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Transient Stability Enhancement of Multi-machine Power System Using UPFC and SSSC

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Abstract*— *Power systems are subjected to various types of disturbances which cause the problem of losing stability. The problem of transient stability is a crucial problem. Transient stability evaluation of large scale power systems is an extremely intricate and highly non-linear problem. The main causes of transient stability may be due to transmission system faults, sudden fault changes, loss of generating units and line switching. So the enhancement of transient stability is essential for a secure power system operation. Transient stability of a system refers to the stability when subjected to large disturbances such as faults and switching of lines. Transient stability of the system can be improved by increasing the system voltage, increasing the X/R ratio, increasing the number of parallel lines between points and placement of the FACTS devices. The FACTS controller can improve the voltage stability, steady-state and transient stability of a power system.UPFC (Unified Power Flow Controller) and SSSC (Static Synchronous Series Compensator) can improve the transient stability of the system. Simulation of transient stability without and with FACTS device was done using MATLAB based program and the analysis is performed on IEEE 6 bus system.

Index Terms-FACTS, Newton-Raphson method, (SSSC) Static Synchronous Compensator, Transient Stability, Unified Power Flow Controller (UPFC)

I. INTRODUCTION

Modern power systems are at risks of transient stability problems due to sudden, large disturbances such as transmission system faults, sudden fault changes, loss of generating units and line switching [1]. Methods to improve transient stability are use of breaking resistor, reduction in system transfer reactance, use of bundled conductors, short circuit current limiters and the placement of FACTS devices. The development of power electronics has introduced the use of Flexible Alternating Current Transmission Systems (FACTS) devices in electric power systems. FACTS devices are capable of controlling the network conditions in very fast manner [2] .The voltage stability, steady state and transient stabilities of a complex power system can be improved by using Facts devices [3]. FACTS devices can control the various parameters of the power system such as voltage, phase angle and line impedance in a rapid and effective manner.

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FACTS controllers can be divided into four categories such as Series controllers such as Thyristor Controlled Series Capacitor (TCSC), Thyristor Controlled Phase Angle Regulators (TCPAR or TCPST), and Static Synchronous Series Compensator (SSSC); Shunt controllers such as Static Var Compensator (SVC), and Static Synchronous Compensator (STATCOM); Combined series-series controllers such as Interline Power Controller (IPFC) and shunt series controllers such as UPFC(Unified Power Flow Controller).

A Static Synchronous Series Compensator (SSSC) is a series FACTS Device which is connected in series with a power system. It consists of a solid state voltage source converter (VSC) which generates a controllable alternating current voltage at fundamental frequency [4]. When the injected voltage is kept in quadrature with the line current, it can emulate as inductive or capacitive reactance so as to influence the power flow through the transmission line. While the primary purpose of a SSSC is to control power flow in steady state, it can also improve transient stability of a power system.

UPFC (Unified Power Flow Controller) is a shunt series FACTS device connected with the transmission line to increase the power transfer capability, improve transient stability and reduce transmission losses [5].

II. OPERATING PRINCIPLE OF FACTS DEVICES

A. Unified Power Flow Controller (UPFC)

A Unified Power Flow Controller (UPFC) consists of two solid state synchronous voltage source converters coupled through a common DC link as shown in Fig.1. The DC link provides a path to exchange active power between the converters [6]. The series converter injects a voltage in series with the system voltage through a series transformer. The power flow through the line can be regulated by controlling voltage magnitude and angle of series injected voltage. The injected voltage and line current determine the active and reactive power injected by the series converter. The converter has a capability of electrically generating or absorbing the reactive power. However, the injected active power must be supplied by the DC link, in turn taken from the AC system through the shunt converter. The shunt converter also has a capability of independently supplying or absorbing reactive power to regulate the voltage of the AC system. When the losses of the converters and the associated transformers are neglected, the overall active power exchange between the UPFC and the AC system become zero. However, both the series and shunt converters can independently exchange reactive power [7]. UPFC can improve both steady sate stability, dynamic stability and transient stability.

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For the convenience practical of application, the series voltage angle of UPFC is kept in perpendicular with a line current.

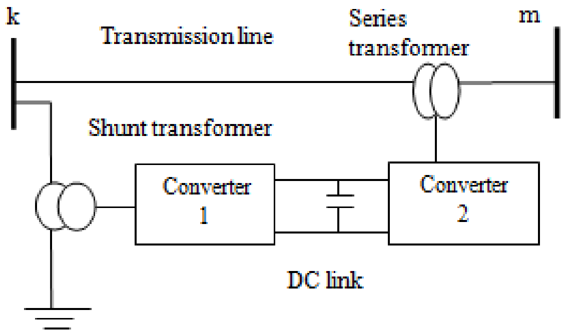

Fig.1.TheUPFC basic circuit arrangement

B. Static Synchronous Series Compensator (SSSC)

The SSSC is one of the most recent FACTS devices for power transmission series compensation. It can be considered as a synchronous voltage source as it can inject an almost sinusoidal voltage of variable and controllable amplitude and phase angle in series with a transmission line. The injected voltage is almost in quadrature with the line current. A small part of the injected voltage that is in phase with the line current provides the losses in the inverter [4].The basic structure of SSSC which basically consists of a capacitor, an inverter and a coupling transformer. Most of the injected voltage, which is in quadrature with the line current, provides the effect of inserting an inductive or capacitive reactance in series with the transmission line.

The SSSC may have four basic control modes. These are bus voltage control, line power flow control, line reactance control and series voltage control. A series capacitor compensates the transmission-line inductance by presenting a lagging quadrature voltage with respect to the transmission-line current [8]. This voltage acts in opposition to the leading quadrature voltage appearing across the transmission-line inductance, which has a net effect of reducing the line inductance. Similar is the operation of an SSSC that also injects a quadrature voltage V_C, in proportion to the line current but is lagging in phase:

$$V_C = -jKX_C I_C$$

where,

V_C → the injected compensating voltage

I_C → the line current

X_C → the series reactance of the transmission line

K → the degree of series compensation

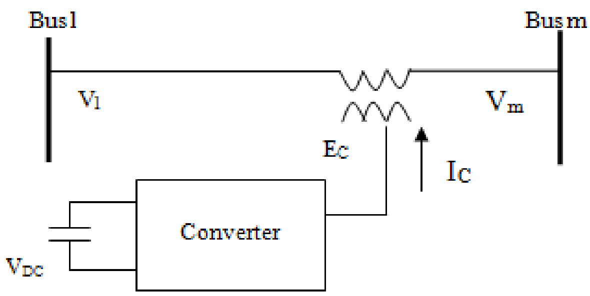

Fig.2 Schematic diagram of SSSC connected to a transmission line

III. MODELLING OF FACTS DEVICES

A. Unified Power Flow Controller (UPFC)

Consider the configuration of UPFC inserted between bus k and bus m of power system as shown in Fig 1.[9] UPFC can be modeled as fictitious active and reactive power injection at bus k and bus m, respectively as can be seen in Fig 3

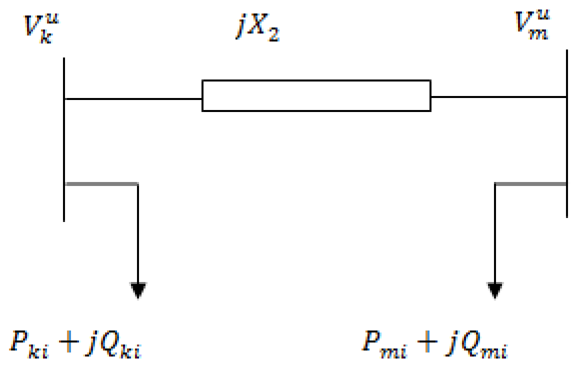

Fig.3.Fictitious active and reactive load model of a UPFC

The fictitious active P_{ki}^u and reactive Q_{ki}^u load of UPFC at bus k as shown are given by,

$$P_{ki}^u = -xyV_k^u V_m^u \sin\left(\theta_{km}^u + \alpha\right) \qquad (1)$$

$$Q_{ki}^u = -I_q V_k^u - ab\left(V_k^u\right)^2 (\cos\alpha) \qquad (2)$$

The fictitious active P_{mi}^u and Q_{mi}^u load of a UPFC at bus m are given by,

$$P_{mi}^u = -xyV_k^u V_m^u \sin\left(\theta_{km}^u + \alpha\right) \qquad (3)$$

$$Q_{mi}^u = -xyV_k^u V_m^u \cos\left(\theta_{km}^u + \alpha\right) \qquad (4)$$

Where,

x= voltage magnitude from a series converter of a UPFC

α = voltage angle from a series converter of a UPFC

I_q = shunt current from a shunt converter of a UPFC.

y = susceptance equivalent between bus k and bus m

V_k^u = voltage magnitude at bus k

V_m^u = voltage magnitude at bus m

θ_{km}^u =Voltage angle difference between bus k and bus m

B. Power System with a UPFC Model

Consider the power system with a UPFC as shown in Fig 4(a). In this Figure, UPFC is represented by its equivalent circuit of Fig 3.The power system can be represented by generator voltage behind transient reactance (E') and reduced admittance matrix Y_{int} excluding bus k and bus m [1]. One of possible way to incorporate the UPFC into power system model is to convert fictitious active and reactive model to susceptance model.

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The admittance Y_k^u and Y_m^u as given in figure 4(b) can be written by,

$$Y_k^u = \frac{P_{ki}^u - jQ_{ki}^u}{\left(V_k^u\right)^2} \quad (5)$$

$$Y_m^u = \frac{P_{mi}^u - jQ_{mi}^u}{\left(V_m^u\right)^2} \quad (6)$$

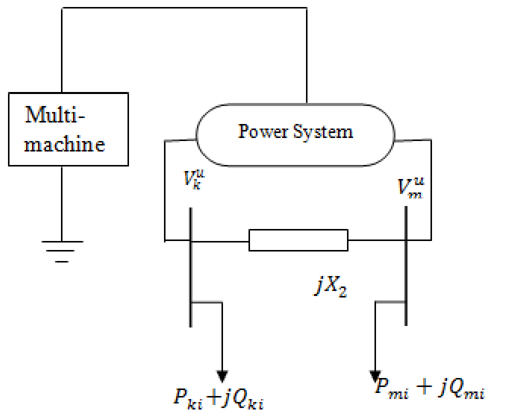

Fig.4 Multi-machine power system with a UPFC (a) Fictitious model of UPFC

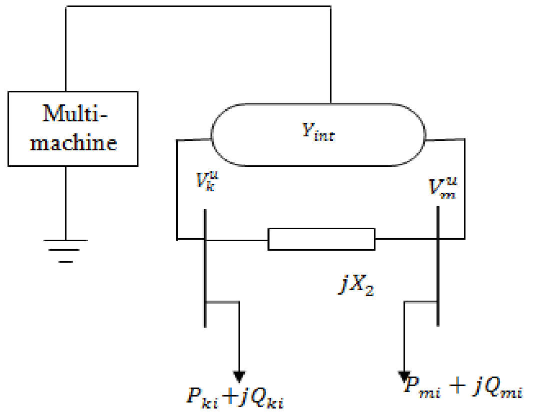

Fig.4 Multi-machine power system with a UPFC (b) Susceptance model of a UPFC

C.Static Synchronous Series Compensator (SSSC)

According to the equivalent circuit, suppose $V_{se} = V_{se}\angle\theta_{se}$. The voltage of bus k is taken as the reference vector, $V_k = V_k\angle\theta_k$. The voltage source, V_{se}, is the series injected voltage, and it is controllable in both its magnitudes and phase angles and is also the control variable of the SSSC. $V_m = V_m\angle\theta_m$ is the voltage at bus m[10].

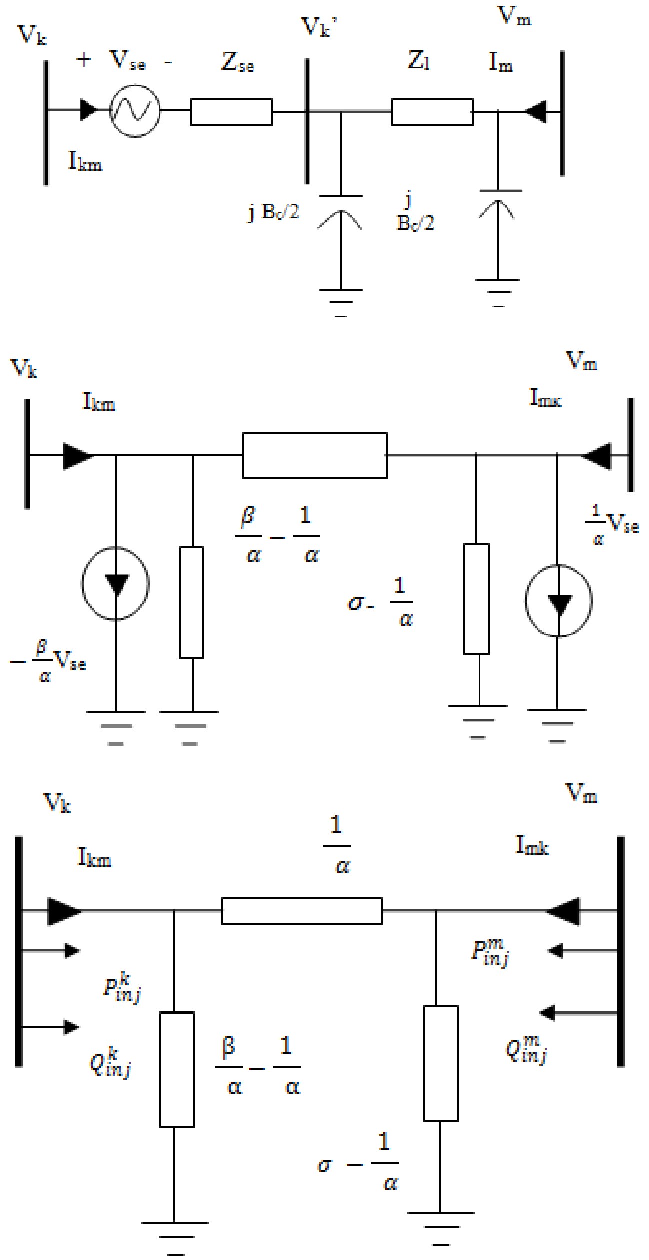

Fig 5 (a)Equivalent circuit of the embedded SSSC using voltage source(b)Representation of the SSSC using current source(c)The power injection π-model of embedded SSSC

$Z_{se} = R_{se} + jX_{se}$ is the impedance of the series coupling transformer. B_c and $Z_l = R_l + jX_l$ are the charging susceptance and the impedance of the line respectively. From Fig.5 (b),

$$\alpha = j\frac{B_C}{2}Z_{se}Z_l + Z_l + Z_{se}$$

$$\beta = \left(1 + j\frac{B_c}{2}Z_l\right)$$

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$$\alpha = Z_{se}\beta + Z_l$$

$$\gamma = jB_C - \frac{B_c^2}{4} Z_l$$

Considering the following vectors:

$$V_{se} = V_{se}\angle\theta_{se}$$

$$V_k = V_k\angle\theta_k$$

$$V_m = V_m\angle\theta_m$$

$$\beta = \beta\angle\theta_\beta$$

From Fig.4 the real and reactive power injections at the sending and receiving bus:

$P_{inj}^k, Q_{inj}^k, P_{inj}^m, Q_{inj}^m$ can be calculated as follows:

$$S_{inj}^{k\,*} = V_k^*\left(-\frac{\beta}{\alpha}V_{se}\right) = -AV_kV_{se}\angle(\theta_{se} - \theta_k + \theta_A) \quad (7)$$

$$\frac{\beta}{\alpha} = A = A\angle\theta_A$$

$$P_{inj}^k = -AV_kV_{se}\cos(\theta_{se} - \theta_k + \theta_A) \quad (8)$$

$$Q_{inj}^k = -AV_kV_{se}\sin(\theta_{se} - \theta_k + \theta_A) \quad (9)$$

$$S_{inj}^{m\,*} = V_m^*\left(\frac{1}{\alpha}V_{se}\right) = \frac{AV_mV_{se}}{\beta}\angle(\theta_{se} - \theta_m + \theta_A - \theta_\beta) \quad (10)$$

$$P_{inj}^m = \frac{AV_mV_{se}}{\beta}\cos(\theta_{se} - \theta_m + \theta_A - \theta_\beta) \quad (11)$$

$$Q_{inj}^m = \frac{AV_mV_{se}}{\beta}\sin(\theta_{se} - \theta_m + \theta_A - \theta_\beta) \quad (12)$$

The admittance Y_k^u and Y_m^u can be written by,

$$Y_k^u = \frac{P_{ki}^u - jQ_{ki}^u}{\left(V_k^u\right)^2} \quad (13)$$

$$Y_m^u = \frac{P_{mi}^u - jQ_{mi}^u}{\left(V_m^u\right)^2} \quad (14)$$

IV.RESULT

The method of improving Transient Stability by using UPFC and SSSC is tested on Multi-machine system. The system consists of 3 generators, 2 transformers and 6 buses [1].

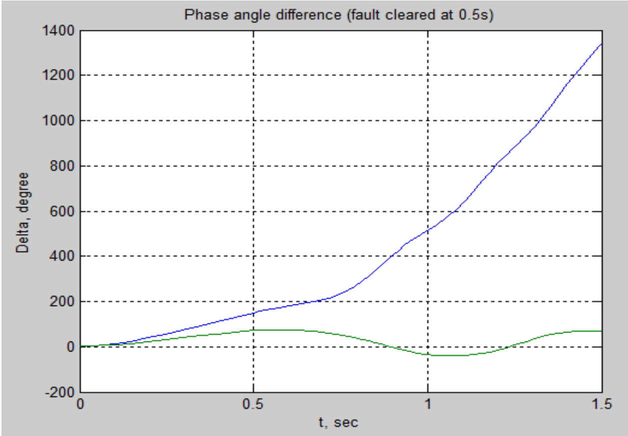

Fig.6 without UPFC

It can be seen from Fig 6 that, without a UPFC, the system is unstable when fault is cleared in 0.5 sec and the phase angle increases without limit.

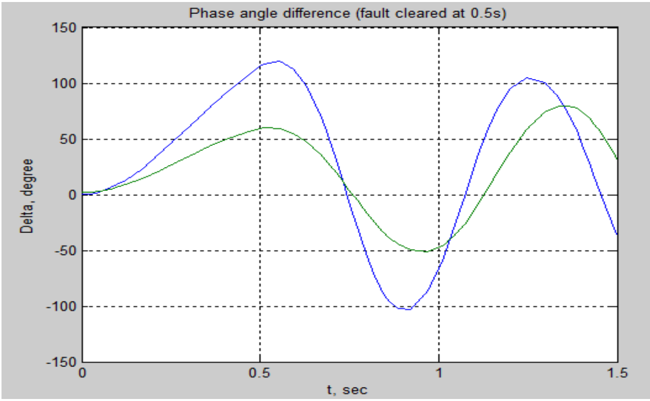

Fig.7 with UPFC in reactive mode

However with a UPFC (a=a_{max} *and* I_q= I_q^{min}), the system is considered as stable when fault is cleared in 0.5sec as shown in Fig.7.

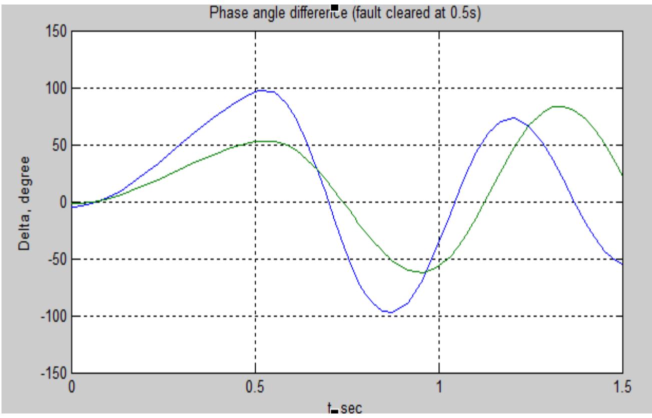

Fig.8.With UPFC in capacitive mode
(a=a_{max} and I_q= I_q^{max})

The effect of SSSC is shown in Fig.9.The system is considered as stable when fault is cleared in 0.5 sec.

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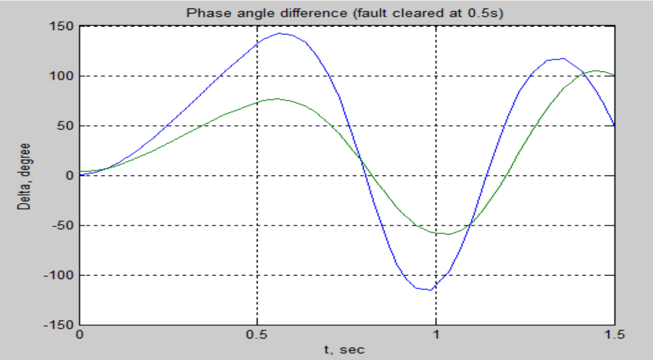

Fig.9 with SSSC

V.CONCLUSION

This paper presents the effects of UPFC and SSSC on transient stability of a multi-machine power system. Transient stability of the system is compared with and without the presence of UPFC and SSSC in the event of a disturbance. It is clear from the results that, there is a considerable improvement in transient stability of the system with the presence of UPFC and SSSC. The performance of the UPFC for transient stability improvement is better than that of SSSC.

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