ARTIFICIAL INTELLIGENCE BASED ADAPTIVE POWER OSCILLATION DAMPING CONTROLLER FOR POWER SYSTEM EQUIPPED WITH UPFC

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Abstract
This paper presents an adaptive neural network based power oscillation damping controller for a single machine infinite bus system equipped with Unified Power Flow Controller (UPFC). UPFC is the most widely used FACTS device to control the power flow and to optimize the system stability in the transmission line. The conventional control system has large power swings during the dynamic period. In order to maintain the system stability, it is essential to control the first swing oscillations. This paper proposes a control scheme which utilizes self learning feed forward neural networks to improve the dynamic performance of the system.

Keywords
Unified Power Flow Controller (UPFC), Neural Networks, Transient stability, Power Oscillation Damping

1. Introduction

With the recent growth in the fields of engineering and technology, there is an increasing demand for electric power supply. Most of the power utility faces challenges in meeting this load demands with reliable and secure power transmission. In order to overcome these challenges, it is essential to fully utilize the existing transmission systems. The performance of the power system can be improved by effective control of the power flow through transmission lines without changing the economic dispatch schedule. It is possible by insertion of controllable components in the transmission system.

Flexible AC transmission devices are the attractive alternatives for increasing the transmission capacity at high transmission levels. Due to the rapid growth in power electronics technology number of FACTS devices have been proposed in recent years for better utilization of existing transmission facilities. Unified Power Flow Controller is considered to be the most powerful FACTS device, which has the capability to control all the three parameters that decides the power flow through the transmission line. The UPFC has got the ability to control the power flow, mitigate the system oscillations, voltage regulation and enhance the transient stability.

Systematic approach for mathematical modeling of UPFCs has been developed for determining the steady-state and dynamic behavior. For systems without power system stabilizers, effective damping can be achieved via proper controller design. In the recent years, different control methods have been introduced for UPFC control such as conventional control, robust control, genetic algorithm approach, fuzzy logic and neural network control methods.

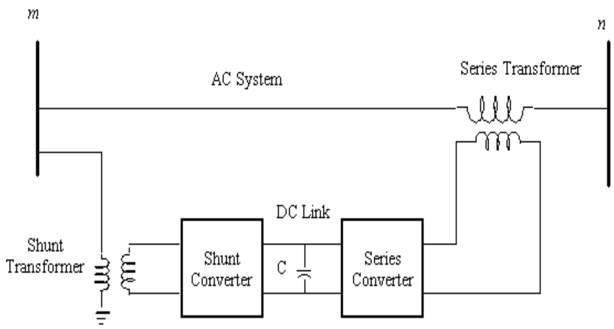
In this study, the performance analysis of UPFC with feed forward neural network is carried out. Neural network based controllers have several advantages such as self learning, fault tolerance capability, high speed processing and ability to implement hardware with VLSI technology. To validate the performance of the proposed neural network controller, a mathematical model developed in [10] is utilized. A comparison of different control methods such as conventional controller, fuzzy logic control and the proposed neural network control has been done.

This paper is organized as follows; model of power system with UPFC under study is presented in section-2. UPFC converter Control mechanisms are presented in Section-3. The simulation results are given in section-4. Finally Conclusions are presented in Section-5.

2. Model of Power System with UPFC

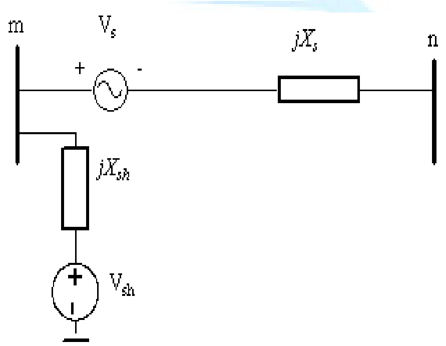
The schematic representation of UPFC is shown in Fig. 1. It consists of two voltage source converters connected back to back with a common DC link. One connected in shunt and the other is connected in series with the transmission line. The series converter does the main functions of UPFC by injecting an AC Voltage with controllable magnitude and phase angle. The exchange of real and reactive power with the AC system is governed by the flow of line current through the series converter. The purpose of the shunt converter is to provide the active power needed by the series converter through the common DC link. Both the converters are capable of controlling the reactive power independent of each other.

Figure 1 : Schematic diagram of UPFC



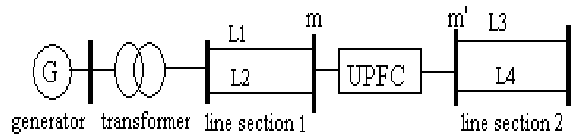
In general, the shunt converter will take care of the voltage control and the series converter will regulate the real and reactive power flows independently. For the purpose of analysis, the converters of UPFC along with its interfacing transformers are considered as simple voltage source in series with its associated reactance. The equivalent circuit of UPFC is shown in Fig -2.

Figure 2 : Equivalent of UPFC



In order to evaluate the performance of UPFC connected to power system, it is required to choose an appropriate model of UPFC to suit the dynamic performance evaluation programme. Many publications have been found in the literature related to the component level as well as mathematical modeling of UPFC. For simplicity of analysis it is considered that the UPFC is connected with a Single Machine Infinite Bus System as shown in fig. 3.

Figure 3 : Single line diagram of SMIB system with UPFC

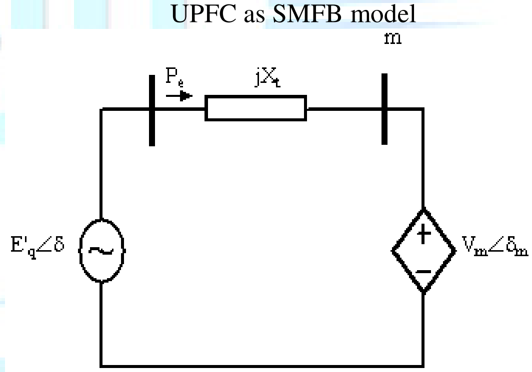


A versatile mathematical model of UPFC proposed in [10] is utilized for evaluating the stability of the system under study. In which the complete SMIB system with UPFC is modeled as single machine finite bus as shown in Fig. 4. (SMFB), so that the complexity involved in incorporating the model with stability studies is simplified. The SMFB model of UPFC is give by eqn (1) & (2)

$$V_m = \frac{X_2 E_q^{'} \cos(\delta - \delta_m) + X_1 V_b \cos\delta + X_1 X_2 I_q}{X_1 + X_2 - X_1 \cos\gamma} \quad -(1)$$

$$\delta_m = \tan^{-1}\left[\frac{E_q^{'} X_2 \sin\delta + X_1 V_b \sin\gamma}{X_2 E_q^{'} \cos\delta - X_1 V_b r \cos\gamma + X_1 V_b}\right] \quad -(2)$$

Figure 4 : Representation of SMIB system with UPFC as SMFB model



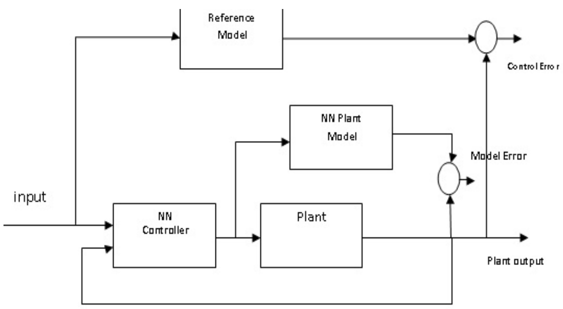
3. UPFC Neural Network Controller

Neural network based control systems have been suggested for many control applications using either feed-forward or recurrent neural networks. Most of them are built around a feed-forward neural network included inside a traditional control system. The ANN is usually made up of sigmoidal activation function neurons and back propagation is normally used to train the network either on-line or off-line. Some applications use neurons with radial base activation function.

In this paper a model reference control network as shown in fig.6 is used for the generation of control signals. It consists of two neural networks, one identified as plant network and the other as controller network. The two networks are trained such that the plant network is identified first and then the controller network is trained in a way that the plant output follows the reference model output.

The dynamic behaviour of the system is dependent on the electric power (Pe) which is a function of the complex injected voltage (Vm). The complex voltage (Vm) can be controlled by controlling the parameters of UPFC.

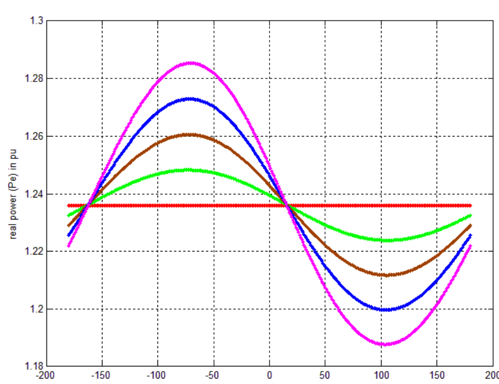
Figure 6: Model reference control network



3.1 Control Mechanism of Series Converter.

The main function of the UPFC carried out through the series converter. The real and reactive power flow through the transmission line is determined by the magnitude and the phase angle of the series injected complex voltage. The real and reactive power exchange between the converter and the AC system depends on the line current flow through the series converter.

Figure 5 : Variation of Pe with r and γ



The stability and damping functions of SMFB model of the system is dependent on the electrical power (Pe). By improving the electrical power to meet the mechanical input power (Pm), stability of the system can also be improved. The electrical output power is dependent on the speed deviation, however the value of Pe is mainly controlled by the series injected voltage of the UPFC. Thus the output power of generation is a function of the variables r, δ, γ, Iq and is given by eqn-(3).

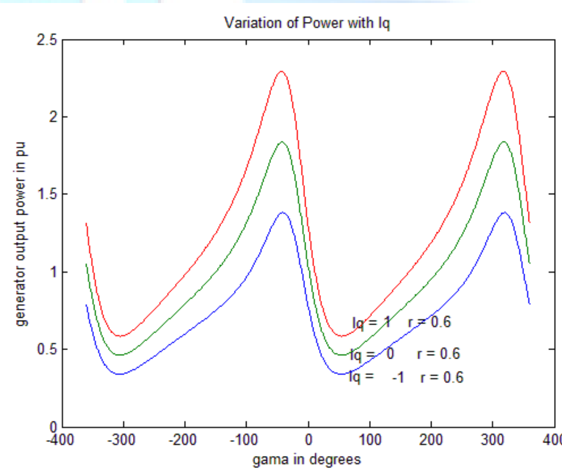
$$P_e = f(\delta, r, \gamma, I_q) \qquad -(3)$$

3.2 Control Mechanism of shunt converter.

The shunt converter draws a controlled current from the transmission line to compensate for the active power requirement of series converter. In addition to this it functions just like a STATCOM. Thus the control strategy of shunt converter current is taken as similar to that of the STATECOM.

$$I_q = K_{sh}\Delta\omega + K_V\Delta V_m \qquad -(4)$$

Figure 6 : Variation of Pe with Iq



4. Simulation Result

The SMFB model of UPFC is used to study the dynamic behaviour of the system of Fig. 3. The data of the system is given in the Appendix. The UPFC is placed at the middle of the transmission line and its ability to control the power swing is tested. It is considered that a three phase symmetrical short circuit fault appears in the line section 2 of the transmission system near to the infinite bus at 1.0 sec and it is cleared at 1.1 sec.

In order to test the dynamic behavior of the system with the above considerations a software programme has been written using MATLAB. The transient stability algorithm has been implemented with R-K4 method as described in [2]. Application of fuzzy logic control for damping the first swing oscillation is discussed in [17]. MATLAB fuzzy logic and neural network toolbox have been utilized for the implementation of fuzzy logic and neural network controllers respectively. Fig. 7 & Fig. 8 show the power angle curve and the speed deviation of the generator in the system with various control strategies. Table 2 summarize the maximum variations in power angle and speed deviations along with the critical clearing time and critical clearing angles for various control methods.

Figure 7 : Power angle curve for the system

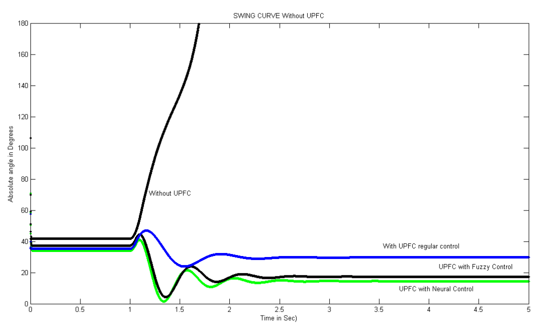


Figure 8 : Speed deviation with respect to time

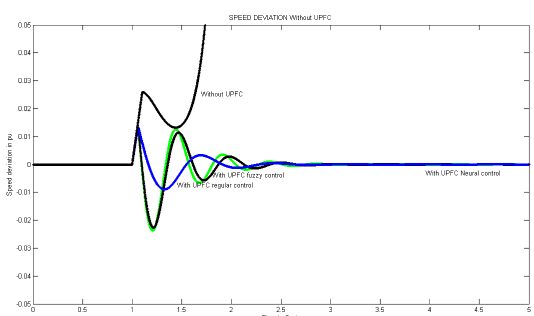


Table 2 : Summary of results obtained

	Maximum power angle (δ) in degrees	Maximum speed deviation in pu	Critical clearing angle in degrees	Critical clearing time in sec
Without UPFC	119.5	0.022	52.04	1.085
UPFC with regular PI control	125.9	0.038	66.03	1.148
UPFC with Fuzzy control	137.44	0.0374	108.48	1.282
UPFC with Neural Network control	139.25	0.0386	110.86	1.296

5. Conclusion

A simple model reference neural network controller for unified power flow controller (UPFC) in a single machine infinite bus (SMIB) system has been implemented. The UPFC and the infinite bus of the system is replaced with a dependent voltage source whose magnitude and angle of the voltage source depend on the UPFC control parameters. The SMIB is represented as a single machine finite bus (SMFB) system. In SMFB the generator output is directly expressed in terms of UPFC control parameters. The dynamic behaviour of the original SMIB system with UPFC devices is determined through the proposed model of the system. Three different control schemes namely regular PI control, Fuzzy Logic Control and Model Reference Neural Network control have been compared. Simulation results indicated that a UPFC with Model Reference Neural Network control is very effective in improving both first swing stability and damping of the system.

Appendix

Data of the single machine infinite-bus system of Fig. 3

Generator Inertia constant H=6.5 s

Direct axis transient reactance X'_d =0.3 pu

Prefault electrical output power Pe=1.0 pu

Prefault internal voltage E'_q =1.22 pu

Prefault operating angle δ=55°

Reactance of line section 1 X_{L1}=0.25 pu

Reactance of line section 2 X_{L2}=0.30 pu

Reactance of Transformer X_t=0.10 pu

Reactance of series transformer X_s=0.05 pu

Reactance of shunt transformer X_{sh}=0.05 pu

Voltage of infinite bus $V_b=1.0\angle 0^o$ pu

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