OPTIMAL FEEDBACK SWITCHING CONTROL FOR UPFC BASED DAMPING CONTROLLER

MASOUD SHIRKHANI\textsuperscript{a1} AND RAMIN SAYADI\textsuperscript{b}

\textsuperscript{a}Science and Research branch, Islamic Azad University, Ilam, Iran

ABSTRACT

UPFC is one of the most comprehensive devices of FACTS which is able to control active and reactive power independently. Also, it is able to control bus voltage. UPFC is a flexible multi-functional AC transmission system. Controlling the power flow is main task of UPFC. Controlling Voltage, improving stability of transient, damping oscillator are secondary tasks of UPFC. This is accompanied with features of Static Synchronous Compensator (STATCOM) and Static Synchronous Series Compensator (SSSC). In this regard, Designing control strategies using FACTS System such as UPFC for optimizing power flow with improving performance is one of main objectives of this investigation related to control of power systems.

KEYWORDS: Optimal Switching-Control Problems, Feedback Control, Power Flow

In the late 1980s, with the introduction of FACTS controllers, a new window was opened on the electricity industry. Various reasons resulted in focusing on using FACTS controllers in power network. Increasing demand of power consumption in various regions was one of these reasons that led to lack of transmission capacity. According to problems of installing new lines, this problem led to draw more attention toward optimal use of available lines. Rearrangement and privatization of electricity networks is another point necessitates emergency of controlling the passing power from various routes. Simultaneously, developments in power electronics provided feasibility of economic production of these controllers. FACTS means using power electronic devises by some methods in the high voltage grid that is controllable electrically (IEEE/ CIGRE, 1995).

Basis formany of the comments made about the FACTS is for several last decades. In one hand, FACTS is a new concept that had useful results in 1980 in Power Electronics Research Institute (EPRI). FACTS means application of special methods for development and using Power electronics equipments for increasing control of power distribution in the high voltage side of network in both stable and Transient situations. FACTS controllers are able to control power systems in both dynamic and permanent states. Unique feature of these devices is hidden in using Power electronic switches by them that are able to open and close in a fraction of a cycle. Therefore, they provide the feasibility of real controlling of power system, without change in its topology or changing the planning of generators. Dynamic performance attractiveness of these devices drew more attention to focus on their dynamic performance. Whereas, using them in control of network power flow was the initial objective of introducing these devices. Recently, after some changes in design and manufacture of power plant equipment, producing power network has been started. They are controllable electronically. Probably, these progresses and methods affect on energy trading kind. Due to economic and industrial profits, they are welcomed too much. So, FACTS was supported by Electric Equipment Manufacturers, Network operators, and research institutions around the world.

Many kinds of FACTS controllers are identified in various kinds of the world. The most important FACTS controllers are as follows
\begin{itemize}
  \item Load Tap changers (LTC)
  \item Phase Rec regulators
  \item SVC
  \item STATCOM
  \item UPFC
\end{itemize}

UPFC can act as a compensator of parallel reactive power (STATCOM)) similar to a series compensator (SSSC) or similar to a Commutator of phase. Although, all of UPFC capabilities will not be used in these states. Controlling parallel converterinautomatic voltage control mode and series inverter control in automatic control of power state; is the control state usually used for UPFC. In automatic control, voltage of reactive injection power is controlled by parallel converters to E bus as voltage of the bus is regulated in the intended amount. Additionally, Controlling Parallel Converters in reactive power control mode is norm as the active and reactive power flow in the line. In control of

\textsuperscript{1}Corresponding author
series converters as automatic control of power, the injected voltage in the line would be regulated in a way that the intended active and reactive power flow in line.

Figure 1: Main structure of UPFC

Figure 1 shows Straight-line view of a UPFC consists of a parallel ac / dc voltage source converter connected to each other by a dc condenser. UPFC is one of the most comprehensive devices of FACTS which is able to control active and reactive power independently. Also, it is able to control bus voltage. UPFC is a flexible multi-functional AC transmission system. Controlling the power is main task of UPFC. Controlling Voltage, improving stability of transient, damping oscillator are Sub-tasks of UPFC. This is accompanied with features of static synchronous compensator (STATCOM) and Static synchronous series compensator (SSSC). Designing control strategies by using FACTS system such as UPFC for optimizing power flow with improving performance is considered as main objectives of this investigation related to controlling power system. Organizing investigation is established based on this point.

Phillips-Heffron linearization model is described. This is done by initial analysis. Firstly, it is done by single controls. Finally, it is done by coordinated controllers.

Switching Model Description for Phillips–Heffron plan according to UPFC controller In connection with the proposed switching rules. Finally, results and analysis are inserted.

Wang has offered a Phillips-Heffron linear model of power system installed on UPFC and main problems. It is regulated based on Based on the issues associated with designing UPFC based damping controller of power oscillator in line with incidence UPFC parameters in order to obtain desirable damping. In addition, any effort is not done for determining the most appropriate control input UPFC in order to obtain robust damping controllers for optimal performance in all fixed variables. recently, researchers have tried to select UPFC control parameter for designing UPFC damping controllers by applying various controlling techniques such as Phase Compensation, Fuzzy Logic, Optimal control techniques such as LQR.

Dynamic models for power systems with UPFC

H. F. Wang offered State space model for improving power system of Phillips-Heffron linear model of SMB (M.Sobha, 2010).

\[ \dot{X} = AX(t) + Bu(t) \]

Equation 1: in this equation, State variables include the tilt of the rotor (\( \Delta \)), SD Speed (\( \Delta W \)), Deviation of theq-axis component (\( \Delta E_{d} \)), the voltage deviation(\( \Delta E_{d} \)). Also, input variables include Modulation index, Phase parallel converters(\( m_{p} , s_{p} \)) and Modulation index and Phase Converter Series (\( m_{B} , s_{B} \)). B and A represent State and control of determined input. All K fix amounts have been examined.

\[
A = \begin{bmatrix}
0 & \omega_{o} & 0 & 0 \\
-K_{1} & -D & -K_{2} & 0 \\
M & M & K_{4} & 0 \\
0 & -K_{5} & 1 & 0 \\
T_{1}do & T_{1}do & T_{1}do & 0 \\
-k_{A}K_{5} & 0 & T_{A} & -1 \\
T_{A} & 0 & TA & T_{A}
\end{bmatrix}
\]

\[
B = \begin{bmatrix}
0 & 0 & -K_{p_{e}} & 0 & -K_{p_{b}} & 0 & -K_{p_{e,b}} \\
M & M & M & M & -K_{q_{e}} & -K_{q_{b}} & -K_{q_{e,b}} \\
T_{do} & T_{do} & T_{do} & T_{do} & -k_{A}K_{\theta} & -k_{A}K_{\theta} & -k_{A}K_{\theta}
\end{bmatrix}
\]

Initial analysis of the optimal control

Initial analysis has been done by the modulation index of parallel and series converters \( m_{B} , m_{E} \) by applying controllers based LQR. The analysis was done in 2 phases. In the first phase, contract optimal control analyses (SOC) was done by \( m_{E} \) selection or Individual control inputs. It resulted in 2 separated systems as single-input and single-exit (SISO).

\[ \dot{X} = AX(t) + Bu(t) \]

In these equations, \( B = B_{s} \). The first column of B is for \( m_{E} \) input and \( B_{3}B_{D3} \) is for \( m_{B} \) input. Control regulations are determined by the following equation:

\[ u = r - Kx \]
In this equation $k_1$ and $k_2$ are gain of controllers for inputs of and . LQR method. They are analyzed by State variables. Referring to figures 1 to 4 in the second stage, COC analysis has been done by both methods. Inputs with the same coordinates result in multi input -output system as MIMO.

$$B = \begin{bmatrix} B_1 & B_3 \end{bmatrix}$$

Therefore, control gain of $K$ is equal to $2*4$ matrix for the MIMO model that is improvised for MIMO system. The analysis results are presented in figures 1 to 4.

According to above optimal control analyses, studying figures 1 to 4 shows that:

- None of the above COCs are not able to provide a better performance for the 4 variables considering ultra-mutation peak and time setting.
- Provides better performance for q-axis component deviation.
- Performance for rotor angle and speed deviation.
- Inputs with the same coordination provide better performance for voltage deviation.

Optimal Control Analysis suggests suitable switching among controllers may improve fixed-state performance for all 4 variables.

In this study, Phillips –Heffron Mathematical modeling with UPFC system as PS linear systems and switching algorithm are studied. PS systems are composed of a group of sub-systems. It is proved that applying suitable switching in control provides better performance compare to performance of a system without switching control system. A linear- PS system model is proposed for new issues.
Switching Strategy is shown in figure 2. Amounts of 1 and 2 based on switching rules are as follows:

Controller gain vector may result from second-order linear regulator theory: LQR controller, make gain parameters by minimizing the error criteria in part 4. Paying attention to linear system in part 1, A and B are fixed here. Cost index of LQR vector by K matrix is as following:

\[ J = \frac{1}{2} \int_0^\infty (x^T Q x + u^T R u) dt \]  
(4)

In this equation, Q, R, and Hermitian are positive-definite or real symmetric matrix. The following equation is obtained from the above equations.

\[ K = -R^{-1} B^T P \]  
(5)

Therefore, control rules are as following:

\[ u(t) = -Kx(t) = -R^{-1} B^T P x(t) \]  
(6)

In this equation, p should provide reduced Riccati equation.

\[ PA + A^T P - PBR^{-1} + B^T P + Q = 0. \]  
(7)

LQR function lets you to select R and Q parameters. It results in relative balance of input and state in cost function. Stages of LQR method is used for control of all outputs.

2 controllers are obtained here. UPFC achieves and . Gain of controller consists of the primary controller and secondary controller. So, 2 Closed-loop parameters will be as follows:

In order to consistency between and , is defined. In order to consistency between and , is defined. The following equations are mentioned as

\[ E_1g(A_1) = E_1g(A - BK_1) = E_1g(A - BK_2) \]

\[ E_1g(A_2) = E_1g(A - BK_1) = E_1g(A - BK_2). \]

1-2-3- Switching algorithm

Switching control algorithm is describable in the following stages:

1- as the main controller id defined for and for . In this equation, has asymptotically stability but does not consist of stability.

2- will be obtained by solving the algebraic Lyapunov equation

3- Applying determines switching matrix.

\[ S = -(A_2^T \Gamma_0 + \Gamma_0 A_2 + C^T C) \]

4- Switching rules utilize sub-controllers according to the following definition:

If not=1

RESULTS

Experimental procedures for testing the proposed algorithm is composed of Phillips –Heffron model of linear SMIBH installed on UPFC described by matrices A and B. primary controller and secondary controller are obtained by solving Riccati equation and using R=1. Matrix C is a vector with amounts as 0. The amount of 1 in each direction depends on state variables. It is based on ultra-mutation peak and time setting. Switching provides optimal feedback – S rule- between 2 controller vectors. It is as follows:

\[
A = \begin{bmatrix}
0 & 377 & 0 & 0 \\
-0.07076 & 0 & -0.0214 & 0 \\
-0.00222 & 0 & 0.4973 & 0.192 \\
1513 & 0 & -3516 & -100
\end{bmatrix}
\]

\[
B = \begin{bmatrix}
0 & 0 \\
-0.0474 & -2.33 \\
-0.23053 & 0.0566 \\
4591 & 1096
\end{bmatrix}
\]

\[
K_1 = \begin{bmatrix}
1.166 & 48.519 & 0.668 & 0.976 \\
0 & 0 & 0 & 0
\end{bmatrix}
\]

\[
K_2 = \begin{bmatrix}
2.127 & -14.981 & 3.859 & 0.911 \\
0 & 0 & 0 & 0
\end{bmatrix}
\]

\[
S = \begin{bmatrix}
-0.9747 & 0.9144 & 0.181 & 0.0328 \\
0.9144 & 0.9689 & 7.833 & -0.0017 \\
0.1811 & 7.8339 & 1.188 & 0.1286 \\
0.0328 & -0.0017 & 0.128 & -1.0001
\end{bmatrix}
\]

Dynamic response curve for 4 variables of state environment includes rotor angle , SD Speed , Deviation of the axis component , field voltage deviation . These are drawn in figures 4 to 6 along with and for each of sc damping controller (Optimal Feedback Switching Control). Additionally, stabilization time for COC and figures 6 to 9 are drawn for of sc in order to show efficiency of presented model. According to this table, it is resulted that the proposed optimal feedback switching control provides robust performance in stable duration and also better performance in stabilization time for all 4 variables.
comparing to system reaction in individual inputs controlled better without switching and also the controlled optimal same-coordinate inputs.

Synchronous machine:

\[ H = 4.0, D = 0.0, \]

Excitation System:

\[
\begin{align*}
  k_A &= 100.7, \quad T_A = 0.01 \\
  k_1 &= 0.5661, \quad k_2 = 0.1712, \quad k_3 = 2.4583 \\
  k_A &= 0.4198, \quad k_3 = -0.513, \quad k_6 = 0.3516 \\
  k_{p_e} &= 0.3795, \quad k_{q_e} = 1.1628, \quad k_{v_e} = -0.4591 \\
  k_{p_b} &= 0.1864, \quad k_{q_b} = 0.2855, \quad k_{v_b} = -0.1096 \\
  k_{p_{b_e}} &= 1.1936, \quad k_{q_{b_e}} = -0.0380, \quad k_{v_{b_e}} = -0.0311 \\
  k_{p_{b_b}} &= 0.0529, \quad k_{q_{b_b}} = -0.0423, \quad k_{v_{b_b}} = 0.0189
\end{align*}
\]

Figure 8: UPFC for the deviation component of q-axis

Figure 9: UPFC for field voltage deviation

REFERENCES


