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Interarea Oscillation Damping By Unified Power Flow Controller-Superconducting Magnetic Energystorageintegrated System

Sreelal Elamana, A. Rathinam

***Abstract*—Interarea oscillations are turned to be a severe problem in large interconnected power systems, hence they cause severe problems like damage to generators, reduce the power transfer capability of transmission lines, increase line losses, increase wear and tear on the network components etc. This paper introduces a new control technique that uses unified power flow controllers (UPFC) with superconducting magnetic energy storage system (SMES) in order to damp the interarea oscillation in an effective manner**

***Index Terms*—Unified Power Flow Controllers (UPFC), Super Conducting Magnetic Energy Storage Systems (SMES), Inter Area Oscillations**

I. INTRODUCTION

Modern power systems are large electromechanically interconnected systems, hence thereis a chance for producing electro mechanical oscillations [2, 3] which will cause severe problems likedamage of generators, reduce the power transfer ability of transmission lines, increase line losses, increase wear and tear on the network components etc. Electromechanical oscillations occur due to the swinging of synchronizing generators with each other. There will be (n-1) electro mechanical modes [3] for an “n” machine system. Such kind of oscillation modes is produced when the rotor of the machines behaves as rigid bodies and oscillation energy will be exchange between the machines through transmission lines. If oscillation occurs between a single machineor a small group of machines with rest of the system then such kind of oscillations are known as local mode oscillations [2, 3].Typical oscillation frequency ranges from 0.7HZ to 2HZ.If oscillation occurs between a large group of machines and rest of the system then such kind of oscillations are known as interarea mode oscillations [2,3].Typical oscillation frequency range from0.1HZ from 0.8H. Typical oscillation frequency ranges from 0.7HZ to 2HZ.If oscillation occurs between a large group of machines and rest of the system then such kind of oscillations are known as interarea mode oscillations[2,3].Typical oscillation frequency range from0.1HZ from 0.8HZ.Inorder to damp such electromechanical oscillations traditionally we use Power system stabilizers on generator excitation control system. Power system stabilizers are effective but usually they are designed for local modes and in large power systems they will not provide enough damping for interarea modes.

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***** Correspondence Author (s)
Sreelal Elamana, Department of Electrical and Electronics Engineering, Paavai Engineering Collage, India.
A. Rathinam, Assistant Professor, Department of Electrical and Electronics Engineering, Paavai engineering collegeEngineering, India.

Hence inorderto improve the damping of these modes FACTS controllers[6,7] like Static synchronous compensator (STATCOM)[4,14],Static series synchronous compensator (SSSC)[11,13],Unified power flow controllers(UPFC)[1,8,9,10]etc. areused. UPFC is a combination of STATCOM and SSSC or in other words which consist of shunt and series converters connected by a common dc link capacitor.” UPFC can simultaneously perform real/reactive power flow in the transmission line and UPFC bus voltage/shunt reactive power control [9].we has to improve the performanceof UPFCduring largetransients .Dclink capacitor in UPFC is capable of charging or discharging to compensate for converter losses in the UPFC. During large transients, the energy stored in the dc-link capacitor is inadequate to accomplish significant damping without severe dc voltage degradation. For overcome this drawback we use substantial power supplies. The term substantial [6] means enough to deliver active power to the power system over an interval of a few seconds or more. If we use electro chemical battery [6, 12] as substantial power supply, we have to face the problems like high impedance, high cost, chemical reaction occurs on electrodes, higher ageing, high heating levels etc. If we use super capacitor [1, 6, 12]as substantial power supply we have to face the problems like low energy density, low voltage, higher self-discharge and unable to use full energy spectrum etc.so in this paper introducing a new control technique using unified power flow controllers (UPFC) with superconducting magnetic energy storage system (SMES) [11, 12, 15, 6] in order to damp the interarea oscillation in an effective manner. Comparing with other substantial energy supplies SMES having the advantages of high energy density, fast response, high efficiency, minimum energy loss during the conversion etc.

II. UNIFIED POWER FLOW CONTROLLER (UPFC)

The general structure of the UPFC contains two "back to back" voltage source converters using insulated gate bipolar transistor (IGBT) or Integrated Gate Commutated Thyristor (IGCT) with a common DC link. First converter is connected as parallel and another converter as series with transmission line. The shunt converter is used to provide active power demanded by the series converter through a common DC link. The series converter provides the main function of the UPFC by injecting an AC voltage with controllable magnitude and phase angle.

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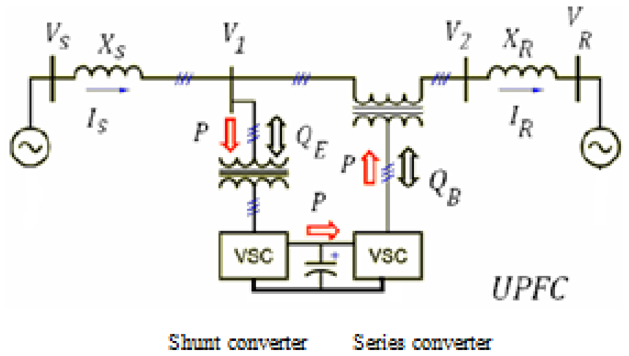

Fig 1: Schematic of UPFC

The transmission line current flows through series converter and therefore, it exchanges the active and reactive power with the AC system. Since the converters are connected to a common DC link, they exchange only active power and there is no reactive power flow between them. It means that reactive power could be controlled independently at both converters. Generally, this structure (Fig.1) enables voltage control by the shunt inverter and independent active and reactive power flow control by the series inverter. It is normally controlled to balance the real power absorbed from or injected into the power system by the series converter plus the losses by regulating the dc bus voltage at a desired value. Various control strategies to control the series voltage magnitude, angle and the shunt current magnitude have been presented [18-21].

A. Parallel Branch of UPFC

In the parallel branch of UPFC, from a DC input voltage source, provided by the charged capacitor *Cs*, the converter produces a set of controllable three-phase output voltages with the frequency of the ac power system. Each output voltage is in phase with, and coupled to the corresponding ac system voltage via a relatively small (0.1-0.15 p.u.) tie reactance. That is, if the amplitude of the converter output voltage is increased above that of the ac system voltage, due to adding load of a systems current will increased and also voltage level decrease, then the current flows through the tie reactance from the converter to the AC system, and the converter generates reactive (capacitive) power for the AC system. If the amplitude of the output voltage is decreased below that of the ac system, then the reactive current flows from the ac system to the converter, and the converter absorbs reactive (inductive) power. If the amplitude of the output voltage is equal to that of the ac system voltage, the reactive power exchange is zero. The reactive current I drawn by the synchronous compensator is determined by

$$I = \frac{V_L - V_C}{X} (1)$$

The corresponding reactive power Q exchanged can be expressed as follows:

$$Q = \frac{1-\frac{V_C}{V_L}}{X} V_L^2 (2)$$

Whereas V_L is Transmission line voltage, V_C is converter output voltage and X reactance plus transformer leakage reactance plus system short circuit reactance.

B. Series Branch of UPFC

In the series branch of UPFC, The series compensator is a reciprocal of the shunt compensator. The series compensator is functionally a controlled voltage source which is connected in series with the transmission line to control its current. This reciprocity suggests that both the admittance and voltage source type shunt compensators have a corresponding series compensator. Indeed, as indicated earlier, the series compensator can be implemented either as variable reactive impedance or as a controlled voltage source in series with the line. That is, in series compensation the basic reference parameter is line current.

(Synchronous) angular frequency	ω
Shunt resistance and inductance Ω	Rs1 and Ls1
Series resistance and inductance	Rs2 and Ls2
Dc-link voltage	Vdc
Dc-link capacitance and resistance	Cdc,Rdc
SMES dc voltage	Vdcsmes
SMES capacitance and equivalent resistance	Csmes and Rsmes

The UPFC model is a combination of the static synchronous compensator (STATCOM) and static synchronous series compensator (SSSC) models. The currents Id1 and Iq1 are the dq components of the shunt current. The currents and are the components of the series current. The voltage v1‹θ1 and v2‹θ2are the sending end and receiving end voltage magnitudes andangles, respectively. The UPFC parameters are the following.

The UPFC is controlled by varying the phase anglesα1and α2 magnitudes K1 and K2of the converter shuntand series output voltages, respectively. The SMES is connected to the dc-link capacitor of the UPFC through aBidirectional dc-dc converter such as the SEPIC/Zeta converter. The steady-state dc-link capacitor voltage and the SMES voltage are related through the duty cycle ratio D as follows

$$V_{dc} = \left\{\frac{D}{1-D}\right\} V_{dcsmes} \ (3)$$

The duty cycle is the percent of a switching cycle in which the SMES discharges. For example, if D=.5, then the SMES is in steady state and discharges (and charges) for half of each cycle, and Vdc= Vdcsmes. If D >.5, then the SMES discharges for a greater portion of the switching cycle Vdcsmes and drops (and vice versa charges for D ‹.5)

The power balance equations at bus 1 are given by

$$0 = V_1\left((i_{d1} - i_{d2})\cos\theta_1 + (i_{q1} - i_{q2})\sin\theta_1\right) - V_1 \sum_{j=1}^{n} V_j Y_{1j} \cos(\theta_1 - \theta_j - \phi_{1j}) \ (4)$$

$$\frac{1}{\omega_s}\frac{d}{dt} i_{d1} = \frac{k_1 V_{dc}}{L_{S1}}\cos(\alpha_1 + \theta_1) + \frac{\omega}{\omega_s} i_{q1} - \frac{R_{S1}}{L_{S1}} i_{d1} - \frac{V_1}{L_{S1}}\cos\theta_1 \ (5)$$

$$\frac{1}{\omega_s}\frac{d}{dt} i_{q1} = \frac{k_1 V_{dc}}{L_{S1}}\sin(\alpha_1 + \theta_1) - \frac{R_{S1}}{L_{S1}} i_{q1} - \frac{\omega}{\omega_s} i_{d1} - \frac{V_1}{L_{S1}}\sin\theta_1 (6)$$

$$\frac{1}{\omega_s}\frac{d}{dt} i_{d2} = -\frac{R_{S2}}{L_{S2}} i_{d2} + \frac{\omega}{\omega_s} i_{q2} + \frac{k_2}{L_{S2}}\cos(\alpha_2 + \theta_1) V_{dc} - \frac{1}{L_{S2}}(V_2\cos\theta_2 - V_1\cos\theta_1)(7)$$

$$\frac{1}{\omega_s}\frac{d}{dt} i_{q2} = -\frac{R_{S2}}{L_{S2}} i_{q2} - \frac{\omega}{\omega_s} i_{d2} + \frac{k_2}{L_{S2}}\sin(\alpha_2 + \theta_1) V_{dc} - \frac{1}{L_{S2}}(V_2\sin\theta_2 - V_1\sin\theta_2) \ (8)$$

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$\frac{C}{\omega_s}\frac{d}{dt}V_{dc} = -k_1\cos(\alpha_1+\theta_1)i_{d1} - k_1\sin(\alpha_1+\theta_1)i_{q1} - k_1\cos(\alpha_2+\theta_1)i_{d2} - k_2\sin(\alpha_2+\theta_1)i_{q2} - \left(\frac{1}{R_{dc}}+\frac{1}{R_{smes}}\right)V_{DC} + \frac{D}{1-D}\frac{V_{dcsmes}}{R_{smes}}$ (9)

$\frac{Csmes}{\omega_s}\frac{d}{dt}V_{dcsmes} = \frac{1}{R_{smes}}(\frac{(1-D)}{D}V_{dc} - V_{dcsmes})$ (10)

$0 = V_1((i_{d1}-i_{d2})\sin\theta_1 - (i_{q1}-i_{q2})\cos\theta_1) - V_1\sum_{j=1}^{n}V_jY_{1j}\sin(\theta_1-\theta_j-\phi_{1j})$(11)

And at bus 2

$0 = V_2(i_{d2}\cos\theta_2 + i_{q2}\sin\theta_2) - V_2\sum_{j=1}^{n}V_jY_{2j}\cos(\theta_2-\theta_j-\phi_{2j})$ (12)

$0 = V_2(i_{d2}\sin\theta_2 + i_{q2}\cos\theta_2) - V_2\sum_{j=1}^{n}V_jY_{2j}\sin(\theta_2-\theta_j-\phi_{2j})$ (13)

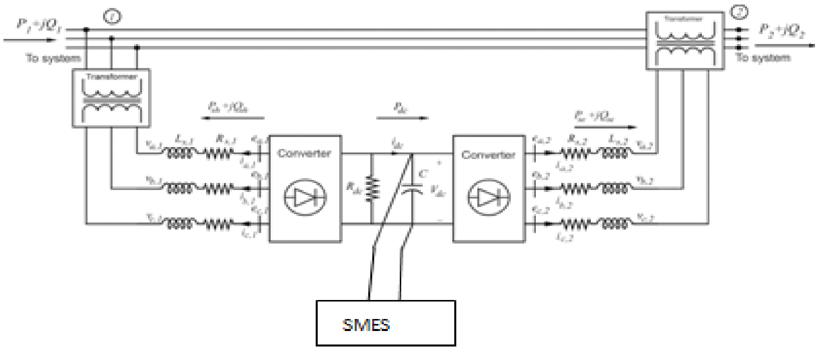

Fig 2: UPFC with SMES Diagram

III. SUPERCONDUCTING MAGNETIC ENERGY STORAGE SYSTEM

Superconducting Magnetic Energy Storage (SMES) systems store energy in the magnetic field created by the flow of direct current in a superconducting coil which has been cryogenically cooled to a temperature below its temperature. A typical SMES system includes three parts: superconducting coil, power conditioning system and cryogenically cooled refrigerator. Once the superconducting coil is charged, the current will not decay and the magnetic energy can be stored indefinitely. The stored energy can be released back to the network by discharging the coilthe power conditioning system uses an inverter/rectifier to transform alternating current (AC) power to direct current or convert DC back to AC power. The inverter/rectifier accounts for about 2–3% energy loss in each direction. SMES loses the least amount of electricity in the energy storage process compared to other methods of storing energy. SMES systems are highly efficient; the round-trip efficiency is greater than 95%.Due to the energy requirements of refrigeration and the high cost of superconducting wire, SMES is currently used for short duration energy storage. Therefore, SMES is most commonly devoted to improving power quality.

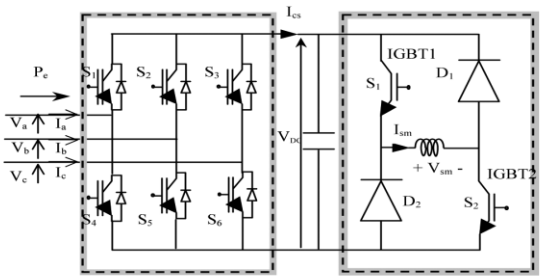

Fig 3: The Configuration of SMES Unit with chopper

An electronic interface known as chopper is neededbetween the energy source and the VSI. For VSI the energy Source compensates the capacitor charge through the electronic interface and maintains the required capacitor voltage. Two-quadrant n-phase DC-DC converter as shown in Fig. 3 is adopted as interface. Here 'n' is related to the maximum current driven by the superconducting device. The DC-DC chopper solves the problems of the high power rating requirements imposed by the superconducting coil to the UPFC. The DC-DC chopper allows to reduce the ratings of the overall power devices by regulating the current flowing from the superconducting coil to the inverter of the UPFC.The two quadrant single-phase chopper is composed of many shunt connected diode-thyristor legs that permit the driving of the high current ratings stored in thesuperconducting coil. The chopper has 3 modes ofoperation to perform the charge, the discharge and thestorage in the SMES device. The chopper is operated in astep down configuration in the charge mode of thesuperconducting coil. Here, the IGBT "s1" isoperated with the duty cycle 'D' while the IGBT "s2" is kept on at all times. The relationship between thecoil voltage and the DC bus voltage is given by the equation.

$V_{SMES} = D * V_{DC}$ (14)

Once the charging of the superconducting coil is completed, the operating mode of the DC-DC converter is changed to the stand-by mode for which the IGBT "s1" is kept off all the time while the IGBT "s2" is kept on constantly. In the discharge mode, the chopper is operated in a step up configuration. The set of thyristors "b" is operated with duty cycle D while the set of thyristors "a" is kept off at all times. The relationship between the coil voltage and the DC bus voltage is given by the equation

$$-V_{SMES} = (1 - D) * V_{DC} \quad (15)$$

The duty cycle ranges from 0 to 1. The relationship between the DC bus voltage and the output voltage of the Inverter is given by the Eq.

$$V_{DC} = K_a V_{inv} \quad (16)$$

Where,

$$K_a = k * a \quad (17)$$

k = Pulse number
a = Ratio of the coupling transformer

III. TEST SYSTEM SPECIFICATION

PARAMETERS	VALUES
Rated voltage	230000V
base voltage	230000V
3 phase short circuit level at base voltage	100000000VA
Fault resistance	.OO1 Ohm
Transition time	.0167Sec,O.41 Sec

V. CONTROLLER RESULTS AND COMPARISONS

In the testing system, a solid symmetrical fault has been applied on bus at 0.0167 s and has been cleared in 0.41 s. The location and duration of the fault were chosen to provide a significant disturbance to the interior of the power system and the below comparisons shows how interarea oscillations are damped and how dc link (capacitor) provides compensation

A. Active Power Comparison with UPFC and UPFC with SMES

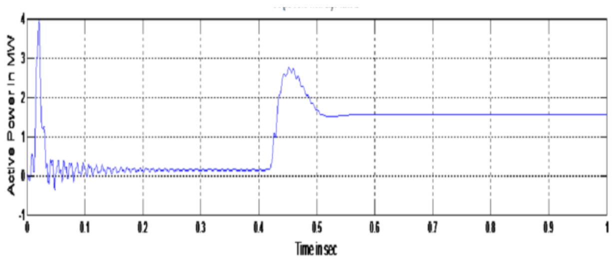

Fig 4: Active Power with UPFC

Figure No 4 and Figure No 5 shows that the simulation result for active power (P) for test system with fault and for damping the oscillations in both cases,UPFC alone and UPFC with SMES. A solid symmetrical fault has been applied on bus at 0.0167 s and has been cleared in 0.41 s.

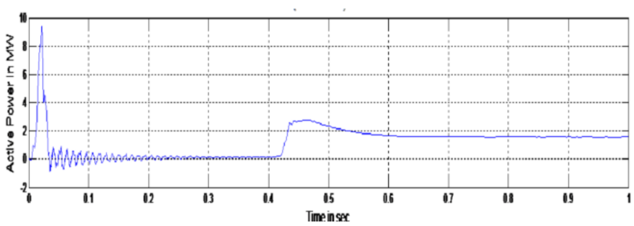

Fig 5: Active Power with UPFC&SMES

It is clear that before the settling of active power, power oscillations are high in the case of UPFC alone compared with the combination of UPFC and SMES.Also power oscillations are damped quickly when we use the combination of UPFC and SMES

B. Reactive Power Comparison with UPFC & UPFC with SMES

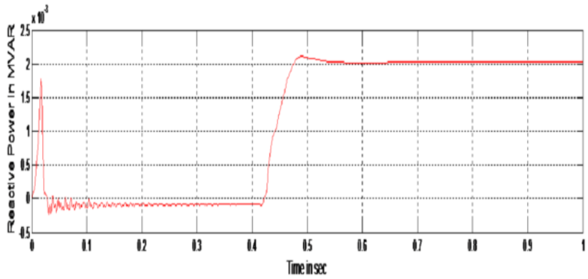

Fig 6: Reactive Power with UPFC

Figure No 7 and Figure No 8 shows that the simulation result for reactive power (Q) for test system with fault and for damping the oscillations in both cases, UPFC alone and UPFC with SMES. A solid symmetrical fault has been applied on bus at 0.0167 s and has been cleared in 0.41 s.

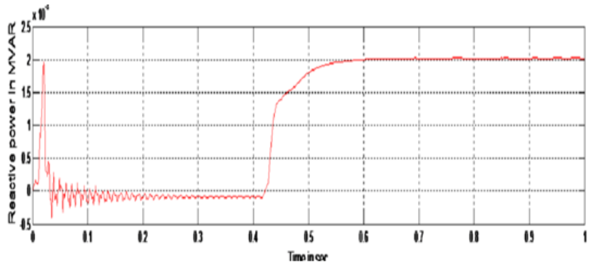

Fig 7: Reactive Power with UPFC and SMES

It is clear that before the settling of reactive power, power oscillations are high in the case of UPFC alone compared with the combination of UPFC and SMES.Also power oscillations are damped quickly when we use the combination of UPFC and SMES

C. DC Link Voltage Comparison with UPFC & UPFC with SMES

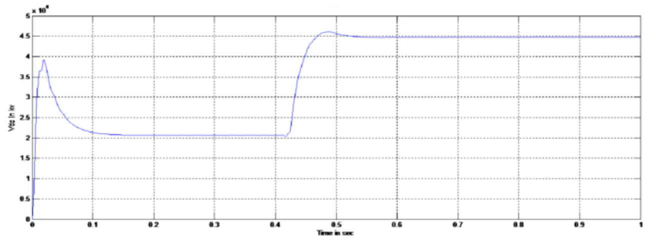

Fig 8: DC Link Voltage with UPFC

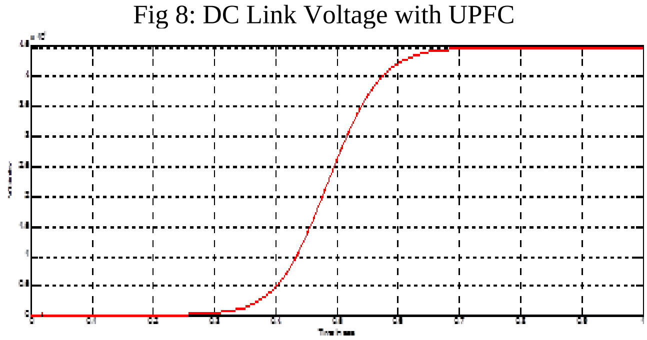

Fig 9: DC Link Voltage with UPFC and SMES

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Figure No 8 and Figure No 9 show the simulation result for voltage in test system with fault and for both cases. A solid symmetrical fault has been applied on bus at 0.0167 s and has been cleared in 0.41 s. It can be seen that the voltage stability increase in case with combination of UPFC and SMES when compared with UPFC alone while providing the compensation voltage for the faulted system. It is observed that settling time for the combination of UPFC – SMES integrated system is minimum when compared with the UPFC alone while providing the voltage compensation for the faulted system

IV. CONCLUSION

The dynamic performance of the UPFC with and without SMES for the test system, are analysed with Mat lab/Simulink. SMES with two quadrant chopper control plays an important role in real power exchange. In order to improve the performance of the power system UPFC with and without has been developed. It is clear from the results that the UPFC with SMES is very effective in damping power oscillations and to maintain power flow through transmission lines after the disturbances.

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