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POWER FLOW STABILITY IN TRANSMISSION LINE USING UPFC BY NEURO FUZZY LOGIC CONTROLLER

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ABSTRACT

In this paper a matrix converter based unified power flow controller (UPFC) is designed with the application of the intelligent techniques such as a combination of neural network and fuzzy logic. In conventional UPFC two voltage source inverters (VSI), operated from a common DC link provided by a DC storage capacitor. One is for static synchronous compensator and another one for static synchronous series compensator. Ratings of this DC link capacitor bank will have a significant impact on the cost and physical size of the UPFC. To overcome these limitations, a matrix converter (MC) is employed. To analyze the performance of the UPFC neuro-fuzzy controller is used. In fuzzy logic controller the membership cannot be adapted with respect to the system operations. To show the performance of proposed scheme simulation is done in MAT lab. Finally the results of neural fuzzy-SVPWM based UPFC is compared with space vector modulation based UPFC in terms of active and reactive power flows in the line and active, reactive power flows at the bus to analyze the performance of UPFC.

Keywords: *Unified Power Flow Controller (UPFC), Matrix converter (MC), Artificial Neuro Fuzzy Inference System (ANFIS), Static Synchronous Compensator (STATCOM) and Static Synchronous Series Compensator (SSSC).*

1. INTRODUCTION

In recent years, due to economics and environment problems, build of new power plant and transmission line become more difficult. Hence, it is advisable to enhance the power transfer capability of the existing transmission lines up to thermal limit instead of constructing new one. The main aim of FACTS devices is rapid compensation and enhancement of flexibility of power line parameter. Some of the main FACTS controllers are Static Var Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC), Static Synchronous Compensator (STATCOM) and Static Synchronous Series Compensator (SSSC). But, due to configuration, these controllers are not able to control the active and reactive power, separately. Among the various FACTS controllers, The unified power-flow controller (UPFC) is a member of the FACTS family with very attractive features. Which has been recognized as one of the best featured FACTS devices [1]-[3]. It is capable of providing simultaneous active and reactive power flow control, as well as voltage magnitude control. The UPFC is a combination of static synchronous compensator and static synchronous series compensator which are connected via a common DC link, to allow bi-directional flow of real power between series output terminals of SSSC and the shunt terminals of the STATCOM, and is allowed to provide concurrent real and reactive power compensation. These two devices are two voltage source inverters (VSI), operated from a common DC link provided by a DC storage capacitor. Ratings of this DC link capacitor bank will have a significant impact on the cost and physical size of the UPFC. The capacitor is sized for a specified ripple voltage, typically 10% of the nominal voltage. The main drawback with this DC link capacitor is its design for maintaining the desired ripple [4]. Also this capacitor has shorter life when compared to AC capacitor of same rating. This limits the life and reliability of the voltage source inverter [5]. To overcome these limitations, a matrix converter (MC) is employed in UPFC whereby the classical AC/DC and DC/AC converter structure with dc link capacitor is replaced by a matrix converter. The matrix converter has several advantages such as bidirectional power flow, less number of switches,

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reduced THD etc., Also matrix converters are more reliable and potentially have much longer life, because of the absence of the DC link capacitor. Various control strategies to control the series voltage magnitude, angle and the shunt current magnitude have been presented [6]-[8]. 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. 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 Proportional and Integral (PI) controller used for the purpose have inadequacy of providing robust control and transient stability over a wide range of power system operating conditions. The advanced control technique recently used is based on fuzzy logic control. The efficiency of fuzzy controller is high when compared to PI controller [6]. Further, it has been proved that it is a variable gain PI. When compared to conventional controllers fuzzy controller has a number of distinguished advantages. But the membership cannot be adapted with respect to the system operations. In this paper an Adaptive Neuro Fuzzy Inference System (ANFIS) is implemented for matrix converter based UPFC to improve the power flow in the transmission line. This combines the fuzzy qualitative approach with the adaptive capabilities of neural networks to achieve improved performance.

2. CONVENTIONAL UPFC

The UPFC is a combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) coupled via a common DC voltage link shown in figure 1. It is used to allow bi-directional flow of real power between series output terminals of SSSC and the shunt terminals of the STATCOM, and also allowed to provide concurrent real and reactive power compensation. These two devices are two voltage source inverters (VSI), operated from a common DC link provided by a DC storage capacitor. The cost and size of the capacitors are increases with the ratings, The main drawback with this DC link capacitor is its design for maintaining the desired ripple, shorter life and reliability of the voltage source inverter [1], [3].

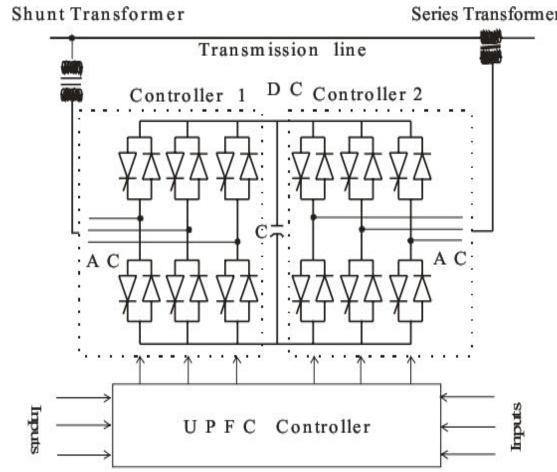

Figure 1: Block diagram of Unified Power Flow Controller

3. MATRIX CONVERTER BASED UNIFIED POWER FLOW CONTROLLER

A matrix converter is capable of converting an input voltage directly into an arbitrary AC voltage, instead of converting that voltage into a DC voltage as inverters. This matrix converter has higher efficiency, smaller size, longer life, fewer input current harmonics than inverters and have high potential for realizing the above mentioned demands [9]. The matrix converter consists of 9 bi-directional switches that allow any output phase to be connected to any input phase. The circuit scheme is shown in figure 2 and 3. The input terminals of the converter are connected to a three phase voltage fed system, usually the grid, while the output terminal are connected to a three phase current fed system, like an induction motor. The capacitive filter on the voltage fed side and the inductive filter on the current fed side represented in the schemes are intrinsically necessary. Their size is inversely proportional to the matrix converter switching frequency. It is worth noting that due to its inherent bi-directionality and symmetry a dual connection might be also feasible for the matrix converter, i.e. a current fed system at the input and a voltage fed system at the output .With nine bi-directional switches, the matrix converter can theoretically assume 512 (2^9) different switching states combinations. But not all of them can be usefully employed. Regardless to the control method used, the choice of the matrix converter switching states combinations (from now on simply matrix converter configurations) to be used must comply with two basic rules. Taking into account that the converter is supplied by a voltage source and usually feeds an inductive load, the input phases should never be short circuited and the

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output currents should not be interrupted. From a practical point of view these rules imply that one and only one bi-directional switch per output phase must be switched on at any instant. By this constraint, in a three phase to three phase matrix converter, 27 are the permitted switching combinations are shown in table 1. The structure of matrix converter based unified power flow controller is shown in figure 3 [10]. Since no energy storage components are present between the input and output sides of the matrix converter, the output voltages have to be generated directly from the input voltages. Each output voltage waveform is synthesized by sequential piecewise sampling of the input voltage waveforms. The input voltage equations for Matrix converter is, as follows:

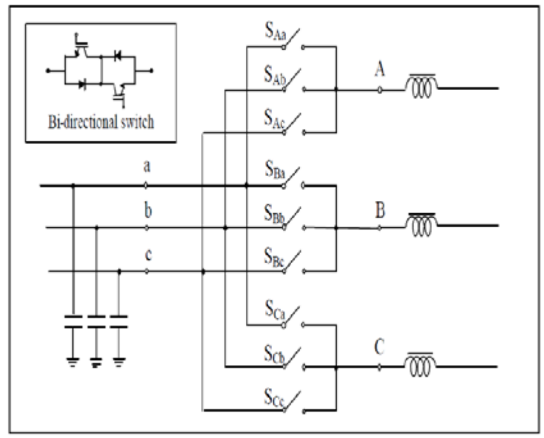

Figure 2: Circuit diagram of matrix converter

Table 1: Switching combinations for matrix converter

Group	State	Phase A	B	C	Output voltage u_{AB}	u_{BC}	u_{CA}	Input current i_{ia}	i_{ib}	i_{ic}	Switching function values sw_{Aa}	sw_{Ab}	sw_{Ac}	sw_{Ba}	sw_{Bb}	sw_{Bc}	sw_{Ca}	sw_{Cb}	sw_{Cc}
I	i	a	b	c	u_{ab}	u_{bc}	u_{ca}	i_A	i_B	i_C	1	0	0	0	1	0	0	0	1
	ii	a	c	b	$-u_{ca}$	$-u_{bc}$	$-u_{ab}$	i_A	i_C	i_B	1	0	0	0	0	1	0	1	0
	iii	b	a	c	$-u_{ab}$	$-u_{ca}$	$-u_{bc}$	i_B	i_A	i_C	0	1	0	1	0	0	0	0	1
	iv	b	c	a	u_{bc}	u_{ca}	u_{ab}	i_C	i_A	i_B	0	1	0	0	0	1	1	0	0
	v	c	a	b	u_{ca}	u_{ab}	u_{bc}	i_B	i_C	i_A	0	0	1	1	0	0	0	1	0
	vi	c	b	a	$-u_{bc}$	$-u_{ab}$	$-u_{ca}$	i_C	i_B	i_A	0	0	1	0	1	0	1	0	0
IIA	i	a	c	c	$-u_{ca}$	0	u_{ca}	i_A	0	$-i_A$	1	0	0	0	0	1	0	0	1
	ii	b	c	c	u_{bc}	0	$-u_{bc}$	0	i_A	$-i_A$	0	1	0	0	0	1	0	0	1
	iii	b	a	a	$-u_{ab}$	0	u_{ab}	$-i_A$	i_A	0	0	1	0	1	0	0	1	0	0
	iv	c	a	a	u_{ca}	0	$-u_{ca}$	$-i_A$	0	i_A	0	0	1	1	0	0	1	0	0
	v	c	b	b	$-u_{bc}$	0	u_{bc}	0	$-i_A$	i_A	0	0	1	0	1	0	0	1	0
	vi	a	b	b	u_{ab}	0	$-u_{ab}$	i_A	$-i_A$	0	1	0	0	0	1	0	0	1	0
IIB	i	c	a	c	u_{ca}	$-u_{ca}$	0	i_B	0	$-i_B$	0	0	1	1	0	0	0	0	1
	ii	c	b	c	$-u_{bc}$	u_{bc}	0	0	i_B	$-i_B$	0	0	1	0	1	0	0	0	1
	iii	a	b	a	u_{ab}	$-u_{ab}$	0	$-i_B$	i_B	0	1	0	0	0	1	0	1	0	0
	iv	a	c	a	$-u_{ca}$	u_{ca}	0	$-i_B$	0	i_B	1	0	0	0	0	1	1	0	0
	v	b	c	b	u_{bc}	$-u_{bc}$	0	0	$-i_B$	i_B	0	1	0	0	0	1	0	1	0
	vi	b	a	b	$-u_{ab}$	u_{ab}	0	i_B	$-i_B$	0	0	1	0	1	0	0	0	1	0
IIC	i	c	c	a	0	u_{ca}	$-u_{ca}$	i_C	0	$-i_C$	0	0	1	0	0	1	1	0	0
	ii	c	c	b	0	$-u_{bc}$	u_{bc}	0	i_C	$-i_C$	0	0	1	0	0	1	0	1	0
	iii	a	a	b	0	u_{ab}	$-u_{ab}$	$-i_C$	i_C	0	1	0	0	1	0	0	0	1	0
	iv	a	a	c	0	$-u_{ca}$	u_{ca}	$-i_C$	0	i_C	1	0	0	1	0	0	0	0	1
	v	b	b	c	0	u_{bc}	$-u_{bc}$	0	$-i_C$	i_C	0	1	0	0	1	0	0	0	1
	vi	b	b	a	0	$-u_{ab}$	u_{ab}	i_C	$-i_C$	0	0	1	0	0	1	0	1	0	0
III	i	a	a	a	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0
	ii	b	b	b	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0
	iii	c	c	c	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1

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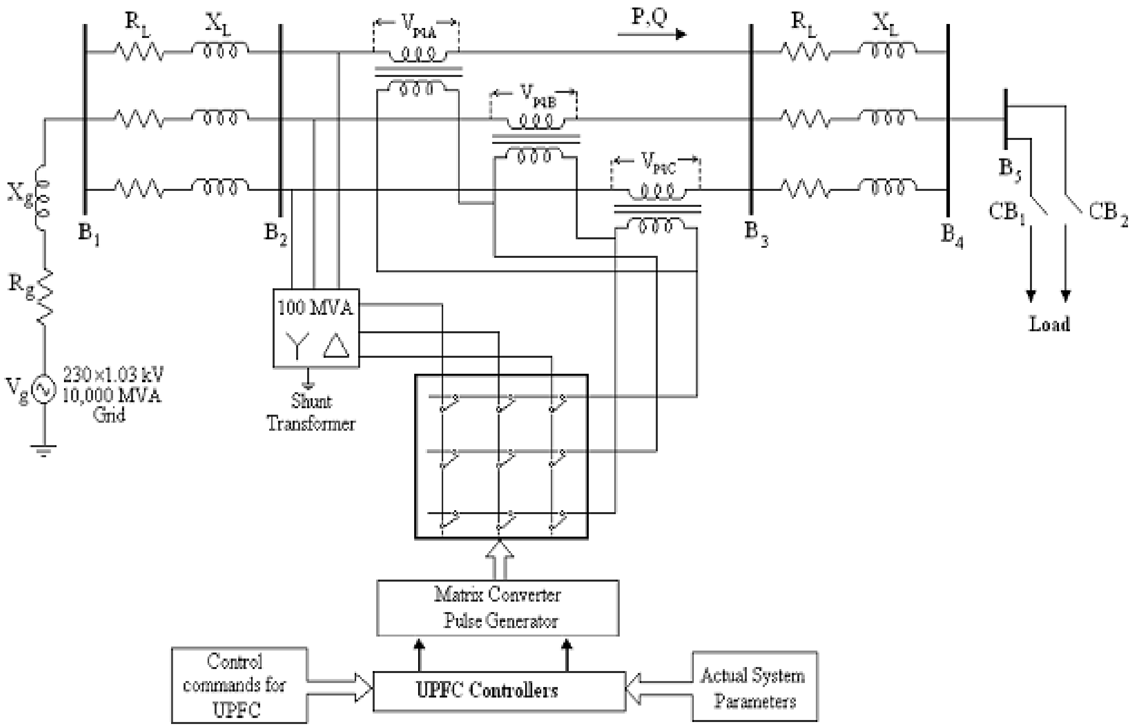

Figure 3: Circuit diagram of matrix converter based UPFC

$$V_a = V_m \cos\theta_{av} = V_m \cos(\omega t) \quad (1)$$

$$V_b = V_m \cos\theta_{bv} = V_m \cos(\omega t - (\tfrac{2\pi}{3})) \quad (2)$$

$$V_c = V_m \cos\theta_{cv} = V_m \cos(\omega t + (\tfrac{2\pi}{3})) \quad (3)$$

The line side current in the shunt side is described as,

$$I_a = I_m \cos\theta_{av} = I_m \cos(\omega t - \psi_{in}) \quad (4)$$

$$I_b = I_m \cos\theta_{bv} = I_m \cos(\omega t - (\tfrac{2\pi}{3}) - \psi_{in}) \quad (5)$$

$$I_c = I_m \cos\theta_{cv} = I_m \cos(\omega t + (\tfrac{2\pi}{3}) - \psi_{in}) \quad (6)$$

The sampling rate has to be set much higher than both input and output frequencies, and the duration of each sample is controlled in such a way that the average value of the output waveform within each sample period tracks the desired output waveform. As consequence of the input ± output direct connection, at any instant, the output voltages have to fit within the enveloping curve of the input voltage system. The output voltage injected into the transmission line:

$$V_u = V_o \cos\theta_{ou} = V_o \cos(\omega t + \varphi_o + \psi_{out}) \quad (7)$$

$$V_v = V_o \cos\theta_{ov} = V_o \cos(\theta_{ou} - (\tfrac{2\pi}{3})) \quad (8)$$

$$V_w = V_o \cos\theta_{ow} = V_o \cos(\theta_{ou} + (\tfrac{2\pi}{3})) \quad (9)$$

4. NEURO FUZZY BASED UPFC

Fuzzy logic is one of the intelligent technique that will show particular problems to a developer:

- Rules. The if-then rules have to be determined somehow. This is usually done by ‘knowledge acquisition’ from an expert. It is a time consuming process that is fraught with problems.
- Membership functions. A fuzzy set is fully determined by its membership function. This has to be determined. If it’s gaussian then what are the parameters?

The ANFIS approach learns the rules and membership functions from data. ANFIS is an adaptive network. An adaptive network is network of nodes and directional links. Associated with the network is a learning rule - for example back propagation. It’s called adaptive because some, or all, of the nodes have parameters which affect the output of the node. These networks are learning a relationship between inputs and outputs. An adaptive network covers a number of different approaches but for our purposes we will investigate in some detail the method proposed by Jang known as ANFIS. The ANFIS architecture is shown figure 4. The circular nodes represent nodes that are fixed

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whereas the square nodes are nodes that have parameters to be learnt [11]-[14].

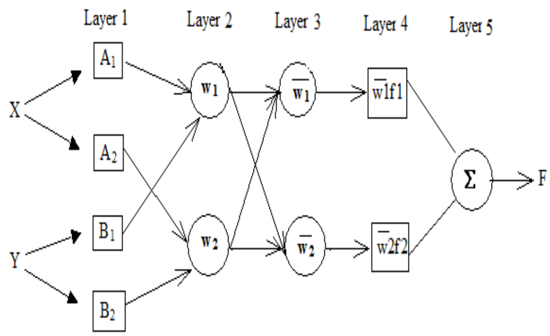

Figure 4: An ANFIS architecture for a two rule Sugeno system

A Two Rule Sugeno ANFIS has rules of the form:

$$\text{If } x \text{ is } A_1 \text{ and } y \text{ is } B_1 \quad \text{THEN } f_1 = p_1x + q_1y + r_1$$
$$\text{If } x \text{ is } A_2 \text{ and } y \text{ is } B_2 \quad \text{THEN } f_2 = p_2x + q_2y + r_2 \quad (10)$$

For the training of the network, there is a forward pass and a backward pass. We now look at each layer in turn for the forward pass. The forward pass propagates the input vector through the network layer by layer. In the backward pass, the error is sent back through the network in a similar manner to back propagation.

Layer 1

The output of each node is:

$$O_{1,i} = \mu_{A_i}(x) \qquad for\ i = 1,2$$

$$O_{1,i} = \mu_{B_{i-2}}(y) \qquad for\ i = 3,4$$

So, the $O_{1,i}(x)$ is essentially the membership grade for x and y. The membership functions could be anything but for illustration purposes we will use the bell shaped function given by:

$$\mu_A(x) = \frac{1}{1 + \left|\frac{x - c_i}{a_i}\right|^{2b_i}} \qquad (11)$$

where a_i, b_i, c_i are parameters to be learnt. These are the premise parameters.

Layer 2

Every node in this layer is fixed. This is where the t-norm is used to 'AND' the membership grades - for example the product:

$$O_{2,i} = w_i = \mu_{A_i}(x)\mu_{B_i}(y), \quad i = 1,2 \qquad (12)$$

Layer 3

Layer 3 contains fixed nodes which calculates the ratio of the firing strengths of the rules:

$$O_{3,i} = \overline{w_i} = \frac{w_i}{w_1 + w_2} \qquad (13)$$

Layer 4

The nodes in this layer are adaptive and perform the consequent of the rules:

$$O_{4,i} = \overline{w_i} f_i = \overline{w_i}(p_i x + q_i y + r_i) \qquad (14)$$

The parameters in this layer (p_i, q_i, r_i) are to be determined and are referred to as the consequent parameters.

Layer 5

There is a single node here that computes the overall output:

$$O_{5,i} = \sum_i \overline{w_i} f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \qquad (15)$$

This then is how, typically, the input vector is fed through the network layer by layer. We now consider how the ANFIS learns the premise and consequent parameters for the membership functions and the rules. There are a number of possible approaches proposed [15] which uses a combination of Steepest Descent and Least Squares Estimation (LSE). This can get very complicated (!) so here I will provide a very high level description of how the algorithm operates. It can be shown that for the network described if the premise parameters are fixed the output is linear in the consequent parameters. We split the total parameter set into three

S = set of total parameters

S_1 = set of premise (nonlinear) parameters

S_2 = set of consequent (linear) parameters

So, ANFIS uses a two pass learning algorithm:

- Forward Pass. Here S_1 is unmodified and S_2 is computed using a LSE algorithm.
- Backward Pass. Here S_2 is unmodified and S_1 is computed using a gradient descent algorithm such as back propagation.

So, the hybrid learning algorithm uses a combination of steepest descent and least squares to adapt the parameters in the adaptive network.

5. RESULTS AND DISCUSSIONS

To analyze the performance of the matrix converter based UPFC suitable simulation is performed using MATLAB/Simulink. The results

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are compared with the help of SVPWM and neural fuzzy-SVPWM based control logic. Load variations are created to study the performance of the proposed scheme. The initial load in the system, equal in value with base power, is 200MW, 10MVAR and is disconnected at time 0.3msecs and other load with rating of 200MW and 100MVAR is applied to the system. Real and reactive power of the transmission line track almost to the references irrespective of load variation. Figure 5shows the switching pulses for neural fuzzy-SVPWM based matrix converter. Figure 6a shows the real power of neural fuzzy-SVPWM based system and figure 6b shows the real power of SVPWM based system. From the output of neural fuzzy-SVPWM based UPFC gives the better response compared to the SVPWM based system. During load changes real power of the neural fuzzy-SVPWM based system reaches peak magnitude of 2.6 p.u, after 0.02 msec it reaches to its steady state value. But in SVPWM based system real power reaches to 3.1 p.u and it takes 0.03 msec to reach its steady state value. Similarly reactive power also shown in figure 7a and 7b. Figure 8a and 8b, 9a and 9b, 10a and 10b shows the output voltage, output current, input real and reactive power of neural fuzzy-SVPWM and SVPWM based UPFC respectively. Table.1 shows the performance comparison during the load change period. From this neural fuzzy-SVPWM based system gives the better response when compared SVPWM based UPFC.

Table. 2: Comparison of SVPWM and Neuro-Fuzzy based UPFC parameters

S. No	Parameters	SVPWM Based UPFC		Neuro-Fuzzy Based UPFC	
		Value (p.u)	Time (msec)	Value (p.u)	Time (msec)
1	Output Real Power	3.1	0.03	2.6	0.02
2	Output Reactive Power	1.7	0.025	1.6	0.02
3	Output Voltage	1.2	0.01	1.0	0.01
4	Output Current	0.021	0.01	0.021	0.01
5	Input Real Power	0.007	0.03	0.011	0.02
6	Input Reactive Power	0.037	0.025	0.0325	0.02

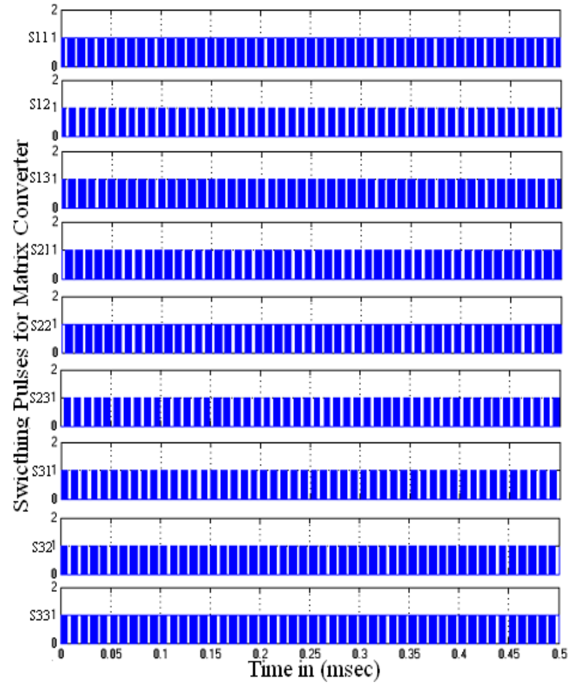

Figure 5: Switching pulses for matrix converter

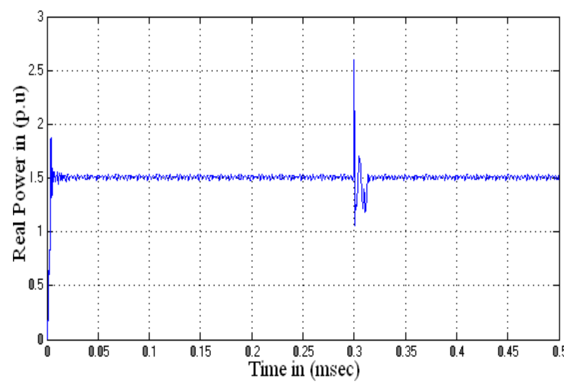

Figure 6a: Real Power of Neuro Fuzzy-SVPWM based UPFC

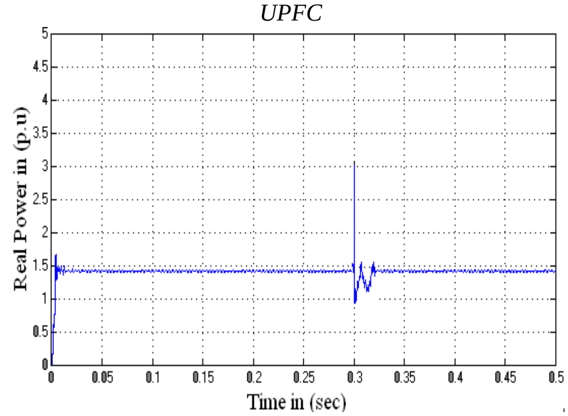

Figure 6b: Real Power of SVPWM based UPFC

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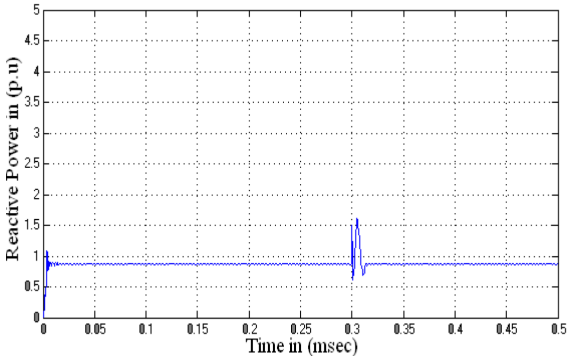

Figure 7a: Reactive Power of Neuro Fuzzy-SVPWM based UPFC

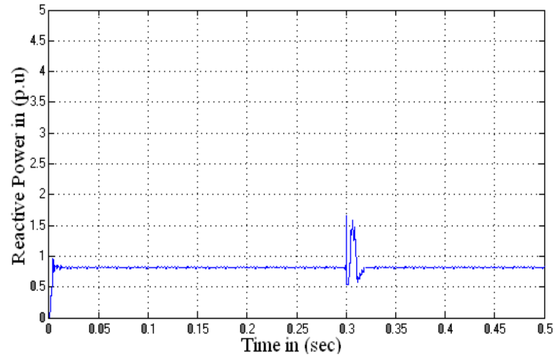

Figure 7b: Reactive Power of SVPWM based UPFC

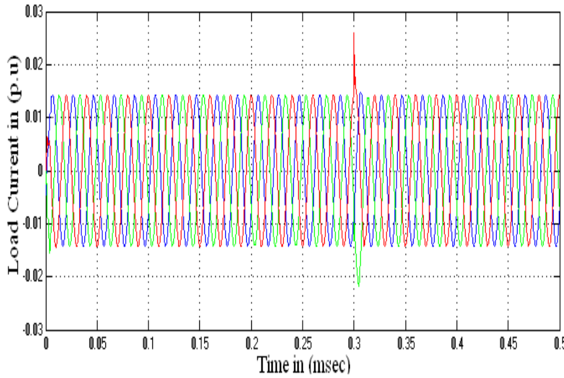

Figure 8a: Output Line Current Waveform of Neuro Fuzzy-SVPWM based UPFC

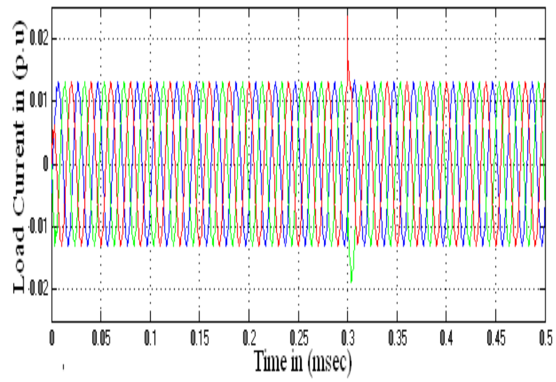

Figure 8b: Output Line Current Waveform of SVPWM based UPFC

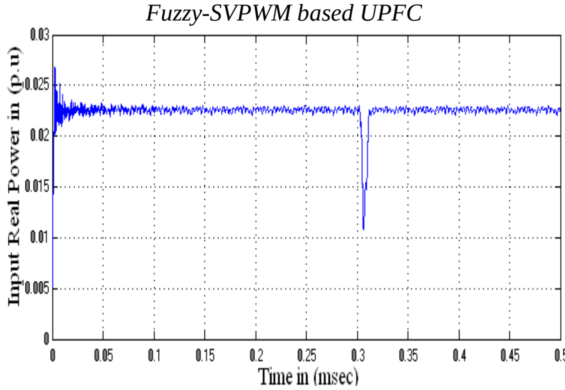

Figure 9a: Input Real Power of Neuro Fuzzy-SVPWM based UPFC

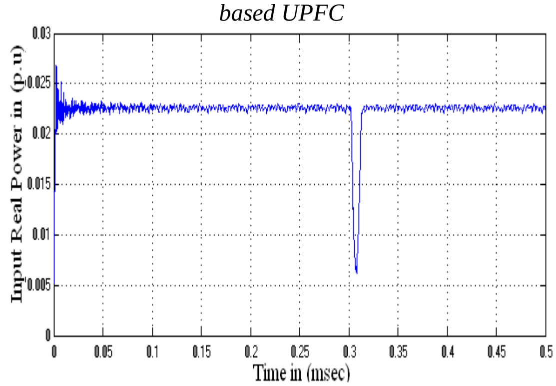

Figure 9b: Input Real Power of SVPWM based UPFC

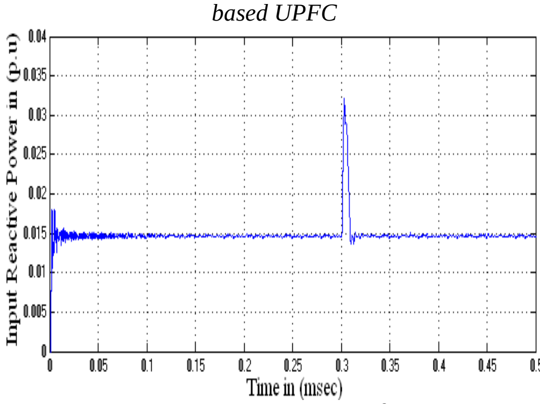

Figure 10a: Input Reactive Power of Neuro Fuzzy-SVPWM based UPFC

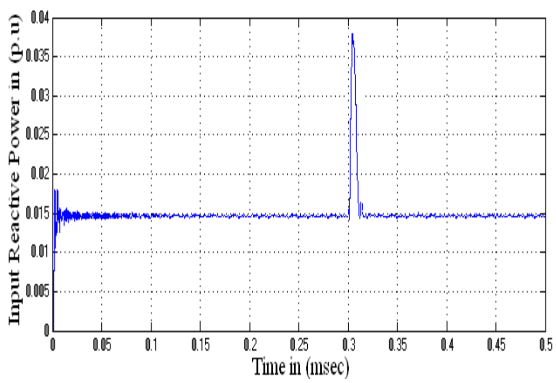

Figure 10b: Input Reactive Power of SVPWM based UPFC

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6. CONCLUSION

In this paper neuro-fuzzy logic controller is implemented for the matrix converter based UPFC to be connected into the transmission line. The cost and space occupied by the dc link capacitor in the existing UPFC structure are quite large which leads to a complex design of UPFC. But in this scheme of UPFC with matrix converter allows a compact design due to the lack of dc link capacitor. Neuro-fuzzy based system response is quick compared to the space vector modulation because it takes time to generate pulses for matrix converter. The performance of the system is analyzed with MATLAB / Simulink assuming that the UPFC is connected with the 230kV.

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