



Power System Oscillations Damping and Transient Stability Enhancement with Application of SSSC FACTS Devices

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ABSTRACT

The massive growth of interconnected power systems due to increasing demand of electrical energy has given rise to numerous challenges. In these situations, Flexible Alternating Current Transmission System (FACTS) controllers. This paper discusses the transient stability enhancement by use of SSSC FACTS controller 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 rotor angle and generator electromotive force responses were analysed.

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

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 [1]. 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 [2-3] 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 [4]. 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 [5].

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 [6]. 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).

Benefits of Utilizing Facts Devices

The benefits of utilizing FACTS devices in electrical transmission systems can be summarized as follows [6]:

- Increased loading capacity of transmission lines,
- Prevent blackout, improves generation productivity,
- Reduce circulating reactive power, Improves system stability limit a,
- Reduce voltage flicker,
- Damping of power oscillations,
- Guaranteeing system stability,
- Security, availability,
- Reliability and economy operation

OPERATION PRINCIPLES OF SSSC FACTS CONTROLLER

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. SSSC circuit diagram is illustrated in Fig. 1. The controllable parameter of this device is the magnitude of the series voltage source V_s . This voltage source is regulated by the controller POD [7]. This controller is used for constant power flow through the line.

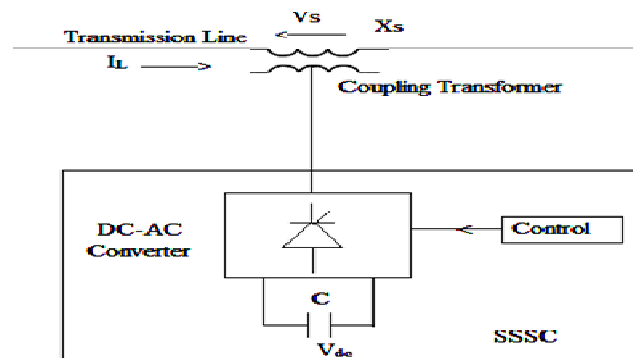


Fig. 1 Voltage source model of SSSC

TRANSIENT STABILITY ENHANCEMENT WITH SSSC FACTS ROTOR SPEED RESPONSES

Rotor Speed Response of Generator 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 Fig. 2. 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 Fig. 3.

Rotor Speed Response of Generator 5

In a similar manner for synchronous generator number 5, SSSC damps the oscillations of the rotor speed (angular frequency) responses to steady state operating condition after about 25 second and pre-fault oscillations way settle after simulation time of 40 seconds. The damping of post fault oscillations is achieved faster with SSSC FACTS device. The oscillations phenomena with and without SSSC exhibiting the post-fault responses are shown in Figs 4 and 5 respectively.

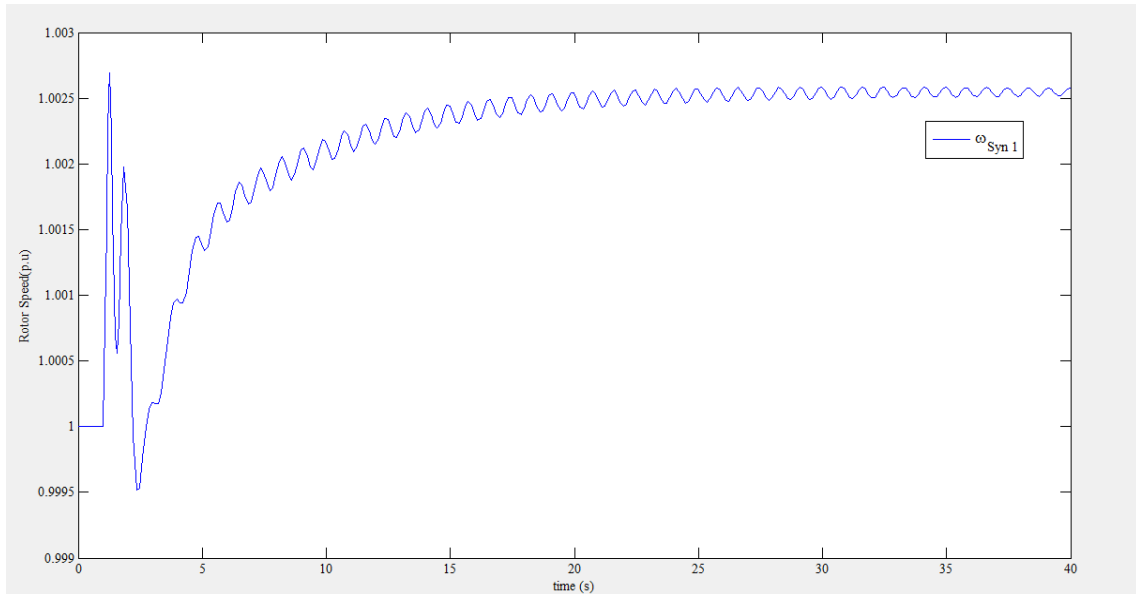


Fig. 2 Generator 1 Rotor Speed for IEEE-14-bus test system with fault applied at bus 4

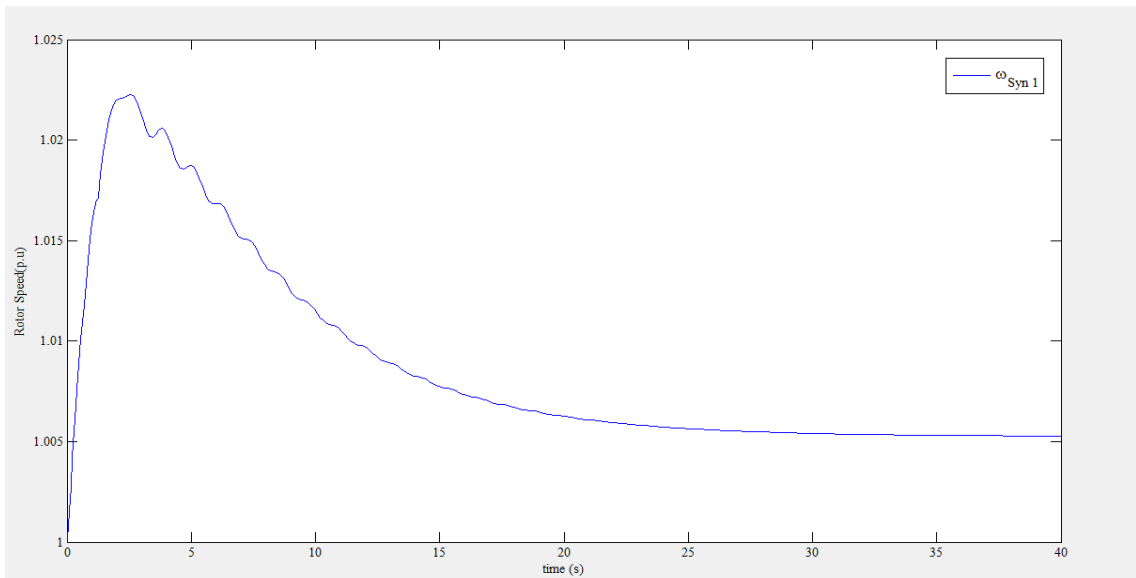


Fig. 3 Generator 1 Rotor Speed, fault applied at bus 4 and SSSC at Bus 14

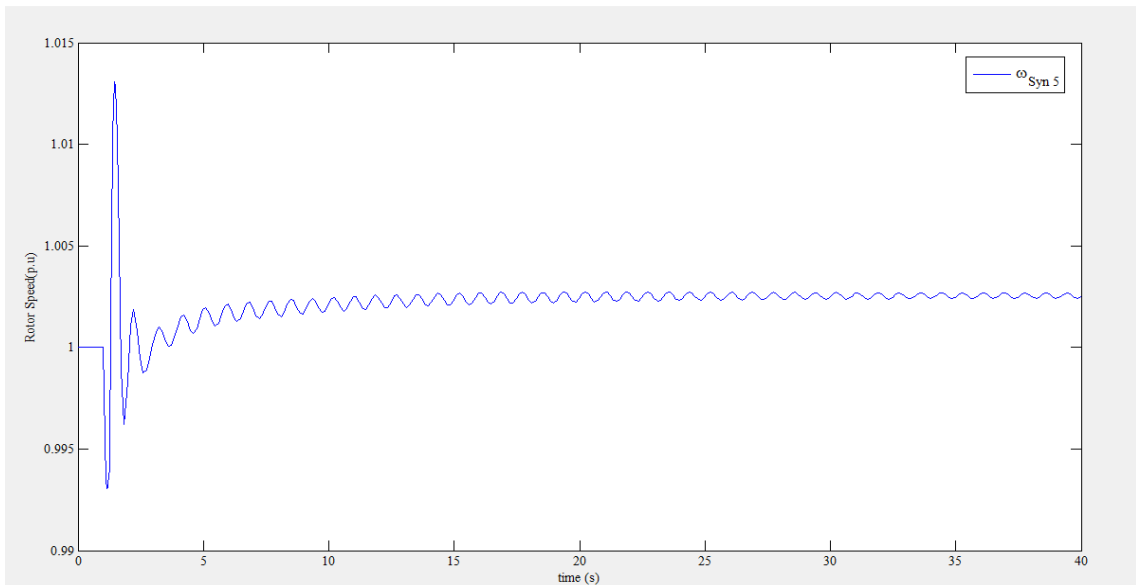


Fig. 4 Generator 5 Rotor Speeds with fault applied at bus 4

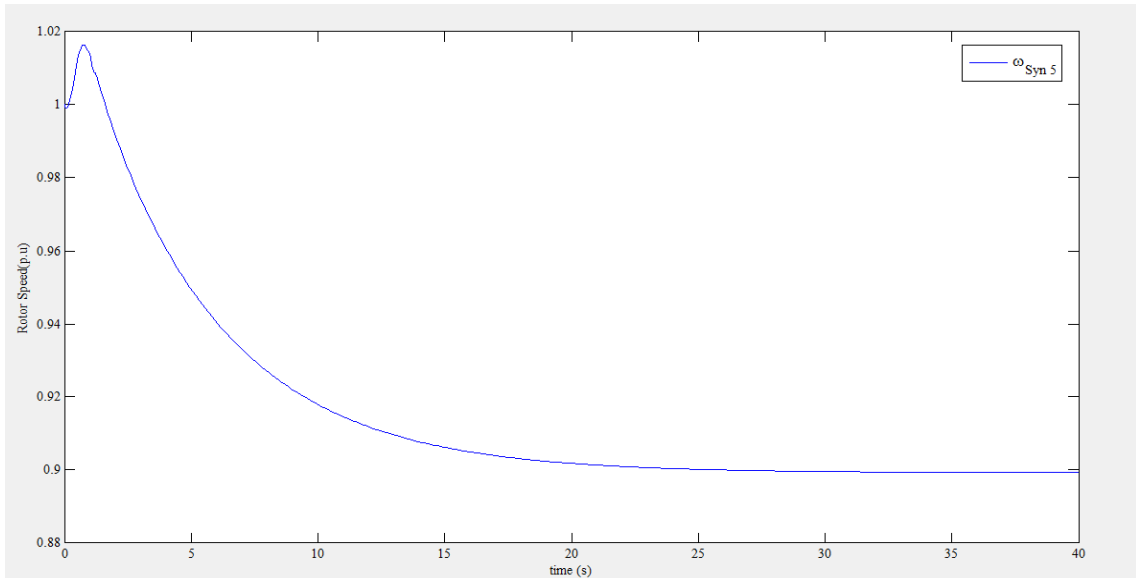


Fig. 5 Generator 5 Rotor Speed, fault applied at bus 4 and SSSC at Bus 14

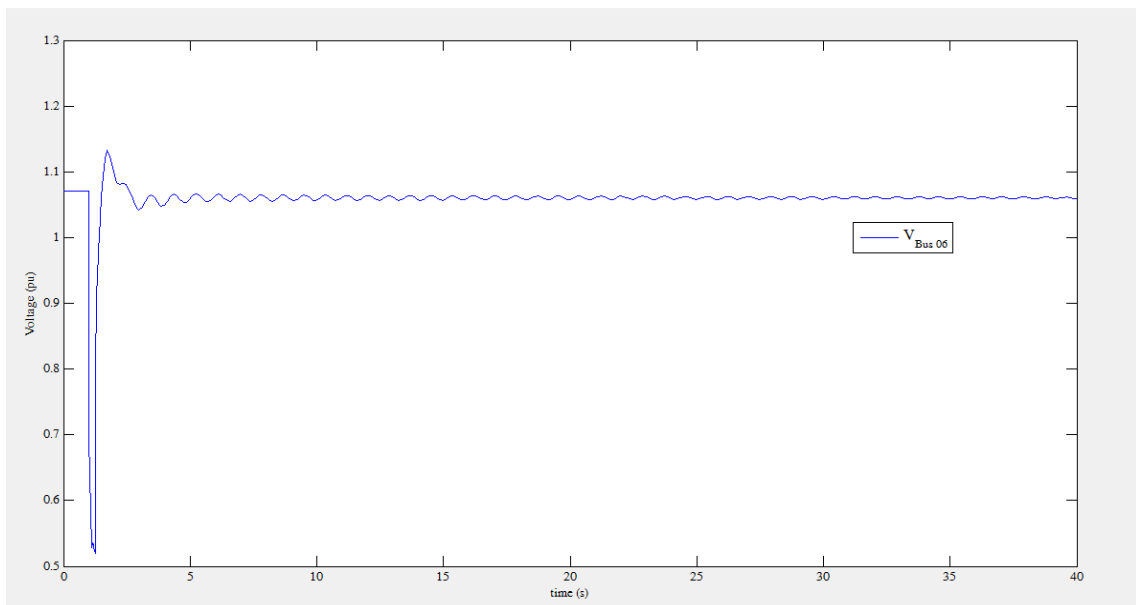


Fig. 6 Bus 06 Voltage Response, fault applied at bus 4

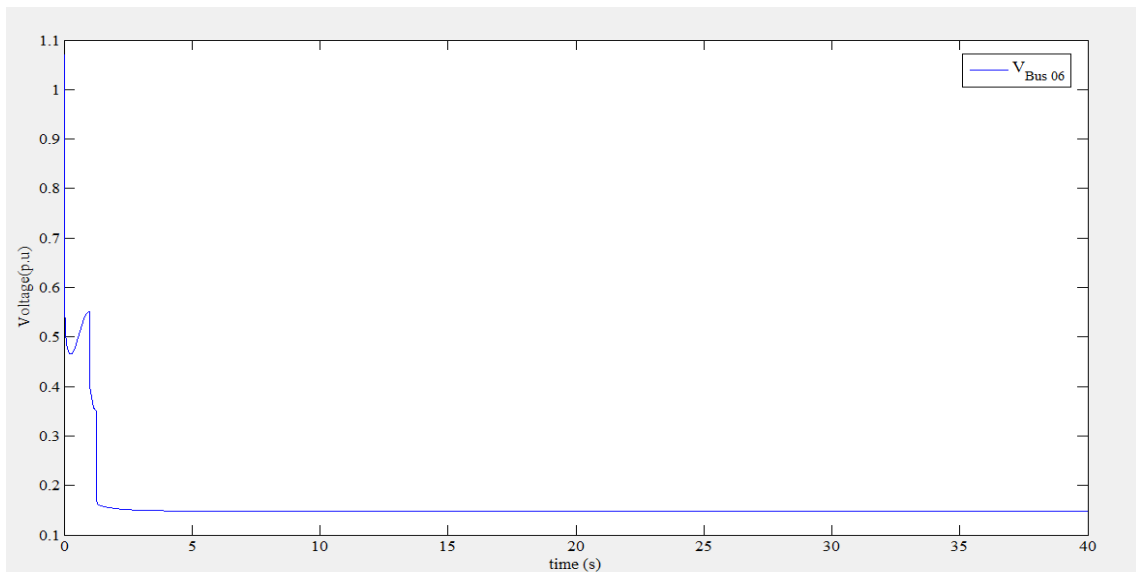


Fig. 7 Bus 06 Voltage response, fault applied at bus 4 and SSSC at Bus 14

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 Fig. 7 from initial value of 1.08p.u to about 0.15p.u. In Fig. 6, 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.

GENERATOR 4 E.M.F PROFILES

For synchronous generator number 5 E.m.f, e'_d , SSSC damps the oscillations to steady state operating condition in about 5 seconds and post-fault oscillations without the SSSC FACTS device settle way after simulation time of 40 seconds. The damping capability of SSSC for post-fault generator E.m.f swings is achieved faster compared to when the device is not connected as shown in transient responses in Figs 8 and 9.

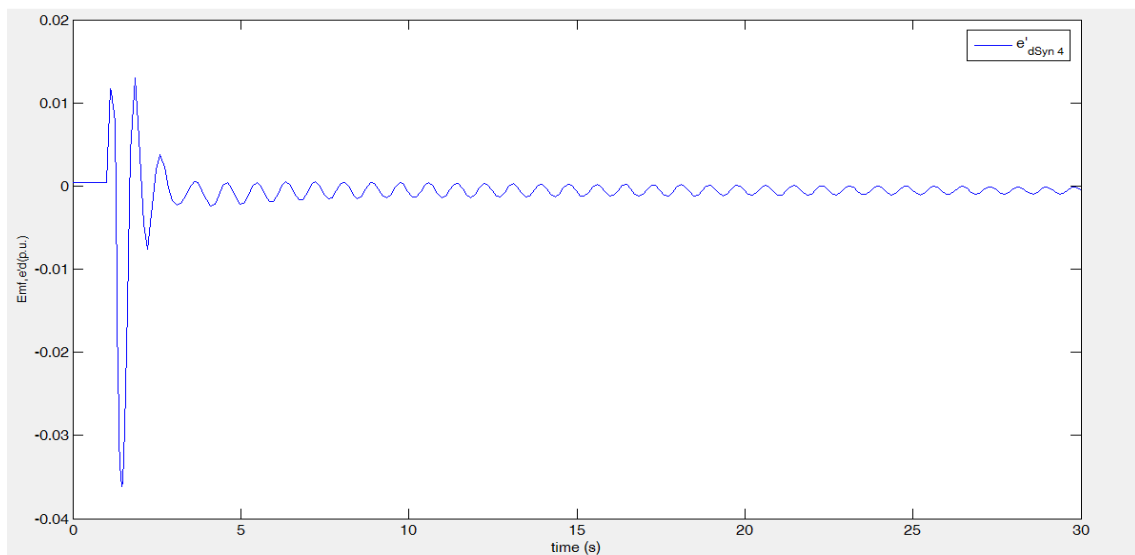


Fig. 8 Generator 4 E.m.f, e'_d Response, fault applied at bus 4

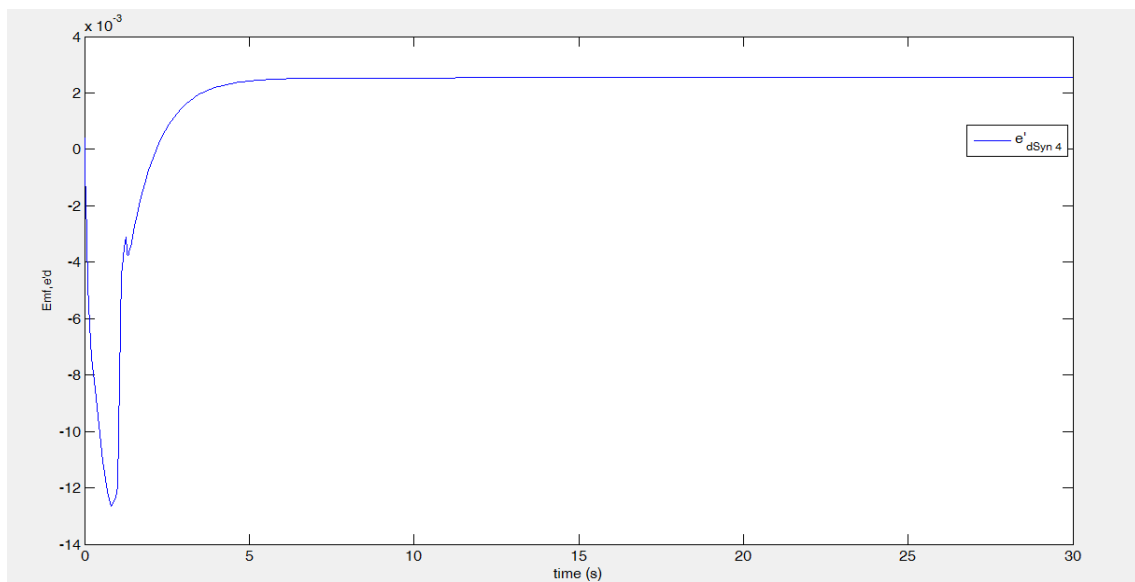


Fig. 9 Generator E.m.f, e'_d Response, fault applied at bus 4 and SSSC at Bus 14

GENERATOR 3 REAL POWER RESPONSE

Real power, P , response of synchronous generator 3 without UPFC is shown in Fig. 10. Fig. 11 displays the response with SSSC. Oscillations after fault clearance at 1.25 seconds continue unsettled and go beyond the simulations ending time set at 40 seconds. However, with SSSC the swings settle to steady state operating condition at about 22 seconds at real power magnitude of slightly less than the original value of 0.4p.u.

GENERATOR 4 REACTIVE POWER RESPONSE

A similar arrangement for reactive power response of synchronous generator 4 without SSSC is shown in Fig. 12. Fig. 13 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.

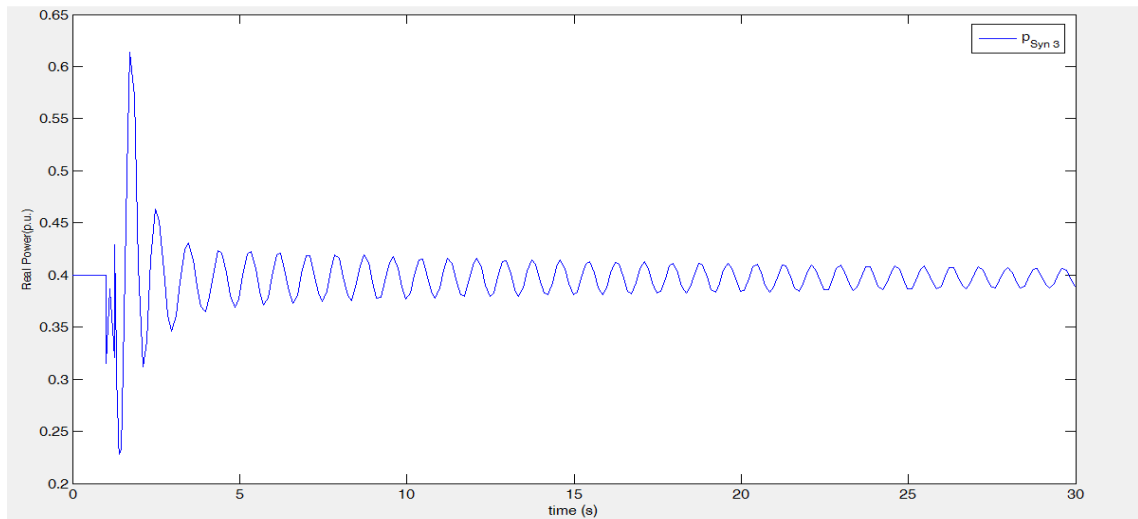


Fig. 10 Generator 3 real power response, fault applied at bus 4

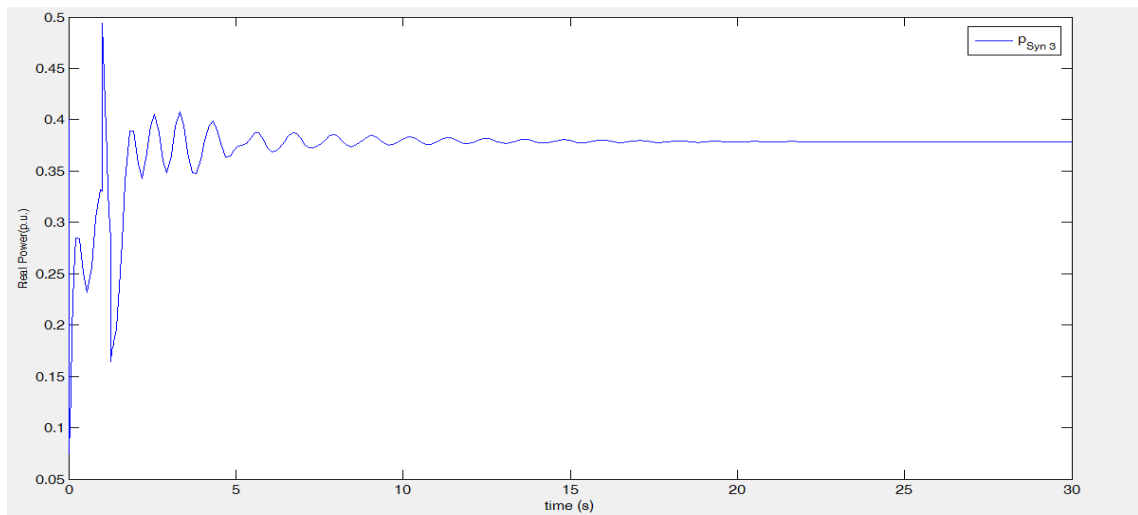


Fig. 11 Generator 3 real power, fault applied at bus 4 and SSSC at Bus 14

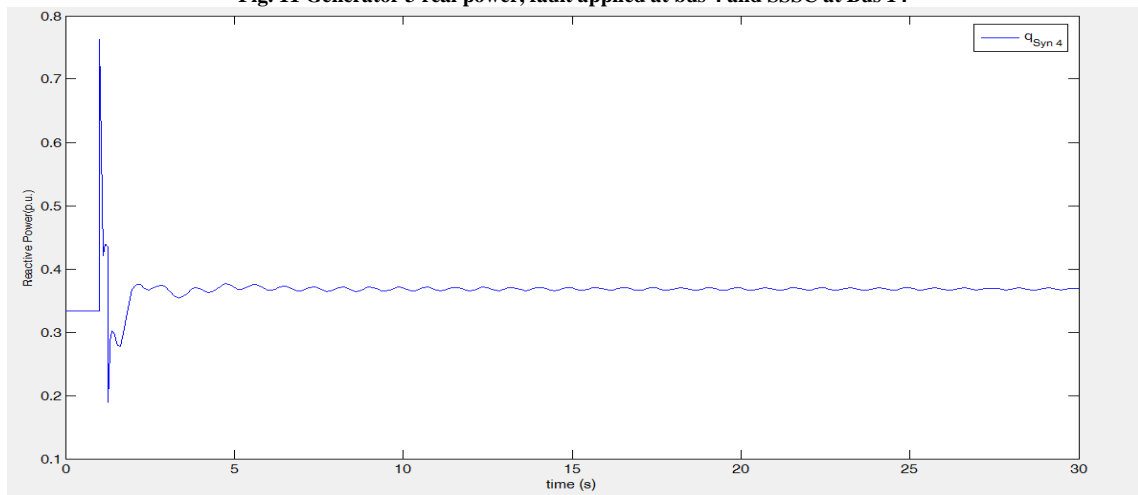


Fig. 12 Generator 4 reactive power response, fault applied at bus 4 without SSSC

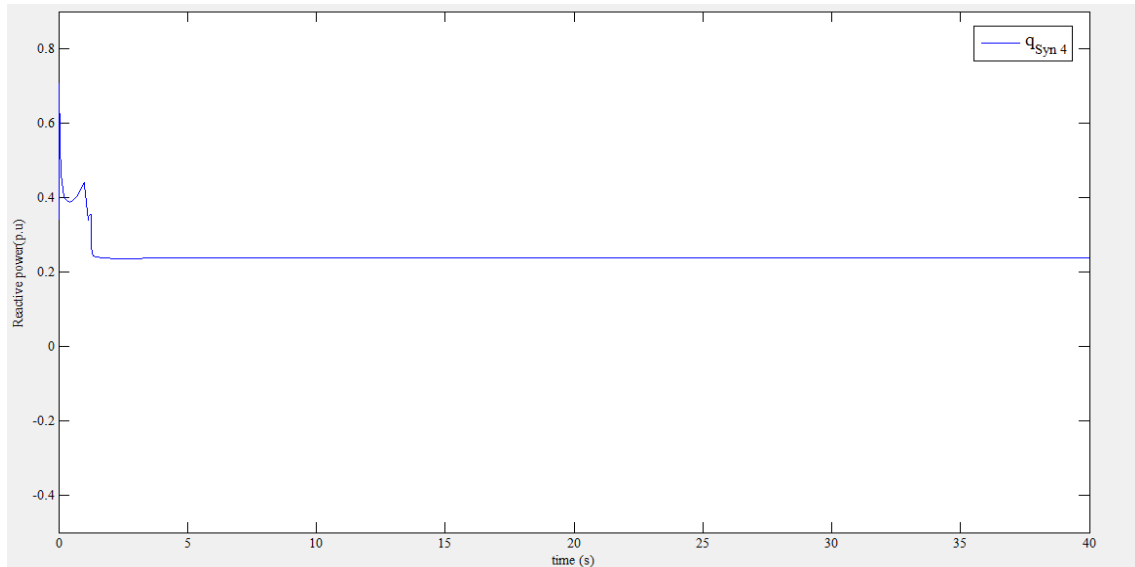


Fig. 13 Generator 4 reactive power, fault applied at bus 04 and SSSC close to Bus 14

CONCLUSION

SSSC FACTS device not only damp the system oscillations of the multimachine system but also reduce the oscillation settling times for generator Emf voltages and rotor speed transient responses when used applied in faulted power systems. To achieve the steady state operating condition after fault applied at bus 4, SSSC exhibited better damping features for reactive power response than for that of the angular frequency responses. It's evident that SSSC FACTS controller provides better compensation for system voltages and reactive compared to other system parameters such as angular frequency.

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