Transient Stability Enhancement with Application of 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 UPFC, 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 rotor angle and generator electromotive force responses were analysed.

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

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I. 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].

II. 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].

Benefits Of Utilizing Facts Devices:

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

Operation Principles Of Facts:

Unified Power Flow Controller (UPFC)

A unified power flow controller (UPFC) is the most promising and versatile device in the FACTS concept. It has the ability to adjust the three control parameters: the bus voltage, transmission line reactance, and phase angle between two buses, either simultaneously or independently [T. Bhaskaraiah and G. U. Reddy 2013 and M. Ahsan et al 2013]. It consists of two voltage source converters (VSC), series and shunt converter, which are connected to each other with a common DC link capacitor which provides bidirectional flow of real power between series connected SSSC and shunt connected STATCOM respectively [A. R. Sam and P.Arul 2013]. As shown in Figure 2.1 this converters are shunt and series transformers with ac voltage bus. The series controller SSSC is used to add controlled voltage magnitude and phase angle in series with the line, while shunt converter STATCOM is used to provide reactive power to the ac system [E. Acha, C. R. Fuerte-Esquivel, and H. Ambriz-Perez 2014].

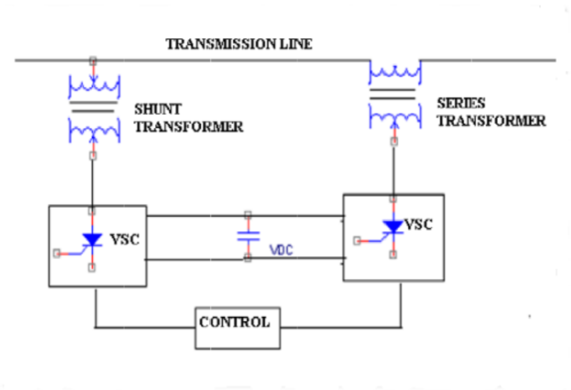

Fig 2.1: UPFC VSC model

Static Synchronous Series Compensator (SSSC)

SSSC is a solid-state Voltage Sourced Converter (VSC), which generates a controllable AC voltage 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.

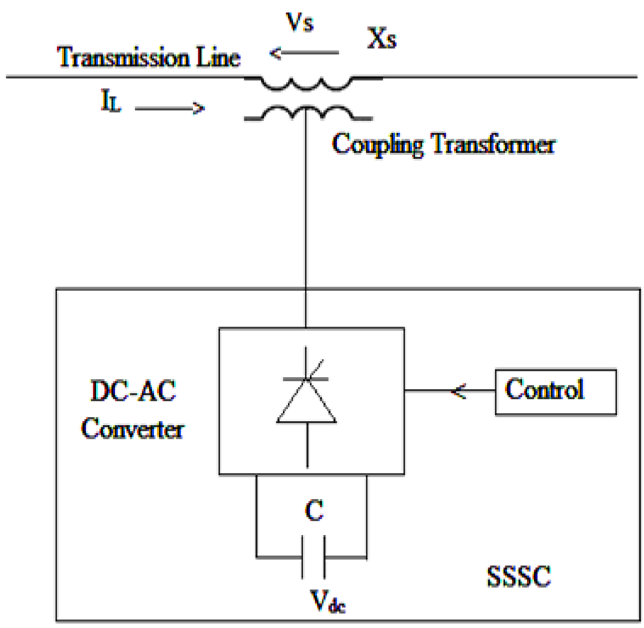

Figure 2.2: Voltage source model of SSSC

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

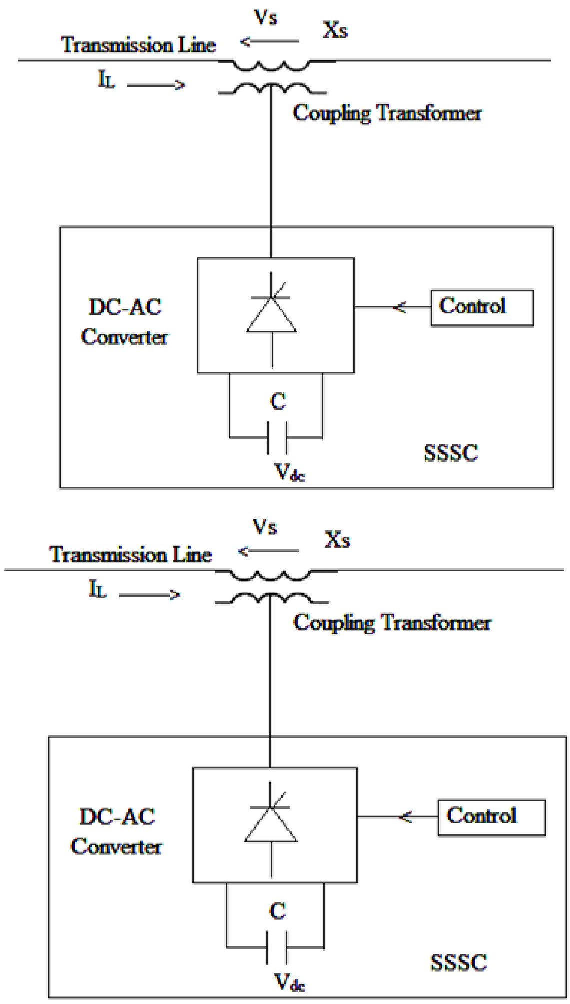

Figure 2.3: Independent VSC IPFC Model (separate DC link)

III. TRANSIENT STABILITY ENHANCEMENT WITH FACTS

Generator Rotor Angle Behavior

The figures 3.1 to 3.4 illustrate the rotor behavior for three synchronous generators 2, 4 and 5 in MATLAB PSAT Version 2.1.9 toolbox. Without using the FACTS devices, the Rotor angles keeps increasing and go out of synchronism as shown in figure 3.1. When the dynamic model with the FACTS is simulated, the responses start decreasing. Generally, for the three generators, the three FACTS decrease the acceleration of the rotor angles. For all of the devices, the rotor angle of generator 5 decreases the most followed by angle of generator 4 and the least decreasing rotor angle is that of the generator 2. The decreasing is as a result of damping characteristics of FACTS devices connected. The decrease is more pronounced with IPFC than SSSC and UPFC.

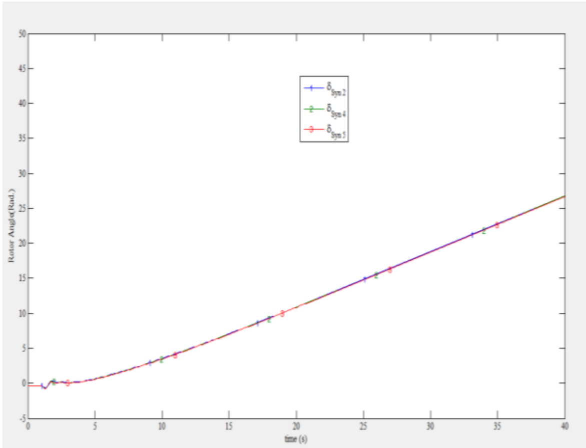

Figure 3.1: Rotor angle responses without FACTS, Fault at Bus 04

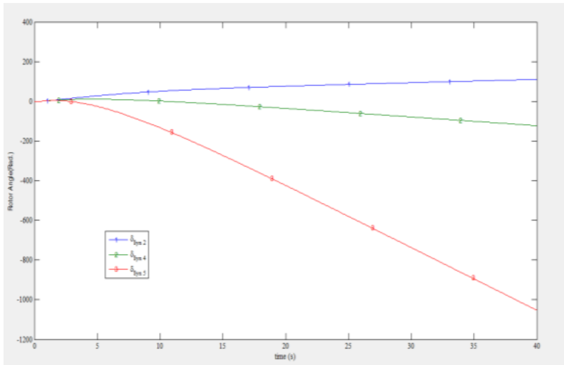

Figure 3.2: Rotor angle responses UPFC FACTS device, fault applied at Bus 04

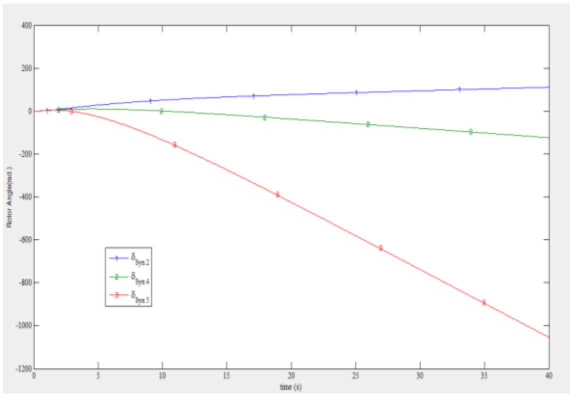

Figure 3.3: Rotor angle responses for SSSC FACTS device, fault applied at Bus 04

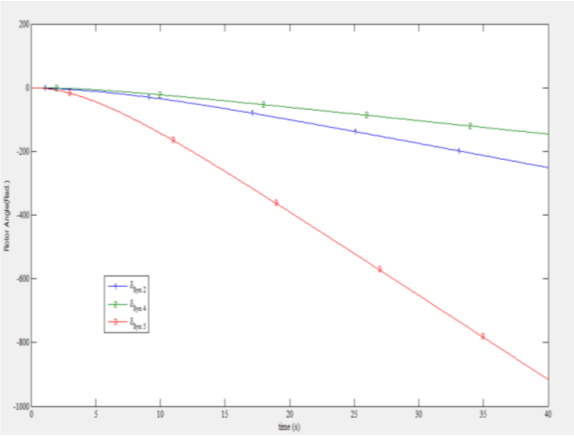

Figure 3.4: Rotor angle responses with IPFC FACTS device, Fault applied at Bus 04

Generator Electromotive Force Behavior

Simulation responses of Emf behavior for the five synchronous generators of from MATLAB®PSAT 2.1.9 Time Domain Simulation without FACTS are displayed in figure 3.5 below. When FACTS are not connected to bus 14voltages keep oscillating keeps increasing and go out beyond the end of simulation time set at 40 seconds except for generator 1 E.m.f where the swings settle to steady state at 35 seconds. When the dynamic model with the FACTS is simulated, the post fault oscillations start decaying. Overall, for the five generators, the three FACTS effectively damp the oscillation as follows, for UPFC and SSSC, generator one at 12 seconds, generator 2 at 33 seconds, generator 3 at 16 seconds and generators 4 and 5 at 1.5 seconds. For IPFC devices, the settling time was; generators 1, 3 and 5 at 1.5 seconds, generator 2 at 0.5 seconds and generator 4 oscillations settle to steady state very close to zero point. This provided the fastest damping characteristic for the system machine Emf transients. It observed that the damping of oscillations is more pronounced with IPFC than SSSC and UPFC. The graphical illustrations are displayed in figures 3.5 to 3.8.

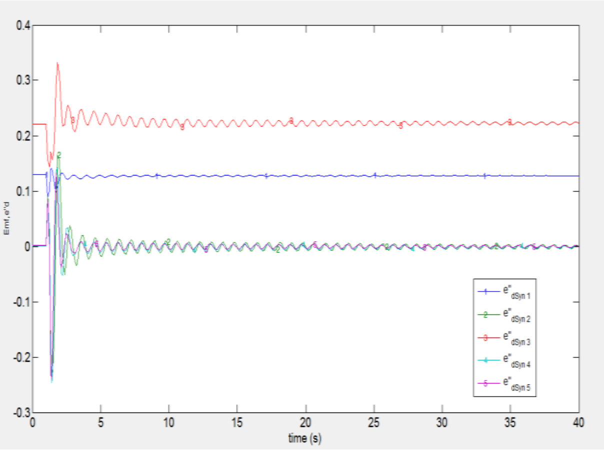

Figure 3.5: E.m.f responses without device, Fault applied at Bus 04

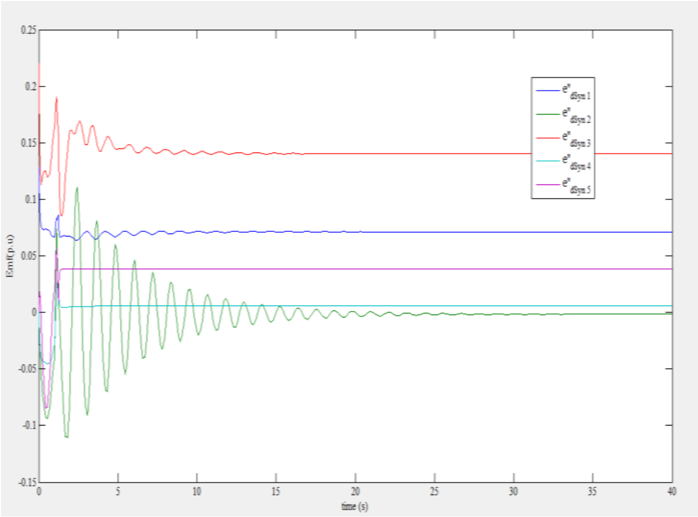

Figure 3.6: E.m.f responses with UPFC device, fault applied at Bus 04

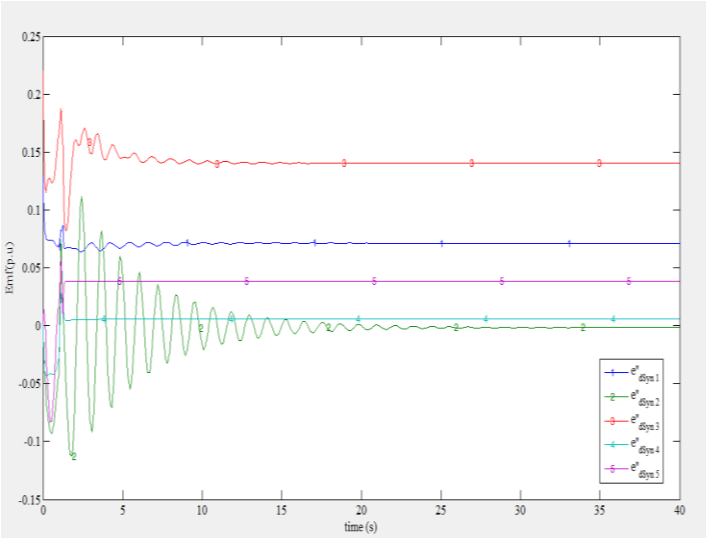

Figure 3.7: E.m.f responses with SSSC device, fault applied at Bus 04

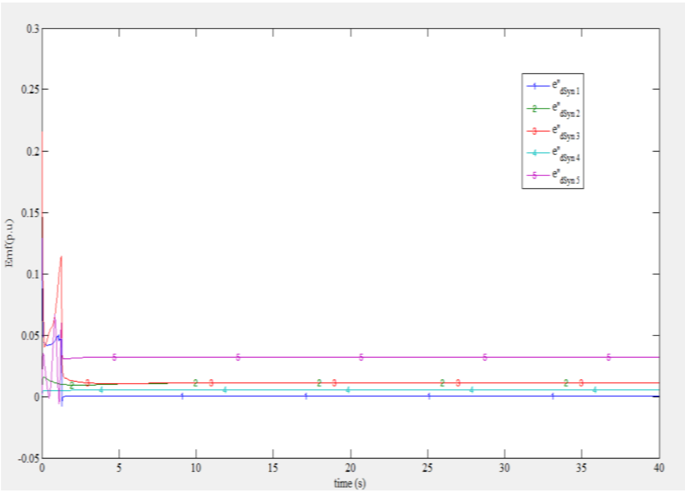

Figure 3.8: E.m.f responses with IPFC device, Fault applied at Bus 04

IV. CONCLUSION

Although individual compensations differ, all the three FACTS devices not only damp the system oscillations of the multimachine system but also reduce the oscillation settling times for generator Emf and rotor angle transient responses. To achieve the steady state operating condition after fault applied at bus 4, UPFC and SSSC exhibited similar oscillations damping characteristics for the variables studied. SSSC and UPFC have better damping features for reactive power response while IPFC provide better damping for generator Emf compared to UPFC and SSSC. It's evident that the damping characteristics of the IPFC are superior to those of SSSC and UPFC.

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