Transient Stability Improvement in Power System Using Unified Power Flow Controller (UPFC)

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Abstract

Flexible AC Transmission Systems (FACTS) technology is the most advanced tool for power flow control in electric network. Unified Power Flow Controller (UPFC) is the most versatile FACTS device for optimization and control of power flow in transmission system. It is a voltage source converter based FACTS controller for series and shunt compensation of the line which controls the real and reactive power independently. This paper deals with Adaptive Neuro Fuzzy Inference System (ANFIS) is used as the controlling technique for UPFC. The controller have been designed and tested for controlling the real and reactive power flow of UPFC. Computer simulation by MATLAB/SIMULINK has been used to verify proposed control strategies.

***Keywords*- Flexible Ac Transmission System, Unified Power Flow Controller, ANFIC controller, Voltage Source Converter, PI Controller.**

I. INTRODUCTION

With increased power transfer, transient and dynamic stability is of increasing importance for secure operation of power systems. FACTS devices with a suitable control strategy have the potential to significantly improve the transient stability margin. FACTS devices are increasingly used as cost effective measures to improve transmission capacity, oscillation damping and stability improvement. This allows increased utilization of existing network closer to its thermal loading capacity, and thus avoiding the need to construct new transmission lines.

Amongst the available FACTS devices, the Unified Power Flow Controller (UPFC) is the most versatile one can be used to enhance system stability [1]. The UPFC is capable of both supplying and absorbing real and reactive power and consists of two ac/dc converters. The model of UPFC implemented in a transmission line is shown in Figure 1.One of the two converters is connected in series with the transmission line through a series transformer and the other in parallel with the line through a shunt transformer [2]. The dc side of the two converters is connected through a common capacitor, which provides dc voltage for the converter operation. The power balance between the series and shunt converters is a prerequisite to maintain a constant voltage across the dc capacitor. As the series branch of the UPFC injects a voltage of variable magnitude and phase angle it can exchange real power with the transmission line and thus improve the power flow capability of the line as well as its transient stability limit.

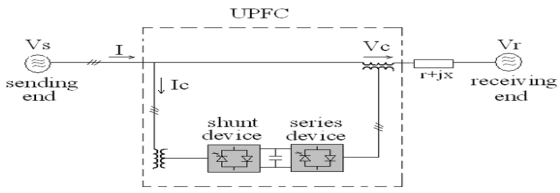


Figure1. Implementation of UPFC

The shunt converter exchanges a current of controllable magnitude and power factor angle with the power system[3]. It is normally controlled to balance the real power absorbed from or injected to the power system by the series converter plus the losses by regulating the dc bus voltage at a desired value. Various control strategies to control

the series voltage magnitude, angle and the shunt current magnitude have been presented. The series converter voltage phasor can be decomposed into in-phase and quadrature components with respect to the transmission line current. The in-phase and the quadrature-voltage components are more readily related to the reactive and real power flows in the transmission system [4]-[5]. During short-circuit and transient conditions, the decrease in real power can be arrested by controlling the quadrature component of the series converter voltage and hence the improvement in transient stability. The vector diagram series and shunt inverters of UPFC is represented in Figure 2.

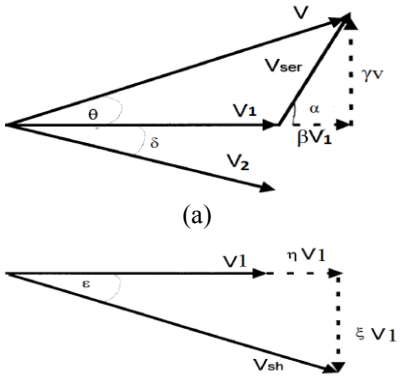


Figure.2:UPFC vector diagram. (a) . series inverter (b). shunt inverter

II. CONTROLLING TECHNIQUES FOR UPFC

Different advanced control techniques are used and simulated to control the UPFC [6]. The Proportional and Integral (PI) regulators used for the purpose of providing robust control and transient stability over a wide range of power system operating conditions. Further, it has been proved that it is a variable gain PI controller whose gain varies according to the operating condition.

The Mamdani type fuzzy controller used for the purpose provides a constant center value in any class for its consequent decision [7]-[9]. But, as the complexity of the control system increases it requires the variation in its center value. On the other hand the neural network has the capability of pattern recognition and nonlinear mapping of input and output. In this paper combination of fuzzy and neural network is attempted to make a variable center Mamdani type fuzzy controller. The optimal value of centers for the output classes of the fuzzy controller at different operating conditions is obtained through Integral Absolute Error Criteria (ITAE) with rotor angle deviation as error. With these centers as output and the pre-disturbance conditions as input a neural network can be trained, which will specify the proper centers for the fuzzy controller at any condition after completion of proper training. Therefore, combining both the fuzzy and neural network will result in an intelligent optimal Mamdani type fuzzy controller.

The Mamdani type fuzzy controller presented in this project uses error (*er*) and integral of error ($\sum er$) as inputs and quadrature component of series injected voltage to the line current as output [10]-[12]. The choice of quadrature component generation from real error is based upon the fact that when the series injected voltage by UPFC is at right angle to line current it directly affects the reactance of the line hence regulates the real power flow. Further, the integral of error being an input to the controller helps to design the rule base more effectively from the physical behavior of the power system following a transient disturbance such as fault.

Radial Basis Function Neural Network (RBFNN) which can approximate nonlinear function to any extent is utilized for the functional approximation [13]-[14]. The neural network is trained with output as the optimal center of the fuzzy controller and real and reactive power at any operating condition as inputs. The fuzzy controller uses the optimal center generated from the RBFNN at any given condition to produce a neuro-fuzzy controller. This neuro-fuzzy UPFC provide excellent damping and dynamic performance improvement in case of power systems subjected to a variety of transient disturbances.

A.Neural Network

ANN and their learning capabilities are examined for many decades. Neural Network has formed a large active area and has been used in many applications [15]. Most prominent feature of neural network is their ability to learn from examples using so called learning algorithm they solve problems by processing a set of training data. The use of ANN in controlling operation of FACTS devices is in its early stage.FLC theory is used to build a control expert system whose rules are deduced from the relationship between UPFC control variable and ac system parameters.

B.Fuzzy Controller

Fuzzy Logic Control (FLC) has proven effective for complex, non-linear and imprecisely defined processes for which standard model based control techniques are impractical or impossible. Fuzzy Logic, unlike Boolean or crisp logic, deals with problems that have vagueness, uncertainty and use membership functions with values varying between 0 and 1. Fuzzy Logic tends to mimic human thinking that is often fuzzy in nature. Basic configuration of fuzzy controller is given in Figure 3.

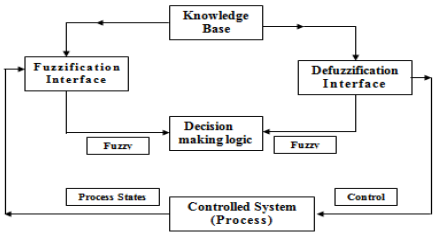


Figure 3. Basic configuration of Fuzzy controller

C. Neuro-Fuzzy Controllers

The fusion of ideas from fuzzy control and neural networks had acknowledged a significant role in improving controller performances. Fuzzy logic has proven effective for complex, non-linear and imprecisely defined systems. The common bottleneck in fuzzy logic is the derivation of fuzzy rules and the parameter tuning for the controller. The neural networks have powerful learning abilities, optimization abilities and adaptation. The fuzzy logic and neural networks can be integrated to form a connectionist Adaptive network based Fuzzy logic controller. This integrated adaptive system modifies the characteristics of the rules, topology of fuzzy sets and/or the structure of control system.

D. Adaptive Neuro-Fuzzy Inference System (ANFIS) Architecture

The architecture of the Adaptive Neuro-fuzzy Inference System (ANFIS) is shown in Figure 4. Consider a first-order sugeno fuzzy model with two input x and y and one output with fuzzy IF-THEN rules. The system has a total of five layers:

Layer 1: Every node I in this layer is an adaptive node performing membership function.

$O_{1,i} = \mu_{Ai}(x_i)$

$i=1,\ldots n.$ …… (1)

Where x_i is the input to node i. The membership function can be any appropriate parameterized membership function. Parameters in this layer are referred to as premise parameters.

Layer2: Every node in this layer is a fixed node whose output is the product of all the incoming signals. (i.e.) these nodes perform the fuzzy AND operation.

$O_{2,i} = w_i = \mu_{Ai}(x_i).\mu_{Bi}(y),$

$i=1,\ldots n.$ .....(2)

Each node output represents the firing strength of a rule.

Layers 3: The nodes of this layer calculate the normalized firing strength of each rule.

$O_{3,i} = w_i = w_i / \sum_i \overline{w_i}$,

$i=1,\ldots n.$ .....(3)

w_i –firing strength of a rule.

Layer 4: Every node i in this layer is an adaptive node with a node function.

$O_{4,i} = \overline{w_i}\, f_i = \overline{w_i}(p_i x + q_i y + r_i)$

$i=1,\ldots n.$ .....(4)

where w_i a normalized firing strength from layer 3 and $\{p_i, q_i, r_i\}$ the parameter set. Parameters in this layer are referred to as consequent parameters.

Layer5: The single node in this layer computes the overall output as the summation of all incoming signals.

$O_{5,1} = \sum w_i f_i = \sum_I w_i f_i / \sum_I \overline{w_i}$

$i=1,\ldots n.$ .....(5)

where $O_{l,i}$ denote the output of the 'i'th node in layer l. This structure can update membership functions and rule base parameters accordingly to the gradient descent update procedure.

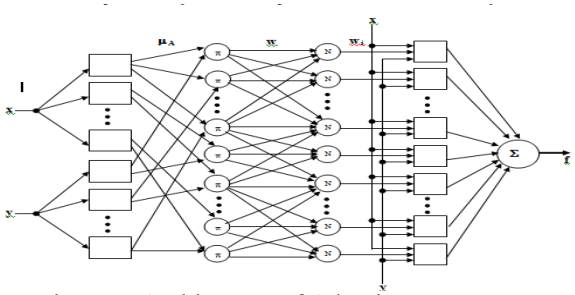


Figure 5. Architecture of Adaptive Neuro-Fuzzy Inference System (ANFIS)

III. MATLAB SIMULATION

The MATLAB / SIMULINK environment is used and the results are presented for the digital simulation of UPFC [16]. The model of power system with UPFC is given in Figure 6.

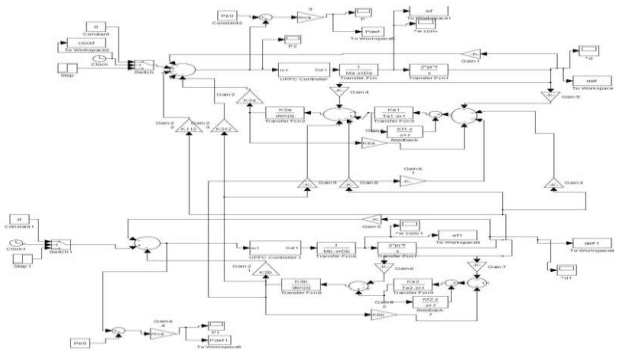


Figure 6. MATLAB model of UPFC

For simulation the proposed method Fuzzy Logic Toolbox in the MATLAB is used. The test system consists of two fully symmetrical areas linked together by two 230 kV lines of 220 km length. Each area is equipped with two identical round rotor generators rated 20kV/100 MVA.

The results are obtained for two control areas. Figure 7.a to Figure 7.c show the transient response of the system with conventional PI, constant center

Mamdani type fuzzy and neuro-fuzzy UPFC of area 1. From the results it can be seen in comparison to both conventional PI and constant center Mamdani type fuzzy controller the significant damping is achieved by using the new neuro-fuzzy controller.

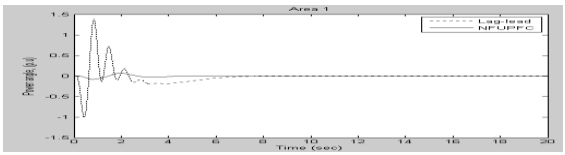


Figure7. a Speed deviations Vs Time

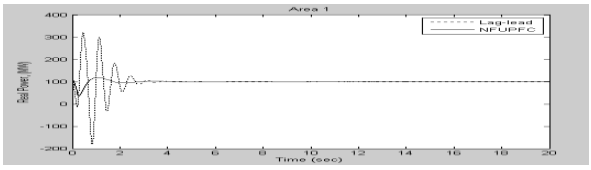


Figure 7.b Power angle Vs Time

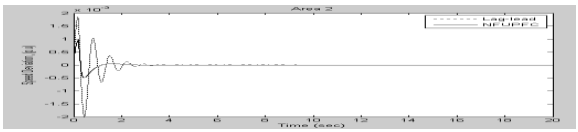


Figure 7.c Real power Vs Time

Speed deviation, Power angle and Real power control with respect to time is given in Figure 8.a-8.b of area 2.

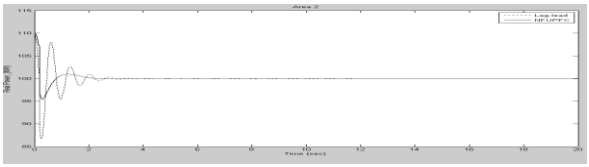


Figure 8.a Speed Deviation Vs Time

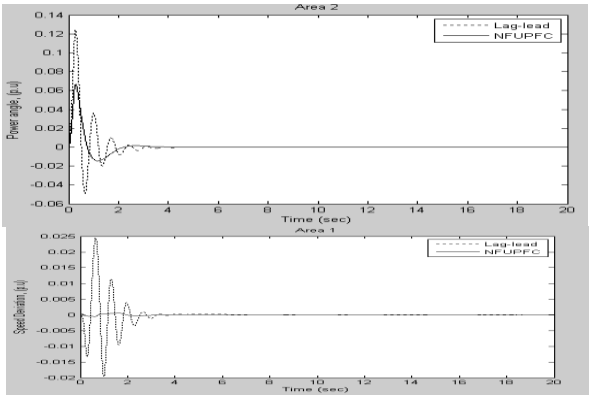


Figure 8.b Power Angle and Real power Vs Time

MATLAB model of UPFC implemented in a 5- bus system controlled by ANFIS controller is represented in Figure 9.

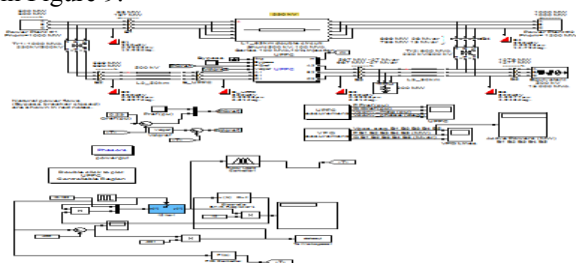


Figure 9. MATLAB circuit model of UPFC

The power system model is tested under two different stability conditions of high short circuit level and low short circuit level. Figure 10.a represents the real power flow with respect to time which compares the performance of ANFIS and PI controller.

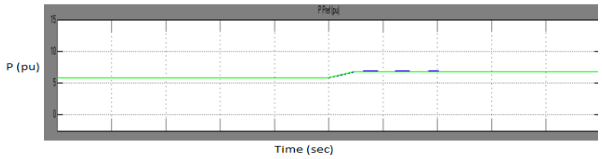


Figure 10.a Real Power Vs Time at HSCL

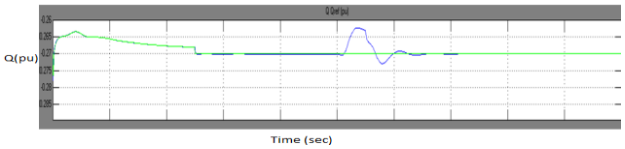


Figure 10.b Reactive Power Vs Time at HSCL

The reactive power flow control and stability analysis in 5-bus system with respect to time is analyzed for HSCL in Figure 10.b.

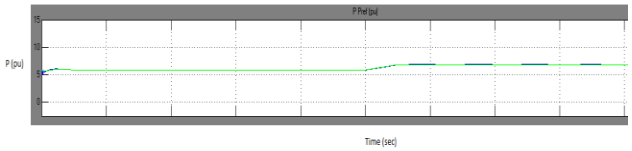


Figure 10.c Real Power Vs Time at LSCL

At LSCL real and reactive power flow is obtained and is given in Figure 10.c and Figure 10.d. The oscillations are damped using ANFIS controller and it provide better performance when compared to with PI controller.

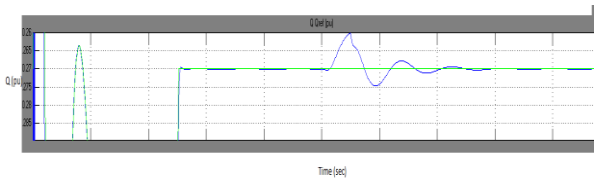


Figure 10.d Reactive Power Vs Time at LSCL

4. Conclusion

This paper presents the modeling of UPFC for power quality improvement. Control and performance of UPFC is analyzed. Simulation results show the effectiveness of UPFC to control the real and reactive powers. It is found that there is an improvement in the real and reactive powers, through the transmission line when UPFC are introduced. Performance of UPFC with advanced controlling methods is also analyzed. By using effective controllers real and reactive powers are more effectively controlled.

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