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Analysis the Effect of UPFC Location in Low Frequency Oscillation Using Intelligent Search Method Based on Fuzzy

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ABSTRACT

Unified Power Flow Controller (UPFC) is use for controlling the real and reactive power on the transmission line and the bus voltage simultaneously and independently. An additional task of UPFC is to increase transmission capacity as result of power oscillation damping. The effectiveness of this controller depends on its optimal location in the power system network. This paper proposed various cases studies to find the optimal location of the UPFC controllers and Eigen value analyses are used to assess the most appropriate input signals (stabilizing signal) for supplementary damping control of UPFC to damp out the inter-area mode of oscillations .The placements of UPFC controllers have been obtained for the base case and for the dynamic critical contingences. The effectiveness of the proposed method of placement is demonstrated on practical network.

KEY WORDS: Flexible AC Transmission System, UPFC, Inter-Area Oscillation, Power System Control, Optimization Approach, Fuzzy Logic Program, Low Frequency Oscillation, Optimal placement.

INTRODUCTION

Power system stability is concerned with the ability of a power system either to reach a new stable operating point or to come back to the original stable equilibrium after a disturbance. Power system stability is a very complex problem .Many different phenomena have been identified as power system stability problems. Classifications of power system stability have been proposed to address such problems .Power system stability problems are classified:

- According to the underlying phenomenon into angle and voltage stability,
- According to the size of the disturbance into large- and small-disturbance, and
- According to the dynamics involved in into short and long-term stability.

Angle stability is interested in the capability of the generators to remain in synchronism.

Voltage stability is concerned with the ability of the generators to supply the loads at acceptable voltage levels.

A disturbance is large when the non-linear differential equations that describe the power system dynamic behavior cannot be linearized for analysis purposes. In contrast, a disturbance is small when the non-linear differential equations can be linearized for analysis purposes. In other words, a linear model characterizes accurately the dynamic behavior of the power system. Powerful techniques can be used for analysis and control of linear systems [Fouad A.A. and V. Vittal, 1992].

Short-term stability is determined by the dynamics of the synchronous generators and their primary controls (voltage and load-frequency). Long-term stability is also affected by the dynamics of the energy sources of the generators (boilers, nuclear reactors, hydro stations with complicate hydraulic circuits, etc) and the Automatic Generation Control and Secondary Voltage Control [(H.F.Wang' 1999),(Erick, T.E., 2000)].
Power system variables such as voltages and power flows may exhibit low frequency poorly damped oscillations. Such oscillations are usually known in the literature as electromechanical oscillations since they are due to the mechanical oscillations of the generator rotors. Electromechanical oscillations lie in the frequency range between 0.1 and 2 Hz. Their frequency depends on the number of generators involved in: local oscillations are of higher frequency since they involve few generators whereas inter-area oscillations are of lower frequency because many generators are involved.

Electromechanical oscillations are natural oscillations of power systems. The damping of the electromechanical oscillations is affected by generator voltage controllers. First instances of poorly damped oscillations occurred when hydro stations equipped with static excitation systems were connected through long transmission lines to the load centers. Power System Stabilizers (PSSs) have been very effective devices to

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mitigate power system electromechanical oscillations [Hassan Barati,et al. 2009]. PSSs modulate the reference of the voltage regulator so the field voltage and the electric power are modulated to provide a forced oscillation that is opposite phase of the natural oscillation of the generator.

Electromechanical oscillations belong to the angle, small-disturbance and short-term stability problems. The small-disturbance nature of electromechanical oscillations facilitates their characterization using linear models of the power system. In addition, the design of control means can be addressed using powerful techniques of linear systems.

FACTS devices are power electronic devices that have been designed to make more flexible the operation of AC transmission systems [K. Phorang, et al., 2002]. Their name comes from a concept developed by N.G. Hingorani for the Electric Power Research Institute in USA called "Flexible AC Transmission Systems".

The first power electronic device incorporated to power systems was the Thyristor Controller Reactors (TCR). Together with the Thyristor Switched Capacitors (TSC) resulted in the Static Var Compensators (SVC) or Static Var Systems (SVS). The SVC was applied to control the voltage through shunt reactive power compensation.

Power flow control in transmission networks used to be addressed using two devices: series capacitors and phase angle regulators. However, they were controlled mechanically[Lo, K.L. and Laiq Khan, 2000].
The incorporation of thyristor control to capacitors and phase angle regulators led to development of Thyristor Controlled Series Capacitors (TCSC), Thyristor Controlled Phase Angle Regulators (TCPAR) and shun capacitor based device such as Unified Power Flow Controller (UPFC), are members of FACTS devices. UPFC can improve both steady sate stability, dynamic stability and transient stability. For the convenience practical of application, the series voltage angle of UPFC is kept in perpendicular with a line current [(L.Gyugyi, et al., 2001),(Tamer Abdelazim, O. P. Malik, 2005)].

It has been reported in many papers that UPFC can improve stability of simple system or single machine infinite bus (SMIB) system and multimachine system. The inter-area power system has special characteristic of stability behavior. This paper investigates the improvement of inter-area system with a UPFC. This paper suggests the method to incorporate UPFC model into the power system model for studying transient stability. The proposed method is then tested on Kundur's inter area-system.

UNIFIED POWER FLOW CONTROLLER DESCRIPTION

The feasibility of different hardware implementations and the basic operating principle of a UPFC have been thoroughly investigated by many researches. Basically the P-Q control function in the UPFC system is accomplished by two dc/ac converter branches, i.e. the series and shunt branches as shown in Fig. 1. These two branches are operated via a common dc link with a dc storage capacitor to allow the active power freely flowing in either direction between the ac terminals of the two branches. UPFC consists of two solid state synchronous voltage source converters coupled through a common DC link as shown. The DC link provides a path to exchange active power between the converters. The series converter injects a voltage in series with the system voltage through a series transformer [Moris,S and et al., 2003]. 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 [M. Nomozian, et.al, 1997]. However, both the series and shunt converters can independently exchange reactive power besides, each branch is able to independently generate or absorb the reactive power at its own ac output terminal connected to the controlled transmission line.

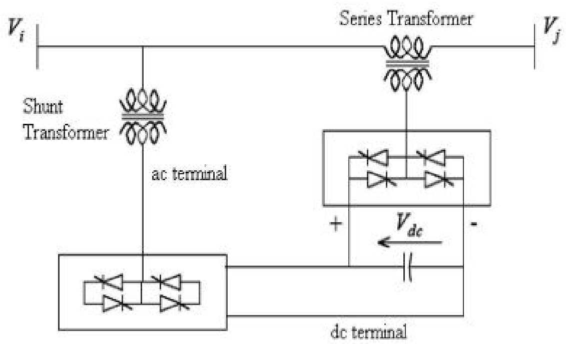

FIGURE 1 Basic circuit arrangement of an UPFC

Basically, a practical UPFC equivalent circuit can be modeled in many ways. However, to better the presentation of the UPFC in both steady-state and transient state simulations, a straightforward UPFC current injection model can be directly obtained from modeling the two voltage-source inverter units into two equivalent current injections, $I_{i,upfc}$ and $I_{j,upfc}$, as shown in Fig. 2.

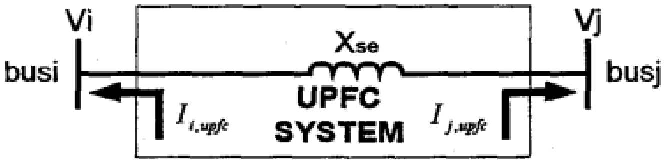

FIGURE 2 UPFC equivalent circuit with controlled current sources

$I_{i,upfc}$ and $I_{j,upfc}$ can be expressed as :

$$I_{j,upfc}=(\frac{-P_{series}\cdot 1.02}{V_i^*}-\frac{F_{se}}{X_{se}})+j(\frac{-Q_{shunt}}{V_i^*}+\frac{E_{se}}{X_{se}})$$

$$=(\frac{-1.02P_{series}E_i}{E_i^2+F_i^2}+\frac{Q_{shunt}F_i}{E_i^2+F_i^2}-\frac{F_{se}}{X_{se}})+j(\frac{-1.02P_{series}F_i}{E_i^2+F_i^2}-\frac{Q_{shunt}E_i}{E_i^2+F_i^2}+\frac{E_{se}}{X_{se}}) \quad 1$$

$$I_{j,upfc}=\frac{F_{se}}{X_{se}}+j\frac{-E_{se}}{X_{se}} \quad 2$$

UPFC DAMPING CONTROL STRATEGY

In the authors' previous work , the control strategy based on TEF approach for damping of power swings by using the UPFC has been developed [(Pavella, M. and P.G. Murthy, 1994), (N. G. Hingorani and L. Gyugyi, 2000)]. In the proposed control algorithm, the three independent UPFC control variables, K_s, γ_s and K_p,(γ_p is a dependent control variable, a function of the inserted series voltage, ye, and the system parameters) are mathematically formulated into a general global TEF of power systems to investigate the possible damping effectiveness of combining different power flow control modes inherently provided by a UPFC system [(Yoshida H, et.al, 2000),(Prechanon Kumkratug, 2009)]. Based on the discussion concluded other reference to achieve the desired damping effects, during the transient the control criteria stated in the following equations, Eq (3) to (8), must be simultaneously satisfied.

$$P_{j,upfc}\frac{d}{dt}(\theta_{ij})\leq 0 \quad 3$$

$$Q_{j,upfc}(\frac{1}{V_i}\frac{dV_i}{dt}-\frac{1}{V_j}\frac{dV_j}{dt})\leq 0 \quad 4$$

$$[2k_s{}^2b_{se}+2b_{sh}(k_p-1)]V_i\frac{dV_i}{dt}\leq 0 \quad 5$$

$$[b_{se}V_i^2\cos(\gamma_s)+2k_sb_{se}V_i^2 - b_{se}V_iV_j\cos(\theta_{ij}+\gamma_s)]\frac{dk_s}{dt}\leq 0 \quad 6$$

$$[k_s b_{se} V_i V_j \sin(\theta_{ij} + \gamma_s) - k_s b_{se} V^2{}_i \sin(\gamma_s)] \frac{d\gamma_s}{dt} \leq 0 \qquad 7$$

$$b_{sh} V_i^2 \frac{dk_p}{dt} \leq 0 \qquad 8$$

After a close examination of equations, E.q. (3) to (8), an interesting fact is found, that is Eq. (3) to (5) provide the information concerning the possible system parameters to be chosen as the input and output signals for the controllers. In addition, Eq. (6) to (8) give the control rules and constraints concerning how the three UPFC control parameters, K_s, γ_s and K_p, could be manipulated by the controllers with respect to the possible changes of system parameter, V_i, V_i, θ_{ij}, such that the control criteria can be satisfied. Based on the above observation, an innovative control scheme is proposed in which three conventional PI and three fuzzy controllers are utilized and designed to have different input signals, which are locally available system parameters, V_i, V_i, θ_{ij}, and different output signals, which are the imaging component, F_{se}, and the real component E_{se}, of the inserted series voltage, V_{se}, and the shunt reactive power injection, Q_{shunt}, of the UPFC. By activating these controllers at the same time the UPFC can be controlled in a way that the damping criteria stated in Eq. (3) to (8) can be satisfied simultaneously and the best damping effects can be achieved. The parameters of UPFC are listed in Table 1.

Table 1.The parameters of UPFC

UPFC parameters	**Value**
Rating of the series branch	100MVA
Rating of the shunt branch	100MVA
The leakage reactance of the series and shunt coupling transformers (Xse and Xsh)	0.025 p.u
Limits of the UPFC internal control parameters: Series branc	$K_{s-\min}$: 0.0 $K_{s-\max}$: 0.15 $\gamma_{s-\min}$: 0.0; $\gamma_{s-\min}$: 2.00
Limits of the UPFC internal control parameters: Shunt branch	$K_{p-\min}$: 0.95; $K_{p-\max}$: 1.05

SIMULATION AND RESULTS

The two-area system shown in Fig. 5 is considered in this study. In this study three various location for UPFC are considered as follow:

- ***Case 1: UPFC is installed in Area1 between bus-5 and bus-6***
- ***Case 2: UPFC is installed in Area1 between bus-10 and bus-11***
- ***Case 3 : UPFC is installed between two Areas between bus-7 and bus-8***

In order to detect the best location of UPFC, It is considered that a 3-phase symmetrical short-circuit fault of 300 mill-seconds duration occurs at bus-3. The system is simulated in Matlab/Simulink environment and the corresponding graphs are shown in Fig. 4 (for Case 3), and Fig. 5. This simulation is implemented based on conventional PI controller in UPFC that shown in Fig.6.

From obtained results it is inferred that without a UPFC, the oscillations in generator rotor angle of Area-1 (Generator 1 and Generator 2) and Area-2 (Generator 3 and Generator 4) increase and the settling time for the oscillations is found to be high. However, also it can be seen that with a UPFC, the oscillations in generator rotor angle of Area-1and Area-2 decrease and the settling time for the oscillations is found to be slightly low. Hence, the transient stability of the two-area power system is improved with UPFC.
Results depicted in Figs.7-10 show that best damping improvement is achieved when UPFC is installed between two areas.

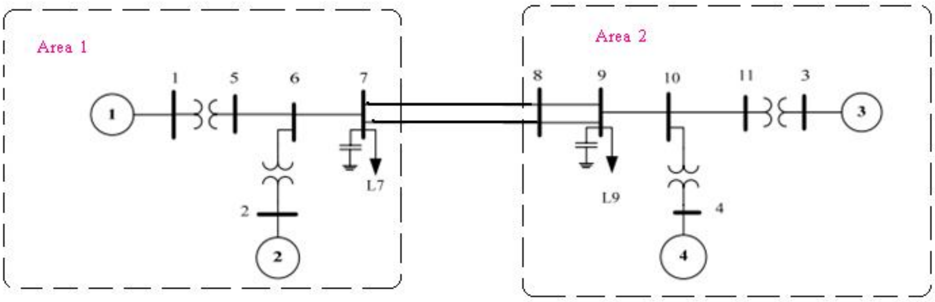

FIGURE 3 Multi-machine power system

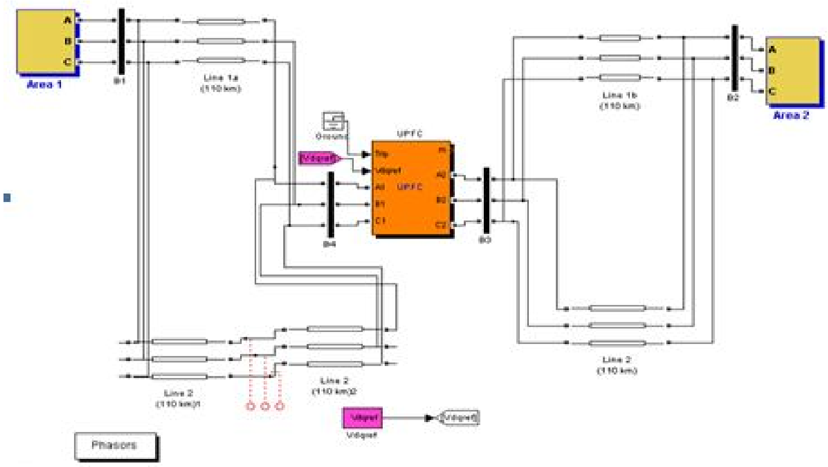

FIGURE 4 Multimachine systems with UPFC between two areas

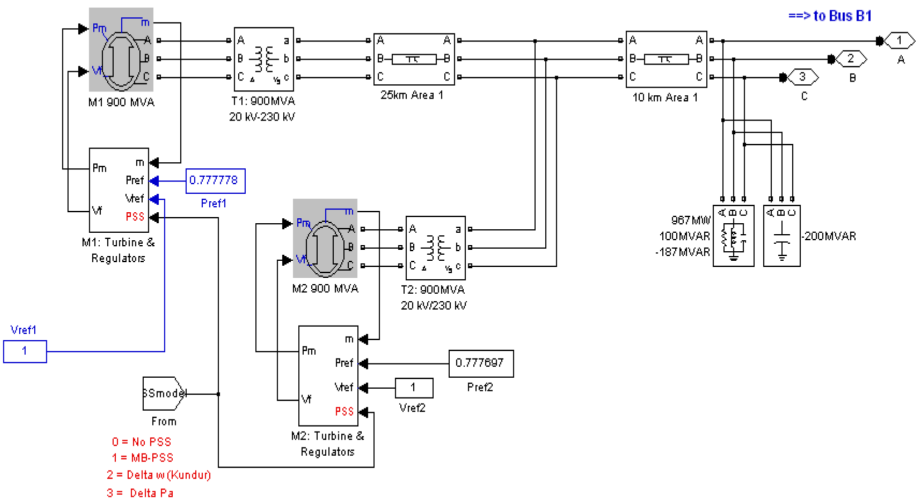

FIGURE 5 Parameters setting in MATLB

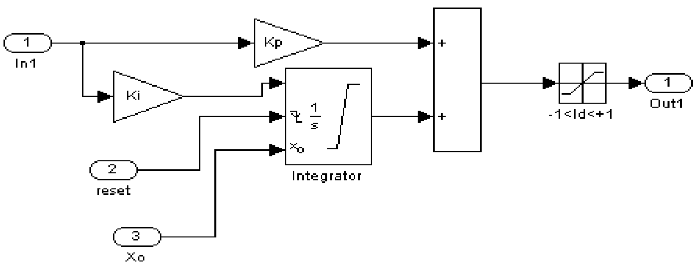

FIGURE 6 Conventional PI controller in UPFC

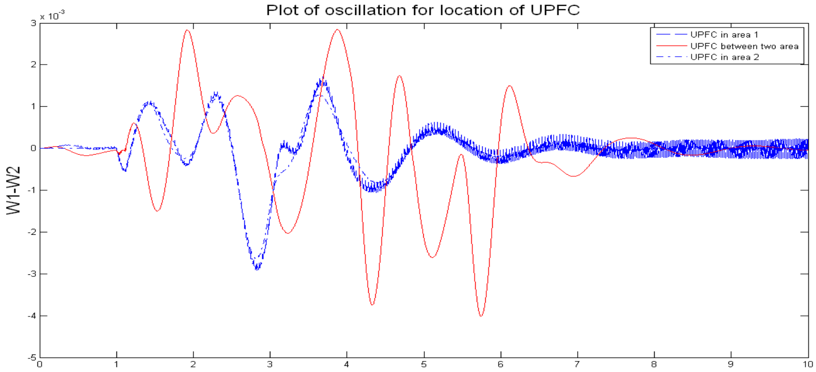

FIGURE 7 Inter-area mode of oscillation for $\omega_1 - \omega_3$

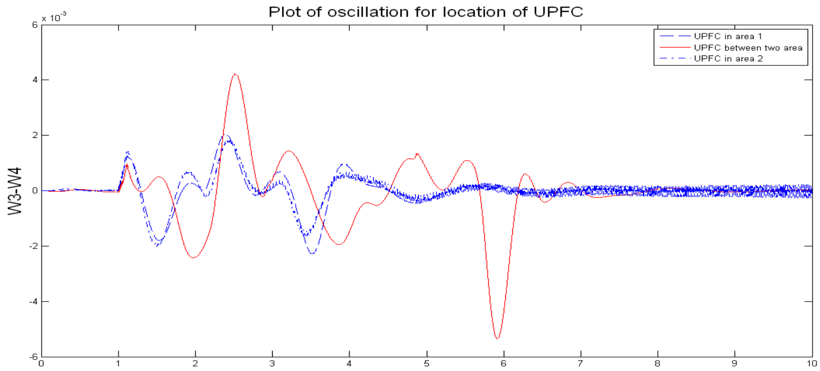

FIGURE 8 Local mode of oscillation for $\omega_4 - \omega_3$

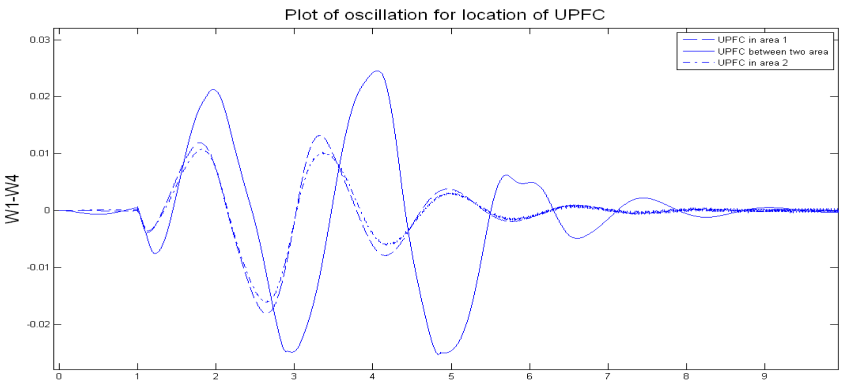

FIGURE 9 Inter-area mode of oscillation for $\omega_1 - \omega_4$

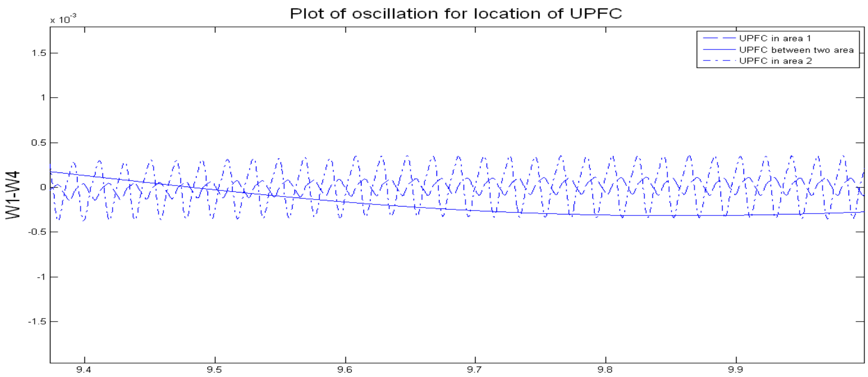

FIGURE 10 Zoom on inter-area mode of oscillation for $\omega_1 - \omega_4$

Conclusion

This paper proposed various cases studies to find the optimal location of the UPFC controllers and Eigen value analyses are used to assess the most appropriate input signals (stabilizing signal) for supplementary damping control of UPFC to damp out the inter-area mode of oscillations .The placements of UPFC controllers have been obtained for the base case and for the dynamic critical contingences. The effectiveness of the proposed method of placement is demonstrated on practical network. also it can be seen that with a UPFC, the oscillations in generator rotor angle of Area-1and Area-2 decrease and the settling time for the oscillations is found to be slightly low. Hence, the transient stability of the two-area power system is improved with UPFC. Results show that best damping improvement is achieved when UPFC is installed between two areas.

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