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Implementation of Matrix Converter Based Unified Power Flow Controller (UPFC) for Power Flow Control in a Transmission Line

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Abstract: Investigation on performance of Unified Power Flow Controller (UPFC) in controlling the flow of power over transmission line by using different control techniques is presented in this study. Matrix Converters (MCs) capable of allowing the direct AC/AC power conversion without DC energy storage links; it is observed that the MC-based UPFC (MC-UPFC) controller reduces volume, cost and capacitor power losses with higher reliability. Genetic algorithm based solution applied to control the matrix converter switches in these converters. As a result, line active and reactive power could be directly controlled by selecting an appropriate matrix converter switching state guaranteeing good steady-state flow of power and dynamic responses. Performance of proposed technique is shown in simulation done in MATLAB. Results of genetic algorithm-SVPWM based UPFC are compared with neuro-fuzzy logic controller-SVPWM and PI controller-SVPWM based UPFC in terms of active and reactive power flows in the line.

Key words: Unified Flow Controller (UPFC), Matrix Converter (MC), Space Vector Modulation (SVM), Genetic Algorithm (GA), India

INTRODUCTION

In recent years, it has become more difficult to construct new generation facilities and transmission lines due to energy and environment problems. To achieve operational reliability and financial profitability, more efficient utilization and control of existing transmission system infrastructure along with the interconnection is required. It would be easier that the power transmitting capabilities of the existing transmission systems are improved up to thermal limit, instead of constructing a fresh or new. The idea behind the FACTS device is rapid compensation and enhancement of flexibility of power line parameters. The following are some of the FACTS controllers vide Static Var Compensator (SVC), Thyristor Control Series Capacitor (TCSC), Static Synchronous Compensator (STATCOM) and Static Synchronous Series Compensator (SSSC). But, due to different configurations of these controllers they were not able to control the active and reactive power separately. The Unified Power-Flow Controller (UPFC) is a member of the FACTS family with many attractive features. UPFC is recognized as one of the important features of FACTS devices (Gyugyi *et al*., 1995; Hingorani and Gyugyi, 1999; Al-Mamsawi, 2003) which can provide simultaneous active and reactive power flow control and 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 and shorter life. This limits the life and reliability of the voltage source inverter (Soto and Green, 2002). To overcome these limitations, a Matrix Converter (MC) is employed in UPFC where 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, lesser number of switches, reduced THD, etc. Also, matrix converters are more reliable and potentially have much longer life,

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because of the absence of the DC link capacitor (Mutschler and Marcks, 2002). The proposed control technique to control the UPFC is Genetic algorithm. A number of conventional techniques have been used are PI controller, fuzzy logic, neuro-fuzzy controller and space vector modulation. 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 fuzzy controller has a number of distinguished advantages but the membership functions cannot be adapted with respect to the system operations (Mishra *et al*., 2000; Nauck *et al*., 1997). In this research, a neuro-fuzzy logic controller is used for UPFC to combine the fuzzy qualitative approach with the adaptive capabilities of neural networks to achieve improved performance. Further, space vector modulation is also developed for UPFC. These techniques were time consuming and require heavy computation burden (Nauck *et al*., 1997; Czogala and Leski, 2000). One of the most promising researches in recent years in this area has been adopting evolutionary techniques to the controller logical programming; these evolutionary techniques are popular with research community due to the design tools and problem solvers because of their versatility and ability to optimize in complex multimodal search spaces applied to non-differentiable objective functions. Recent researches show that the Genetic algorithm model is promising evolutionary technique for handling the multi objective optimization problems (Noorossana *et al*., 2012). GA has been popular in academia and the industry mainly because of its intuitiveness, ease of implementation and the ability to effectively solve highly non-linear, mixed integer optimization problems that are typical of complex engineering systems. In this study, Genetic algorithm model is proposed for matrix converter in UPFC. The results of genetic algorithm-SVM based UPFC is compared with neuro-fuzzy logic controller-SVM and Space Vector Modulation (SVM) based UPFC in terms of active and reactive power flows in the line and active, reactive power flows at the bus to analyse the performance of UPFC.

MATERIALS AND METHODS

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 Fig. 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 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. 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 (Seo *et al*., 2001; Cataliotti *et al*., 2002).

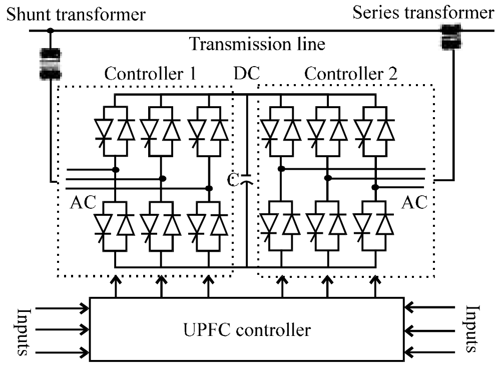

Fig. 1: Block diagram of unified power flow controller

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 increases with the ratings and 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 (Gyugyi *et al*., 1995; Hingorani and Gyugi, 1999; Al-Mamsawi, 2003).

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. 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 Fig. 2. 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 (Table 1, Fig. 3).

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:

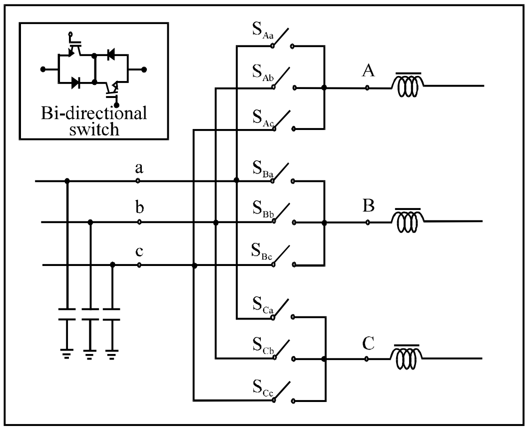

Fig. 2: Circuit diagram of matrix converter

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

$$V_b = V_m \cos\theta_{bv} = V_m \cos\left(\omega t - \left(\frac{2\pi}{3}\right)\right) \tag{2}$$

$$V_c = V_m \cos\theta_{cv} = V_m \cos\left(\omega t + \left(\frac{2\pi}{3}\right)\right) \tag{3}$$

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

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

$$I_b = I_m \cos\theta_{bv} = I_m \cos\left(\omega t - \left(\frac{2\pi}{3}\right) - \psi_{in}\right) \tag{5}$$

$$I_c = I_m \cos\theta_{cv} = I_m \cos\left(\omega t + \left(\frac{2\pi}{3}\right) - \psi_{in}\right) \tag{6}$$

Table 1: Switching combinations for matrix converter

Group	Phase			Output voltage			Input current			Switching function values								
state	A	B	C	u_{AB}	u_{BC}	u_{CA}	i_{ia}	i_{ib}	i_{ic}	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	0	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	$-u_{ac}$	u_{ac}	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	$-u_{ac}$	u_{ac}	$-i_C$	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

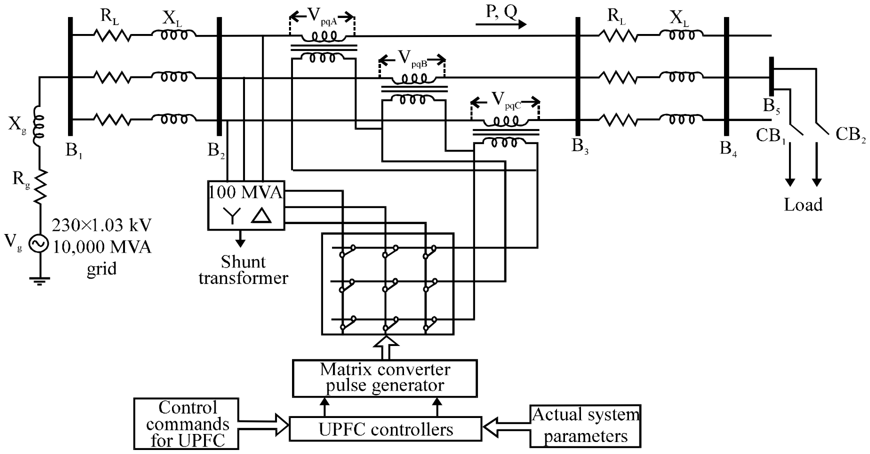

Fig. 3: Circuit diagram of matrix converter based UPFC

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:

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

$$V_v = V_o \cos\theta_{ov} = V_o \cos\left(\theta_{ou} - \left(\frac{2\pi}{3}\right)\right) \tag{8}$$

$$V_w = V_o \cos\theta_{ow} = V_o \cos\left(\theta_{ou} + \left(\frac{2\pi}{3}\right)\right) \tag{9}$$

Control methodologies

Space vector modulation: Looking at the basic features of the matrix converter that have been described, it might be surprising to establish that this converter topology, today has not found a wide utilization yet. The reasons are described in many researches, number of practical implementation problems that have slowed down the development of this technology. Space Vector Modulation (SVM) is an algorithm for the control of Pulse Width Modulation (PWM). It is used for the creation of Alternating Current (AC) waveforms; most commonly to drive 3 phase AC powered motors at varying speeds from DC using multiple class-D amplifiers. There are various variations of SVM that result in different quality and computational requirements. One active area of development is in the reduction of Total Harmonic Distortion (THD) created by the rapid switching inherent to these algorithms (Seo *et al*., 2001).

Space vector theory: Let x_a, x_b and x_c be the instantaneous values of arbitrary three phase variables forming the space vector:

$$X = \frac{2}{3}(x_a + ax_b + a^2x_c) \tag{10}$$

where, $a = e^{j(2\pi/3)}$. When the three phase system considered contains a zero sequence component of an average x_0, it has to be taken into account separately:

$$X = |x|x^{j\omega}x^{t} \tag{11}$$

$$X = \frac{x_a + x_b + x_c}{3} \tag{12}$$

$$X = \mathrm{Re}\{x\} + j\mathrm{Im}\{x\} = X_\alpha + X_\beta \tag{13}$$

It is often to present x using two axis components, i.e., to separate it into the projections of the real and imaginary axis, Re and Im, respectively. In a stationary reference frame, the transformation from a three phase to the two axis and zero sequence components can be performed as follows:

$$\begin{bmatrix} X_\alpha \\ X_\beta \\ X_o \end{bmatrix} = \left(\frac{2}{3}\right) \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{1}{2} & -\frac{1}{2} \end{bmatrix} \tag{14}$$

Sometimes, it is advantageous to use some other reference frame instead of the stationary one. Let θ_k be the instantaneous angle of an arbitrary reference frame, Let θ_x be the angle of the x in the stationary reference frame at the same instant as θ_k, i.e., $\theta_x = \omega_x t$ and let x_k be the space vector transformed from the stationary to the arbitrary reference frame:

$$X = |x| e^{j(\theta x - \theta k)} \tag{15}$$

The transformations are then in matrix form:

$$\begin{bmatrix} X_{xd} \\ X_{kq} \\ X_o \end{bmatrix} = \begin{bmatrix} \cos\theta & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{1}{2} & -\frac{1}{2} \end{bmatrix} \tag{16}$$

The output voltage of the SVM technique is defined as:

$$V_{oL} = \left(\frac{2}{3}\right)\left(V_{AB} + V_{BC} e^{+j120^\circ} + V_{CA} e^{-j120^\circ}\right) \tag{17}$$

Voltage source rectifier input current SVM: The input current SVM is completely analogous to the output voltage SVM. The Voltage Source Rectifier (VSR) hexagon is shown in Fig. 4. The VSR duty cycles are:

$$d_\gamma = \frac{T_\gamma}{T_S} = m_i \sin\left(\frac{\pi}{3}\right) - \theta_{Si} \tag{18}$$

$$d_\delta = \frac{T_\delta}{T_S} = m_i \sin\theta_{Si} \tag{19}$$

$$d_{oi} = \frac{T_{oi}}{T_S} = 1 - d_\gamma - d_\delta \tag{20}$$

To implement space vector modulation a reference signal V_{ref} is sampled with a frequency f_s ($T_s = 1/f_s$). The reference signal may be generated from three separate phase references using the transform. The reference vector is then synthesized using a combination of the two adjacent active switching vectors and one or both of the zero vectors. Various strategies of selecting the order of the vectors and which zero vector(s) to use exist. Strategy selection will affect the harmonic content and increase the switching losses. Where, M_i is the modulation index of the rectifier stage:

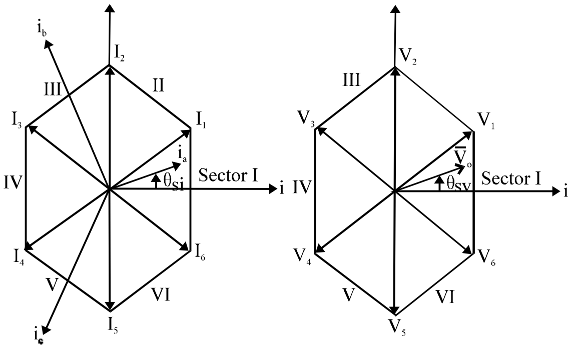

Fig. 4: Input current SVM and output voltage SVM

I_γ				I_δ			
$\xleftrightarrow{T_\gamma}$				$\xleftrightarrow{T_\delta}$			
V_0	V_α	V_β	V_0	V_0	V_β	V_α	V_0
$\frac{T_0}{4}$	$\xleftrightarrow{T_{\gamma\alpha}}$	$\xleftrightarrow{T_{\gamma\beta}}$	$\frac{T_0}{4}$	$\frac{T_0}{4}$	$\xleftrightarrow{T_{\delta\beta}}$	$\xleftrightarrow{T_{\delta\alpha}}$	$\frac{T_0}{4}$

Fig. 5: ISVM switching pattern

$$M_i = \frac{2 I_m}{\sqrt{3} I_{om}} \cos\varphi_L, \quad 0 \le M_i \le 1 \tag{21}$$

Matrix converter output voltage and input current SVM: To obtain a proper balance between the input currents and the output voltages in the same switching period, the switching pattern of the inversion stage should include both its active switching vectors during each active sequence of the rectification stage as shown in Fig. 5.

In the first active portion of the rectification stage, the durations of the inversion stage active switching vectors are obtained by the following product:

$$d_{\gamma\alpha} = d_\gamma d_\alpha$$

$$d_{\gamma\beta} = d_\gamma d_\beta$$

In second active portion these durations are calculated as follows:

$$d_{\delta\alpha} = d_\delta d_\alpha$$

$$d_{\delta\beta} = d_\delta d_\beta$$

Each duty cycle sequence is a result of the products of the rectification and inversion stage duty cycles. One switching sequence is completed by the zero vectors with a duty ratio of:

$$d_o = 1 - d_{\alpha\gamma} + d_{\delta\alpha} + d_{\delta\beta} \quad (22)$$

The duration of each sequence is found by multiplying the corresponding duty cycle to the switching period. Thus, in the ISVM Method, the four active states and the zero state to be applied in each PWM period are determined according to the sector in which the space vectors of output voltage and input current lie. In order to reduce harmonic distortion, duty cycles are symmetrically distributed round the zero state duty cycle as shown in Fig. 5 (Cataliotti *et al*., 2002; Mondal *et al*., 2003; Mishra *et al*., 2000).

Neuro fuzzy based UPFC: Fuzzy logic is one of the intelligent techniques 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.

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. The ANFIS architecture is shown in Fig. 6. The circular nodes represent nodes that are fixed whereas the square nodes are nodes that have parameters to be learnt (Nauck *et al*., 1997; Czogala and Leski, 2000). A Two Rule Sugeno ANFIS has rules of the form: If x is A_1 and y is B_1 THEN $f_1 = p_1x+q_1y+r_1$ and If x is A_2 and y is B_2 THEN $f_2 = p_2x+q_2y+r_2$.

For the training of the network, there is a forward pass and a backward pass. researchers 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:

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

$$O_{1,i} = \mu_{B_{i-2}}(x) \quad \text{for } i = 3, 4$$

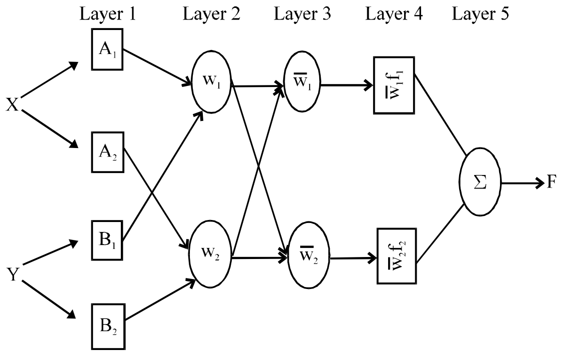

Fig. 6: An ANFIS architecture for a two Rule Sugeno System

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 researchers will use the bell shaped function given by:

$$\mu_A(x) = \frac{1}{1 + \left|\frac{x - C_i}{a_i}\right|^{2b_i}} \quad (23)$$

where, a_i, b_i, c_i are parameters to be learned. 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:

$$O_{2,i} = W_i = \mu_{A_i}(x)\mu_{B_i}(y) \quad \text{for } i = 1, 2 \quad (24)$$

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

$$O_{3,i} = \overline{W}_i = \frac{W_i}{W_1 + W_2} \quad (25)$$

Layer 4: The nodes in this layer are adaptive and perform the consequent of the rules:

$$O_{4,i} = \overline{W}_i f_i = \overline{W}_i(P_i x + q_i y + r_i) \quad (26)$$

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:

$$O_{5,i} = \sum_i \overline{W}_i f_i = \frac{\sum_i W_i f_i}{\sum_i W_i} \quad (27)$$

This then is how, typically, the input vector is fed through the network layer by layer. There are a number of possible approaches proposed (Jange *et al*., 1997) which uses a combination of Steepest Descent and Least Squares Estimation (LSE). This can be very complicated so the total parameter set is divided into three:

- S = Set of total parameters
- S_1 = Set of premise (non-linear) 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.

Genetic algorithm: Genetic based UPFC controllers are designed to minimize the power system oscillation after a disturbance so as to improve the stability. Genetic algorithms are the heuristic search and optimization techniques that mimic the process of natural evolution. Genetic Algorithms (GA) are direct, parallel, Stochastic Method for global search and optimization which imitates the evolution of the living beings. These evolutionary algorithms use the three main principles of the natural evolution: reproduction, natural selection and diversity of the species, maintained by the differences of each generation with the previous. GA works with a set of individuals, representing possible solutions of the task.

Every individual in the population gets an evaluation of its adaptation (fitness) to the environment. In the terms of optimization this means that the function that is maximized or minimized is evaluated for every individual. The basic search mechanism of GA is provided by the genetic operators. There two basic types of operators: crossover and mutation. These operators are used to produce new solutions based on existing solutions in the population. Crossover takes two individuals to be parents and produces two new individuals while mutation alters one individual to produce a single new solution. Initialization, termination and evaluation function: an initial population is needed to start the Genetic algorithm procedure. The initial population can be randomly generated. The inserted voltage of UPFC ΔU_{UPFC} has a maximum magnitude 0.1 V_m where V_m is the rated voltage of the transmission line where the UPFC is installed. The angle of ΔU_{UPFC} can be varied from -180° to +180°. Therefore, r_f is converted into the working angle of r_{upfc} using the following equation:

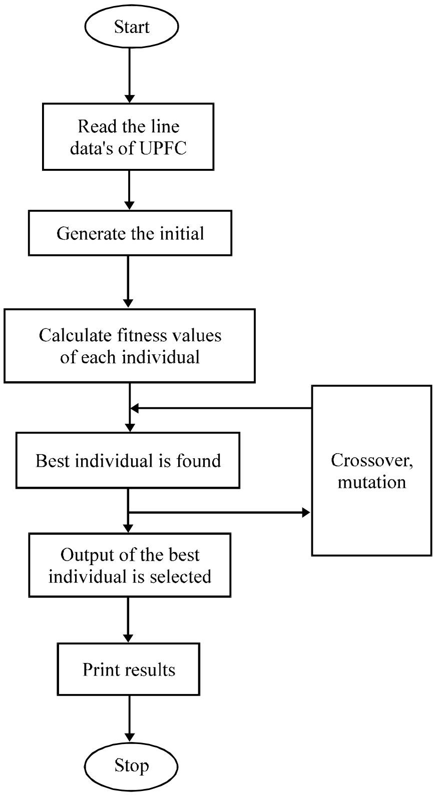

Fig. 7: Flow chart for GA based UPFC

$$r_{upfc} = r_f \times 180° \qquad (28)$$

The selection chooses the best gene combinations (individuals) which through crossover and mutation should drive to better solutions in the next population. Figure 7 shows the algorithm for UPFC by using Genetic algorithm.

RESULTS AND DISCUSSION

The performance of the matrix converter based UPFC is analysed by using various control techniques such as Genetic algorithm with SVPWM, Neuro-Fuzzy with SVPWM and PI-SVPWM are used and the simulation is done by using MATLAB/Simulink. Load variations are created to study the performance of the proposed system. The initial load in the system is 200 MW, 10 MVAR and is disconnected at time 0.3 sec and other load with rating of 200 MW and 100 MVAR is applied to the system. The real and reactive power of the transmission line tracks almost to the references irrespective of load variation.

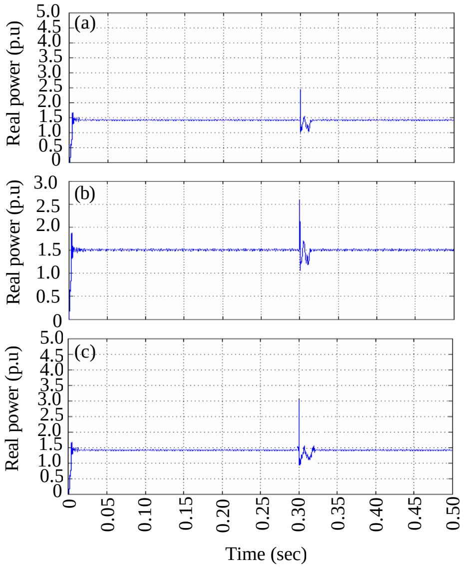

Fig. 8: a) Real power of Genetic algorithm-SVPWM based UPFC; b) real power of neuro fuzzy-SVPWM based UPFC and c) real power of PI controller-SVPWM based UPFC

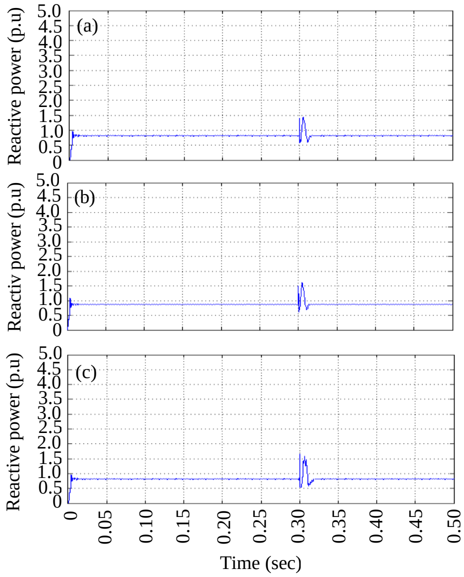

Fig. 9: a) Reactive power of Genetic algorithm-SVPWM based UPFC; b) reactive power of neuro fuzzy-SVPWM based UPFC; c) reactive power of PI controller-SVPWM based UPFC

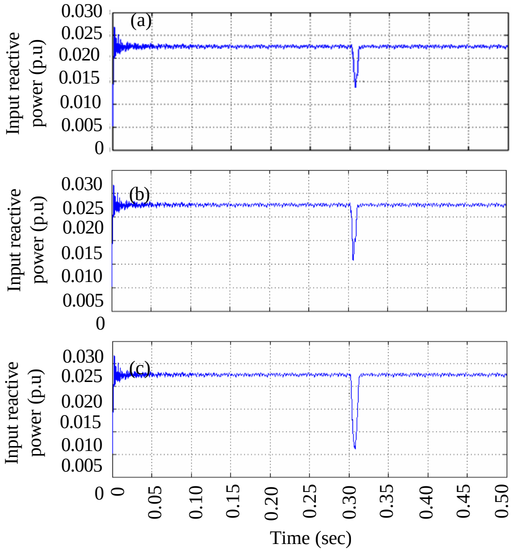

Fig. 10: a) Input real power of Genetic algorithm-SVPWM based UPFC; b) input real power of neuro fuzzy-SVPWM based UPFC and c) input real power of PI controller-SVPWM based UPFC

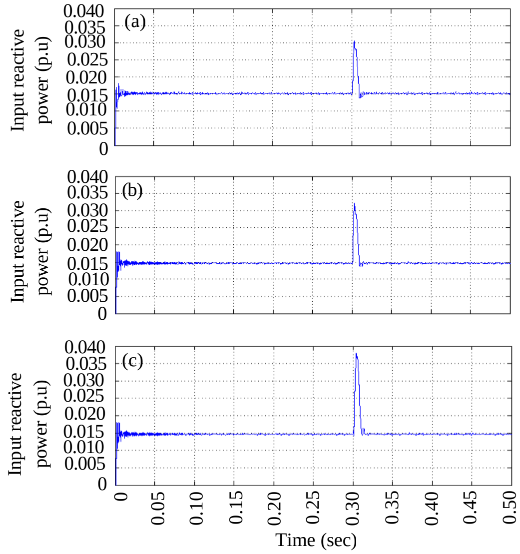

Fig. 11: a) Input reactive power of Genetic algorithm-SVPWM based UPFC; b) input reactive power of neuro fuzzy-SVPWM based UPFC and c) input reactive power of PI controller-SVPWM based UPFC

Figure 8a shows the real power of Genetic algorithm-SVPWM based system and Fig. 8b and c show the real power of neuro-fuzzy-SVPWM and PI-SVPWM based system. From these outputs, the Genetic algorithm-SVPWM based UPFC gives out the better response compared to the neuro-fuzzy-SVPWM and PI-SVPWM based system. During load changes real power based on the Genetic algorithm reaches peak magnitude of 3.1 p.u., after 0.03 sec it reaches to its steady state value. But, in neuro-fuzzy and SVPWM based system real power reaches to 2.6 and 2.4 p.u., respectively then it takes 0.02 sec to reach its steady state value. Similarly, from the Fig. 9a-c reactive power disturbance when load applied at 0.3 msec quickly tracked to its reference value (Fig. 10a-c,

Table 2: Comparison of SVPWM and neuro-fuzzy based UPFC parameters

	PI-SVPWM based UPFC		Neuro-fuzzy-SVPWM based UPFC		Genetic algorithm-SVPWM based UPFC	
Parameters	Value (p.u.)	Time (sec)	Value (p.u.)	Time (sec)	Value (p.u.)	Time (sec)
Output real power	3.100	0.030	2.600	0.020	2.400	0.020
Output reactive power	1.600	0.025	1.500	0.020	1.400	0.020
Output voltage	1.200	0.015	1.100	0.015	1.100	0.015
Output current	0.026	0.010	0.026	0.010	0.025	0.010
Input real power	0.007	0.030	0.011	0.015	0.014	0.010
Input reactive power	0.037	0.010	0.032	0.010	0.030	0.010

11a-c) input real and reactive power of Genetic algorithm, neuro fuzzy and SVPWM based UPFC, respectively. Table 2 shows the performance comparison during the load change period. From this Genetic algorithm based system gives the better response when compared neuro-fuzzy and SVPWM based UPFC.

CONCLUSION

In this study, Genetic algorithm is implemented for the matrix converter based UPFC. 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 which has been reduced to a larger extent by this scheme of UPFC with matrix converter which allows a compact design due to the lack of dc link capacitor. Genetic algorithm-SVPWM based system tracks its steady state value quickly when compared to the neuro-fuzzy-SVPWM and PI-SVPWM controller based system because it consumes more time to generate pulses for matrix converter.

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