Usha [22]&[23].

The authors are unaware of any literature dealing STATCOM using Push-pull and Z-Source Inverter based STATCOM for closed loop system using PI-controller.This work compares responses of Push-pull and Z-source inverter based STATCOM.

IV. Simulation Results

Matlab model for closed loop Push-Pull Inverter based STATCOM is shown in Fig3a.The STATCOM using Push-pull inverter is shown in Fig3b.The load voltage is sensed and rectified using an uncontrolled rectifier. It is compared with reference voltage. The error is given to a PI controller. The output of PI controller adjusts the pulse width to get the required voltage at output. The voltage across load1 and load2 are shown in Fig3c.The load voltage decreases due to the application of additional load.RMS value of load voltage is shown in Fig3d.RMS output current is shown in Fig3e.Variation of real power and reactive powers are shown in Fig3f and Fig3g respectively. From the response it can be seen that the system takes 0.25sec to reach the steady state value.

Matlab model for closed loop Z-Source Inverter based STATCOM is shown in Fig4a.The STATCOM using ZSI is shown in Fig4b. The voltage across load1 and load2 are shown in Fig4c.The load voltage decreases due to the application of additional load.RMS value of load voltage and current are shown in Fig4d.RMS output current is shown in Fig4e.Variation of real and reactive powers are shown in Fig4f and Fig4g respectively.The output voltage reaches steady state value in 0.15sec.Therefore the response of ZSI system is faster than that of Push-Pull inverter based system.

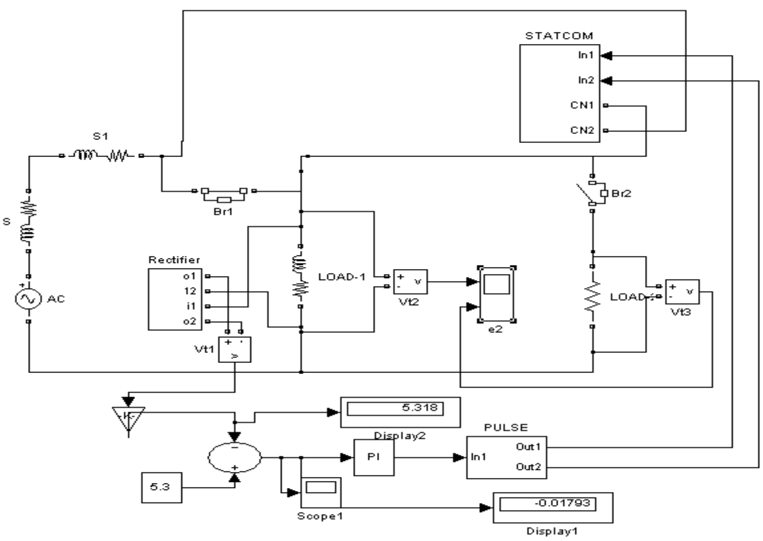


Fig. 3a Closed-loop Push-pull Inverter based STATCOM circuit

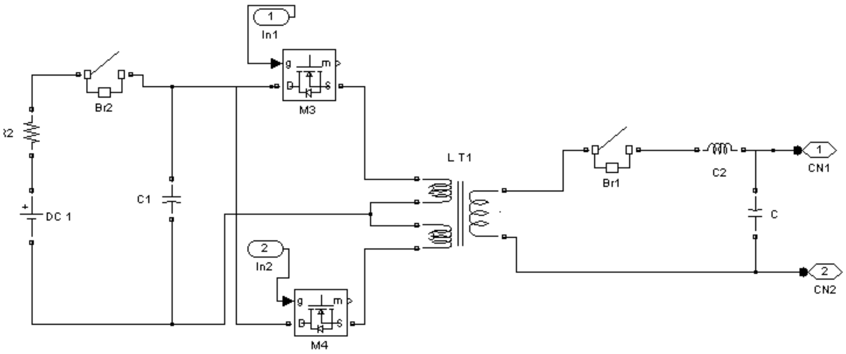


Fig.3b Push-Pull Inverter circuit

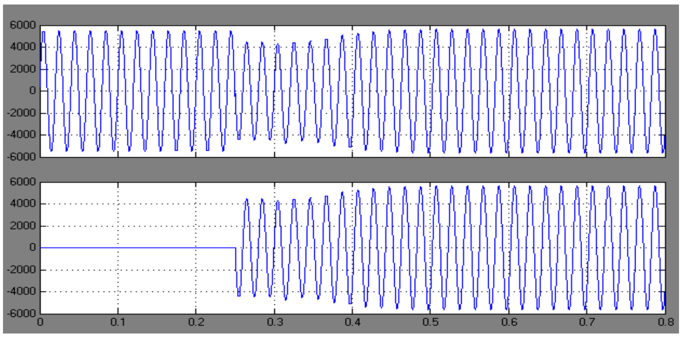


Fig.3c Voltage across Load-1 & Load-2

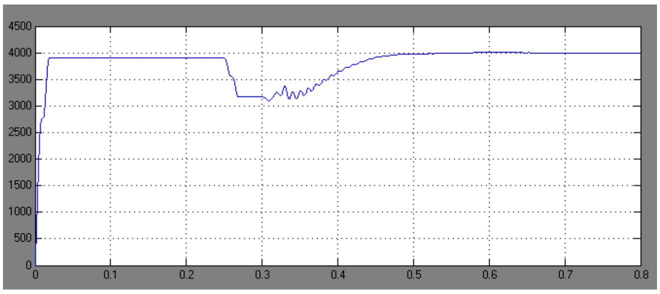


Fig. 3d RMS voltage

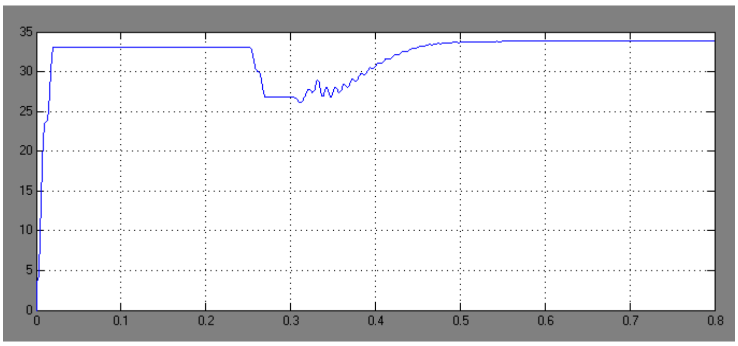


Fig. 3e RMS current

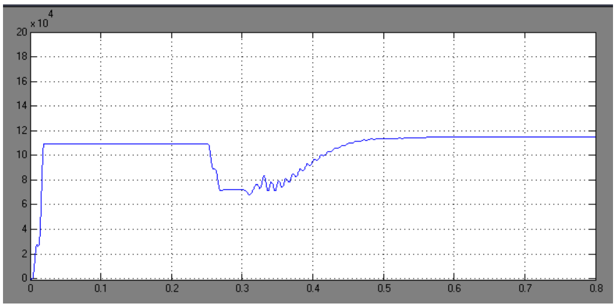


Fig. 3f Real power

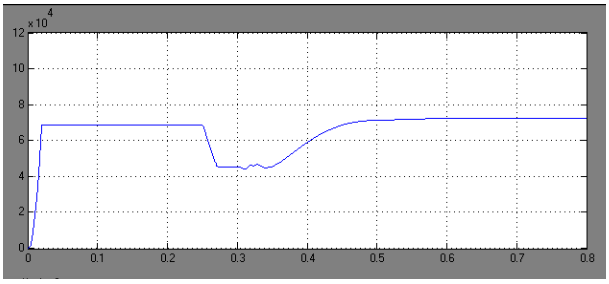


Fig. 3g Reactive power

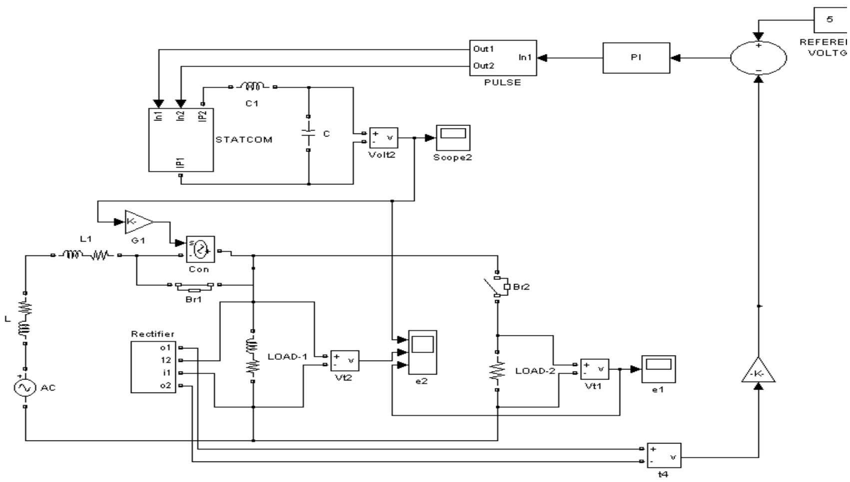


Fig. 4a Closed-loop Z-source inverter Circuit

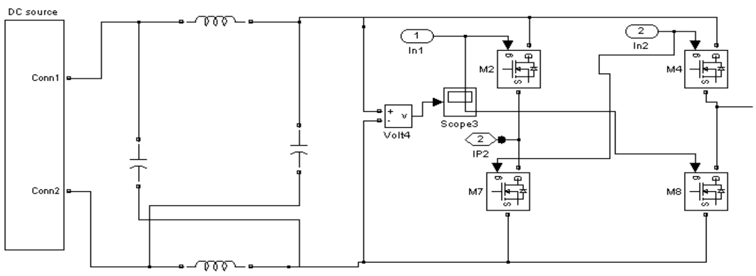


Fig. 4b Z-source inverter circuit

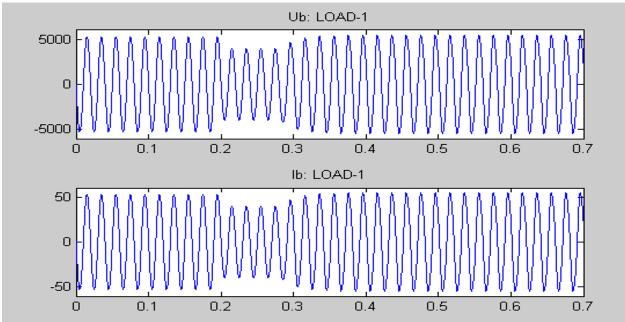


Fig. 4c Voltage across Load-1 &Load-2

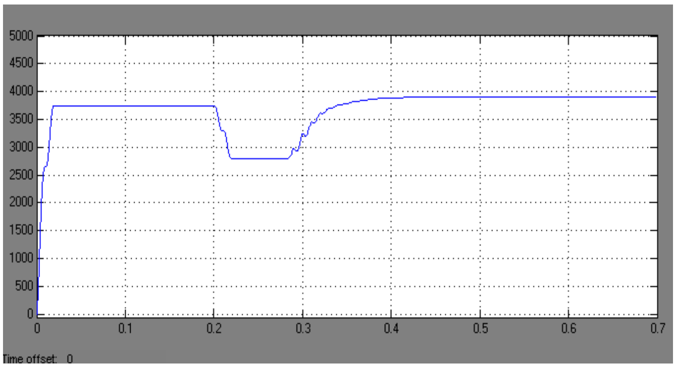


Fig. 4d RMS voltage

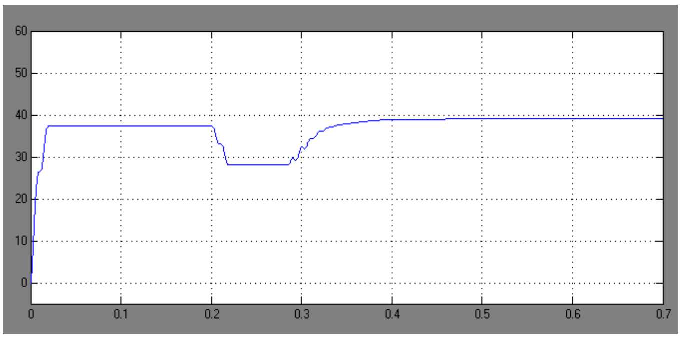


Fig. 4e RMS current

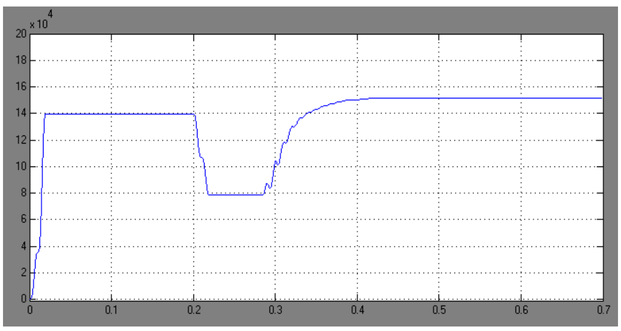


Fig.4f Real power

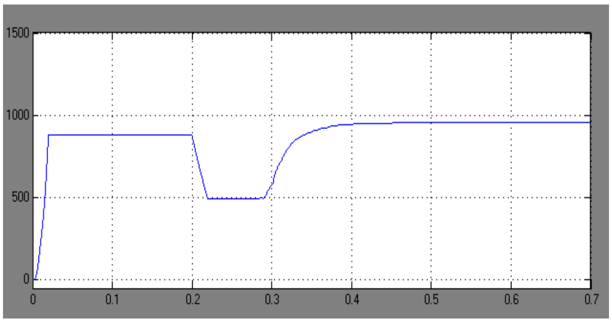


Fig. 4g Reactive power

V. Conclusion

This paper compares Push-pull and ZSI based STATCOM systems to improve the voltage stability of a system.closed loop simulink models are developed for Push-Pull and ZSI based STATCOM systems. Power system with these STATCOM are simulated and the results are presented.The responses of these two systems are compared and it is observed that ZSI based system has faster response compared to Push-pull Inverter system. The simulation studies indicate the usefulness of STATCOM to mitigate the voltage sag. The simulation results are in line with the predictions.

The scope of this paper includes the simulation using single phase model. The simulation has considered a balanced load. ZSI system has capability like low shoot through current and boosting the input voltage. Therefore ZSI based STATCOM is better than that of Push-Pull type of STATCOM.

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