International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol.2, Issue.4, July-Aug 2012 pp-2574-2577 ISSN: 2249-6645

Modelling and Controlling Of Unified Power Flow Controller (Upfc)

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Abstract: Unified Power Flow Controller (UPFC) has its unique capability to control simultaneously real and reactive power flows on a transmission line as well as to regulate voltage at the bus where it is connected, this device creates a tremendous quality impact on power system stability. These features become even more significant knowing that the UPFC can allow loading of the transmission lines close to their thermal limits, forcing the power to flow through the desired paths. This will give the power system operators much needed flexibility in order to satisfy the demands that the deregulated power system will impose. The controller used in the control mechanism has an important effect on the performance of UPFC and it operates in several modes of operations using different control mechanisms based on Proportional-Integral controller has been studied. In this paper a proposed control method, ANFIS based controller has been developed by using ANFIS EDITOR of MATLAB using Takagi-Sugeno Inference system and this will applied to STATCOM part of the detailed model of UPFC. The MATLAB simulation results shows that ANFIS controller has an effective power flow control, less settling time and less overshoot when compared to PI controller in different operating modes.

Key words*:* ANFIS, FACTS, Power System, UPFC.

I. Introduction

The static series synchronous compensator (SSSC) can control active and reactive in a transmission line in a small range via storied energy in capacitor DC-link where static synchronous compensator (STATCOM) with injecting reactive power can regulate the bus voltage in a transmission line. Unified Power Flow Controller (UPFC) is the most versatile and complex Flexible AC Transmission Systems (FACTS) equipment that has emerged for the control and optimization of power flow in power transmission systems [1-3]. It has the combining features of both series converter and shunt converter based FACTS devices, and is capable of realizing voltage regulation, series compensation, and phase angle regulation at the same time. Therefore, the UPFC is capable of independently controlling the active power and reactive power on the compensated transmission line [4, 5].

The electric utilities are continuously looking for new devices that will enable interconnected systems to have increased power transfer abilities with transmission lines. UPFC and IPFC are FACTS devices that can control the power flow in transmission line by injecting active and reactive voltage component in form series to the transmission line. The UPFC is a flitting multi-purpose FACTS device that extends their capability to inject shunt current or series voltage that involve real power flow as well With UPFC, the real and reactive power can be controlled independently. The unified power flow controller is capable of controlling all the power system parameters such as voltage magnitudes, phase angles, and effective line impedance simultaneously consists of two voltage source Converters (VSCs) that are connected to a common DC-link. One of the VSCs is connected in series with a transmission line while the other one is connected in shunt with the same transmission line. The DC bus of both VSCs are supplied through a common DC capacitor, hence UPFC combines the functions of a STATCOM and a SSSC. STATCOM maintains constant the bus voltage and provide energy for DC link of SSSC and it can regulates capacitor's voltage of DC link, SSSC with injection controllable voltage controls the active and reactive power flow control in the transmission line.

It can simultaneously perform the function of transmission line real/reactive power flow control in addition to UPFC bus voltage/shunt reactive power control. The control mechanism and the controller have important effect on the performance of UPFC. In literature, several control mechanisms are used in the UPFC model. A novel fuzzy inference system is proposed and used to improve the dynamic control of real and reactive power .control scheme is used in the control mechanism of UPFC. In the simulation results, there is a high Overshoot values occurred both real power and bus voltage during the three phase faults applied. However, the real power value is increased but there is no value changed in the reactive power. In the simulation results, the variation of the real power direction can be observed easily. According to results; the values of real and reactive power are changed in large values with UPFC because of the low values of bus voltage. This paper presents the performance evaluation of UPFC in different modes by using different control mechanisms based on PI and ANFIS based controllers. “Takagi-Sugeno Inference System” is used in the decision making of fuzzy model.

II. Unified Power Flow Controller

Unified power flow controller (UPFC) is a combination of static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) which are coupled via a common dc link, to allow bi-directional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source. The UPFC, by means of angularly unconstrained series voltage injection, is able to control, concurrently or selectively, the transmission line voltage, impedance and angle or alternatively, the real and reactive power flow in the line. The UPFC may also provide independently controllable shunt reactive compensation. Viewing the operation of the UPFC from the standpoint of conventional power transmission based on reactive shunt compensation, series compensation and phase shifting, the UPFC can fulfil all these functions and thereby meet multiple control objectives by adding the injected voltage Vinj with appropriate amplitude and phase angle.

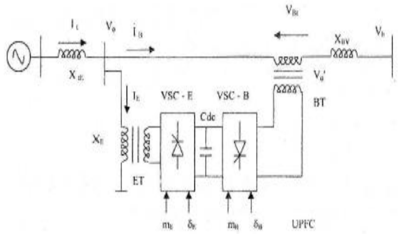

Fig 1. UPFC Installed in SMIB System

A combination of SHUNT controller and SERIES controller action is works as a unified power flow controller (UPFC) is used to control the power flow in a 500 kV transmission system. The SSSC and STATCOM located at the left end of the 75-km line L2, between the 500 kV buses B1 and B2, is used to control the active and reactive powers flowing through bus B2 while controlling voltage at bus B1. It consists of two 100-MVA, three-level, 48-pulse GTO-based converters, one connected in shunt at bus B1 and one connected in series between buses B1 and B2. The shunt and series converters can exchange power through a DC bus. The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87 kV) in series with line L2. This pair of converters can be operated in three modes: Unified Power Flow Controller (UPFC) mode, when the shunt and series converters are interconnected through the DC bus. When the disconnect switches between the DC buses of the shunt and series converter are opened, two additional modes are available: Shunt converter operating as a Static Synchronous Compensator (STATCOM) controlling voltage at bus B1 Series converter operating as a Static Synchronous Series Capacitor (SSSC) controlling injected voltage, while keeping injected voltage in quadrature with current.

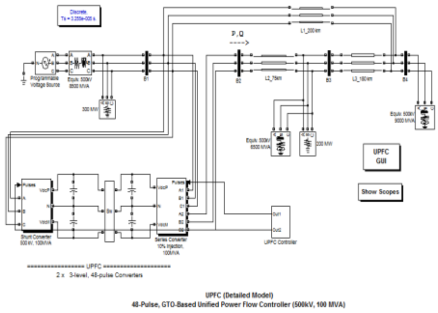

Fig 2. UPFC Simulink Model

III. Power control in UPFC mode:

Open the UPFC GUI block menu. The GUI allows you to choose the operation mode (UPFC, STATCOM or SSSC) as well as the Pref/Qref reference powers and/or Vref reference voltage settings .Also, in order to observe the dynamic response of the control system, the GUI allows you to specify a step change of any reference value at a specific time. Make sure that the operation mode is set to “UPFC (Power Flow Control)”. The reference active and reactive powers are specified in the last two lines of the GUI menu. Initially, Pref= +8.7 pu/100MVA (+870 MW) and Qref=-0.6 pu/100MVA (-60 Mvar). At t=0.25 sec Pref is changed to +10 pu (+1000MW). Then, at t=0.5 sec, Qref is changed to +0.7 pu (+70 Mvar). The reference voltage of the shunt converter will be kept constant at Vref=1 pu during the whole simulation 0.8 sec. When the UPFC is in power control mode, the changes in STATCOM reference reactive power and in SSSC injected voltage as are not used. Run the simulation for 0.8 sec. Open the “Show Scopes” subsystem. Observe on traces 1 and 2 of the UPFC scope the variations of P and Q. After a transient period lasting approximately 0.15 sec, the steady state is reached (P=+8.7 pu; Q=-0.6 pu). Then P and Q are ramped to the new settings (P=+10 pu Q=+0.7 pu). Observe on traces 3 and 4 the resulting changes in P Q on the three transmission lines. The performance of the shunt and series converters can be observed respectively on the STATCOM and SSSC scopes. If you zoom on the first trace of the STATCOM scope, you can observe the 48-step voltage waveform Vs generated on the secondary side of the shunt converter transformer superimposed with the primary voltage Vp and the primary current Ip. The dc bus voltage varies in the 19kV-21kV range. If you zoom on the first trace of the SSSC scope, you can observe the injected voltage waveforms Vinj measured between buses B1 and B2.

IV. VAR control in STATCOM mode:

In the GUI block menu, change the operation mode to “STATCOM (VAR Control)”. Make sure that the STATCOM references values (1st line of parameters, [T1 T2 Q1 Q2]) are set to [0.3 0.5 +0.8 -0.8]. In this mode, the STATCOM is operated as a variable source of reactive power. Initially, Q is set to zero, then at T1=0.3 sec Q is increased to +0.8 pu (STATCOM absorbing reactive power) and at T2=0.5 sec, Q is reversed to -0.8 pu (STATCOM generating reactive power). Run the simulation and observe on the STATCOM scope the dynamic response of the STATCOM. Zoom on the first trace around t=0.5 sec when Q is changed from +0.8 pu to -0.8 pu. When Q=+0.8 pu, the current flowing into the STATCOM is lagging voltage, indicating that STATCOM is absorbing reactive power. When Qref is changed from +0.8 to -0.8, the current phase shift with respect to voltage changes from 90 degrees lagging to 90 degrees leading within one cycle. This control of reactive power is obtained by varying the magnitude of the secondary voltage Vs generated by the shunt converter while keeping it in phase with the bus B1 voltage Vp. This change of Vs magnitude is performed by controlling the dc bus voltage. When Q is changing from +0.8 pu to -0.8 pu, Vdc (trace 3) increases from 17.5 kV to 21 kV.

V. Series voltage injection in SSSC mode:

In the GUI block menu change the operation mode to “SSSC (Voltage injection)”. Make sure that the SSSC references values (3rd line of parameters) [Vinj_Initial Vinj_Final StepTime] are set to [0.0 0.08 0.3]. The initial voltage is set to 0 pu, then at t=0.3 sec it will be ramped to 0.8 pu. Run the simulation and observe on the SSSC scope the impact of injected voltage on P and Q flowing in the 3 transmission lines. Contrary to the UPFC mode, in SSCC mode the series inverter operates with a constant conduction angle (Sigma= 172.5 degrees). The magnitude of the injected voltage is controlled by varying the dc voltage which is proportional to Vinj (3rd trace). Also, observe the waveforms of injected voltages (1st trace) and currents flowing through the SSSC (2nd trace). Voltages and currents stay in quadrature so that the SSSC operates as a variable inductance or capacitance.

VI. Anfis Controller

The ANFIS is the abbreviated of *adaptive neuro-fuzzy inference system[13]*. The performance of this method is like both ANN and FL. In both ANN and FL case, the input pass through the input layer (by input membership function) and the output could be seen in output layer (by output membership functions). Using a given input/output data set, the toolbox function ANFIS construct a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted).This adjustment allows your fuzzy systems to learn from the data they are modeling. Rule structure is essentially predetermined by the users' interpretation of the characteristic of the variables in the model. ANFIS applies FIS technique to data modeling [14]. We can choose membership function parameters automatically using ANFIS tool in MATLAB. Using ANFIS we can apply fuzzy inference to a system for which we already have a collection of input/ output data sets of parameters .Gradient vector reduce some error measures. This error measures is usually defined by the sum of the squared difference between the actual and desired outputs. ANFIS uses either back propagation or a combination of least squares estimation. Collect input/output data in a form that will be usable by ANFIS for training. You can create, train and test Sugeno type fuzzy systems using the ANFIS editor GUI. GUI includes four distinct areas to support a typical work flow (1)Loading ,plotting and clearing data (2)Generating or loading the initial FIS structure (3) training the FIS.(4)Validating the trained FIS. To get the FIS (Fuzzy inference system) from ANFIS tool, Training data is required for this, simulations were carried out on the original model with different values of voltage amplitude the data is shown in table below

Table I: Testing Data

Sr.No	input data	Output data
1	.9707	.9703
2	.9776	.7763
3	.9795	.6468
4	.9812	.5821
5	.983	.5174
6	.9847	.4527
7	1.004	-.2595
8	1.006	-.3242
9	1.007	-.3889
10	1.009	-.4536
11	1.011	-.5184
12	1.013	-.5831

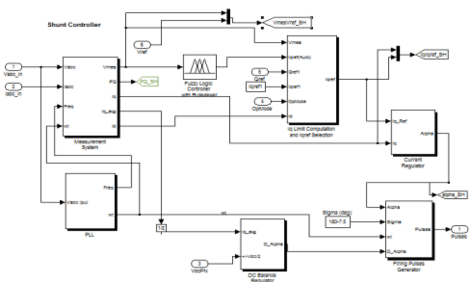

Fig 3.UPFC with ANFIS based Fuzzy controller

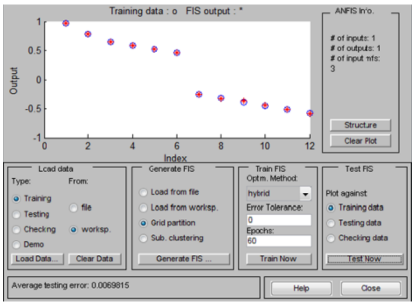

Fig 4. Errors in checking the testing and training data

VII. RESULTS and DISCUSSION

(i) Dynamic response of the system when it is used in UPFC mode With PI Controller.

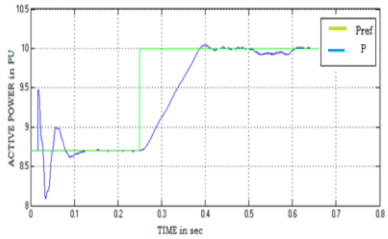

Fig 5. Active Power control with PI controller

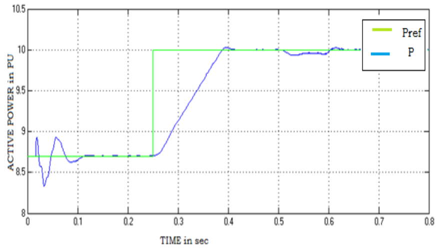

Fig 6. Active Power Control with ANFIS based controller

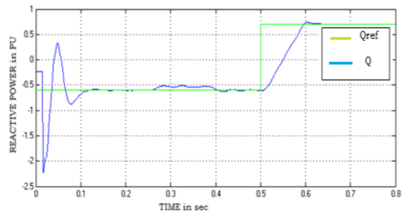

Fig 7. Reactive Power control with PI controller

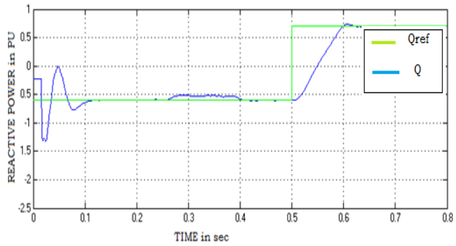

Fig 8.Reactive Power control with ANFIS based controller

(ii) Reactive Power Control in STATCOM mode with PI Controller

STATCOM operates as variable source of reactive power.Current lagging voltage during absorbing of reactive power and it is leading when reactive power is generated and it is controlled by DC Voltage

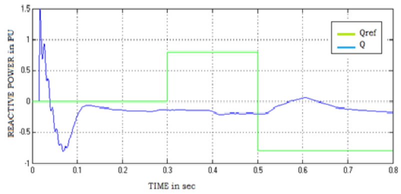

Fig 9. Reactive Power control during STATCOM mode with PI Controller

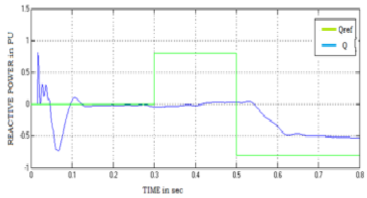

Fig 10. Reactive Power control during STATCOM mode with ANFIS based controller

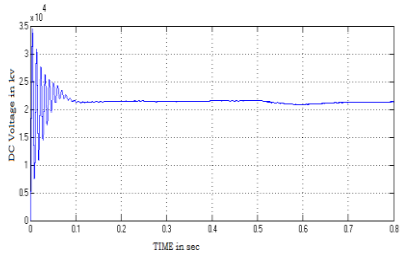

Fig 11. Variation of DC Voltage as per change in Vinj with PI Controller

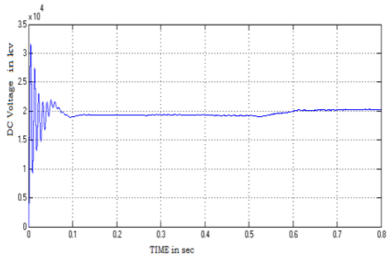

Fig 12. Variation of DC Voltage as per change in Vinj with ANFIS based Controller

VIII. Conclusion

Simulation results show that ANFIS based controlled slightly increases the power flow control by increasing the damping rate and decreases the amplitude of low frequency oscillations. Results comparison between conventional PI controller and the proposed ANFIS based controller for UPFC indicates that the proposed ANFIS based controller has less settling time and less overshoot when compared with the conventional PI controller.

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