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Transient Stability Improvement of Multi Machine Power Systems using Matrix Converter Based UPFC with ANN

V. Bharathi[1] P.Lakshmanan[2]
[1]PG Student [2]Assistant Professor
[1,2]Department of Electronics & Electrical Engineering
[1,2]V.S.B Engineering College, Karur, Tamilnadu, India

Abstract— In present decades, owing to the swell and growing power systems electrical power demand, it is required to make exploit of the transmission lines equipped to its utmost loading limit. The transient stability restricts the steady state loading of the power system and the system becomes unstable prior attaining the state stability limit. Stability is an immense menace in the power system during the conflicts in the system. The electromechanical oscillations occurring in the rotor are generally damped out by means of power system stabilizers, which cannot damp inter area oscillations that will cause the system to lose its synchronism. Bringing back the system into synchronism is tedious and leads Flexible AC Transmission Systems (FACTS) devices, which rapidly and independently controls the actual and reactive power flows in a transmission line [1]-[5].In this paper, the enhancement of transient stability of the study system using matrix converter based UPFC employing space vector modulation technique is simulated using MATLAB – Simulink environment beneath fault condition with and without matrix converter [5]-[7]. The results obtained on both the case are compared and the efficiency of the matrix converter is revealed.

Key words: Transient Stability, UPFC, MATLAB Matrix Converter

I. INTRODUCTION

The erection of new generating stations and transmission systems are deferred due to the environment, economic and further problems. Hence it is essential to alter the existing strategies used for maintaining the power systems which lead the system to get loaded to its maximum allowable limit to have better reliability, control and flexibility. For this purpose FACTS devices gets employed. Unified Power Flow Controller is a combination of both series and shunt controller is an effective device employed for ensuring transient stability. The main limitation of the usual UPFC is the presence of the DC link capacitor between the converters that build the converter hulking and its concert will decline. This difficulty can be overcome by make use of Matrix Converter based UPFC [9]-[11]. The power flow in the transmission line is enhanced to its capable limit and the system is said to continue its synchronism by maintaining the load angle within the generator limits even after subjected to a disturbance [1].

II. CONVENTIONAL UPFC

UPFC is a grouping of SSSC series connected device and STATCOM shunt connected device. It comprises of series and shunt connected voltage source inverters allied by means of a DC link. The actual power demand is met by maintaining the DC link voltage as constant Vdc and thus discharging the stored energy into the line when demand occurs. UPFC can simultaneously control the three parameters (voltage, line impedance, phase angle) of the transmission line [6]. Converter connected in series maintains the voltage profile of the line and converter connected in parallel supplies the requirement of the series connected converter [7]. The limitation of the DC capacitor overcomes the advantages but the best possible operating point is achieved by the use of

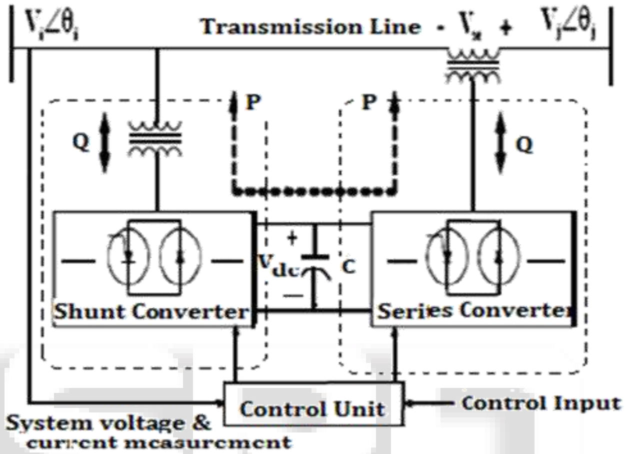

Fig. 1: Schematic diagram of UPFC

III. MATRIX CONVERTER BASED UPFC

Matrix Converter is the single step converter which affords the conversion of AC directly into AC quite than converting AC into DC and again to AC. It undergoes operation with only nine bidirectional switches replacing the voltage source converters and the DC link capacitor in the conventional UPFC.

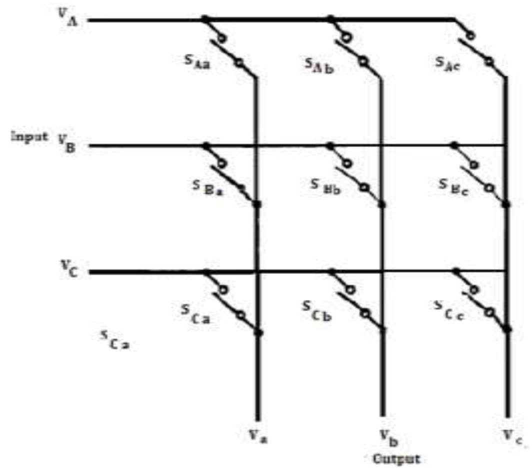

Fig. 2: Schematic diagram of Matrix converter

With nine switches, the possible switching combinations are 512 and out of the possible combinations only 27 switching combinations are accepted by obeying the rules at any moment of operation. Three switches conduct at a time and so switching losses are minimized in evaluation with conventional UPFC. The sequential sampling of input waveform gives the output waveform. As the energy storage components are absent at both the input and output sides of the converter, the output voltages gets generated directly as of the input voltages.

The voltage equations at the input side of the Matrix converter is given below

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

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

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

The line side current in the shunt converter is given 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 output voltage injected to the line is given as,

$$V_u = V_o \cos\theta_{ou} = V_o \cos(\omega t + \varphi_o + \psi_{out}) \quad (8)$$

$$V_v = V_o \cos\theta_{ov} = V_o \cos(\theta_{ou} - (\tfrac{2\pi}{3})) \quad (9)$$

$$V_w = V_o \cos\theta_{ow} = V_o \cos(\theta_{ou} + (\tfrac{2\pi}{3})) \quad (10)$$

Group	State	Phase A	B	C	Output voltage u_{AB}	u_{BC}	u_{CA}	Input current i_a	i_b	i_c	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

Table 1: Matrix Converter Switching Vector

The rate of sampling have to be set superior than both input and output frequencies, and the time interval of the sample should be controlled in such a way that the average value of The output voltages fit in with the desired curve of the input voltage system as the input and output waveforms gets connected without any energy storage elements [9].

IV. MODULATION TECHNIQUE

Space Vector Modulation (SVM) is applied to control the matrix converter since it has reduced harmonic distortion and high input output transfer ratio than the pulse width modulation technique [11]. SVM is applied concurrently to input current vectors and output voltage vectors. This modulation technique has the intact control of output voltage and of input current displacement angle in the presence of disturbances in the system. The output voltage is given by

$$V_o = \frac{2}{3}\left[v_{ab} + v_{bc}\exp(-j120°) + v_{ca}\exp(j120°)\right] \quad (10)$$

Group II and Group III switching topologies shown in the table are used in SVM as they follow the two rules. Group II with stationary or active vectors are having constant angular positions and Group III with only zero vectors are worn with stationary vectors of group II to attain output voltage. Four stationary vectors and two zero vectors are preferred for the algorithm to construct the reference voltage for the period of every sampling period T_s. After computing the voltage amplitude and phase angle, input current phase angle is calculated. The equations used for calculating on time of the four stationary vectors in SVM are

$$t_1 = \frac{2qT_s}{\sqrt{3}\cos\varphi_i}\sin(60° - \theta_o)\sin(60° - \theta_i) \quad (11)$$

$$t_2 = \frac{2qT_s}{\sqrt{3}\cos\varphi_i}\sin(60° - \theta_o)\sin(\theta_i) \quad (12)$$

$$t_3 = \frac{2qT_s}{\sqrt{3}\cos\varphi_i}\sin(\theta_o)\sin(60° - \theta_i) \quad (13)$$

$$t_4 = \frac{2qT_s}{\sqrt{3}\cos\varphi_i}\sin(\theta_o)\sin(\theta_i) \quad (14)$$

Where q denotes the voltage transfer ratio, φ_i denotes the input displacement angle, θ_o and θ_i indicates the phase displacement angles of output voltage and input current vectors correspondingly. The equation for calculating the two zero vector time is given as

$$t_o = T_s - \sum_{i=1}^{4} t_i \quad (15)$$

V. ANN CONTROLLER FROM PI CONTROLLER

In the matrix converter based UPFC system for transient stability enhancement four controllers are engaged, two controllers in series and two controllers in shunt. ANN controller is a derivative of a PI controller. All neuron output is the function of its input neuron. The jth neuron output is denoted by the equations

$$U_j = \sum(X_i \,.\, W_{ij}) \quad (16)$$

$$Y_j = F_{th}(U_j + t_j) \quad (17)$$

This corrective process algorithm is known as back propagation as the error propagates back from the output layer to the input layer and continues its action until optimal output (the total error gets reduced and meets the specified criteria) is generated. At this instant, the controlled has been completely learned the process and efficiently. The following equations are used to start the back propagation algorithm at the output layer.

$$W_{ij} = W'_{ij} + LR.e_j.X_i \quad (18)$$

$$e_j = Y_j.\left(1 - Y_j\right).(d_j - Y_j) \quad (19)$$

The PI controller is tuned to its upmost effectiveness such that the system behaves efficient with the

ANN controller. A single PI controller is first considered for the process of tuning for having enhanced system stability and quick response.

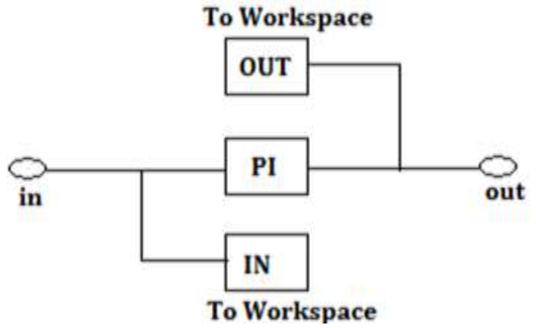

Fig. 3: Obtaining array data's using PI controller

From the Mat lab the PI system is run and the output gets saved in the workspace. The neural network fitting tool is nessecary for designing ANN such that the tool is selected and the input and output datas which gets stored in array format in the workspace are selected.The increase in selection of the hidden layer increases the efficiency of the network.The network it trained to its maximum number of epoches. The training stops when the mean squared value is close to zero and the value of regression is equal to one. Once the network gets trained simulate the diagram and replace with the PI controller.This procedure is adopted for all the four controllers and replaced with the existing PI controller. After the replacement a trigger signal is fed to each ANN controller such the procss ends and the system runs with ANN controller.

Weight enhances the effectiveness and increases the speed. Since there is no standard weights the values are assigned randomly. In general values of weights are elected from a choice [-a, +a] where 0.1 < a < 2. The weight adjustment progression is made by means of the following equation.

$$W_{ij} = W'_{ij} + (1-M).LR.e_j.X_j + M.(W''_{ij} - W'_{ij}) \quad (20)$$

Biases are usually having the value as one which is added to the value at each node excluding the input node in the feed forward phase. The bias related with a exacting node is added to the expression Bj,

$$B_j = \sum_i w_{ij} a_i \quad (21)$$

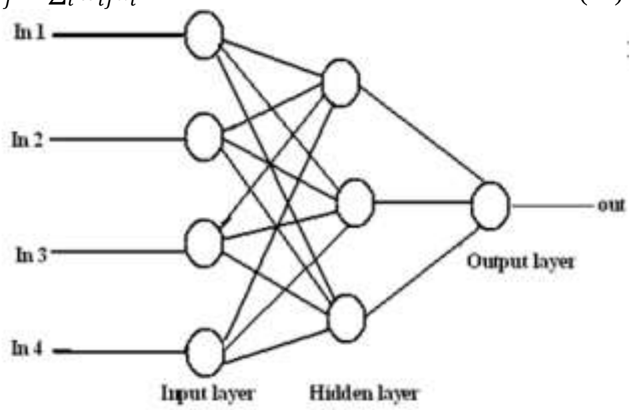

Fig. 4: Neural network with input, hidden and output layer

Threshold is defined as the negative of a bias output using the output layer for eliminating the error in the output. The Levenberg-Marquardt back propagation training algorithm is adopted to train the neural network Epoch is the number of iterations finished to attain the utmost concert of the system the validation should be maximum after completing all epochs.

VI. SIMULATION RESULTS

The nine bus system consists of three generator buses and three load buses. The generating voltages of three generators are at different voltage levels but they are stepped up into 230 kV for transmission purpose. The nine bus system is shown in the Fig. 1. Three phase fault is simulated in the bus 8 and the UPFC is connected between the buses 5 and 7. Buses 5, 6 and 8 are load buses which are having load of 125MW, 90MW and 100 MW respectively. The machine ratings and other details are attached in appendix. The simulation diagram in MATLAB-Simulink environment is shown in Fig. 5.

A. *Simulation Diagram:*

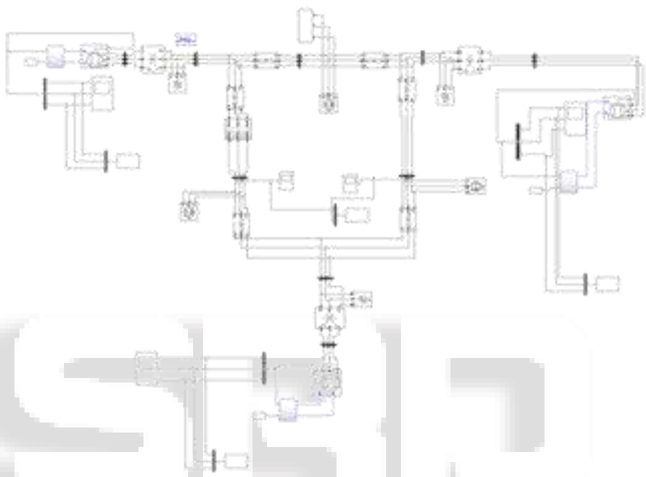

Fig. 5: Simulation diagram with matrix converter based UPFC

B. *Waveforms:*

Three phase fault is simulated in bus 8 for duration of 0.3seconds and the system behaviour analyzed is shown below.

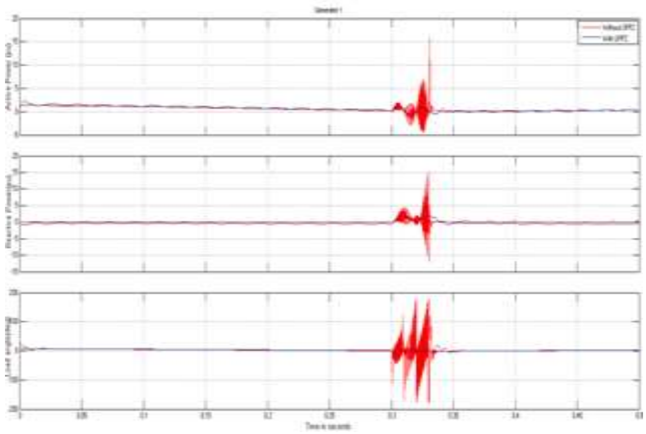

Fig. 6: Generator 1 waveforms

The real power, reactive power and load angle of generator 1 are 0.3pu, -0.2pu and 5 degree respectively during normal operation whereas during the fault condition without UPFC it is 15.8pu, 15pu and -180 to 180 degree respectively and with matrix converter based UPFC it is -0.6pu, 2pu and 20 degree respectively which is shown in the Fig.6.

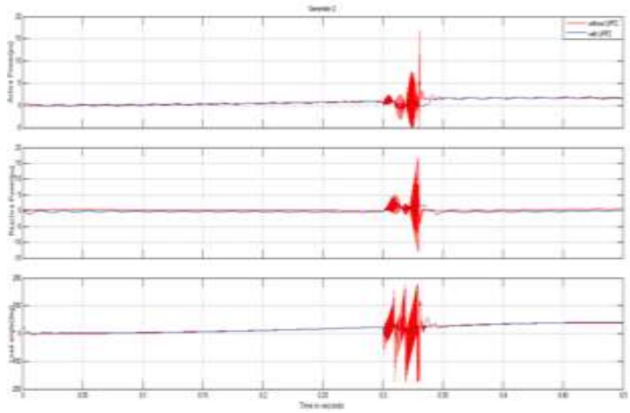

Fig. 7: Generator 2 waveforms

The real power, reactive power and load angle of generator 2are 1.6pu, -0.5pu and 40 degree respectively during normal operation whereas during the fault condition without UPFC it is 17pu, 17pu and -180 to 180 degree respectively and with matrix converter based UPFC it is -0.5pu, 2pu and 60 degree respectively which is shown in the Fig.7.

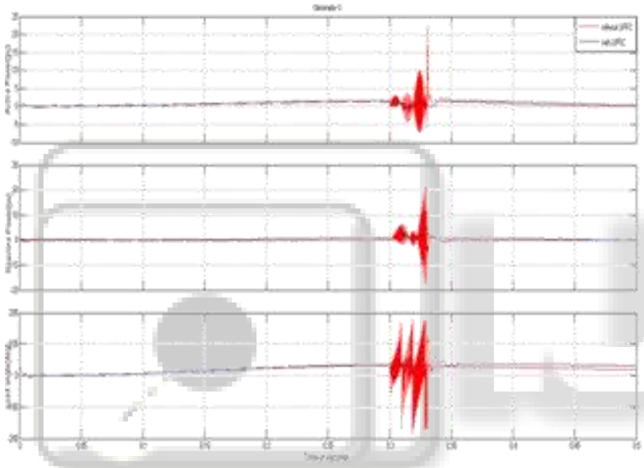

Fig. 8: Generator 3waveforms

The real power, reactive power and load angle of generator 3 are 0.8pu, 0.2pu and 36 degree respectively during normal operation whereas during the fault condition without UPFC it is 22pu, 21.4pu and -180 to 180 degree respectively and with matrix converter based UPFC it is -0.4pu, 2.8pu and 58 degree respectively which is shown in the Fig.8.

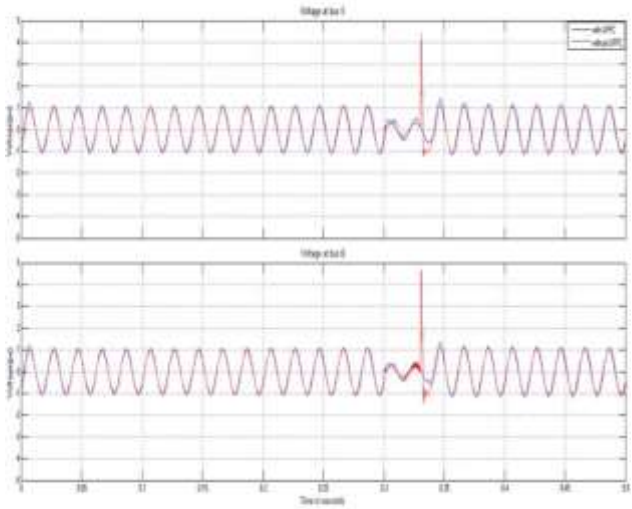

Fig. 9: Voltage at bus 5 and 6

During the fault duration the UPFC supplies 0.9 pu of real power and absorbs 0.35 p.u of reactive power in the transmission line which is shown in the Fig.10. During fault the load buses 5 and 6 are having voltage of 0.28pu and 0.4pu respectively without UPFC and with UPFC the bus voltages are maintained as 0.5p.u which is shown in the fig.9.

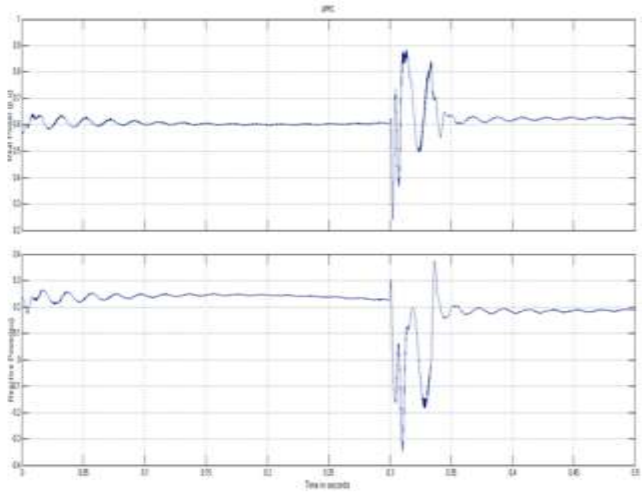

Fig. 10: UPFC active and reactive power output

VII. Conclusion

The system under three phase fault without the UPFC becomes unstable and by employing the matrix converter based UPFC the system attains its stability, hence the system is said to be in synchronism. Thus the transient stability of the system is enhanced.

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