UPFC Based on Adaptive Neuro-Fuzzy for Power Flow Control of Multimachine Power Systems

by Ramadoni Syahputra

UPFC Based on Adaptive Neuro-Fuzzy for Power Flow Control of Multimachine Power Systems

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ABSTRACT: *The Optimization of electric power transmission system capacity requires a reliable power flow controller. The power flow controllers must be able to control the level of electrical voltage and active and reactive power flow without reducing the level of stability and security of the transmission system. Latest technology in the control of power flow is a Unified Power Flow Controller (UPFC). The entire transmission line parameters are impedance, voltage, and phase angle can be controlled simultaneously by the UPFC. The method used in the conventional algorithms based UPFC is still firmly with logic. These algorithms have difficulties to electric power transmission systems multimachine very dynamic, i.e. systems that are experiencing rapid changes in the electrical load from time to time. Therefore, in this study was developed based on neuro-fuzzy method is applied to the adaptive UPFC for adaptively controlling the power flow in electric power transmission systems multimachine very dynamic. Three phase fault is applied to the multimachine system. The results are taken to be consideration of neuro-fuzzy controller. The neuro-fuzzy controller show a low overshoot occurred during the fault in results. According to results that UPFC improves the system performance under the transient and the normal conditions. However, it can control the power flow in the transmission line, effectively.*

KEYWORDS: *Power flow, UPFC, fuzzy logic controller, neural networks, adaptive controller.*

I. INTRODUCTION

Modern electrical power systems are characterized by extensive system interconnections and increasing dependence on control for optimum utilization of existing resources. The supply of reliable and economic electric energy is a major determinant of industrial progress and consequent rise in the standard of living [1]. The growth of the power systems in the future will rely on increasing the capability of existing power transmission systems rather then building the new transmission lines and the power stations for an economical and an environmental reasons. The requirement of the new power flow controllers, which is capable of increasing the transmission reliability and controlling the power flow through the predefined corridors, will certainly increase due to the deregulation of the electricity markets. Additionally, these new controllers must be regulate the voltage levels and the flow of the real and reactive power in the transmission line to use full capability of the system in some cases with no reduction in the system stability and security margins [2]. Flexible Alternating Current Transmission Systems (FACTS) is an evolving technology based solution to help electric utilities fully utilize their transmission assets. The technology was presented in the late of 1980s [3]. FACTS devices enhance the stability of the power system with its fast control characteristics and continuous compensating capability. The two main objectives of FACTS technology arethe controlling of the power flow and increasing the transmission capacity of the existing transmission lines [4].

The utilization of the existing electrical power system comes into optimal condition and the controllability of the power system is increased with these objectives. Unified Power Flow Controller (UPFC) is the member of FACTS device that has emerged for the controlling and the optimization of power flow in the electrical power transmission systems [5]. This device formed of the combination of two other FACTS devices namely as Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC). These are connected to each other by a common DC link, which is a typical storage capacitor. The all parameters of the power transmission line (impedance, voltage and phase angle) can be control simultaneously by UPFC. In addition, it can perform the control function of the transmission line real/reactive power flow, UPFC bus voltage and the shunt-reactive-power flow control [6].

The control mechanism and the controller have an important effect on the performance of UPFC. In the literature, several control mechanisms are used in UPFC models. A fuzzy inference system described in matrix form is proposed and used to improve the dynamic control of real and reactive power [7]. Two fuzzy logic controllers based on Mamdani type fuzzy logic are used. One of the controllers is proportional fuzzy logic controller (PF-UPFC) and the other is Hybrid fuzzy logic UPFC (HF-UPFC). The selection of suitable location

for UPFC is studied and composite-criteriabased fuzzy logic is used to evaluate the network contingency ranking. The power-feedback control scheme is used in the control mechanism of UPFC [8]. The power fluctuation is damped readily and the value of reactive power is minimized as possible by using several time constants. However there is no value changed in the real power. The control method of variable interval-fuzzy-mutual is used in the control mechanism of UPFC [9]. 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. The performance of UPFC is observed by using three different controllers [10]. In the simulation results, the variation of the real power direction can be observed easily. However, the value of reactive power is kept at zero because of there is no reactive power flow in the system.

In this paper, the capability of UPFC on controlling of the power flow and the effectiveness of controllers on performance of UPFC in the power transmission line are examined by using different control mechanisms based on PI and neuro-fuzzy controllers. In the modeling of fuzzy controller, Takagi-Sugeno Inference System is used in the decision making process and "Weighted Average" method which is the special case of "Mamdani" model is used in the defuzzification process. The Matlab-Simulink software is used to create UPFC model and to obtain the results of case studies.

II. FUNDAMENTAL THEORY

1. UPFC in Power Transmission Lines

A Unified Power Flow Controller (UPFC) consists of 2 forced-commutated voltage source converters (VSC) connected through a common DC link [11]. One converter is shunt-connected and the other is connected in series with the transmission line, asillustrated in Figure 1. The name "unified power flow controller" comes from the fact that it is possible forthe device to control both transmitted active and reactive power as well as the AC bus voltage at the pointwhere the shunt converter is connected (i.e., point A). The UPFC can provide different functions when the inserted series voltages v_s have different magnitudes and phase angles. It will function as a pure voltageregulator if the inserted series voltage is in phase with the AC bus voltage. It is also possible for the UPFCto function as a phase angle regulator. Each UPFC converter can independently generate or absorb reactivepower. This arrangement enables the free flow of active power in either direction between the AC terminalsof the 2 converters. In the case of the parallel branch of the UPFC, the active power exchanged with thesystem primarily depends on the phase shift of the converter output voltage with respect to the system voltage,and the reactive power is controlled by varying the amplitude of the converter output voltage. However, theseries branch of the UPFC controls active and reactive power flows in the transmission line by the amplitudeand phase angle of the series injected voltage. Therefore, the active power controller can significantly affect thelevel of reactive power flow and vice versa.
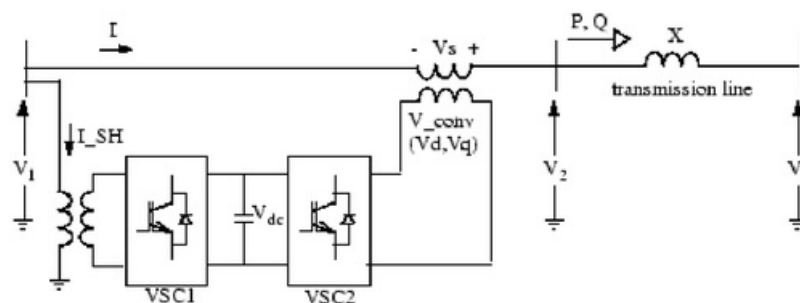

Figure 1. Circuit of a UPFC in power transmission line.

To improve the performance of the UPFC, the interaction between the active and reactive power flow control system must be reduced. In recent years, a number of investigations have been carried out to demonstrate the capabilities of UPFC as an effective power flow control [4], providing voltage control [5], transient stability enhancement [6], and oscillation damping [7-9]. It has been reported in the literature that a strong dynamic interaction exists between the active and reactive power flows through a transmission line when they are controlled by series injected voltage v_s of the UPFC. Furthermore, the UPFC is highly nonlinear because it consists of converters, power transformers, filters, and surge arrestors. Uncertainties in the power system make it difficult to model the transmission system accurately.

2. Adaptive Neuro-Fuzzy Method

During the last two decades adaptive neuro-fuzzy approach has been became a popular method in control area. In this part, a brief description of the adaptive neuro-fuzzy inference system (ANFIS) principles is given which are refered to [12-13]. The fundamental structure of the type of fuzzy inference system (FIS) could be seen as a model that maps input characteristics to input membership functions. Then it maps input membership function to rules and rules to a set of output characteristics. Finally it maps output characteristics to output membership functions, and the output membership function to a single valued output or a decision associated with the output. It has been considered only fixed membership functions that were chosen arbitrarily. Fuzzy inference system (FIS) is only applied to only modelling systems whose rule structure is essentially predetermined by the user's interpretation of the characteristics of the variables in the model. However, in some modelling situations, it cannot be distinguish what the membership functions should look like simply from looking at data. Rather than choosing the parameters associated with a given membership function arbitrarily, these parameters could be chosen so as to tailor the membership functions to the input/output data in order to account for these types of variations in the data values. In such case the necessity of the adaptive neuro fuzzy inference system becomes obvious.

$$f_1 = p_1x + q_1y + r_1$$

$$f_2 = p_2x + q_2y + r_2$$

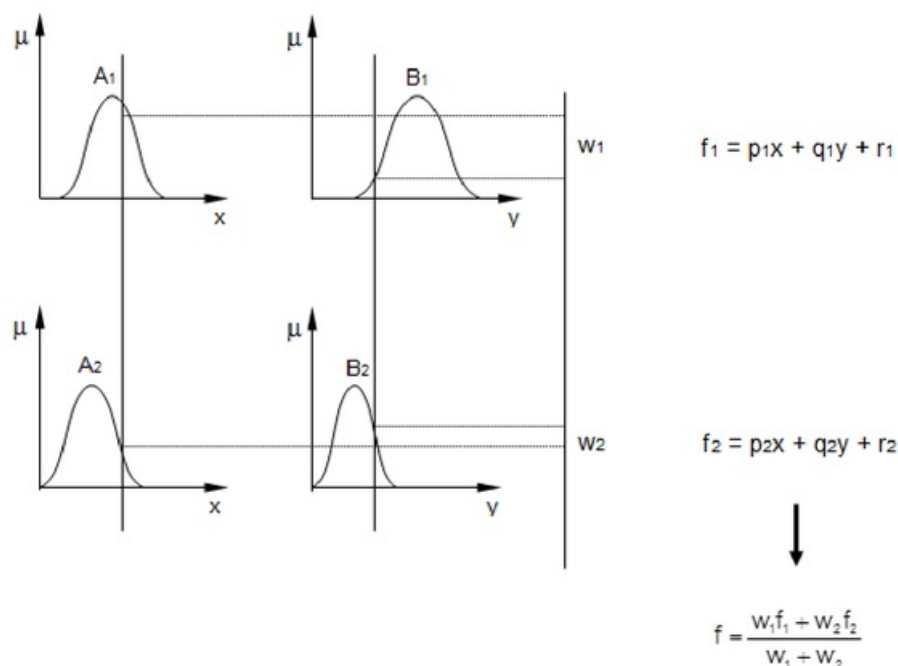$$f = \frac{w_1f_1 + w_2f_2}{w_1 + w_2}$$

Figure 2. Sugeno's fuzzy logic model

The neuro-adaptive learning method works similarly to that of artificial neural networks. Neuro-adaptive learning techniques provide a method for the fuzzy modelling procedure to learn information about a data set. It computes the membership function parameters that best allow the associated fuzzy inference system to track the given input and output data. A network-type structure similar to that of an artificial neural network can be used to interpret the input and output map so it maps inputs through input membership functions and associated parameters, and then through output membership functions and associated parameters to outputs. The parameters associated with the membership functions changes through the learning process. The computation of these parameters (or their adjustment) is facilitated by a gradient vector. This gradient vector provides a measure of how well the fuzzy inference system is modelling the input/output data for a given set of parameters. When the gradient vector is obtained, any of several optimization routines can be applied in order to adjust the parameters to reduce some error measure (performance index). This error measure is usually defined by the sum of the squared difference between actual and desired outputs. ANFIS uses a combination of back propagation procedure and least squares estimation for membership function parameter estimation.
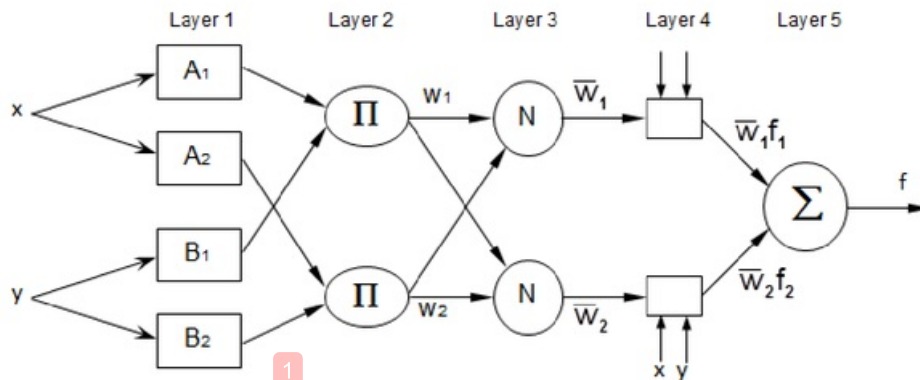
Figure 3. The architecture of the ANFIS

The suggested ANFIS has several properties:
The output is zero-th order Sugeno-type system.
It has a single output, obtained using weighted average defuzzification. All output membership functions are constant.

It has no rule sharing. Different rules do not share the same output membership function, namely the number of output membership functions must be equal to the number of rules.
It has unity weight for each rule.

Figure 2 shows Sugeno's fuzzy logic model. Figure 3 shows the architecture of the ANFIS, comprising by input, fuzzification, inference and defuzzification layers. The network can be visualized as consisting of inputs, with N neurons in the input layer and F input membership functions for each input, with F*N neurons in the fuzzification layer. There are FN rules with FN neurons in the inference and defuzzification layers and one neuron in the output layer. For simplicity, it is assumed that the fuzzy inference system under consideration has two inputs x and y and one output z as shown in Figure 3. For a zero-order Sugeno fuzzy model, a common rule set with two fuzzy if-then rules is the following:

Rule 1: If x is A_1 and y is B_1, Then $f_1 = r_1$ (1)
Rule 2: If x is A_2 and y is B_2, Then $f_2 = r_2$ (2)

Here the output of the i-th node in layer n is denoted as On,i:
Layer 1. Every node i in this layer is a square node with a node function:

$$O_i^1 = \mu Ai(x), \text{ for } i = 1, 2,$$ (3)

or,

$$O_i^1 = \mu Bi\text{-}2(y), \text{ for } i = 3, 4$$ (4)

where x is the input to node-i, and Ai is the linguistic label (small , large, etc.) associated with this node function. In other words, O_i^1 is the membership function of Ai and it specifies the degree to which the given x satisfies the quantifier Ai. Usually $\mu Ai(x)$ is chosen to be bell-shaped with maximum equal to 1 and minimum equal to 0, such as the generalized bell function:

$$\mu_A(x) = \frac{1}{1 + \left[\dfrac{x - c_i}{a_i}\right]^{2b_i}}$$ (5)

Parameters in this layer are referred to as premise parameters.
Layer 2. Every node in this layer is a circle node labeled Π which multiplies the incoming signals and sends the product out. For instance,

$$O_i^2 = wi = \mu Ai(x) \times \mu B(y), \ i = 1, 2.$$ (6)

Each node output represents the firing strength of a rule. (In fact, other T-norm operators that performs generalized AND can be used as the node function in this layer.)

Layer 3. Every node in this layer is a circle node labeled N. The i-th node calculates the ratio of the i-th rule's firing strength to the sum of all rules firing strengths:

$$O_i^3 = \overline{w} = \frac{w_i}{w_1 + w_2} , \quad i = 1, 2. \tag{7}$$

For convenience, outputs of this layer will be called normalized firing strengths.

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

$$O_i^4 = \overline{w}_i f_i = \overline{w}_i \, (p_i x + q_i y + r_i) \tag{8}$$

where $\overline{w}_i$ is the output of layer 3, and {pi, qi, ri} is the parameter set. Parameters in this layer will be referred to as consequent parameters.

Layer 5. The single node in this layer is a circle node labeled Σ that computes the overall output as the summation of all incoming signals, i.e.,

$$O_i^5 = \sum \overline{w}_i f_i \tag{9}$$

III.   METHODOLOGY

The procedure of this research is shown in Fig. 4. The simulation environment based on Matlab software package is selected. It is used as the main engineering tool for performing modeling and simulation of multi-machine power systems, as well as for interfacing the user and appropriate simulation programs. Matlab has been chosen due to availability of the powerful set of programming tools, signal processing, numerical functions, and convenient user-friendly interface. In this specially developed simulation environment, the evaluation procedures can be easily performed. We have used Fuzzy logic Toolbox of Matlabto develop the ANFIS model with 4 inputs and single output as given in Fig. 5.
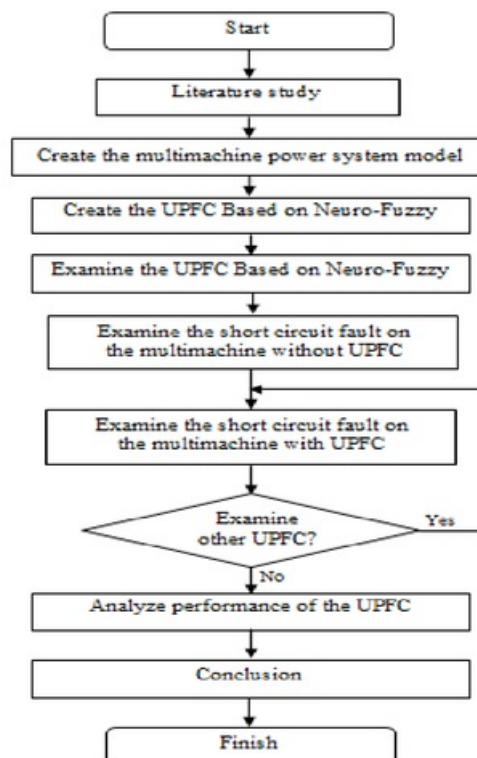
Figure 4. Procedure of the research.

IV. RESULT OF SIMULATION

1. Adaptive Neuro-Fuzzy for UPFC

The design process of the Adaptive Neuro-Fuzzy (ANFIS) for power flow control using UPFC go through the following three steps:

a. Generation a suitable training data.

In order to use the ANFIS technique for power flow control using UPFC, the input parameters limit should be determined precisely. The input parameters are obtained from recording devices sparsely located at sending end in a power system network. Due to limited available amount of practical fault data of transmission lines, it is necessary to generate training/testing data using simulation. To generate data for the typical transmission system, a computer program have been designed to generate training data for different faults.

b. Selection of a suitable ANFIS structure for a given application.

Various ANFIS are designed for UPFC to extend stability limits by modulating generator excitation to provide damping to the oscillation of synchronous machine rotors relative to one another. Membership function of inputs variable for PSS is shown in Figure4, while the structure of Sugeno type ANFIS for UPFC is shown in Figure 5.

c. Training the ANFIS.

Various network configurations were trained in order to establish an appropriate network with satisfactory performances.
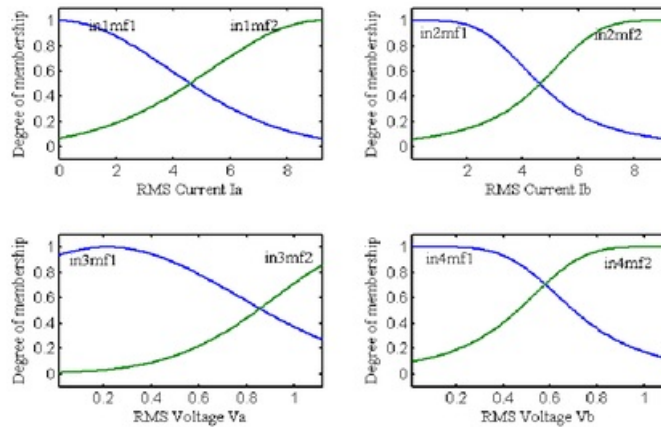
Figure 4. Membership function of Inputs Variable for UPFC
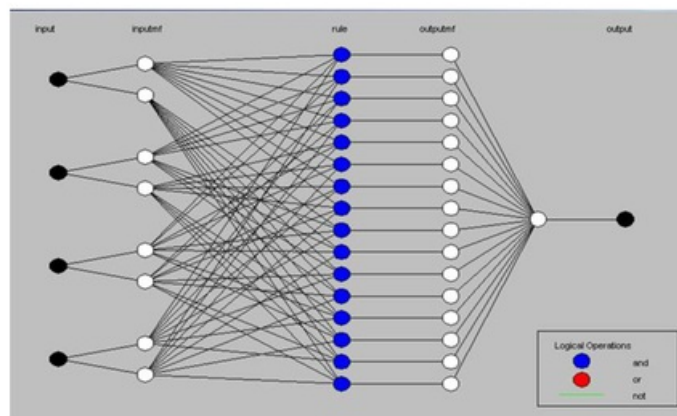
Figure 5. Structure of Sugeno type ANFIS for UPFC.

2. UPFC Model

In this study, we have made a model of a multi-machine power system in Matlab-Simulink software. A UPFC is used to control the power flow in a 500 kV /230 kV transmission system, as shown in Figure 6. The system, connected in a loop configuration, consists essentially of five buses (B1 to B5) interconnected through three power transmission lines (L1, L2, L3) and two 500 kV/230 kV power transformer banks Tr1 and Tr2. Two power plants located on the 230 kV system generate a total of 1500 MW which is transmitted to a 500 kVtransmission line, 15000 MVA equivalent and to a 200 MW load connected at bus B3. Each plant model includes a speed regulator, an excitation system as well as a power system stabilizer (PSS). In normal operation, most of the 1200 MW generation capacity of power plant #2 is exported to 500 kV transmission system equivalent through two 400 MVA power transformers connected between buses B4 and B5. For this demo we are considering a contingency case where only two power transformers out of three are available (Tr2= 2*400 MVA = 800 MVA). The load flow shows that most of the power generated by plant #2 is transmitted through the 800 MVA transformer bank (899 MW out of 1000 MW) and that 96 MW is circulating in the loop. Transformer Tr2 is therefore overloaded by 99 MVA. The example illustrates how a UPFC can relieve this power congestion. The UPFC located at the right end of line L2 is used to control the active and reactive powers at the 500 kV bus B3, as well as the voltage at bus B_UPFC. The UPFC consists of two 100 MVA, IGBT-based, converters (one shunt converter and one series converter interconnected 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.
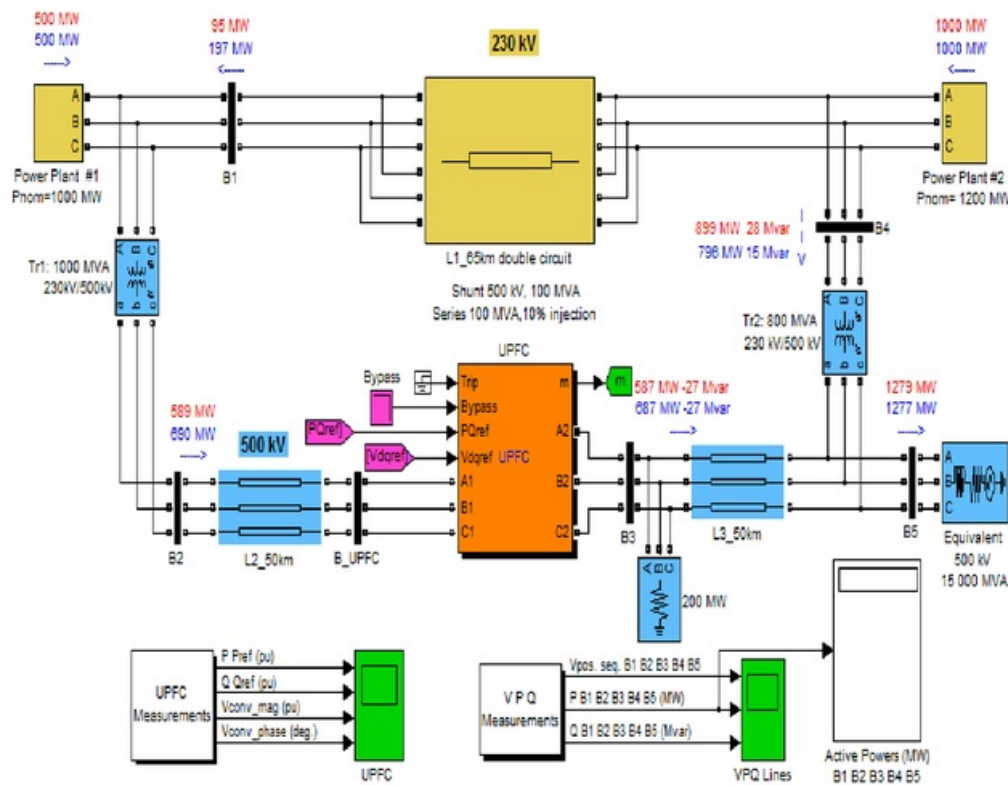

Figure 6. A UPFC model in power transmission systems.

Three phase fault is applied to the multimachine system. The series converter is rated 100 MVA with a maximum voltage injection of 0.1 pu. The shunt converter is also rated 100 MVA. Also, the shunt converter is in Voltage regulation mode and that the series converter is in Power flow control mode. Dynamic responses of the UPFC has shown in Figure 5. The UPFC reference active and reactive powers are set in the magenta blocks labeled Pref(pu) and Qref(pu). Initially the Bypass breaker is closed and the resulting natural power flow at bus B3 is 587 MW and -27 Mvar. The Pref block is programmed with an initial active power of 5.87 pu corresponding to the natural power flow. Then, at t=10s, Pref is increased by 1 pu (100 MW), from 5.87 pu to 6.87 pu, while Qref is kept constant at -0.27 pu.
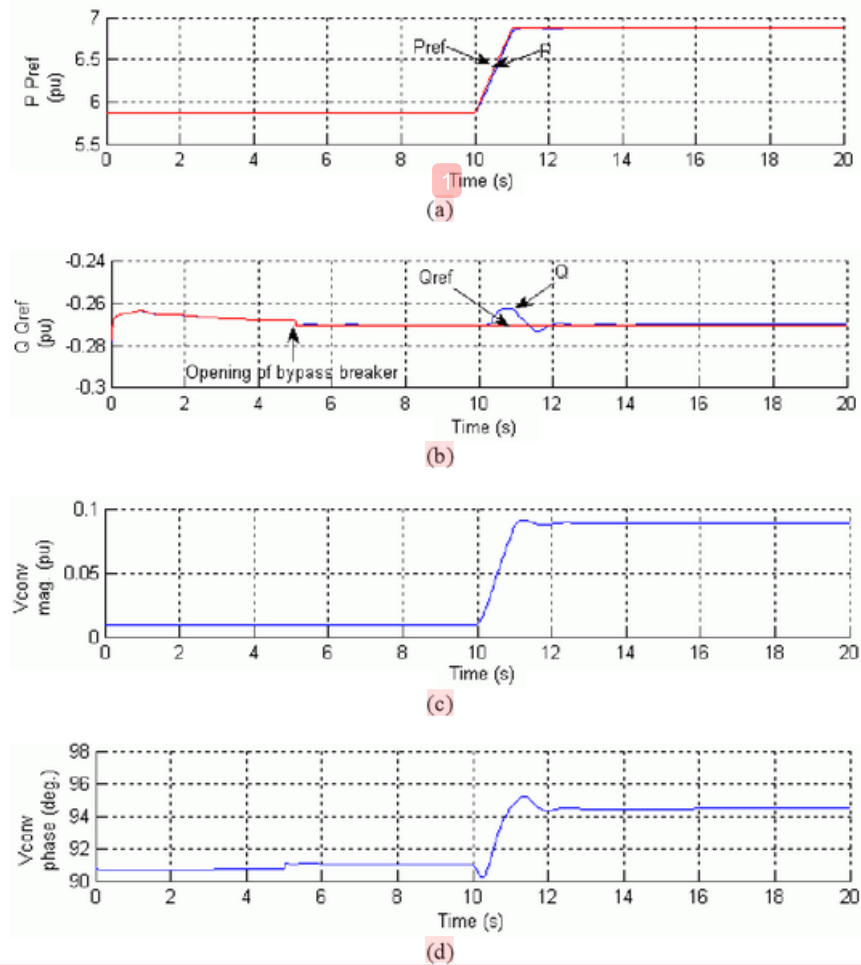
(a)

(b)

(c)

(d)

Figure 7. UPFC dynamic responses to changes in load of power system from 587 MW to 687 MW.
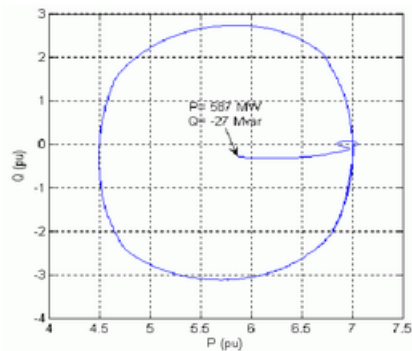
Figure 8. Controllability region of UPFC.

Further results are shown in Figure 7. The figure shows the UPFC dynamic response to changes in load of power system from 587 MW to 687 MW. Figure 8 shows the controllability region of UPFC. In Figure 8 are shown the results of UPFC control for active power through bus B3 and B4 with tap position changes of PST. Based on Figure 8, it can be seen that the neuro-fuzzy UPFC is able to provide a response that controls the flow of electrical power is good.

In Figure 9 is shown the action of PSS in damping power oscillations. In this design also included the role of Power System Stabilizer (PSS) in order to control the generator in the event of changes in the electrical load so that power oscillations that occur can take place in a short time.
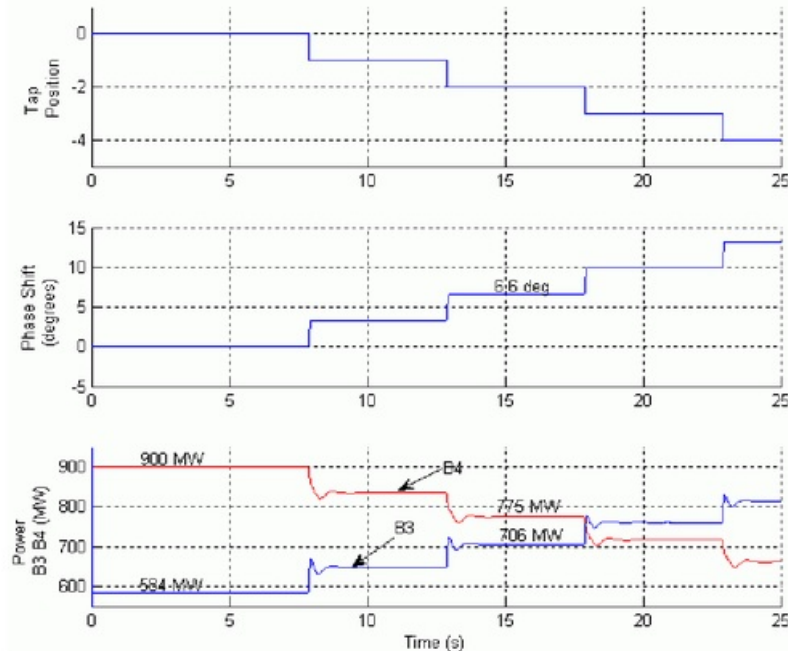
Figure 9. Results UPFC control for active power through bus B3 and B4 with tap position changes of PST.

V. CONCLUSION

In this study, neuro-fuzzy based method is applied to the UPFC for adaptively controlling the power flow in electric power transmission systems multimachine very dynamic. Three phase fault is applied to the multimachine system. The results are taken to be consideration of neuro-fuzzy controller. The neuro-fuzzy controller show a low overshoot occurred during the fault in results. According to results that UPFC improves the system performance under the transient and the normal conditions. However, it can control the power flow in the transmission line, effectively.

VI. ACKNOWLEDGEMENTS

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FINAL GRADE

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GENERAL COMMENTS

Instructor

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