

Effects of Power Oscillations Damping Controllers by UPFC Using Different Fault Conditions

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Abstract-- Weakly damped power swings are one of the main problems endangering secure operation of power systems. This paper presents two methods, based on the use of nonlinear system model, to improve damping of power swings using UPFC. A state-variable control strategy has been derived using local available signals of real and reactive power. The results of simulation tests of two control methods, undertaken using a small multi-machine system model, have been presented. The simulations show that the methods make good results in different fault places and clearing time. The results present that controlling series part of UPFC can damp power oscillation by state-variable control method, but simultaneous control of shunt and series part of UPFC can damp voltage oscillations by direct Lyapunov method.

Key-Words: - Transient stability, Local measurement, Flexible ac transmission systems (FACTS), UPFC, Power oscillations damping.

1 Introduction

Power systems exhibit various modes of oscillation due to interactions among system components. Most of the oscillations are due to synchronous generator rotors swinging relative to each other. Stressed power systems are known to exhibit nonlinear behaviour. Load changes or faults are the main causes of power oscillations.

If the oscillation is not controlled properly, it may lead to a total or partial system outage. If no adequate damping is possible, the oscillations may be sustained for minutes affecting power flows and grow to cause loss of synchronism between systems. Application of power system stabilizer (PSS) has been one of the first measures to enhance the damping of power swings. With increasing transmission line loading over long distances, the use of conventional PSS might in some cases, not provide sufficient damping for power swings. PSS increases damping torque of a generator by affecting the generator excitation control, while FACTS devices improve damping by modulating the equivalent power-angle characteristic of the system [1]. By using power electronics controllers a Flexible AC Transmission System which offers greater control of power flow, secure operation and damping of power system oscillations. FACTS devices are used in power systems to improve both the steady state and dynamic performances of the systems [2].

Damping can be improved by using one of the flexible AC transmission systems (FACTS) devices, which offers an alternative means to mitigate power system oscillation. Thus, a question of great importance is the selection of the input signals and a control strategy for these devices in order to damp power oscillation in an effective and robust manner.

The work reported here was to derive a state-variable control using a nonlinear system model in order to take into account the influence of changing operating conditions and changes in the network parameters. To achieve this goal, the direct Lyapunov method was used [3].

Unlike the PSS at a generator location, the speed deviations of the machines are not readily available to a FACTS controller located on a transmission line. For a UPFC based damping controller, we want to use an input signal to the damping controller from the locally measurable quantities at the UPFC location. The electrical active and reactive power flows can be easily measured at the UPFC location and hence may be used as an input signal to the damping controller.

The paper [6] used the rate of dissipation of transient energy as an index to determine and compare the additional damping provided by a STATCOM and SSSC. The SSSC can be operated in many different modes and the final outcome is such that the SSSC injects a voltage in series with transmission line [7].

Since a fault appears in any point of a power system with different clearing times, the ability of damping controllers in different fault conditions is important. Stability of the system depends on operating point before faults and strength of disturbance [8].

The UPFC parameters can be controlled in order to achieve maximal desired effect where transient stability problems appear when bulk power is transmitted by long transmission lines [9].

In this paper we consider the stabilizing control of the UPFC by two methods [3]-[4], and their effects for different fault places and clearing delay times. Ability of two control methods were studied in the presense of three-phase short circuit with different durations (100, 150, 200 msec) placed in different locations. The voltage oscillations are well damped with direct Lyapunov method. This method gives better power oscillations damping results.

2 Power System Oscillations

The dynamic equations of the single-machine-to-infinite-bus system are given in Fig.1 as below [1]:

$$\begin{cases} \frac{d\Delta\omega_r}{dt} = \frac{1}{2H} [\Delta\tau_m - \Delta\tau_e - D\Delta\omega_r] \\ \frac{d\Delta\delta}{dt} = \omega_0\Delta\omega_r \end{cases} \quad (1)$$

The state equation of above relations is given by:

$$\frac{d}{dt} \begin{bmatrix} \Delta\omega_r \\ \Delta\delta \end{bmatrix} = \begin{bmatrix} -\frac{D}{2H} & -\frac{K_S}{2H} \\ \omega_0 & 0 \end{bmatrix} \begin{bmatrix} \Delta\omega_r \\ \Delta\delta \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} \Delta\tau_m \quad (2)$$

The above equations form nonlinear state equations of $\dot{x} = f(x, u)$, in which $x = (\Delta\delta, \Delta\omega_r)$ are the state variables. The equations (1) and (2) make the base of most stability and low frequency oscillations studies in power systems.

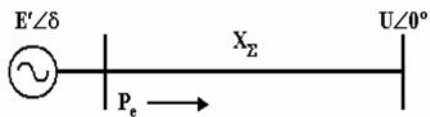


Fig. 1 Single-machine-to-infinite-bus.

The eigenvalues of the system are calculated from the following equation:

$$|A - \lambda I| = 0 \quad (3)$$

The standard form of the characteristic equations is given by:

$$s^2 + 2\xi\omega_n s + \omega_n^2 = 0 \quad (4)$$

$$s_{p1, p2} = -\xi\omega_n \pm j\omega_d$$

The damping coefficient (D) is very small in

synchronous generators, so they are working in oscillatory and underdamped states ($0 < \xi < 1$).

Increasing of D, causes increasing of ξ and so the system oscillations are damping very fast.

3 Unified Power Flow Controller

The unified power flow controller (UPFC) is the most versatile device in the FACTS family which can provide simultaneous control of power system parameters such as transmission voltage, line impedance and phase angle [5]. It has a capability of improving both steady-state and dynamic performances of a power system. It can be connected in series with a transmission line inside a system or in a tie-line connecting subsystems in a large interconnected system.

It consists of two solid-state synchronous voltage-source converters coupled through a common DC link capacitor as shown in Fig. 2.

As shown in Fig. 2, the UPFC consists of a boosting transformer and an excitation transformer linked by back-to-back converters VSC1 and VSC2. First converter (VSC1) is connected in shunt and the second one (VSC2) in series with the line. The shunt converter is primarily used to provide active power demand of the series converter through a common DC link. Converter 1 can also generate or absorb reactive power and thereby provide independent shunt reactive compensation for the line. Converter 2 provides the main function of the UPFC by injecting additional voltage ΔU , with controllable magnitude and phase angle in series with the transmission line through series transformer.

The main task of the UPFC is to control the flow of power in steady-state conditions. In addition, high speed of operation of thyristor devices makes it possible to control real and reactive power flow. The UPFC can be employed to enhance power system damping by modulating the converter voltages. That area of application is the main subject of this paper.

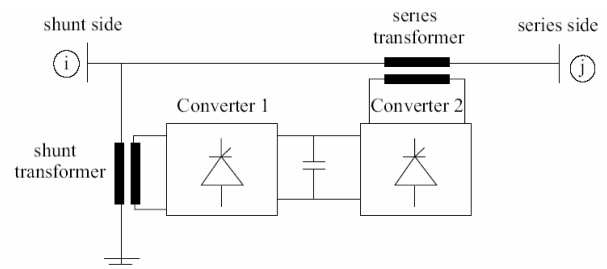


Fig. 2 Schematic diagram of UPFC.

4 Control Strategy Based On State Variables

4.1 UPFC control and modeling

Please, follow our instructions faithfully, otherwise you have to resubmit your full paper. This will enable us to maintain uniformity in the conference proceedings as well as in the post-conference luxurious books by WSES Press. The better you look, the better we all look. Thank you for your cooperation and contribution. We are looking forward to seeing you at the Conference. For simplicity a UPFC is connected at the end of the transmission line, near the infinite bus. Fig. 5 shows the single-line diagram of SMIB system with the UPFC. The vector diagram of a UPFC connected to a network (Fig.3) is presented in Fig.4.

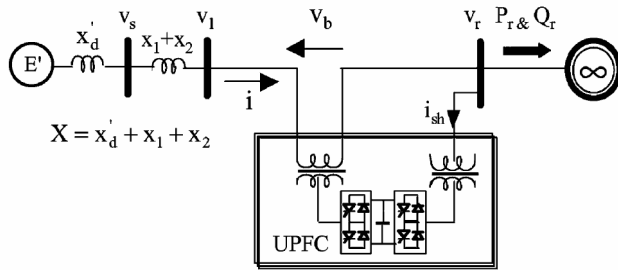


Fig. 3 SMIB system with the UPFC.

According to Fig.4, V_{bp} and V_{bq} are the in-phase and quadrature components of the series voltage of UPFC [4].

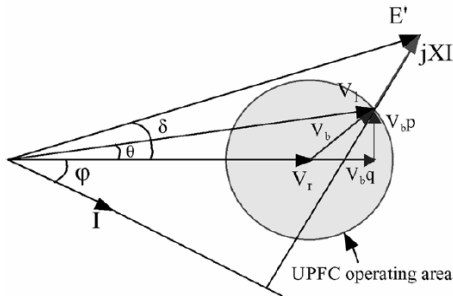


Fig.4 Vector diagram of a UPFC connected to a network

They are proportional to the voltage at the point of connection of UPFC and can be written as:

$$V_{bp} = V_r \gamma(t) \quad (5)$$

$$V_{bq} = V_r \beta(t) \quad (6)$$

where $\beta(t)$ and $\gamma(t)$ are the control variables.

The generator swing equation is :

$$M \frac{d^2 \delta}{dt^2} = P_m - A \cdot \sin(\delta) - D \frac{d\delta}{dt} - P_{UPFC} \quad (7)$$

where

$$P_{UPFC} = -A \cos(\delta) \gamma(t) + A \sin(\delta) \beta(t) \quad (8)$$

In equations (7) and (8), $(A = E' V_r / X)$ presents amplitude of power-angle characteristic in case of series voltage and is equal zero where P_{UPFC} introduces additional damping to the system if it is positive and proportional to the speed deviation $\Delta\omega = d\delta/dt$. The control strategy for achieving these aims are given as the following relations:

$$\gamma(t) = -K \cos(\delta) \frac{d\delta}{dt} \quad \text{and} \quad \beta(t) = -K \sin(\delta) \frac{d\delta}{dt} \quad (9)$$

The state variables defined by (9) can be executed by using time derivatives of the receiving active and reactive powers. According to Fig. 4, we can calculate the partial derivatives of P_r and Q_r as below [4], [10]:

$$\frac{dP_r}{dt} = \frac{(-V_{bp})E'}{KX} - \frac{V_r}{X} \frac{d(V_{bp})}{dt} \quad (10)$$

$$\frac{dQ_r}{dt} = \frac{(-V_{bq})E'}{KX} - \frac{V_r}{X} \frac{d(V_{bq})}{dt} \quad (11)$$

Fig. 8 shows the proposed block diagram of a modulation controller for the in-phase component of the series injected voltage of UPFC by using (10). The quadrature component is similar and driven by (11).

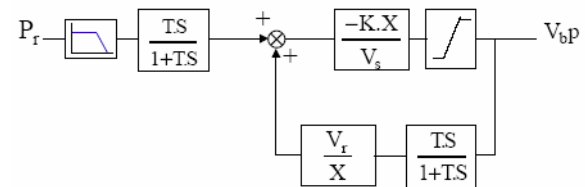


Fig. 8 Modulation controller for V_{bp} .

5 Control Strategy Based On Direct Lyapunov Method

5.1 Power system model with UPFC

The thyristor controlled UPFC can be treated as a lag element with a very small time constant or, as a proportional element. Hence the series part of the UPFC can be modeled by the series reactance of the left-hand side of the transmission link X_a and by the ideal complex transformation ratio:

$$\frac{I_b}{I_a} = \eta^* = |\eta| e^{-j\theta} \quad \eta = \frac{U_a}{U_b} = |\eta| e^{j\theta} \quad (12)$$

The shunt part of the UPFC can be modelled as a controlled shunt susceptance B_r (Fig.5b). Voltage ΔU injected by the booster transformer can be

resolved into two orthogonal components (Fig. 6): direct ΔU_Q and quadrature ΔU_P . The direct and quadrature components ΔU_Q and ΔU_P influences the reactive and real power flow.

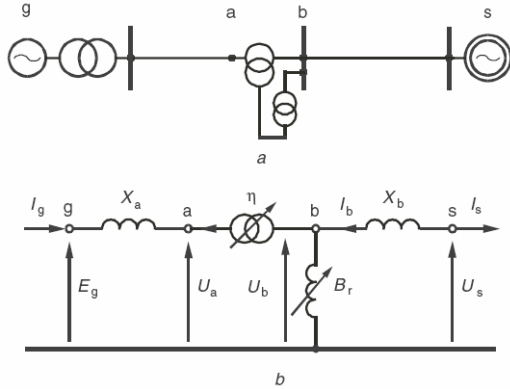


Fig. 5 SMIB with UPFC : (a) Schematic diagram; (b) Single-phased diagram

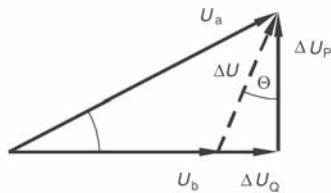


Fig. 6 SMIB with UPFC: Phasor diagram.

5.2 Control Strategy Based on Local Measurements

The control strategy is given by relations(13)-(15):

$$\gamma(t) \approx K_\gamma \frac{dP_b}{dt} \quad (13)$$

$$\beta(t) = \frac{K_\beta}{K_X} \frac{dQ_b}{dt} = K_{\beta(Q)} \frac{dQ_b}{dt} \quad (14)$$

$$B_r(t) \approx -\frac{K_\beta}{K_X} \frac{dQ_b}{dt} = -K_{B(Q)} \frac{dQ_b}{dt} \quad (15)$$

A block diagram of a controller operating on P_b or Q_b and controlling γ or β respectively, is shown in Fig. 7. The shunt part of the UPFC can operate as the reactive power compensator controlling the voltage U_b and susceptance B_r .

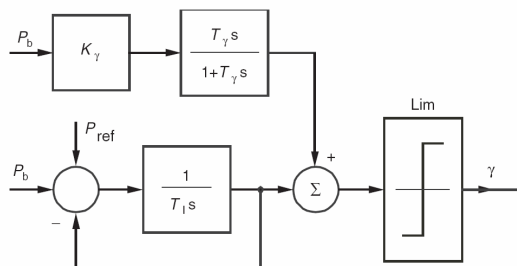


Fig. 7 Block diagram of the controller.

6 Simulation Results

The effectiveness of the two proposed control strategies will be illustrated using a three-machine test system. A diagram of a three-machine sample system is shown in Fig. 8. The inertia coefficient of generator G1 is much greater than that of generator G2. Therefore, the swings of generator G1 are little slower than that of generator G2. The parameters of this sample system are shown in reference [3].

To illustrate typical results, Figs. 9-11 show real power variations following a temporary three-phase short-circuits on buses B4,B5 and B6 with duration time 200msec.

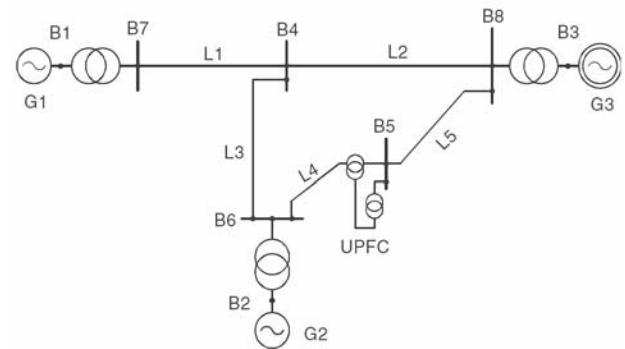


Fig. 8 Three-machine test system.

The following notations are used :

- dotted line: UPFC was not active;
- dashed line: UPFC is controlled by state-variable control with local measured powers (method-1).
- solid line: UPFC is controlled by direct Lyapunov method (method-2).

Damping of rotor and power swings due to both control methods is much stronger than for the uncompensated case.

6.1 Short circuit in bus B4

The method-2 gives slightly weaker damping than method-1 for G1, and an increase in the amplitude of the first and second swings for G2 (Fig. 9).

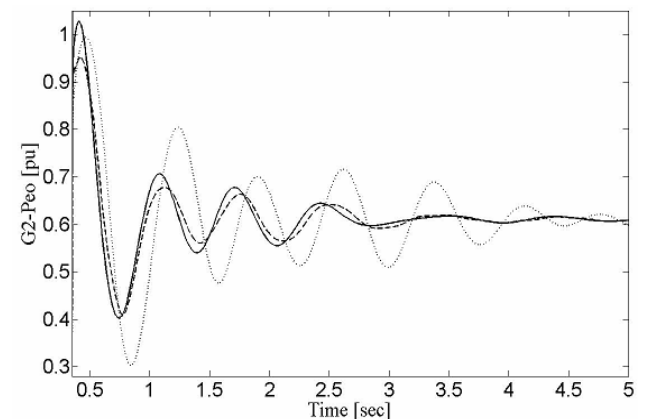


Fig. 9 Fault in bus B4, real power of generator G2.

6.2 Short circuit in bus B5

The method-2 gives stronger damping than method-1 for G1 and G2 (Fig. 10).

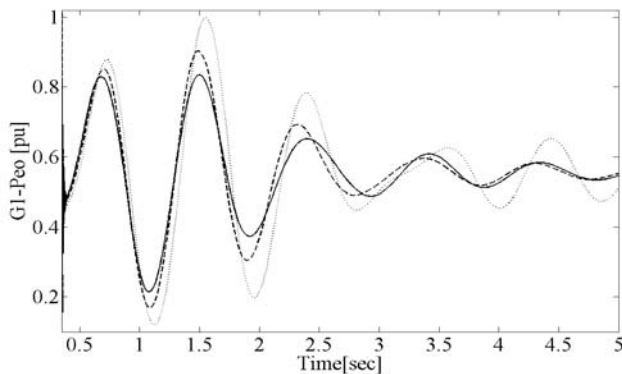


Fig. 10 Fault in bus B5, real power of generator G1.

6.3 Short circuit in bus B6

The method-2 gives stronger damping than method-1 for G1, but an considerable increase in the amplitude of the first and second swings for G2 with faster damping (Fig. 11).

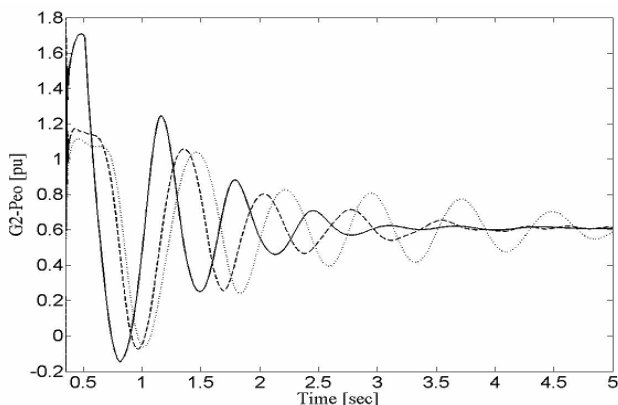


Fig. 11 Fault in bus B6, real power of generator G2.

6.5 Voltage Oscillations in Bus B6

The Voltage oscillations are well damped with method-2 and voltage drop is fastly reach to steady state value as Fig. 12.

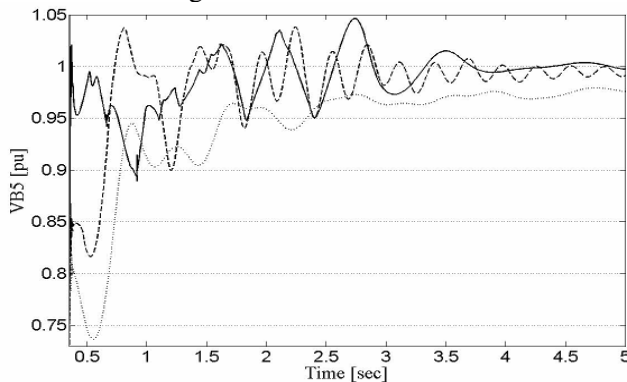


Fig. 12 Fault in bus B6 and voltage at bus B5.

6.6 Manual voltage injection reference

The series converter operates in manual voltage injection mode. The reference values of injected voltages V_{dref} and V_{qref} are used to synthesize the converter voltage. The simulations of two method with MATLAB, V_q in-quadrature with U_b controls active power and V_d in-phase with U_b controls reactive power. Whereas, MATLAB uses the model of UPFC with shunt before series part, so the U_b substituted by input voltage U_a , but results are similar. (Fig. 13,14)

The references of series injected voltages and shunt injected current are calculated and applied to the control system of UPFC.

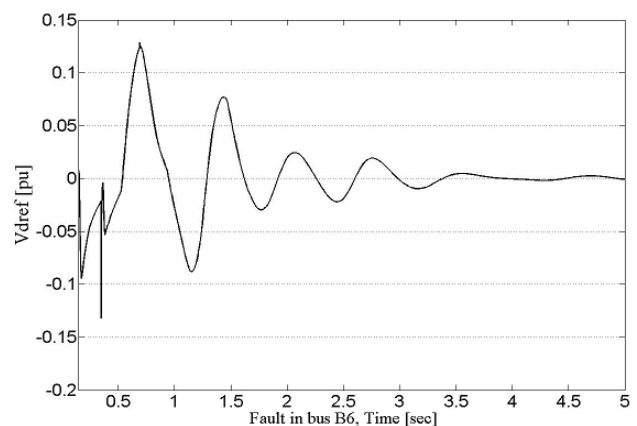


Fig. 13 Reference value of direct-axis injected voltage (pu) of UPFC.

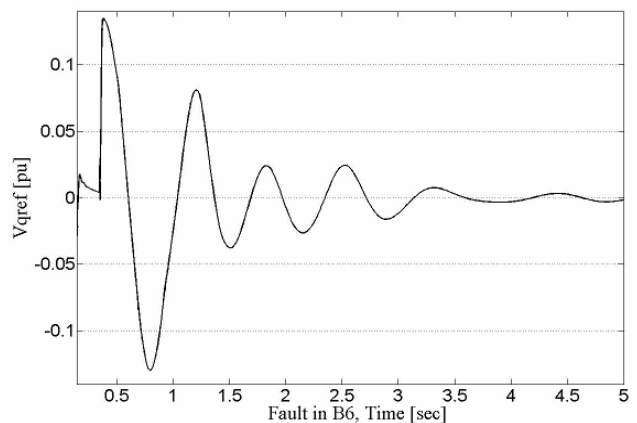


Fig. 14 Reference value of quadrature-axis injected voltage (pu) of UPFC.

7 Conclusion

The paper has presented a comparison between two methods with UPFC for first swing transient stability and oscillations damping. The advantages of these two methods are using the local variables

of system and offer better transient stability and fast oscillations damping.

Approximately in most cases, method-2 gives better stability and damping results than method-1, but in view of voltage oscillations, method-2 is better than the other because of shunt part help for voltage regulation. The important problem is reduction of second and third swing with respect to first swing. Single-phase and two-phase to ground faults and increasing of loads have similar results.

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