MODELLING AND ANALYSIS OF UPFC CONNECTED SINGLE MACHINE SYSTEM WITH PSS DESIGN USING SLIDING MODE CONTROL TECHNIQUE

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ABSTRACT: The unique capability of the Unified Power Flow Controller in multiple line compensation are integrated into a generalized power flow controller that is able to maintain prescribed and independently controllable, real power and reactive power flow within the line. We demonstrate the proposed technique on a single machine infinite bus system. In this paper, we propose UPFC with PSS design scheme based on multirate output feedback control technique. Using different plant rates including the former plant output information, sampling error at multiple sampling intervals is thought-about. As a result, management and stability performance can be improved.

Keywords: FACTS, UPFC, PSS, sliding mode control, multirate output feedback

I. INTRODUCTION:
The deregulation and competitive environment in the contemporary power networks will imply a new scenario in terms of load and power flow condition and so causing problems of line transmission capability. It's tough to vary this structure of transmission system. So, the requirement for brand new power flow controllers capable of increasing transmission capacity and controlling power flows through predefined transmission corridors is increased. For this reason, as well known in recent years a new class of controllers, Flexible AC Transmission System (FACTS) controllers have speedily met with favour. Indeed, the 2 main objectives of FACTS technology are to control power flow and increase the transmission capacity over an existing transmission corridor [1].

The UPFC is a device which can control simultaneously all three parameters of line power flow (line electrical phenomenon, voltage and part angle). Such new FACTS devices combine along the options of 2 FACTS devices: the Static Synchronous Series Compensator (SSSC) [2]. As the would like for versatile and quick power flow controllers, like the UPFC, is anticipated to grow within the future due to the changes in the and realistic models of these controllers to investigate the impact of them on the performance of the power system.

II. UPFC CHARACTERISTICS:

Synchronous Series Compensator (SSSC) [2]. As the would like for versatile and quick power flow controllers, like the UPFC, is anticipated to grow within the future due to the changes in the and realistic models of these controllers to investigate the impact of them on the performance of the power system.

III. POWER SYSTEM MODELLING:

Synchronous Generator Modeling

The synchronous generator is represented by a third-order nonlinear mathematical model given by

$$\frac{d\delta}{dt} = \Delta \omega$$

Fig.1 General Configuration of UPFC

The basic components of the UPFC are two voltage source inverters (VSIs) sharing a common dc storage electrical condenser, and connected to the system through coupling transformers. One VSI is connected in shunt to the gear via a shunt electrical device, whereas the opposite one is connected serial through a series electrical device. A basic UPFC purposeful theme is shown in Fig.1 [2].
\frac{d\Delta\delta}{dt} = \frac{1}{M} \left[ P_m \Delta E'q - (X_q - X'd) \Delta\delta \right] \tag{2}

\frac{d\Delta\omega}{dt} = \frac{1}{T'} \left[ E_{fd} - \Delta E'q - (X_d - X'd) \Delta\omega \right] \tag{3}

where \Delta\delta = \delta - \delta_0 and \Delta\omega = \omega - \omega_0

Power System Stabilizer (PSS) Modeling:

The main objective of PSS is to extend the angular stability of a power system by providing supplementary damping to the oscillation of synchronous machine rotors through the generator excitation. This damping is provided by electrical force applied to the rotor that is in phase with the speed variation. The oscillations of concern generally occur in the frequency range of 0.2-3.0 Hz and insufficient damping of these oscillations may limit the ability to transmit power.

Classical stabiliser implementation procedure:

\begin{align*}
\text{FIG. 2 Block diagram of PSS}
\end{align*}

Implementation of a PSS implies adjustment of its frequency characteristics and gain to produce the desired damping of the system oscillations in the frequency range of 0.2-3.0 Hz. A ‘lead-lag’ PSS structure is shown in fig. 3. The sign of any PSS could be a voltage signal (Vpss), & additional as a signal to the exciter. For the structure shown in fig. 3, the transfer function of PSS is given by

\begin{align*}
VPSS(s) = \frac{1}{1 + s Tw} \left( 1 + s T1 \right) \left( 1 + s T3 \right) \frac{1}{1 + s Tw} \left( 1 + s T2 \right) \left( 1 + s T4 \right) \text{Input}(s)
\end{align*}

Where, Ks represent device gain. The device frequency characteristic is adjusted by varying the time constant Tw, T1, T2, T3, T4 [4].

Since PSS must produce a component of electrical torque in phase with the speed deviation, phase ‘lead-lag’ block circuits are used between the PSS output and the control action i.e. the electrical torque. The number of lead lag blocks are needed depends on the particular system. The damping provided by the PSS is directly proportional to the gain up to a certain value, after it begins to decrease and hence gain Ks is an important factor during the tuning of PSS. All variables of the PSS must be determined for each type of generator separately because of the dependence on the machine parameters. The facility system dynamics additionally influence the PSS values.

\begin{align*}
\text{FIG. 3 Lead-Lag power system stabilizer}
\end{align*}

The control equations for this lead-lag PSS are given by

\begin{align*}
\text{VPSSmax if } V5 \geq VPSSmax \\
Vs if VPSSmax > V5 > VPSSmin \\
VPSSmin if V5 \leq VPSSmin
\end{align*}

\begin{align*}
VPSS(s) = KsV3^* \frac{Vs}{Tw} \\
= \frac{V3^* T1}{T4} V1^* \frac{V1-V3}{T4} \\
= \frac{V1^* T1}{T2} \Delta \text{Input}^* \frac{\Delta \text{Input} - V1}{T2}
\end{align*}

\begin{align*}
\Delta \text{Input} = \{ \Delta\omega = \omega_{mech} - \omega_0 \text{ or } \Delta Pn = P_{mech} - P_{elec} \}
\end{align*}

A PSS can be most effectively applied if it is tuned with an understanding of the associated power characteristics and the function to be performed by the stabilizer. Single machine power system is used to determine the frequency of intra-plant mode oscillations. Single machine infinite bus power system is considered in this work. The load and the UPFC are connected at the load bus located between the generator bus and the infinite-bus.

IV. MODELING OF UPFC:

The dynamic model of UPFC is derived by performing standard \(d-q\) transformation of the current through the shunt transformer and series transformer. They are as given below.

Shunt converter

\begin{align*}
\frac{di_{pd}}{dt} &= -\frac{R_p}{L_p} i_{pd} + \omega i_{pd} + \frac{1}{L_p} (Vsd - Vpd) \tag{9}
\end{align*}

\begin{align*}
\frac{di_{pq}}{dt} &= -\frac{R_p}{L_p} i_{pq} + \omega i_{pq} + \frac{1}{L_p} (Vsq - Vpd) \tag{10}
\end{align*}
\[ \frac{dibd}{dt} = -\frac{wbre}{xe}ibd + \omega ibd + \frac{wb}{xe}(Vud - Vbsin\delta) \quad \text{Eqn. (11)} \]

\[ \frac{dibq}{dt} = -\frac{wbre}{xe}ibq - \omega ibd + \frac{wb}{xe}(Vuq - Vbcos\delta) \quad \text{Eqn. (12)} \]

The proposed UPFC is proved to be very effective and robust in damping power system oscillations and thereby enhancing system transient stability.

V. MULTIRATE OUTPUT FEEDBACK SLIDING MODE CONTROL:

The feature of a sliding mode control system is that the controller is switched between distinctive control structures and the system trajectory is forced to reach the sliding surface and to slip on it. Once the states of the system enter the sliding mode, the dynamics of the system are determined by the selection of sliding surface and are independent of uncertainties and disturbances. As a result, the sliding mode control is a robust control method and it has found broad applications. Considering the sliding mode control with multirate feedback, some studies and analysis were undertaken.

In real management applications, totally different management signal rates and device output rates area unit typically used. Such type of system is called as multirate system. The continuous time sliding mode controller is robust to disturbances but the discrete-time controller is sensitive to output measuring error, as a result of a shift perform is enclosed within the controller. The state of the sliding mode controller is complete by combining the use of multirate output feedback and past plant outputs, then the management gains embrace extra style parameters. As a result, management performance is improved. The multirate output feedback also guarantees closed loop system stability.

Consider the subsequent single input single output continuous time LTI system represented by state equation

\[ X(t) = AX(t) + BU(t) \quad \text{Eqn. (13)} \]

\[ Y(t) = CX(t) \quad \text{Eqn. (14)} \]

Where \( X(t) \) is n-dimensional state(t) is input and \( Y(t) \) is output.

Let the above system sampled at a sampling time \( \tau \) we have,

\[ X(k\tau) = \phi(t)X(k\tau) + \Gamma U(k\tau) \quad \text{Eqn. (15)} \]

\[ y(k\tau) = CX(k\tau) \quad \text{Eqn. (16)} \]

It is assumed that the pair \( (\phi, \Gamma) \) is controllable and the pair \( (\phi, C) \) is observable.

Switching surface is considered by using multirate output feedback, namely, using plant output samples along time controller is sensitive to output measuring error, as a result of a shift performance is enclosed within the controller. The state of the sliding mode controller is complete by combining the use of multirate output feedback and past plant outputs, then the management gains embrace extra style parameters. As a result, management performance is improved. The multirate output feedback also guarantees closed loop system stability.

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The original continuous time system Eqn. (13) and (14) is observable, discrete time system Eqn. (15) and (16) is observable, and \( Co \) is rank \( n \) and \( n \times n \) matrix.

From Eqn. (25) and (26)

\[ X(k\tau) = Co^{-1}Y_{k+1} - Co^{-1}DoU(k\tau) \quad \text{Eqn. (28)} \]
and

\[ X(k+1) = C_0^{-1}Y_{k+1} + (\Gamma - \phi \tau U)C_0^{-1}D\omega(k\tau) \]  

Let \( k+1 \) be \( k \). then

\[ X(k\tau) = Ly Y_k + Lu U((k-1)\tau) \]  

\[ Ly = \Phi C_0^{-1} \]  

\[ Lu = T_\tau - \Phi \tau C_0^{-1} \]  

That is state variable \( X(t) \) is calculated by using multirate output \( Y_k \) and input \( U((k-1)\tau) \) coefficients \( Ly \) and \( Lu \) are determined by above equation and have no redesign parameters.

By adding past output \( Y((k-1)\tau - \Delta) \) to \( Y_k \),

\[ y(k - 1)\tau - \Delta \]

\[ Y_k = \begin{bmatrix} y((k-1)\tau) \\ y((k-1)\tau + \Delta) \end{bmatrix} \]  

and consider the following relationships,

\[ Y((k-1)\tau + \Delta) = Y(k\tau - \Delta) = CX((k-1)\tau + \Delta) \]  

\[ Y(k\tau) = CX(k\tau) \]  

\[ Y(k\tau + \Delta) = CX(k\tau + \Delta) \]  

\[ X(k\tau) = \Phi X((k-1)\tau + \Delta) = \Gamma U((k-1)\tau) \]  

\[ X((k-1)\tau + \Delta) = X(k\tau + \Delta) = X(k\tau) + \Gamma u(k\tau) \]  

The control input \( F_x X(k\tau) \) can be realized as

\[ U(k\tau) = F_x X(k\tau) + F_u \begin{bmatrix} u(k-2) \\ u(k-1) \end{bmatrix} \]  

Considering (38), the multirate output feedback based quasi sliding mode control law can be represented by

\[ U(k) = F_y Y_k + F_u \begin{bmatrix} u(k-2) \\ u(k-1) \end{bmatrix} - (c^T \Gamma)^{-1} \epsilon \text{sgn}(c^T L_y Y_k + c^T L_u u((k-1)\tau)) \]  

The feedback gain \( F_y \) includes extra parameters.
FIG.6 ROTOR ANGLE STABILITY
(a) WITHOUT UPFC & (b) WITH UPFC

FIG.7 ROTOR SPEED
(a) WITHOUT UPFC & (b) WITH UPFC

FIG.8 ACTIVE POWER
(a) WITHOUT UPFC & (b) WITH UPFC

FIG.9 REACTIVE POWER
(a) WITHOUT UPFC & (b) WITH UPFC

CONCLUSION:

An UPFC model with PSS design scheme using multirate output feedback sliding mode control technique has been proposed in this paper. The proposed scheme provides good damping enhancement and increases transient stability for single machine infinite bus system. Proposed model can be extended for multi-machine bus system for providing good damping to electromechanical oscillations in power system.

REFERENCES:


