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IMPROVEMENT OF TRANSIENT STABILITY IN A SYSTEM USING A UNIFIED POWER FLOW CONTROLLER BY ARTIFICIAL NEURAL NETWORK

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ABSTRACT

This paper illustrates the neural network predictive control strategy for mitigating the electromechanical oscillations i.e. load angle deviation of the generator using Unified power flow controller (UPFC). Comparative study is done with UPFC controlled system and a system without UPFC. The stability of the system is maintained by operating the UPFC, with independent control of real and reactive power. UPFC is designed to supply/absorb the power in the transmission line according to the variation in the line voltage. The system is modeled under PI controller and the operating data are analyzed. Using the obtained training data set, the artificial neural network (ANN) controller is modeled in the back to back propagation methodology and trained using the Levenberg-Marquardt algorithm method. The obtained results reveals that the system with ANN controlled UPFC has better efficiency, quicker response and settling to the normal operation criteria during a sudden three phase fault when compared with the system without UPFC. The development and training of the neural network is done under MATLAB/ Neural Network Fitting Tool (NNFT) environment.

Keywords*: Artificial Neural Network, Oscillation damping, Shunt converter, Series converter, Transient stability, UPFC.*

1. INTRODUCTION

The electrical power demand in the power system increases dramatically in a higher growth which leads to a complex and less secure system. Maintaining the stability of the system during a severe disturbance is under great threat. Normally most of the generators employed are synchronous generators. Maintaining synchronism is the major part of the system.Generators are employed with governor and exciter controls but they cannot damp the oscillations all time and takes time for the controller operation which is not allowable in a large complex system. These drawbacks give rise to the high power semiconductor devices employed Flexible AC Transmission Systems (FACTS). For damping the electromechanical oscillations, secure loading and for maintaining the powerflow FACTS devices are used. Unified Power Flow Controller(UPFC) is the most versatile FACTS controller developed so far. It has the great capability of voltage regulation, series compensation and phase shifting. UPFC can independently and rapidly control both real and reactive power flows in the transmission line [2].For the improvement of transient stability certain factors are to be considered they are Voltage, impedance and phase angle. UPFC has unique characteristics to control all these parameters. Most of the control strategies comprised of PID controller (Proportional + Integral + Derivative) as it is easy to design and implemented in the system. But they have serious drawbacks when employed in the wide range of operating conditions. Due to the unwanted large disturbances, there will be a loss of synchronism among the synchronous generator, which is to be considered as the transient stability of the power system. Usage of PID and PI controllers for the transient stability improvement has achieved a peak role of development. A new control strategyis implemented in the shunt and series branch controllers by using the generators output active power as one of the reference. Conventional linear and non-linear method are replaced by the neural network controller as they have an advantage of storing the input and output data. ANN is usedas it well suits on the real time applications. Neural network predictive controller method is employed on both the shunt branch and Series branch controllers to produce variation in the reference to the pulse generator during the transient. The neural network controller is designed in a way to store the input and output variations and made to act during the disturbance periods. This made neural network controller toact well during a huge three phase fault. With the comparativestudy of the system with the UPFC using ANN controller and with the PI controller the damping of the electromechanical oscillations are clearly understood.

2. TRANSIENT STABILITY

The power system stability is broadly classified into rotor angle stability, frequency stability and voltage stability. The transient stability comes under the classification of rotor anglestability with the small-disturbance angle stability both of these occur for a short term. On the other hand the voltage stability is classified into large disturbance and small disturbance voltage stability of which small disturbance is long term and other is short term. Frequency stability has bothshort and long term. Rotor angle stability is the ability of the system to remain in synchronism when subjected to a disturbance. Frequency stability has both short and long term. Remaining in synchronism means that all the generators electromagnetic torque (generator electrical power output) is exactly balanced by the mechanical torque (input mechanical power through a prime mover) [9]. If in some generator the balance between electromagnetic and mechanical torque is disturbed, due to disturbances in the system, then this will lead to oscillations in the rotor angle.

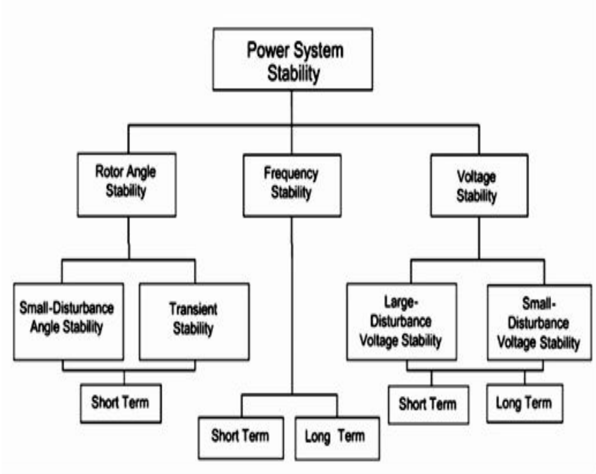

Fig 1: Classification of power system stability

Large-disturbance or transient angle stability is the ability of the system to remain in synchronism when subjected to large disturbances. It occurs for about 0.1 to 10 seconds. Large disturbances are due to faults, switching on or off of large loads, large generators tripping etc. In depth stability is divided into Steady state stability, dynamic stability and transient stability. Steady state stability is basically concerned with the determination of the upper limit of machine loadings before losing synchronism. Dynamic stability occurs when any small disturbances continuously occurring in a power system which are small enough to lose synchronism but do excite the system into the state of natural oscillations. It takes place at time duration of 5-10s. In case of large disturbance changes in the angular difference may be so large as to cause the machine to fall out of synchronism is termed as Transient stability. It occurs for a very short duration of one second. The Reasons for the transient stability is due to the tripping of heavily loaded generator, dropping of a large load and occurrence of short circuit faults. The controlling of the transient stability depends on the swing equation (1) which states

$$M \left(\frac{d^2\delta}{dt^2}\right) = P_e - P_m \qquad (1)$$

Where,

$P_m - P_e$ is the accelerating power

$P_m$is the input mechanical power

P_e is the output electrical power

The operation of UPFC can be explained with the three casesof operation in swing equation

Case 1: $P_m = P_e$ There is no accelerating power so systemoperates on Normal operating condition.

Case 2: $P_m > P_e$ The Rotor accelerates which is occurred dueto the loss of a large load.

Case 3: $P_m < P_e$ The Rotor decelerates which is occurredduring three phase fault

For controlling electrical output of alternator

$$P_e = \left(\frac{EV}{X}\right) \sin \delta \qquad (2)$$

In the equation (2) by changing the value of X theaccelerating power can be controlled within the limits. If the case 2 of swing equation occurs the generator acceleratesduring such period the UPFC inject a voltage in such a way that to introduce a capacitive reactance in the line. If the case3 of swing equation occurs generator decelerates during that the UPFC is made to inject a voltage in such a way that to introduce an inductive reactance in the line.

3. UPFC OPERATION

UPFC consists of STATCOM and DVR with a common dc link capacitor (shown in Fig.2). UPFC allows simultaneous control of active power flow, reactive power flow and maintaining the voltage magnitude at its terminals. The schematic representation of UPFC is shown in Fig.3 and the equivalent circuit model is shown in Fig.5. The controller is designed in a way to control one or more parameters by combination of the control units. The active power requirement of the series converter is drawn by the shuntconverter from the AC network through the dc link.

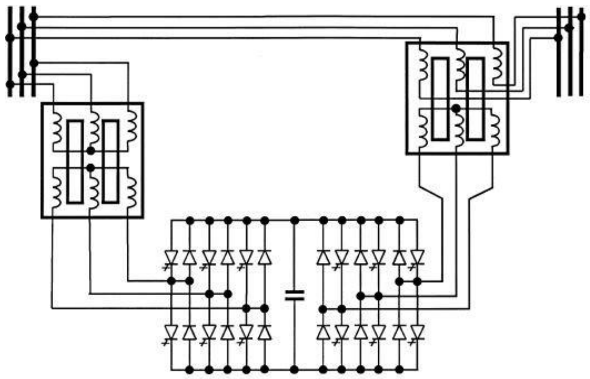

Fig 2: Connection of shunt and series converter to thetransmission line

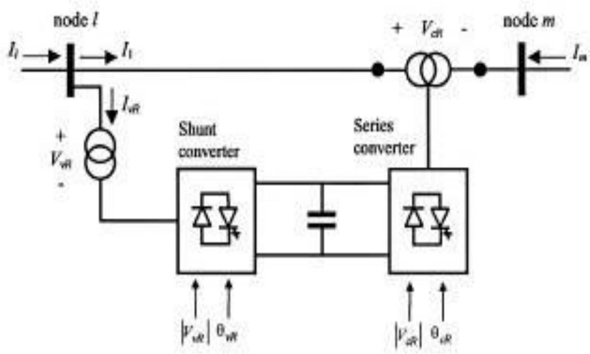

Fig 3: Schematic diagram of UPFC

The voltage magnitude of the inverted voltage $|V_{cR}|$ provides voltage regulation and the phase angle θ_{cR} determines themode of power flow control (Hingorani and Gyugyi, 2000):

1. If θ_{cR} is in phase with the voltage phase angleθ_l, it regulates no active power flow.
2. If θ_{cR} is in quadrature with the voltage phase angleθ_l, it controls active power flow performing as a phase shifter but drawing no reactive power from the AC network.
3. If θ_{cR} is in quadrature with the current angle then it controls active power flow performing as a variable series impedance compensator.
4. At any other value of θ_{cR}, it performs as a combination of a phase shifter and a variable series impedance compensator. This is in addition to being a voltage regulator by suitable control of $|V_{cR}|$.

Shunt converter not only supports the active power demand of the series converter but also generate or absorb reactive power to provide independent voltage regulation at the connecting point to the AC system. The power flow model of UPFC is shown in Fig.4, which consists of shunt connected voltage source and series connected voltage source. The two voltage sources are linked with the power flow constrain equations shown in equations (3 to 5). To satisfy the specific control requirement these equations are adjusted in a coordinated fashion. The two voltage sources (shunt and series) used in the UPFC application have certain limits. For the shunt converter the voltage magnitude and phase angle limits are:$V_{vRmin} \leq V_{vR} \leq V_{vRmax}$ and $0 \leq \theta_{vR} \leq 2\pi$. Similarly for the series converter $V_{cRmin} \leq V_{cR} \leq V_{cRmax}$ and $0 \leq \theta_{cR} \leq 2\pi$

4. MODELLING AND CONTROLLINGOF UPFC

A more flexible UPFC power flow model is derived below:

These equations are used to derive UPFC model. Based on UPFC model is derived: one by representation of the fundamental component of the Fourier series of the switched voltage waveform at the AC terminals of the shunt connected converter, and the other representing a similar parameter at the AC terminals of the series connected converter.

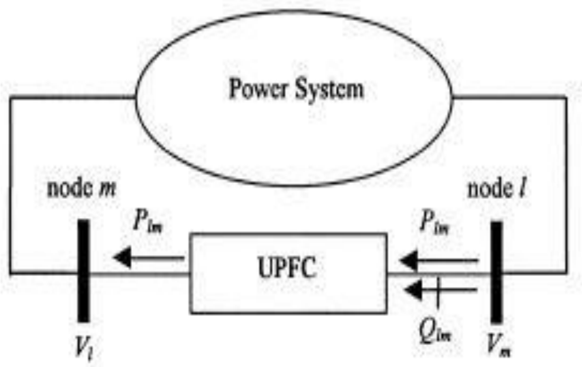

Fig 4: UPFC power flow model

The working characteristics of these two voltage sources are not independent from each other. Although they combined to supply a common active power exchange with the external network.

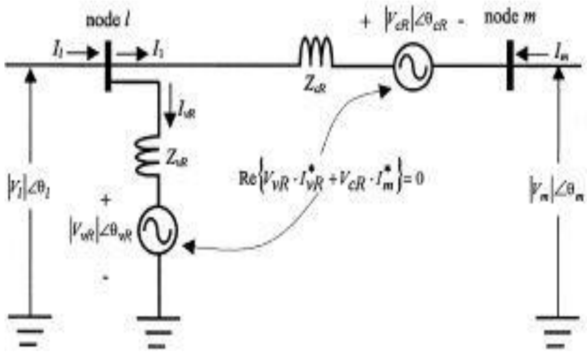

Fig 5: Equivalent circuit of UPFC

The equivalent circuit representation is shown in Fig 5. The only restriction in the UPFC for power flow studies is that the losses in valves are not considered. Even though the UPFC active power converter valve losses are expected to be small and this makes the use of UPFC in power flow studies. The active power demand of the series converter$Re\{V_{cR}. I^*\}$is satisfied by the active power supplied to the shunt converter $Re\{V_{vR}. I^*\}$. The impedance of the series and shunt transformers, Z_{cR} and Z_{vR}, are included explicitly in the model[12]. The ideal voltage sources and the constraint powerequation are

$$V_{vR} = |V_{vR}|(\cos\theta_{vR} + j\sin\theta_{vR}) \quad (3)$$

$$V_{cR} = |V_{cR}|(\cos\theta_{cR} + j\sin\theta_{cR}). \quad (4)$$

Combining active power demand of series and shuntconverter,

$$Re\{-V_{vR}.I^*_{vR} + V_{cR}.I^*_m\}=0. \quad (5)$$

the equivalent circuit shown in Fig.5 the following transfer admittance equation can be written as

$$(Y \quad + Y \quad) \quad -Y \quad -Y \quad -Y \quad \begin{matrix} V_l \\ V \end{matrix}$$

$$I_m \quad -Y_{cR} \quad Y_{cR} \quad Y_{cR} \quad 0 \quad \begin{matrix} V_{cR} \\ V_{vR} \end{matrix}$$

Using the complex power equation the injected active andreactive powers at nodes l and m are derived as,

$$\begin{bmatrix} S_l \\ S_m \end{bmatrix} = \begin{bmatrix} V_l & 0 \\ 0 & V_m \end{bmatrix} \begin{bmatrix} I_l^* \\ I_m^* \end{bmatrix} \qquad (7)$$

$$= \begin{bmatrix} V_l & 0 \\ 0 & V_m \end{bmatrix} \begin{bmatrix} (Y_{cR}^* + Y_{vR}^*) & -Y_{cR} & -Y_{cR} & \cdots \\ \cdots & & & \end{bmatrix} \begin{bmatrix} V_l^* \\ V_m^* \\ V_{cR}^* \\ V_{vR}^* \end{bmatrix}. \qquad (8)$$

After the algebraic calculations the following active andreactive power equations are obtained

$$\begin{aligned} P_l = |V_l|^2 G_{ll} + |V_l||V_m|\{ & G_{lm} \cos(\theta_l - \theta_m) \\ & + B_{lm} \sin(\theta_l - \theta_m) \\ & + |V_l||V_{cR}|\{G_{lm} \cos(\theta_l - \theta_{cR}) \\ & + B_{lm} \sin(\theta_l - \theta_{cR}) \\ & + |V_l||V_{vR}|\{G_{lm} \cos(\theta_l - \theta_{vR}) \\ & + B_{lm} \sin(\theta_l - \theta_{vR})\} \end{aligned} \qquad (9)$$

$$\begin{aligned} Q_l = -|V_l|^2 B_{ll} + |V_l||V_m|\{ & G_{lm} \sin(\theta_l - \theta_m) \\ & - B_{lm} \cos(\theta_l - \theta_m) \\ & + |V_l||V_{cR}|\{G_{lm} \sin(\theta_l - \theta_{cR}) \\ & - B_{lm} \cos(\theta_l - \theta_m) \\ & + |V_l||V_{vR}|\{G_{l_o} \sin(\theta_l - \theta_{vR}) \\ & - B_{l_o} \cos(\theta_l - \theta_{vR})\} \end{aligned} \qquad (10)$$

$$\begin{aligned} P_m = |V_m|^2 G_{mm} + |V_m||V_l|\{ & G_{ml} \cos(\theta_m - \theta_l) \\ & + B_{ml} \sin(\theta_m - \theta_l) \\ & + |V_m||V_{cR}|\{G_{mm} \cos(\theta_m - \theta_{cR}) \\ & + B_{lm} \sin(\theta_m - \theta_{cR})\} \end{aligned} \qquad (11)$$

$$\begin{aligned} Q_m = -|V_m|^2 B_{mm} + |V_m||V_l|\{ & G_{ml} \sin(\theta_m - \theta_l) \\ & - B_{lm} \cos(\theta_m - \theta_l) \\ & + |V_l||V_{cR}|\{G_{mm} \sin(\theta_m - \theta_{cR}) \\ & - B_{mm} \cos(\theta_m - \theta_{cR}). \end{aligned} \qquad (12)$$

Active and reactive powers for the series converter are derivedas follows:

$$P_{cR} = |V_{cR}|^2 G_{mm} + |V_{cR}||V_l|\{G_{ml} \cos(\theta_{cR} - \theta_l) + B_{ml} \sin(\theta_{cR} - \theta_l) + |V_{cR}||V_m|\{G_{mm} \cos(\theta_{cR} - \theta_m) + B_{mm} \sin(\theta_{cR} - \theta_m)\} \quad (13)$$

$$Q_{cR} = -|V_{cR}|^2 B_{mm} + |V_{cR}||V_l|\{G_{ml} \sin(\theta_{cR} - \theta_l) - B_{lm} \cos(\theta_{cR} - \theta_l) + |V_{cR}||V_m|\{G_{mm} \sin(\theta_{cR} - \theta_m) - B_{mm} \cos(\theta_{cR} - \theta_m) \quad (14)$$

Active and reactive powers for the shunt converter are derivedas follows:

$$P_{vR} = -|V_{vR}|^2 G_{l0} + |V_{vR}||V_l|\{G_{l0} \cos(\theta_{vR} - \theta_l) + B_{l0} \sin(\theta_{vR} - \theta_l) \quad (15)$$

$$Q_{cR} = |V_{vR}|^2 B_{l0} + |V_{vR}||V_l|\{G_{l0} \sin(\theta_{vR} - \theta_l) - B_{l0} \cos(\theta_{vR} - \theta_l). \quad (16)$$

Assuming lossless converters, the UPFC neither absorbs nor injects active power with respect to the AC system. Hence, the following constraint equation must be satisfied

$$P_{vR} + P_{cR} = 0. \quad (17)$$

The UPFC state variables are adjusted automatically in order to satisfy specified power flows and voltage magnitudes. For instance, if nodes l and m are the nodes where the UPFC and the power network join together and the UPFC is set to control voltage magnitude at node l, active power flowing from node m to node l and reactive power injected at node m. It has been found that for the series voltage source such initial conditions may be obtained by assuming lossless couplingtransformers together with null voltage phase angles as inequations (10)to(13). For the shunt voltage source the exerciseinvolves equations (13) and (17) (Fuerte Esquivel et al., 2000). It should be remarked that the power flow equations for the DVR become readily available from the above equations by eliminating the contribution of the shunt voltage source from equations (10) to (15).

5. ANN CONTROLLER

There are different types of artificial neural networks (ANN) depending on the nature of the neurons and how they are interconnected.

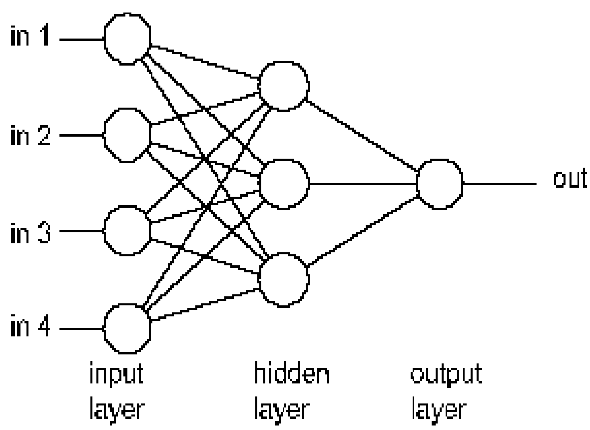

Fig 6: Neural network architecture

is used, as the relationship between inputs and desired outputs is better defined and it is easier to control. By increasing the number of neurons in the hidden layer, the training operation gives efficient result. The main aspect of the efficient operation of ANN is the selection of training data set. If the training data set is finite and setting it to cover all the aspects of input-output mapping, then the network will be able to generate correct answers for input that were not used during the training period, called as generalization.

5.1 Development of ANN controller

For the transient stability improvement using UPFC it employs four artificial neural network controllers.

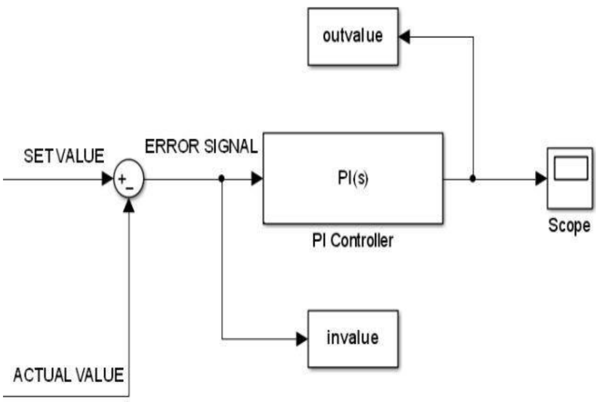

Fig 7: Formation of training data set

Shunt converter controller has two separate controllers: one for maintaining the dc link voltage and the other for supplyingthe active power demand of the series converter. Similarly there are two controllers in the series converter controller: one for supply/absorb real power to the transmission i.e. AC line and the other for the reactive power generation. The training data set is obtained as shown in the fig.7. The system is first simulated with the PI controller and the data are saved to the workspace in the array format. The training data denotes the variation in the output as per the input variation. The obtained training data is used for training the neural network with the neural network fitting tool in the MATLAB/NNFT.

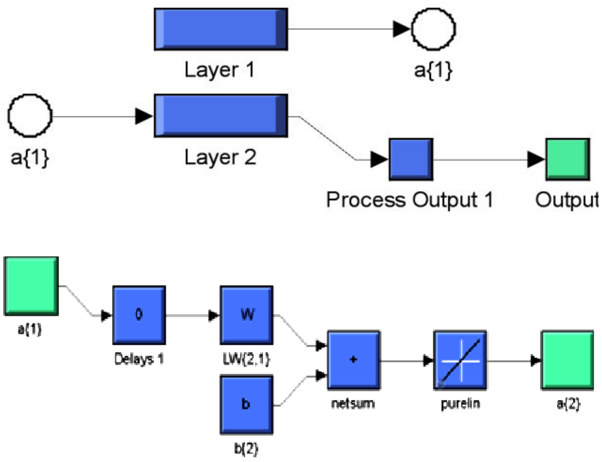

Fig 8: Developed ANN controller with input, hidden andoutput layers

It is necessary to derive a formula to propagate the weight matrices and the bias values in the feed forward network. For the determination of bias and weight matrix the following equations are used. Let the input vector be X , weight matrix between input and hidden W_{ih}, bias vector on hidden layer b, activation function on hidden nodes f, output of the hidden layer Y_h, weight matrix between hidden and output W_{ho}, B is the matrix that has every row equal to the vector b and output vector Y. The total input Z entering the hidden layer is

$$Z = X * W_{ih} + B. \quad (18)$$

Applying the activation function

$$Y_h = f(Z) = f(X * W_{ih} + B). \quad (19)$$

Output vector Y is equal to:

$Y = Y_h * W_{ho} = f(X * W_{ih} + B) * W\_ho.$ (20)

For every additional hidden layer the steps are repeated and the output layer gets modified.

6. SIMULATION RESULTS ANDDESCRIPTION

The developed artificial neural network controller for the UPFC is used for the improvement of transient stability of the system. The simulation diagram of the UPFC with ANN controller is shown in the Fig.9. The developed neural network controller occupies the PI controller position. The simulation diagram describes the three phase programmable source supplying the load. The voltage sag and voltage swell are created in the supply by means of variation in the voltage amplitude in the table of amplitude values at specific time.The main operation of UPFC in the transient stability improvement is to maintain the load angle deviation at the instant of sudden three phase fault. Fig.10 describes the load angle, active power and reactive power supplied by the generator to the grid. The active and reactive power supplied/absorbed by the UPFC during the three phase fault is shown in fig.12. It describes that the load angle deviation is within the limits, active power supplied by the generator is limited to supply the fault current and the increased reactive power for adding additional impedance to the line. Whereas when the same system is taken without UPFC the load angle deviation is above the stability limit causing the generator to loss the synchronism and also shows the additional active power supplied to the fault current as shown in the fig.11.

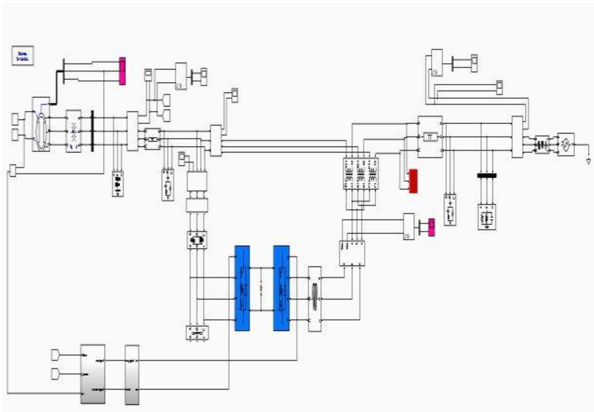

Fig 9: Simulation diagram of UPFC with ANN controller

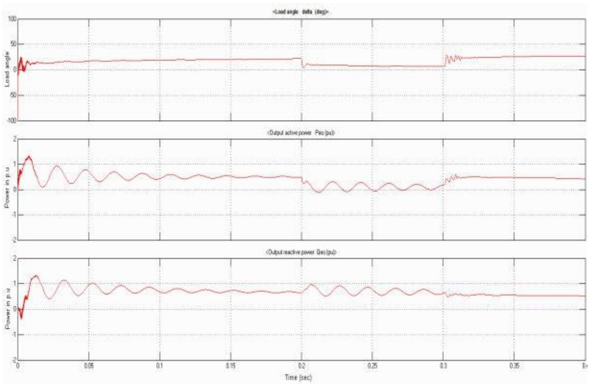

Fig 10: Generators load angle deviation, active power andreactive power with UPFC

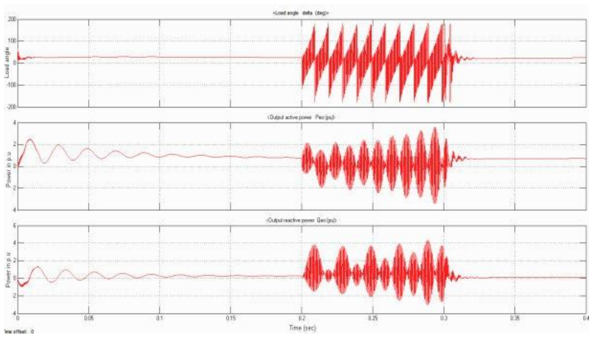

Fig 11: Generators load angle deviation, active power andreactive power without UPFC

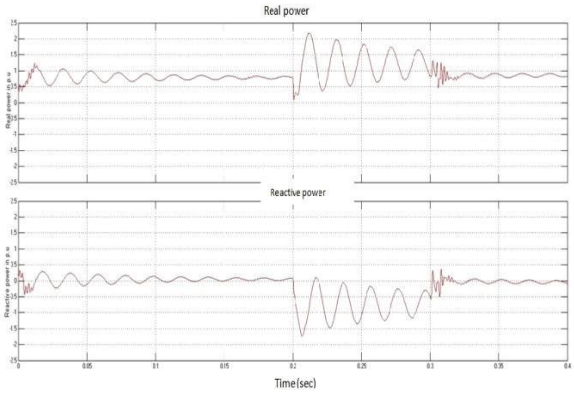

Fig 12: Active and reactive power supplied by UPFC

Table 1 Comparison of system parameters between the power system without UPFC and power system with UPFC using ANNcontroller during the fault condition

DURING THREE PHASE FAULT AT INTERVAL 0.2 to 0.3 Seconds		
Parameters	**Power system without UPFC**	**Power system with UPFC using ANN controller**
Load angle deviation in degree	-190° to 190°	5° to 15°
Generator active power output in p.u	-4p.u to 4p.u	0.5p.u to -0.1p.u
Generator reactive power output in p.u	-3p.u to 4p.u	0.8p.u to 1p.u
UPFC injected active power in p.u	-	0.75p.u to 2.3p.u
UPFC injected reactive power in p.u	-	0.1p.u to -1.75p.u

Table 1 describes the comparative results between the powersystem with and without UPFC. It is clear that the UPFC limits the generators active power output by supplying the active power and absorbing the reactive power.

7. CONCLUSION

Thus an artificial neural network controller is developed for mitigating the transient stability problems in the power systemusing Unified power flow controller (UPFC). The load angle deviation of the synchronous generator is maintained within the limits. The Fault current do not affect the generator to loss synchronism as the UPFC supplies the power to the fault. The obtained simulation results states that the system with ANN controlled UPFC have better efficiency and quicker response when compared with the system without UPFC during the occurrence of severe three phase fault. The development and training of the artificial neural network is done under MATLAB/ Neural Network Fitting Tool (NNFT) environment and it is described. The future part of this paperis to implement the multilevel converter in place of voltage source converters for supplying sinusoidal power to the AC network and switching of the multilevel converter is to be done by sinusoidal pulse width modulation for eliminating theharmonics.

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