POWER SYSTEM TRANSIENT STABILITY ENHANCEMENT WITH APPLICATION OF SSSC AND IPFC FACTS DEVICES

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ABSTRACT
The complexity due to massive growth of power systems has to increased demand of electrical energy giving rise to numerous stability challenges. In these situations, Flexible Alternating Current Transmission System (FACTS) controllers have increasing been applied. This paper discusses and compares the transient stability enhancement by use of SSSC and IPFC FACTS controllers when applied in Transient Stability Enhancement (TSE) in a dynamic IEEE 14 bus system with fault applied at bus 04. It is achieved by observing the behaviour of damping power oscillations. Time domain responses for angular frequencies and voltages responses have been analysed.

Keywords: FACTS, Power Oscillation Damping, Reactive and Active Power UPFC, SSSC, STACOM, IPFC, Transient Stability Enhancement

1.0 INTRODUCTION
An electrical power system is a complex interconnected network comprising of numerous generators, transmission lines, variety of loads and transformers. The term Flexible Alternating Current Transmission System (FACTS) devices or controllers describe a wide range of controllers, many of which incorporate large power electronic converters that can increase the flexibility of power systems making them more controllable and stable. FACTS devices stabilize transmission systems with increased transfer capability and reduced risk of line trips [A. Kumar and S. B. Dubey 2013].The major problem in power system is

upholding steady acceptable system parameters like transients and voltage under normal operating and anomalous conditions, which is usually referred as voltage regulation problem and regaining synchronism after a major fault. This results in system overloading. Overloading may also due to faults, heavy loading, long transmission lines with uncontrolled buses at the receiving end, radial transmission lines, and shortage of local reactive power, intrinsic factors, and small generation reserve margins. This leads to the introduction of FACTS such as Static Var Compensator (SVC), SSSC, STATCOM, UPFC and IPFC [M.Karthik and P.Arul 2013 and Makkar and L. Dewan 2010**,**] for system support. In stable power system, the synchronous machines when disturbed, synchronism will either go back to their original state if there is no net change of power or will reach a new state without loss of synchronism [A. Satheesh and T. Manigandan 2013]. Due to FACTS devices, the power can be flown through the chosen routes with consideration on an increase in transmission line capability and improvement for the security, reliability and economy of the power system. UPFC and IPFC, for instance, are very versatile FACTS controllers [M. A. Abido 2010].

2.0 FACTS DEVICES

The development of FACTS devices started with the growing capabilities of power electronic components. Devices for high power levels have been made available in converters for different voltage levels. The overall starting points are network elements influencing the reactive power the parameters of power system. FACTS devices boost power system operation through their control attributes and injection models [B. Singh et al 2012]. The devices are mainly grouped as:

1. Series controllers such as Thyristor Controlled Series Capacitor (TCSC), Thyristor Controlled Phase Angle Regulators (TCPAR or TCPST), and Static Synchronous Series Compensator (SSSC)
2. Shunt controllers such as Static Var Compensator (SVC), and Static Synchronous Compensator (STATCOM).
3. Combined series-series controllers and combined series-shunt controllers such as Interline Power Flow Controller (IPFC), Unified Power Flow Controller (UPFC) [K. Vasudevan 2013].

2.1 SIGNIFICANCE OF FACTSCONTROLLERS

The benefits of utilizing FACTS devices in electrical transmission systems can be summarized as follows [B. Singh et al 2012]:

1. Increased loading capacity of transmission lines,
2. Prevent blackout, improves generation productivity,
3. Reduce circulating reactive power, Improves system stability limit a,
4. Reduce voltage flicker,
5. Damping of power oscillations,
6. Guaranteeing system stability,
7. Security, availability,
8. Reliability and economy operation

2.2 OPERATION PRINCIPLES OF FACTS

2.2.1 STATIC SYNCHRONOUS SERIES COMPENSATOR (SSSC)

SSSC is a solid-state Voltage Sourced Converter (VSC), which generates a controllable AC voltage, and connected in series to power transmission lines in a power system. SSSC virtual compensates virtually a transmission line impedance by injecting controllable voltage (V_S) in series with the transmission line. V_S are in quadrature with the line current, and emulate an inductive or a capacitive reactance so as to influence the power flow in the transmission lines. The virtual reactance inserted by V_S influences electric power flow in the transmission lines independent of the magnitude of the line current. The variation of V_S is performed by means of a VSC connected on the secondary side of a coupling transformer. A capacitor connected on the DC side of the VSC acts as a DC voltage source. To keep the capacitor charged and to provide transformer and VSC losses, a small active power is drawn from the line. VSC uses IGBT-based PWM inverters. The machine speed is determined by the machine Inertia constant and by the difference between the mechanical torque, resulting from the applied mechanical power, and the internal electromagnetic torque and so the responses are obtained considering the inertia. Further, the gate limits are also considered in the analysis. VSC using IGBT-based Pulse Width Modulation (PWM) inverters is used in the present study. The details of the inverter and harmonics are not represented in power system stability studies; a GTO-based model can also be used. This type of inverter uses PWM technique to synthesize a sinusoidal waveform from a DC voltage with a typical chopping frequency of a few kilohertz. Harmonics are cancelled by connecting filters at the AC side of the VSC. This type of VSC uses a fixed DC voltage V_{DC}. Converter voltage V_C is varied by changing the modulation index of the PWM modulator [M. Ahsan et al 2013] .SSSC circuit diagram is illustrated in figure 2.2.The controllable parameter of this device is the magnitude of the series voltage source V_S[M. Ahsan, A. Murad, F. J. Gómez and L. Vanfretti 2013]. This voltage source is regulated by the controller POD [M. Ahsan et al 2013]. This controller is used for constant power flow through the line.

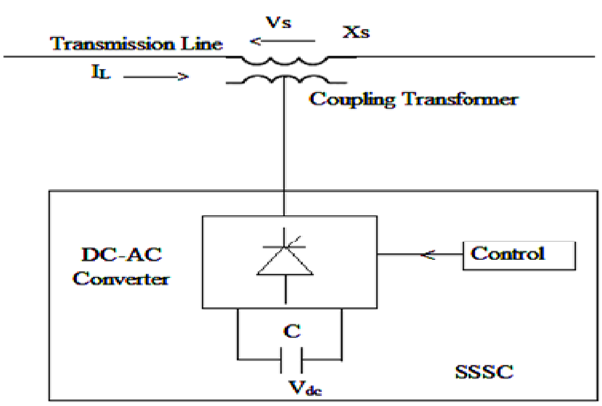

Figure 2.2: Voltage source model of SSSC

2.2.2 INTERLINE POWER FLOW CONTROLLER (IPFC)

The inter line power flow controller employ DC-to-AC converters each providing series compensation for a different line. In other words, the IPFC comprises a number of SSSC. The simplest IPFC consist of two back-to-back DC-to-AC converters (the one as master and the other as slave) as shown figure 2.2. They are connected in series with two transmission lines through series coupling transformers and the dc terminals of the converters are connected together via a common DC link [M. Ahsan et al 2013]. The IPFC can be used to provide double or compensation of the SSSC controller or compensate two transmission lines at the same time through integrated configuration where the SSSC controllers share a common DC link or independent configuration where each SSSC has its own DC link. The IPFC double SSSC configuration is shown in figure 2.3

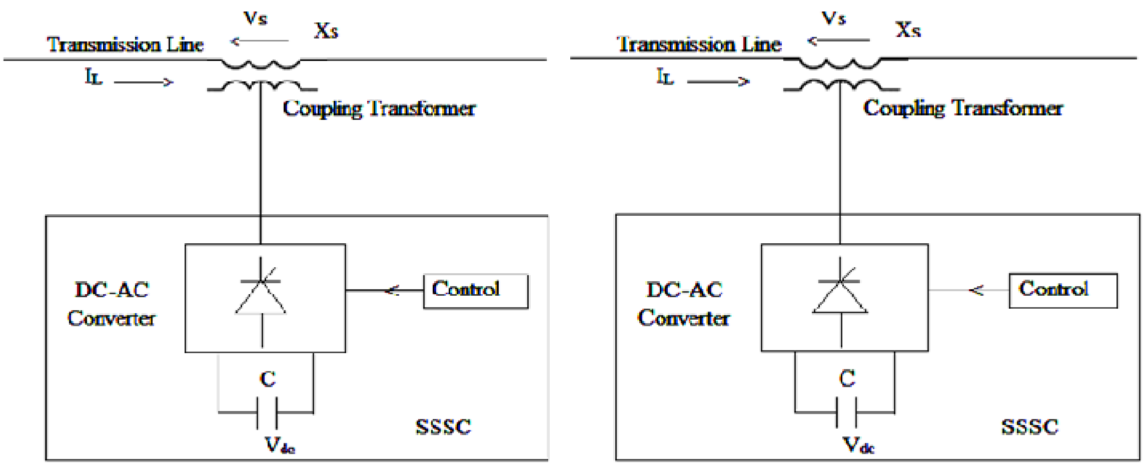

Figure 2.3: Independent VSC IPFC Model (separate DC link)

3 TRANSIENT STABILITY ENHANCEMENT WITH FACTS

3.1.1 TSE WITH SSSC

A. ROTOR SPEED RESPONSES (GEN 1)

When the SSSC FACTS was not connected, the oscillations of the rotor speed also referred to as angular frequency of synchronous generator 1 settle to steady state operating condition after simulation end time set at 40 seconds as observed in figure 4.14. The damping of post fault oscillations is improved considerably by SSSC FACTS device. The device damps the oscillations giving rotor speed settling time of about 25 seconds as shown in figure 4.15 shown below.

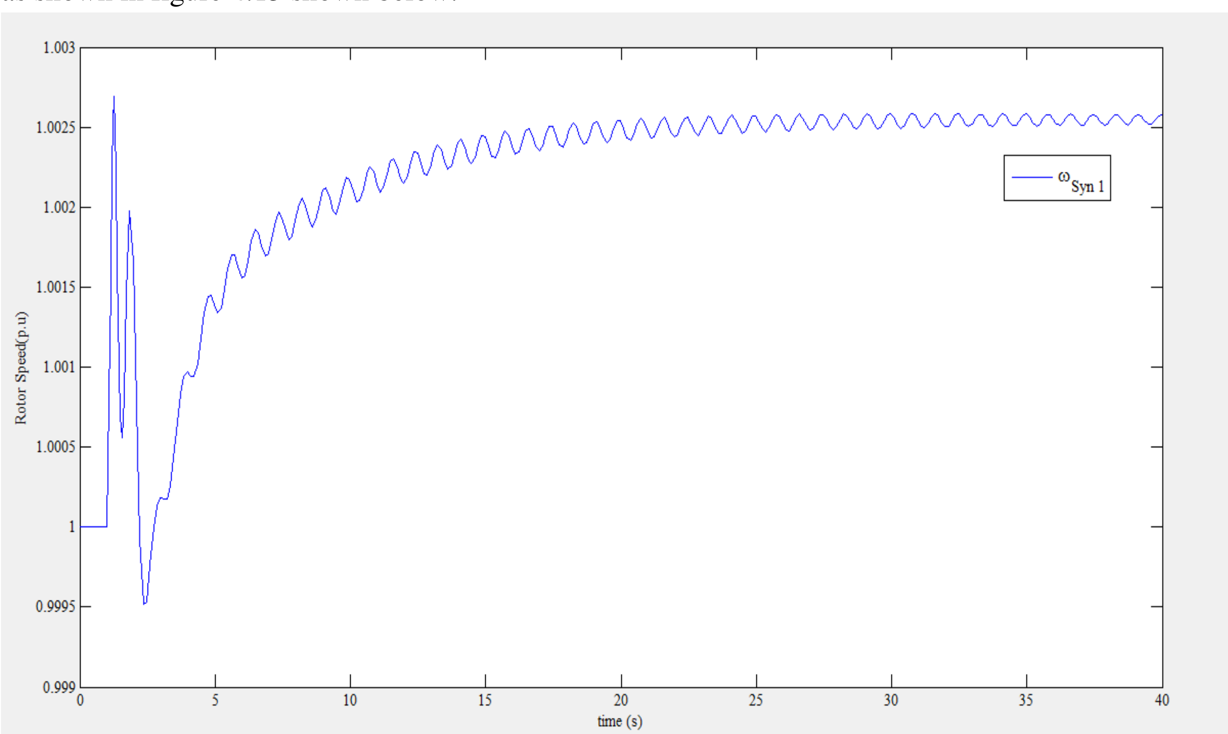

Figure 4.14: Generator 1 Rotor Speed for IEEE-14-bus test system with fault applied at bus 4

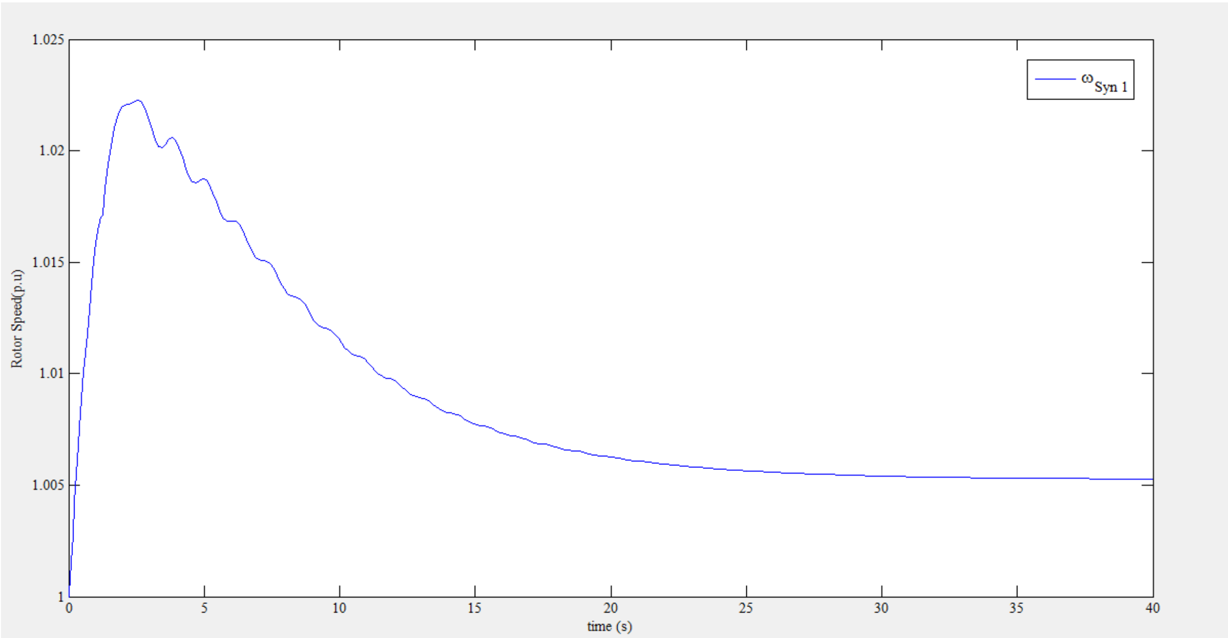

Figure 4.15: Generator 1 Rotor Speed, fault applied at bus 4 and SSSC at Bus 14

B. BUS VOLTAGE RESPONSE

TDS with SSSC FACTS Device, the voltage response settling time is about 1 second for the voltage to reach the steady state operating condition, whereas without SSSC it takes more than 40 seconds due to the oscillations after the 3 phase fault applied at bus 04 cleared with clearing time of 1.25 seconds. To maintain power balance, the SSSC absorbed voltage at bus 14 as shown in figure 4.19 from initial value of 1.08p.u to about 0.15p.u. In figure 4.18, voltage profile response of Bus 06 after fault clearance time without IPFC is shown. It can be seen that it takes more time to damp oscillation and reaches the steady state after end of simulation time set at 40 seconds.

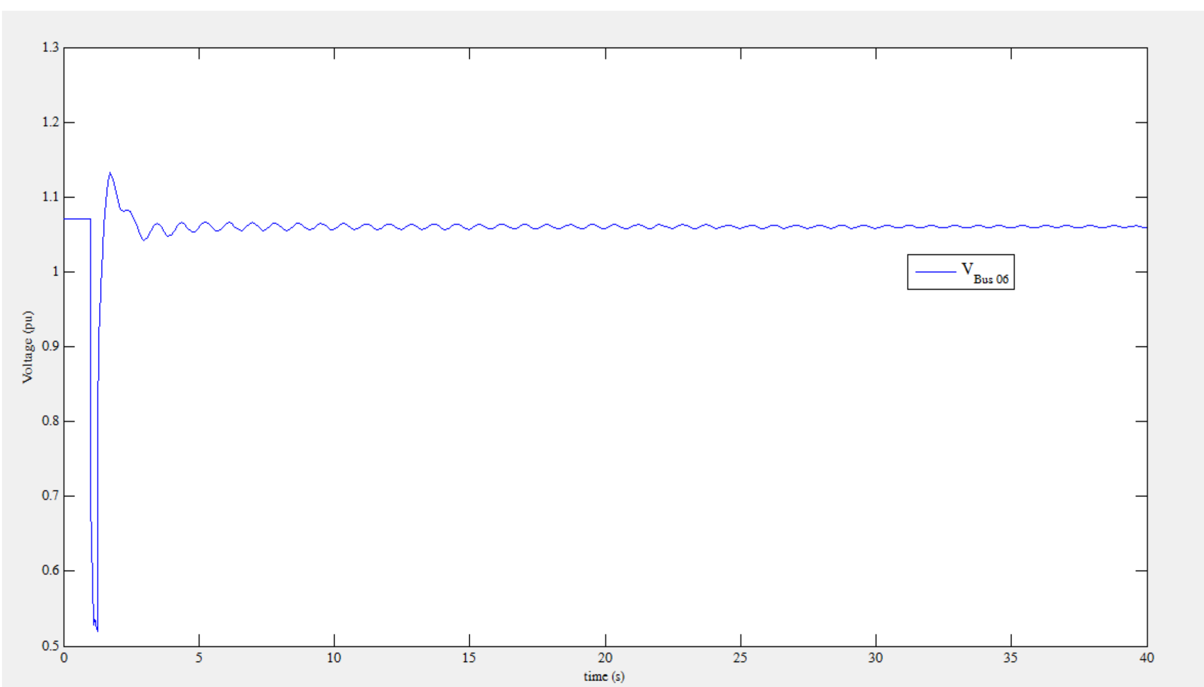

Figure 4.18: Bus 06 Voltage Response, fault applied at bus 4

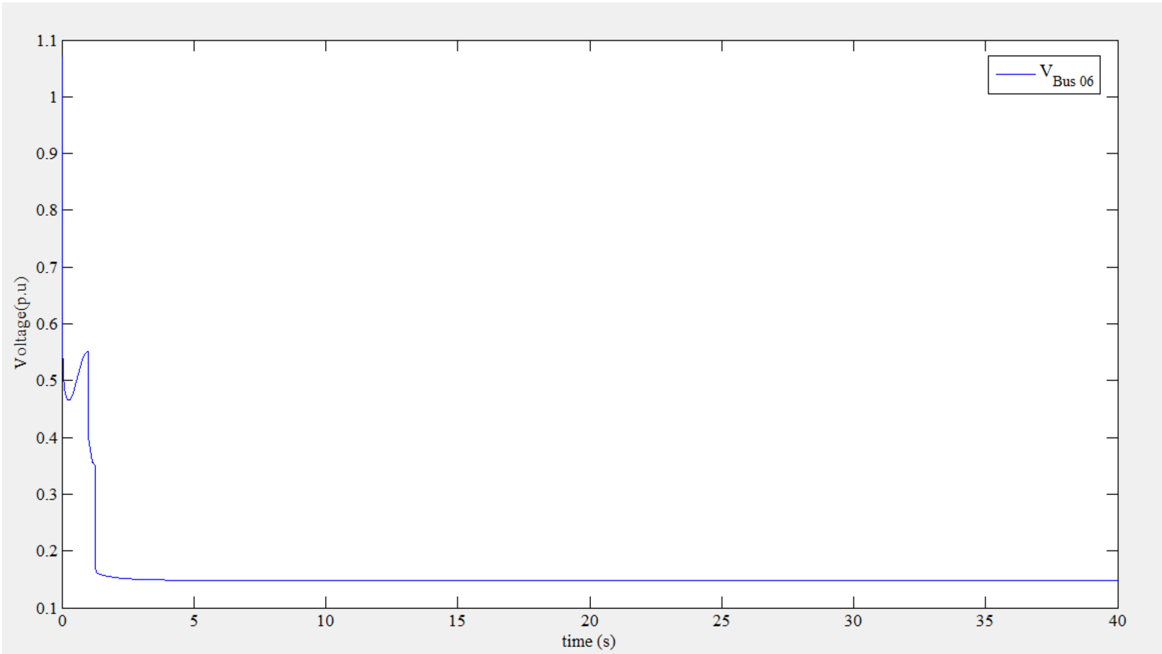

Figure 4.19: Bus 06 Voltage response, fault applied at bus 4 and SSSC at Bus 14.

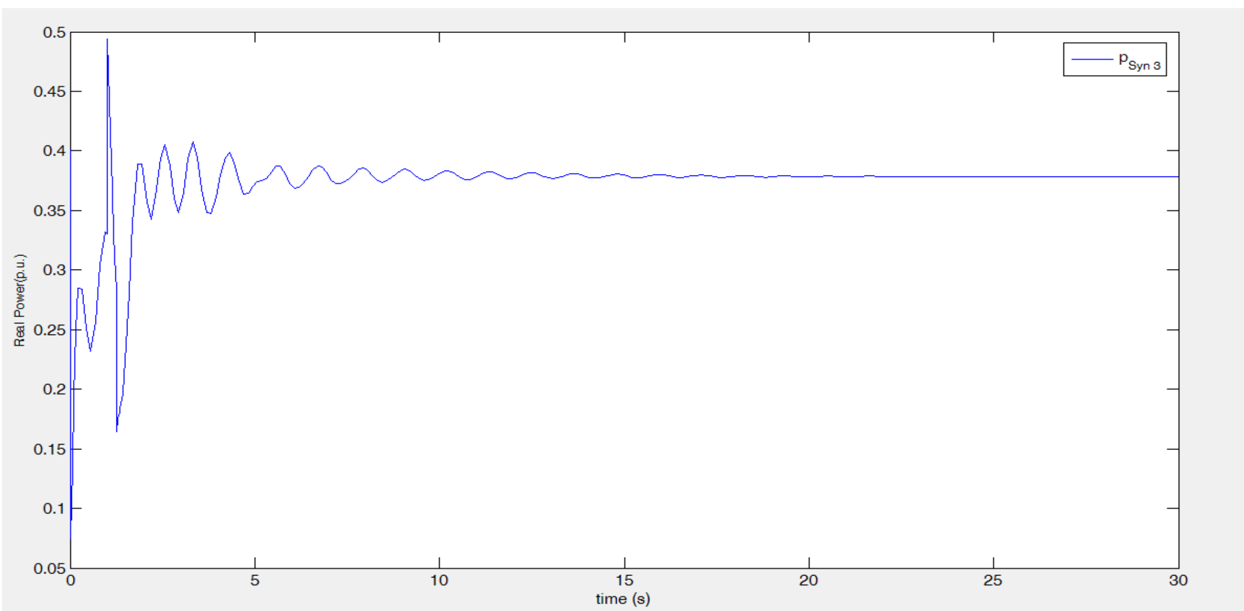

Figure 4.23: Generator 3 real power, fault applied at bus 4 and SSSC at Bus 14

C. GENERATOR 4 REACTIVE POWER RESPONSE

A similar arrangement for reactive power response of synchronous generator 4 without SSSC is shown in figure 4.24. Figure 4.25 is an illustration of Q response with SSSC. Oscillations after fault clearance at 1.25 seconds continue unsettled and go beyond the simulations ending time set at 30 seconds. However, with SSSC the swings settle to steady state operating condition at about 2 seconds with reactive power magnitude of lesser magnitude (0.23p.u) than the original value of about 0.34p.u.It can be observed that fault oscillations of the un-damped system before settlement to steady state reached a peak of 0.75p.u. This is similar to the response with UPFC system.

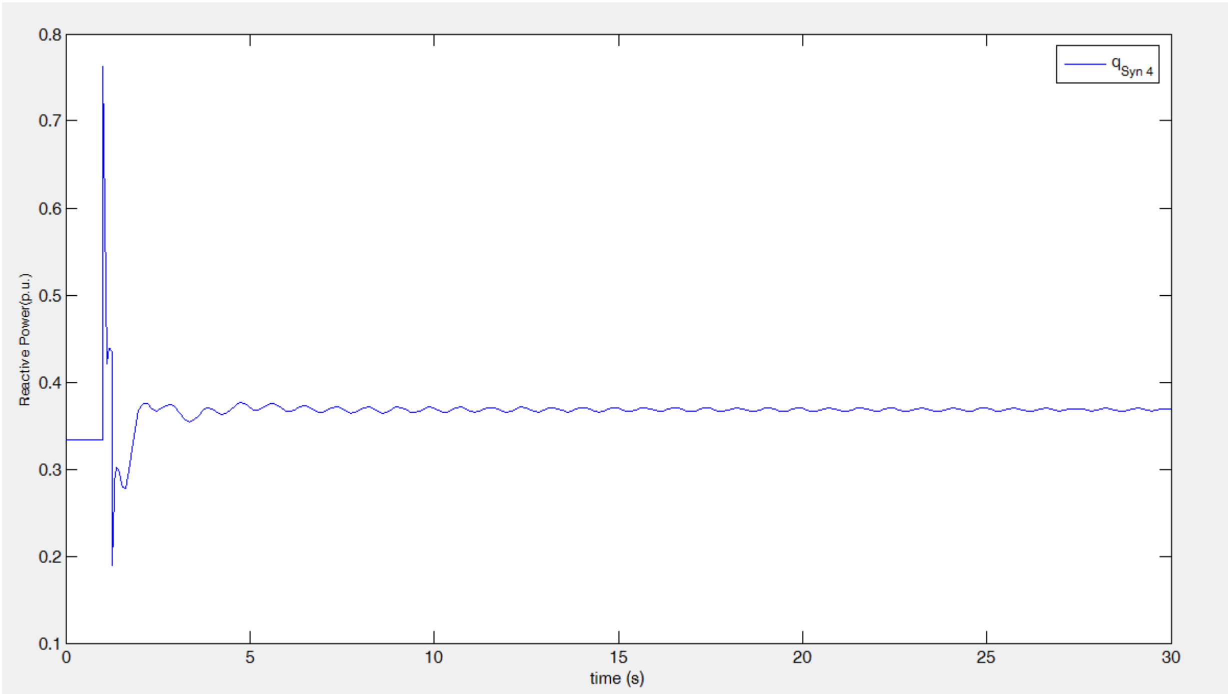

Figure 4.24: Generator 4 reactive power response, fault applied at bus 4 without SSSC

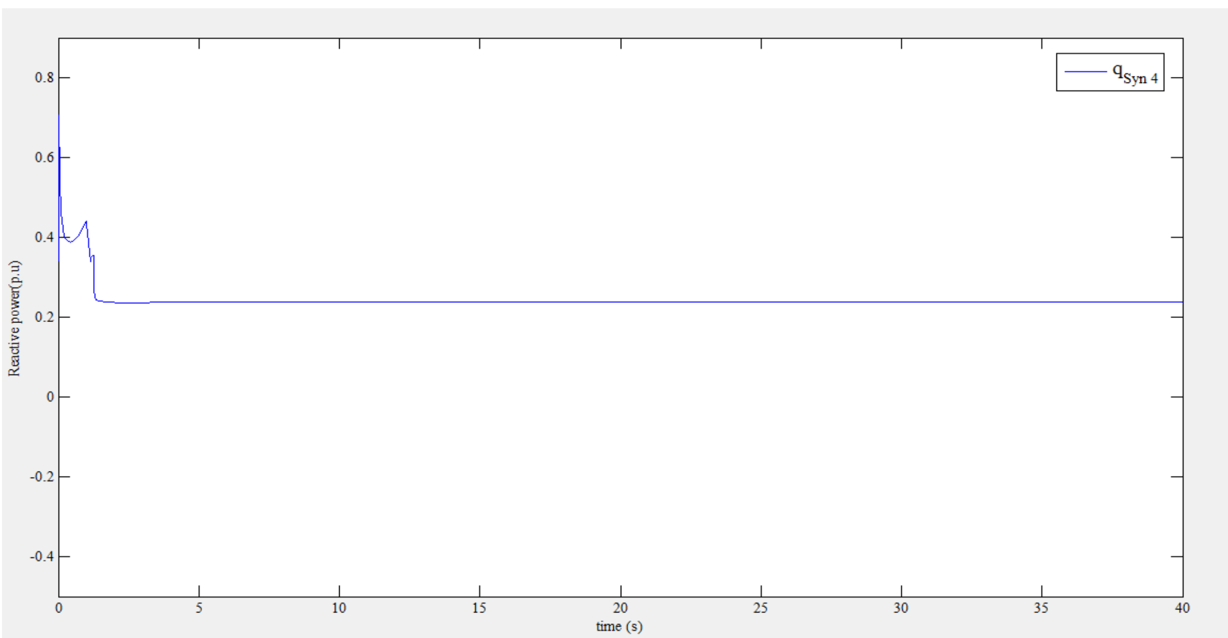

Figure 4.25: Generator 4 reactive power, fault applied at bus 04 and SSSC close to Bus 14

3.1.2 TSE WITH IPFC

A. ROTOR SPEED RESPONSES (GEN 1)

When the IPFC FACTS is not connected at the weakest bus (bus14), the oscillations of the rotor speed of synchronous generator 1 settle to steady state operating condition after simulation time of 40 seconds as observed in figure 4.26. The damping of post fault oscillations is improved significantly by placing IPFC FACTS device at bus 14. The device damps the oscillations giving rotor speed settling time of about 25 seconds as shown in figure 4.27 shown below.

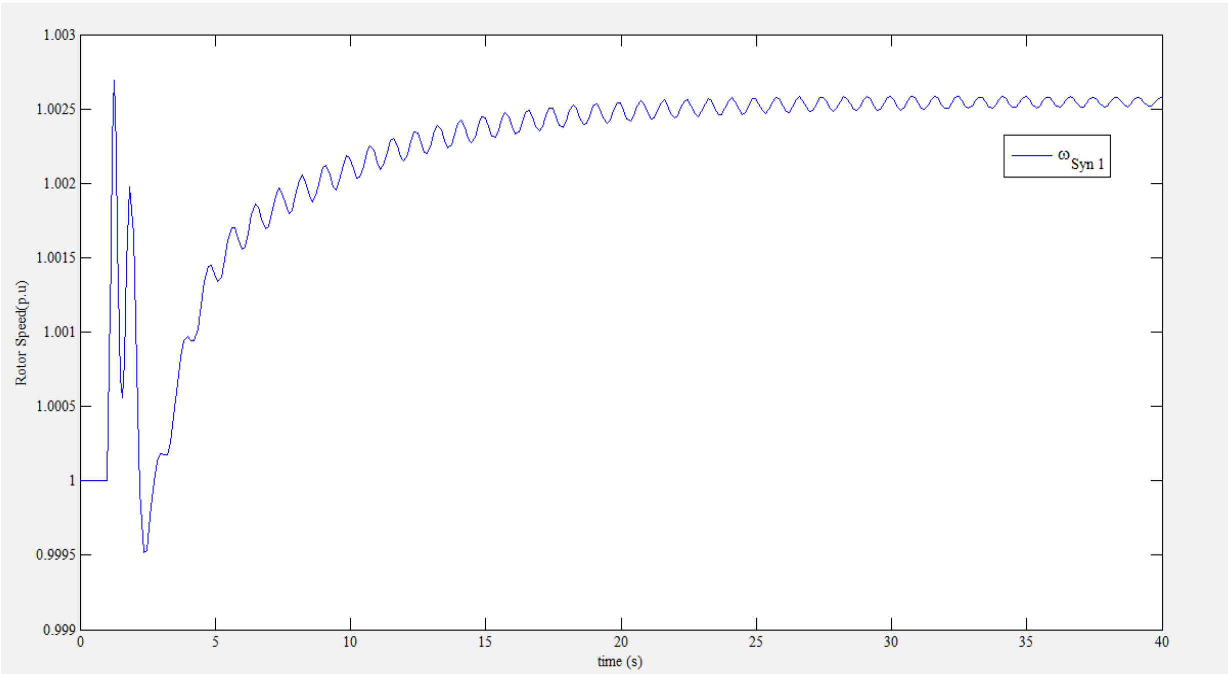

Figure 4.26: Generator 1 Rotor Speed for IEEE-14-bus test system with fault applied at bus 4

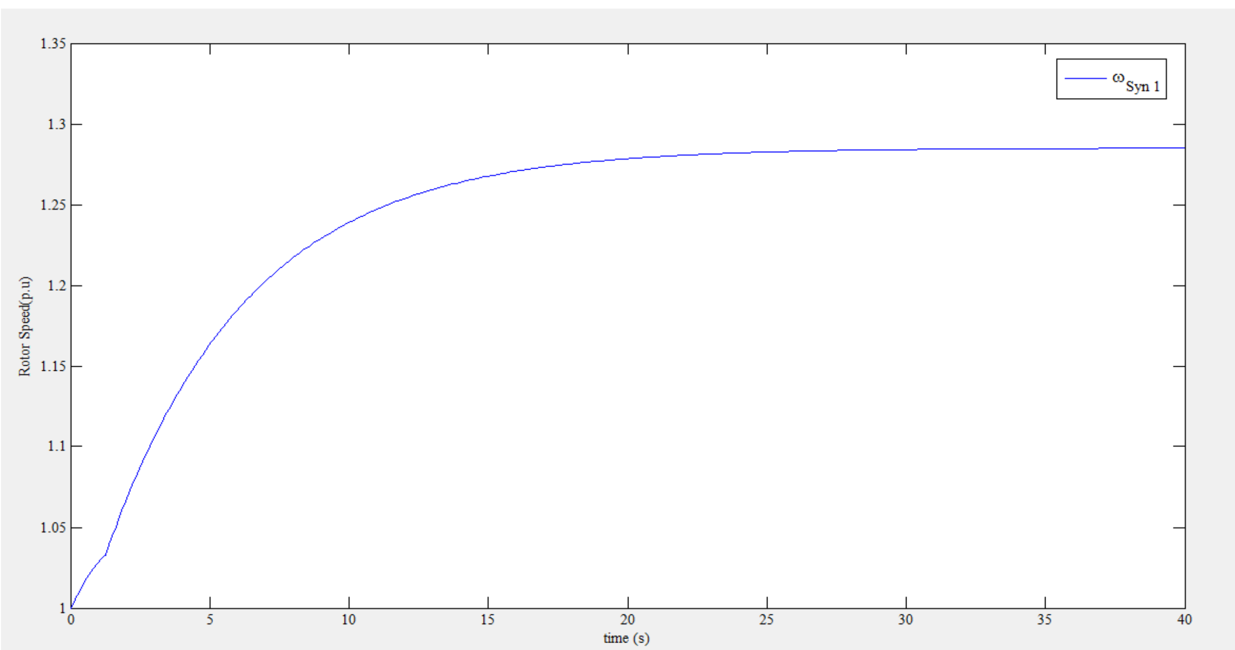

Figure 4.27: Generator 1 Rotor Speed with fault applied at bus 4 and IPFC

B. BUS VOLTAGE RESPONSE

TDS simulation with IPFC FACTS Device, the voltage response settling time is about 1 second for the voltage to reach the steady state operating condition, whereas without IPFC it takes more than simulation time of 40 seconds due to the oscillations after the 3 phase fault applied at bus 04 cleared with clearing time of 1.25 seconds. To maintain power balance, the IPFC absorbed voltage at bus 14 as shown in figure 4.31 from initial value of 1.08p.u to about 0.15p.u. In figure 4.30, voltage profile response of Bus 06 after fault clearance time without IPFC is shown. It can be seen that it takes more time to settle down.

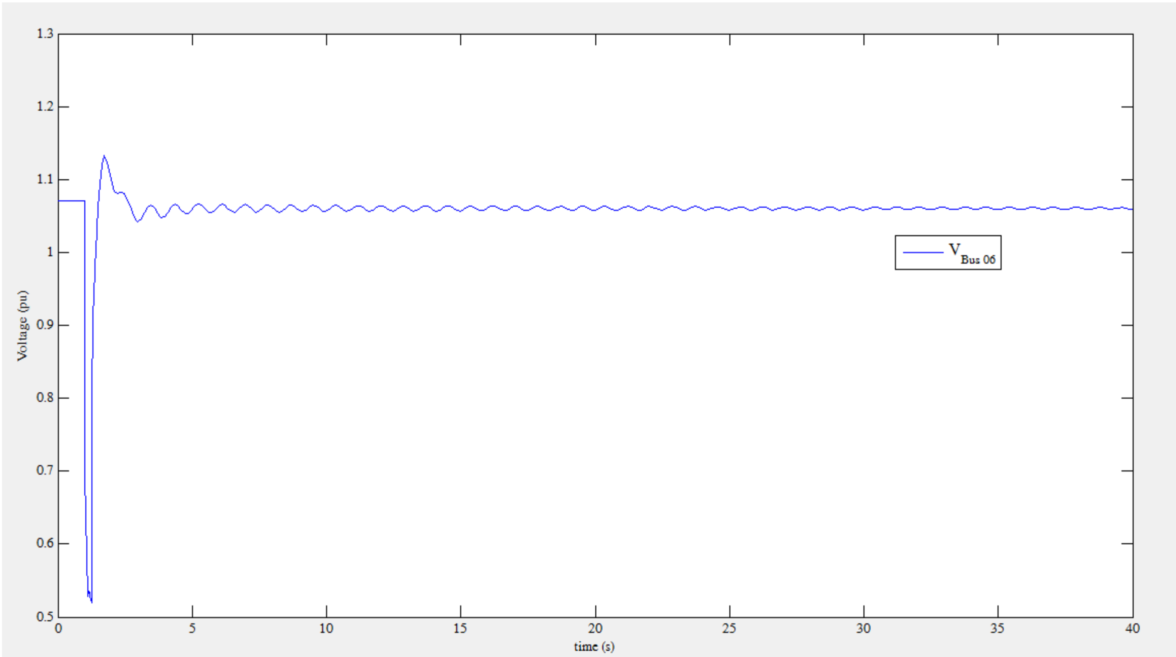

Figure 4.30: Bus 06 voltage response with fault applied at bus 4

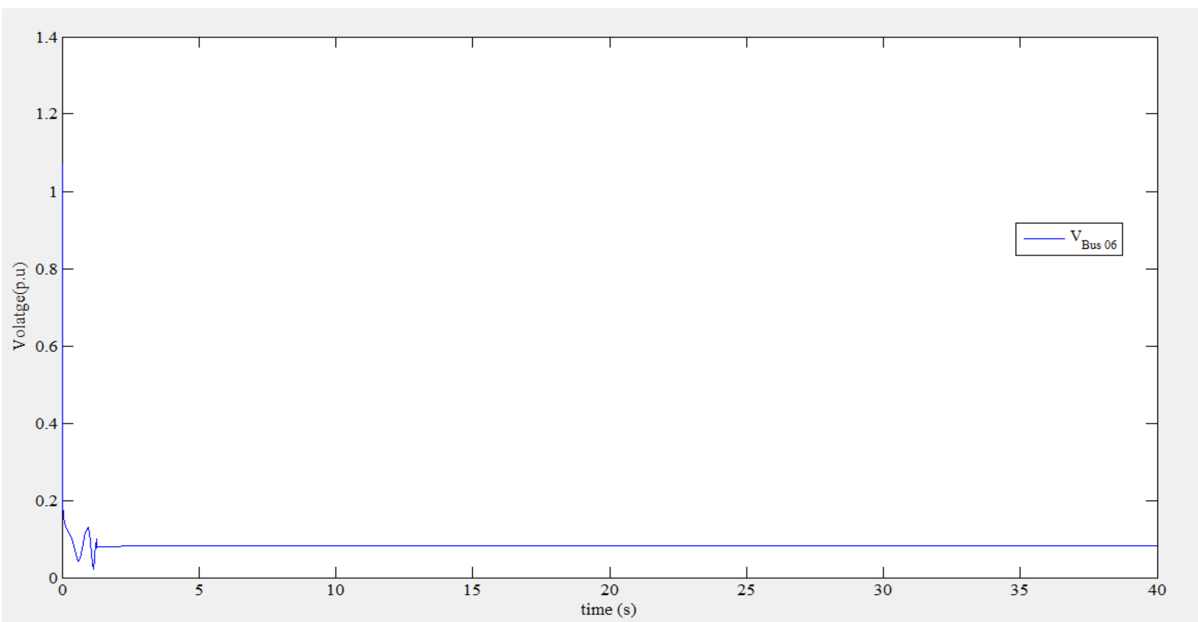

Figure 4.31: Bus 14 Voltage Response with fault applied at bus 4 and IPFC close to 14

C. GENERATOR 4 REACTIVE POWER RESPONSE

A similar arrangement for reactive power response of synchronous generator 4 without IPFC is shown in figure 4.36. Figure 4.37 is an illustration of Q response with IPFC. Oscillations after fault clearance at 1.25 seconds continue unsettled and go beyond the simulations ending time set at 30 seconds. However, with IPFC of independent configuration (dual SSSC) the swings settle to steady state operating condition at about 5 seconds. It can be observed that fault oscillations of the un-damped system before settlement reached a peak of 0.75p.u. This is similar to the response with UPFC system. IPFC has been utilized to damp power transients efficiently.

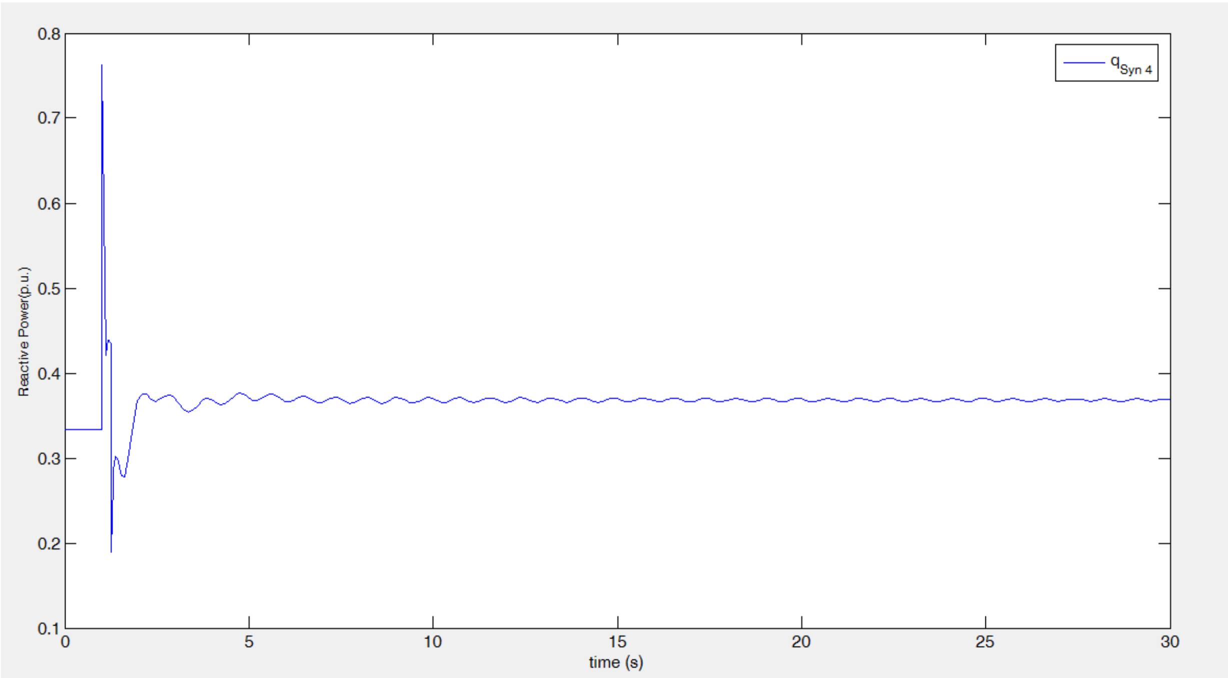

Figure 4.36: Generator 4 Reactive Response with fault applied at bus 4

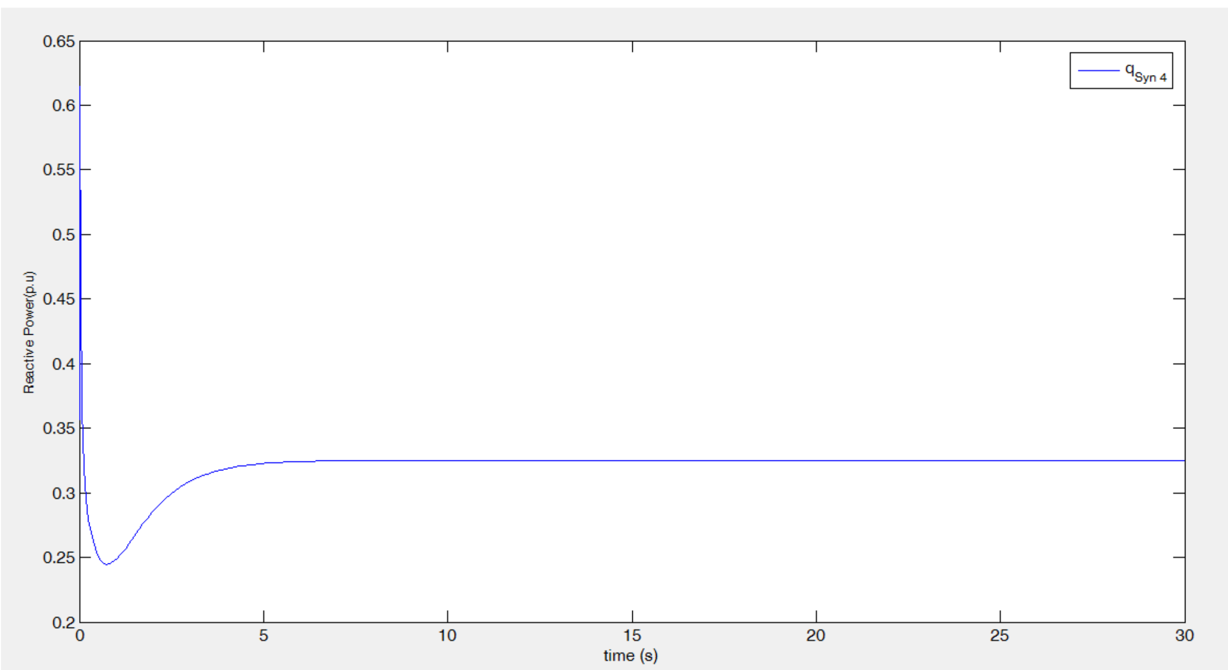

Figure 4.37: Generator 4 reactive response with fault applied at bus 4 and IPFC close to bus 14

CONCLUSION

The SSSC and IPFC FACTS devices not only damp the system oscillations of the multi machine system but also reduce the oscillations transient periods accordingly. The transient state period of rotor speed responses is longer than those of voltage responses hence FACTS provide better support to system voltages compared to other parameters like rotor angle. To achieve steady state operating after disturbances, it's evident that the damping characteristics of the IPFC are superior to those of SSSC.

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