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Novel Direct Switching Power Control Method of UPFC by Using Matrix Converter Based On SVPWM Techniques

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Abstract: *This paper presents a direct Switching power control for three-phase matrix converters operating as unified power flow controllers (UPFCs). Matrix converters (MCs) allow the direct ac/ac power conversion without dc energy storage links; therefore, the MC-based UPFC (MC-UPFC) has reduced volume and cost, reduced capacitor power losses, together with higher reliability. Theoretical principles of direct Switching power control based on sliding mode control techniques are established for an MC-UPFC dynamic model including the input filter. As a result, line active and reactive power, together with ac supply reactive power, can be directly controlled by selecting an appropriate matrix converter switching state guaranteeing good steady-state and dynamic responses. Experimental results of DSPC controllers for MC-UPFC show decoupled active and reactive power control, zero steady-state tracking error, and fast response times. Compared to an MC-UPFC using active and reactive power linear controllers based on a modified Venturing high-frequency PWM modulator, the experimental results of the advanced DSPC-MC guarantee faster responses without overshoot and no steady state error, presenting no cross-coupling in dynamic and steady-state responses.*

Index Terms: *Direct Switching Power Control, matrix converter (MC), unified power-flow controller (UPFC).*

I. Introduction

In the last few years, electricity market deregulation, together with growing economic, environmental, and social concerns, has increased the difficulty to burn fossil fuels, and to obtain new licenses to build transmission lines (rights-of-way) and high-power facilities. This situation started the growth of decentralized electricity generation (using renewable energy resources).

Unified Power-Flow Controllers (UPFC) enable the operation of power transmission networks near their maximum ratings, by enforcing power flow through well-defined lines. These days, UPFCs are one of the most versatile and powerful flexible ac transmission systems (FACTS) devices.

The UPFC results from the combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) that shares a common dc capacitor link.

The existence of a dc capacitor bank originates additional losses, decreases the converter lifetime, and increases its weight, cost, and volume. These converters are capable of performing the same ac/ac conversion, allowing bidirectional power flow, guaranteeing near sinusoidal input and output currents, voltages with variable amplitude, and adjustable power factor. These minimum energy storage ac/ac converters have the capability to allow independent reactive control on the UPFC shunt and series converter sides, while guaranteeing that the active power exchanged on the UPFC series connection is always supplied/absorbed by the shunt connection.

Recent nonlinear approaches enabled better tuning of PI controller parameters. Still, there is room to further improve the dynamic response of UPFCs, using nonlinear robust controllers. In the last few years, direct power control techniques have been used in many power applications, due to their simplicity and good performance. In this project, a matrix converter- based UPFC is proposed, using a direct Switching power control approach (DSPC-MC) based on an MC-UPFC dynamic model (Section II).

In order to design UPFCs, presenting robust behavior to parameter variations and to disturbances, the proposed DSPC-MC control method, in Section III, is based on sliding mode-control techniques, allowing the real-time selection of adequate matrix vectors to control input and output electrical power. Sliding mode-based DSPC-MC controllers can guarantee zero steady-state errors and no overshoots, good tracking performance, and fast dynamic responses, while being simpler to implement and requiring less processing power, when compared to proportional-integral (PI) linear controllers obtained from linear active and reactive power models of UPFC using a modified Aventurine high-frequency PWM modulator.

The dynamic and steady-state behavior of the proposed DSPC-MC P, Q control method is evaluated and discussed using detailed simulations and experimental implementation (Sections IV and V). Simulation and experimental results obtained with the nonlinear DSPC for matrix converter-based UPFC technology show decoupled series active and shunt/series reactive power control, zero steady state error tracking, and fast response times, presenting faultless dynamic and steady state responses.

II. Modeling of the UPFC Power System

A. General Architecture

A simplified power transmission network using the proposed matrix converter UPFC is presented in Fig. 1, where a_0 and are, respectively, the sending-end and receiving-end sinusoidal voltages of the and generators feeding load. The matrix converter is connected to transmission line 2, represented as a series inductance with series resistance through coupling transformers and .Fig. 2 shows the simplified three-phase equivalent circuit of the matrix UPFC transmission system model. For system modeling, the power sources and the coupling transformers are all considered ideal. Also, the matrix converter is considered ideal and represented as a controllable voltage source, with amplitude and phase . In the equivalent circuit, is the load bus voltage? The DSPC-MC controller will treat the simplified elements as disturbances. Considering a symmetrical and balanced three-phase system and applying Kirchhoff laws to the three-phase equivalent circuit (Fig. 2), the ac line currents are obtained in coordinates

$$\frac{dI_d}{\mathrm{dt}} = \omega I_q - \frac{R_2}{L_2} I_d + \frac{1}{L_2}(V_{Ld} - V_{R0d}) \qquad (1)$$

$$\frac{dI_q}{\mathrm{dt}} = -\omega I_d - \frac{R_2}{L_2} I_q + \frac{1}{L_2}(V_{Lq} - V_{R0q}). \qquad (2)$$

The active and reactive power of end generator are given in dq coordinates by

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V_d & V_q \\ V_q & -V_d \end{bmatrix} \begin{bmatrix} I_d \\ I_q \end{bmatrix}. \qquad (3)$$

The active and reactive power P and Q are given by (4) and (5) respectively

$$P = V_d I_d \qquad (4)$$

$$Q = -V_d I_q. \qquad (5)$$

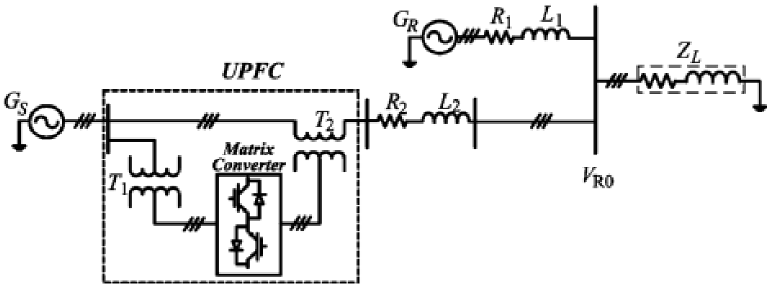


Fig. 1Transmission network with matrix converter UPFC

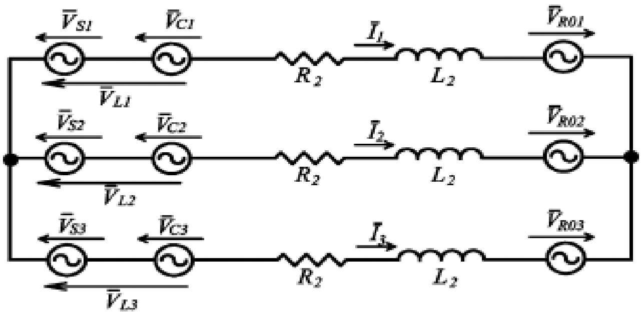


Fig.2.Three-phase equivalent circuit of the matrix UPFC and transmission line

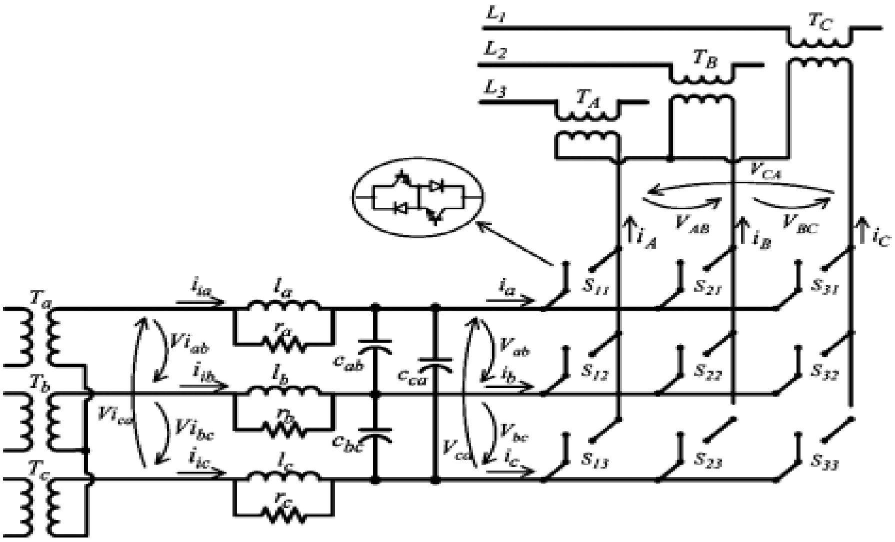


Fig. 3. Transmission network with matrix converter UPFC

B. Matrix Converter Output Voltage and Input Current Vectors

A diagram of the UPFC system (Fig. 3) includes the three-phase shunt input transformer (with windings Ta, Tb, Tc),the three-phase series output transformer (with windings) and the three-phase matrix converter, represented as an array of nine bidirectional switches with turn-on and turn-off capability, allowing the connection of each one of three output phases directly to any one of the three input phases. The three-phase input filter is required to re-establish a voltage-source boundary to the matrix converter, enabling smooth input currents. Applying coordinates to the input filter state variables presented in Fig. 3 and neglecting the effects of the damping resistors, the following equations are obtained.

Where V, i represent, respectively, input voltages and input currents in dq components (at the shunt transformer secondary) and V,i are the matrix converter voltages and input currents in components, respectively.

Assuming ideal semiconductors, each matrix converter bidirectional switch can assume two possible states: “ Sk=1” if the switch is closed or “Skj=0 ” if the

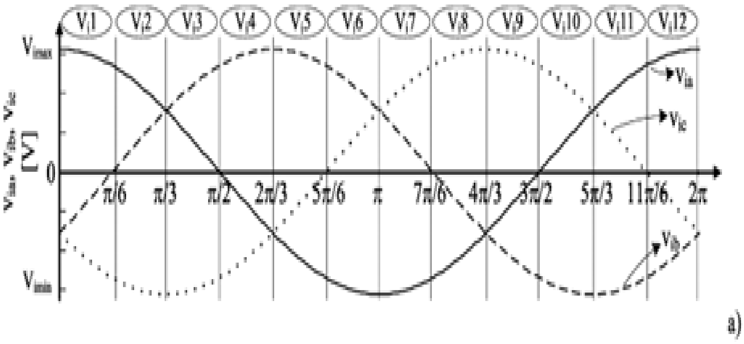


Fig. 4. (a) Input voltages and their corresponding sector

switch is open. The nine matrix converter switches can be represented as a 3× 3 matrix (7)

$$\begin{cases} \dfrac{di_{id}}{dt} = \omega i_{iq} - \dfrac{1}{2l}V_d - \dfrac{1}{2\sqrt{3}l}V_q + \dfrac{1}{l}V_{id} \\ \dfrac{di_{iq}}{dt} = -\omega i_{id} + \dfrac{1}{2\sqrt{3}l}V_d - \dfrac{1}{2l}V_q + \dfrac{1}{l}V_{iq} \\ \dfrac{dV_d}{dt} = \omega V_q - \dfrac{1}{2\sqrt{3}C}i_{iq} + \dfrac{1}{2C}i_{id} - \dfrac{1}{2C}i_d + \dfrac{1}{2\sqrt{3}C}i_q \\ \dfrac{dV_q}{dt} = -\omega V_d + \dfrac{1}{2\sqrt{3}C}i_{id} + \dfrac{1}{2C}i_{iq} - \dfrac{1}{2\sqrt{3}C}i_d - \dfrac{1}{2C}i_q \end{cases}$$

(6)

$$\boldsymbol{S} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}. \qquad (7)$$

The relationship between load and input voltages can be expressed as

$$[v_A \quad v_B \quad v_C]^T = \boldsymbol{S}[v_a \quad v_b \quad v_c]^T. \qquad (8)$$

The input phase currents can be related to the output phase currents (9), using the transpose of matrix (9)

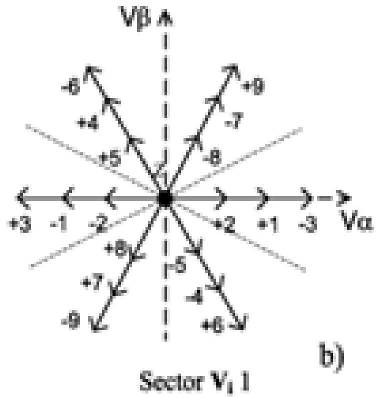
$$[i_a \quad i_b \quad i_c]^T = \boldsymbol{S}^T[i_A \quad i_B \quad i_C]^T. \qquad (9)$$

From the 27 possible switching patterns, time-variant vectors can be obtained (Table I) representing the matrix output voltages and input currents coordinates, and plotted in the frame [Fig. 4(b)].
The active and reactive power DSPC-MC will select one of these 27 vectors at any given time instant.

III. Direct Power Control of MC-UPFC

A. Line Active and Reactive Power Sliding Surfaces

The DSPC controllers for line power flow are here derived based on the sliding mode control theory. From



(b) Output voltage state-space vectors when the input voltages are located at sector.

Fig. 2, in steady state, is imposed by source . From (1) and (2), the transmission-line currents can be considered as state variables with first-order dynamics dependent on the sources and time constant of impedance . Therefore, transmission-line active and reactive powers present first-order dynamics and have a strong relative degree of one [25], since from the control viewpoint, its first time derivative already contains the control variable (the strong relative degree generally represents the number of times the control output variable must be differentiated until a control input appears explicitly in the dynamics) [26]–[29].

From the sliding mode control theory, robust sliding surfaces to control the and variables with a relatively strong degree of one can be obtained considering proportionality to a linear combination of the errors of between the power references and the actual transmitted powers , respectively the state variables [29]. Therefore, define the active power error and the reactive power error as the difference

TABLE I
Switching Combinations and Output Voltage / Input Current State-Space Vectors

		v_{AB}	v_{BC}	v_{CA}	i_a	i_b	i_c	V_o	δ_o	I_i	μ_i
I	1g	v_{ab}	v_{bc}	v_{ca}	i_A	i_B	i_C	v_i	δ_i	i_o	μ_o
	2g	$-v_{ca}$	$-v_{bc}$	$-v_{ab}$	i_A	i_C	i_B	$-v_i$	$-\delta_i+4\pi/3$	i_o	$-\mu_o$
	3g	$-v_{ab}$	$-v_{ca}$	$-v_{bc}$	i_B	i_A	i_C	$-v_i$	$-\delta_i$	i_o	$-\mu_o+2\pi/3$
	4g	v_{bc}	v_{ca}	v_{ab}	i_C	i_A	i_B	v_i	$\delta_i+4\pi/3$	i_o	$\mu_o+2\pi/3$
	5g	v_{ca}	v_{ab}	v_{bc}	i_B	i_C	i_A	v_i	$\delta_i+2\pi/3$	i_o	$\mu_o+4\pi/3$
	6g	$-v_{bc}$	$-v_{ab}$	$-v_{ca}$	i_C	i_B	i_A	$-v_i$	$-\delta_i+2\pi/3$	i_o	$-\mu_o+4\pi/3$
II	+1	v_{ab}	0	$-v_{ab}$	i_A	$-i_A$	0	$\frac{2}{\sqrt{3}}v_{ab}$	$\pi/6$	$\frac{2}{\sqrt{3}}i_A$	$-\pi/6$
	-1	$-v_{ab}$	0	v_{ab}	$-i_A$	i_A	0	$-\frac{2}{\sqrt{3}}v_{ab}$	$\pi/6$	$-\frac{2}{\sqrt{3}}i_A$	$-\pi/6$
	+2	v_{bc}	0	$-v_{bc}$	0	i_A	$-i_A$	$\frac{2}{\sqrt{3}}v_{bc}$	$\pi/6$	$\frac{2}{\sqrt{3}}i_A$	$\pi/2$
	-2	$-v_{bc}$	0	v_{bc}	0	$-i_A$	i_A	$-\frac{2}{\sqrt{3}}v_{bc}$	$\pi/6$	$-\frac{2}{\sqrt{3}}i_A$	$\pi/2$
	+3	v_{ca}	0	$-v_{ca}$	$-i_A$	0	i_A	$\frac{2}{\sqrt{3}}v_{ca}$	$\pi/6$	$\frac{2}{\sqrt{3}}i_A$	$7\pi/6$
	-3	$-v_{ca}$	0	v_{ca}	i_A	0	$-i_A$	$-\frac{2}{\sqrt{3}}v_{ca}$	$\pi/6$	$-\frac{2}{\sqrt{3}}i_A$	$7\pi/6$
	+4	$-v_{ab}$	v_{ab}	0	i_B	$-i_B$	0	$\frac{2}{\sqrt{3}}v_{ab}$	$5\pi/6$	$\frac{2}{\sqrt{3}}i_B$	$-\pi/6$
	-4	v_{ab}	$-v_{ab}$	0	$-i_B$	i_B	0	$-\frac{2}{\sqrt{3}}v_{ab}$	$5\pi/6$	$-\frac{2}{\sqrt{3}}i_B$	$-\pi/6$
	+5	$-v_{bc}$	v_{bc}	0	0	i_B	$-i_B$	$\frac{2}{\sqrt{3}}v_{bc}$	$5\pi/6$	$\frac{2}{\sqrt{3}}i_B$	$\pi/2$
	-5	v_{bc}	$-v_{bc}$	0	0	$-i_B$	i_B	$-\frac{2}{\sqrt{3}}v_{bc}$	$5\pi/6$	$-\frac{2}{\sqrt{3}}i_B$	$\pi/2$
	+6	$-v_{ca}$	v_{ca}	0	$-i_B$	0	i_B	$\frac{2}{\sqrt{3}}v_{ca}$	$5\pi/6$	$\frac{2}{\sqrt{3}}i_B$	$7\pi/6$
	-6	v_{ca}	$-v_{ca}$	0	i_B	0	$-i_B$	$-\frac{2}{\sqrt{3}}v_{ca}$	$5\pi/6$	$-\frac{2}{\sqrt{3}}i_B$	$7\pi/6$
	+7	0	v_{ab}	v_{ab}	i_C	$-i_C$	0	$\frac{2}{\sqrt{3}}v_{ab}$	$3\pi/2$	$\frac{2}{\sqrt{3}}i_C$	$-\pi/6$
	-7	0	v_{ab}	v_{ab}	$-i_C$	i_C	0	$-\frac{2}{\sqrt{3}}v_{ab}$	$3\pi/2$	$-\frac{2}{\sqrt{3}}i_C$	$-\pi/6$
	+8	0	$-v_{bc}$	v_{bc}	0	i_C	$-i_C$	$\frac{2}{\sqrt{3}}v_{bc}$	$3\pi/2$	$\frac{2}{\sqrt{3}}i_C$	$\pi/2$
	-8	0	v_{bc}	$-v_{bc}$	0	$-i_C$	i_C	$-\frac{2}{\sqrt{3}}v_{bc}$	$3\pi/2$	$-\frac{2}{\sqrt{3}}i_C$	$\pi/2$
	+9	0	$-v_{ca}$	v_{ca}	$-i_C$	0	i_C	$\frac{2}{\sqrt{3}}v_{ca}$	$3\pi/2$	$\frac{2}{\sqrt{3}}i_C$	$7\pi/6$
	-9	0	v_{ca}	$-v_{ca}$	i_C	0	$-i_C$	$-\frac{2}{\sqrt{3}}v_{ca}$	$3\pi/2$	$-\frac{2}{\sqrt{3}}i_C$	$7\pi/6$
III	z_a	0	0	0	0	0	0	0	-	0	-
	z_b	0	0	0	0	0	0	0	-	0	-
	z_c	0	0	0	0	0	0	0	-	0	-

$$e_P = P_{\text{ref}} - P \qquad (10)$$
$$e_Q = Q_{\text{ref}} - Q. \qquad (11)$$

Then, the robust sliding surfaces must be proportional to these errors, being zero after reaching sliding mode

$$S_P(e_P, t) = k_P(P_{\text{ref}} - P) = 0 \qquad (12)$$
$$S_Q(e_Q, t) = k_Q(Q_{\text{ref}} - Q) = 0. \qquad (13)$$

The proportional gains and are chosen to impose appropriate switching frequencies

B. Line Active and Reactive Power Direct Switching Laws

The DPC uses a nonlinear law, based on the errors and to select in real time the matrix converter switching states (vectors). Since there are no modulators and/or pole zero-based approaches, high control speed is possible. To guarantee stability for active power and reactive power controllers, the sliding-mode stability conditions (14) and (15) must be verified

$$S_P(e_P,t)\dot{S}_P(e_P,t) < 0 \qquad (14)$$

$$S_Q(e_Q,t)\dot{S}_Q(e_Q,t) < 0. \qquad (15)$$

According to (12) and (14), the criteria to choose the matrix vector should be

1. If $S_P(e_P,t) > 0 \Rightarrow \dot{S}_P(e_P,t) < 0 \Rightarrow P < P_{\mathrm{ref}}$, then choose a vector suitable to increase P.
2. If $S_P(e_P,t) < 0 \Rightarrow \dot{S}_P(e_P,t) > 0 \Rightarrow P > P_{\mathrm{ref}}$, then choose a vector suitable to decrease P.
3. If $S_P(e_P,t) = 0$,

To designs the DSPC control system, the six vectors of group I will not be used, since they require extra algorithms to calculate their time-varying phase [14]. From group II, the variable amplitude vectors, only the 12 highest amplitude voltage vectors are certain to be able to guarantee the previously discussed required levels of and needed to fulfill the reaching conditions. The lowest amplitude voltages vectors, or the three null vectors of group III, could be used for near zero errors. If the control errors and are quantized using two hysteresis comparators, each with three levels (and), nine output voltage error combinations are obtained. If a two-level comparator is used to control the shunt reactive power, as discussed in next subsection, 18 error combinations will be defined, enabling the selection of 18 vectors. Since the three zero vectors have a minor influence on the shunt reactive power control, selecting one out 18 vectors is adequate. As an example, consider the case of and Then, and imply that and . According to Table I, output voltage vectors depend on the input voltages (sending voltage), so to choose the adequate output voltage vector, it is necessary to know the input voltages location [Fig. 4(a)]. Suppose now that the input voltages are in sector [Fig. 4(b)], then the vector to be applied should be 9 or 7. The final choice between these two depends on the matrix reactive power controller result , discussed in the next subsection. Using the same reasoning for the remaining eight active and reactive power error combinations and generalizing it for all other input voltage sectors, Table II is obtained. These P, Q controllers were designed based on control laws not dependent on system parameters, but only on the errors of the controlled output to ensure robustness to parameter variations or operating conditions and allow system order reduction, minimizing response times [26].

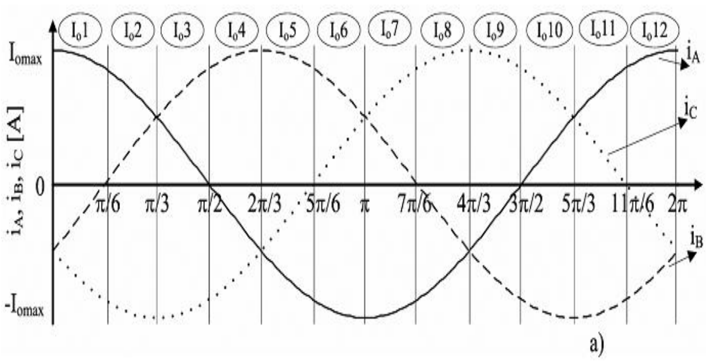


Fig.5: (a) Output currents and their corresponding sector.

C. Direct Control of Matrix Converters Input Reactive Power

In addition, the matrix converter UPFC can be controlled to ensure a minimum or a certain desired reactive power at the matrix converter input. Similar to the previous considerations, since the voltage source input filter (Fig. 3) dynamics (6) has a strong relative degree of two [25], then a suitable sliding surface (19) will be a linear combination of the desired reactive power error and its first-order time derivative [29] (19) The time derivative can be approximated by a discrete time difference, as has been chosen to obtain a suitable switching frequency, since as stated before, this sliding surface

$$S_{Q_i}(e_{Q_i},t) = (Q_{i_{\text{ref}}} - Q_i) + K_{Q_i}\frac{d}{\text{dt}}(Q_{i_{\text{ref}}} - Q_i).$$

$$\dot{S}_{Qi}(e_{Qi},t) =$$

$$V_{id}\left(\frac{\text{di}_{iq}}{\text{dt}} + K_{Qi}\frac{\text{d}^2\text{i}_{iq}}{\text{dt}^2}\right) = V_{id}\left(-\omega i_{id} + \frac{1}{2\sqrt{3}l}V_d - \frac{1}{2l}V_q\right) +$$

$$V_{id}K_{Qi}\left(-\omega^2 i_{iq} + \frac{\omega}{l}V_d + \frac{\omega}{\sqrt{3}l}V_q - \frac{\omega}{l}V_{id} - \frac{i_{iq}}{3lC} + \frac{i_q}{3lC}\right).$$

The sliding mode is reached when vectors applied to the converter have the necessary current amplitude to satisfy stability conditions, such as (15). Therefore, to choose the most adequate vector in the chosen reference frame, it is necessary to know the output currents location since the input current depends on the output currents (Table I). Considering that the –axis location is synchronous with the input voltage (i.e., reference frame depends on the input voltage location), the sign of the matrix reactive power can be determined by knowing the location of the input voltages and the location of the output currents (Fig. 5).

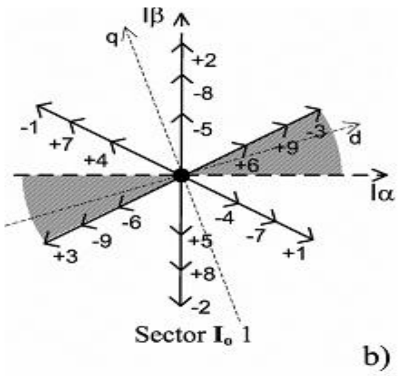


Fig. 5. (a) Output currents and their corresponding sector.

1. If $S_{Q_i}(e_{Q_i},t) > 0 \Rightarrow \dot{S}_{Q_i}(e_{Q_i},t) < 0$, then select vector with current $i_q < 0$ to increase Q_i
2. If $S_{Q_i}(e_{Q_i},t) < 0 \Rightarrow \dot{S}_{Q_i}(e_{Q_i},t) > 0$, then select vector with current $i_q > 0$ to decrease Q_i.

-

Considering the previous example, with the input voltage at sector and sliding surfaces signals and both vectors or would be suitable to control the line active and reactive powers errors (Fig. 4). However, at sector , these vectors have a different effect on the value: if has a suitable amplitude, vector leads to while vector originates So, vector should be chosen if the input reactive power sliding surface is quantized as 1, while vector 7 should chosen when is quantized as 1. When the active and reactive power errors are quantized as zero, 0 and 0, the null vectors of group III, or the lowest amplitude voltages vectors at sector at Fig. 4(b) could be used. These vectors do not produce significant effects on the line active and reactive power values, but the lowest amplitude voltage vectors have a high influence on the control of matrix reactive power. From Fig. 5(b), only the highest amplitude current vectors of sector should be chosen: vector if is quantized as , or vector 2 if is quantized as

IV. Implementation Of The DSPC-MC As UPFC

As shown in the block diagram (Fig. 6), the control of the instantaneous active and reactive powers requires the measurement of voltages and output currents necessary to calculate and sliding surfaces. The output current measurement is also used to determine the location of the input currents component. The control of the matrix converter input reactive power requires the input currents measurement to calculate. At each time instant, the most suitable matrix vector is chosen upon the discrete values of the sliding surfaces, using tables derived from Tables II and III for all voltage sectors.

TABLE II
State-Space Vectors Selection for Different Error Combinations

C_α	C_β	Sector V_i 12; 1	V_i 2; 3	V_i 4; 5	V_i 6; 7	V_i 8; 9	V_i 10; 11
-1	+1	-9; +7	-9; +8	+8; -7	-7; +9	+9; -8	-8; +7
-1	0	+3; -1	+3; -2	-2; +1	+1; -3	-3; +2	+2; -1
-1	-1	-6; +4	-6; +5	+5; -4	-4; +6	+6; -5	-5; +4
0	+1	-9; +7; +6; -4	-9; +8; +6; -5	+8; -7; -5; +4	-7; +9; +4; -6	+9; -8; -6; +5	-8; +7; +5; -4
0	0	Za; Zb; Zc; -8;+2;-5;+8;-2;+5	Za; Zb; Zc; -7;+1;-4; +7;-1;+4	Za; Zb; Zc; +9;-3;+6;-9;+3;-6	Za; Zb; Zc; -8;+2;-5;+8;-2;+5	Za; Zb; Zc; -7;+1;-4; +7;-1;+4	Za; Zb; Zc; -9;+3;-6; +9;-3;+6
0	-1	-6; +4; +9; -7	+5; -6; -8; +9	+5; -4; -8; +7	-4; +6; +7; -9	+6; -5; -9; +8	-5; +4; +8; -7
+1	+1	+6; -4	+6; -5	-5; +4	+4; -6	-6; +5	+5; -4
+1	0	-3; +1	+2; -3	-1; +2	+3; -1	-2; +3	+1; -2
+1	-1	+9; -7	+9; -8	+7; -8	+7; -9	-9; +8	+8; -7

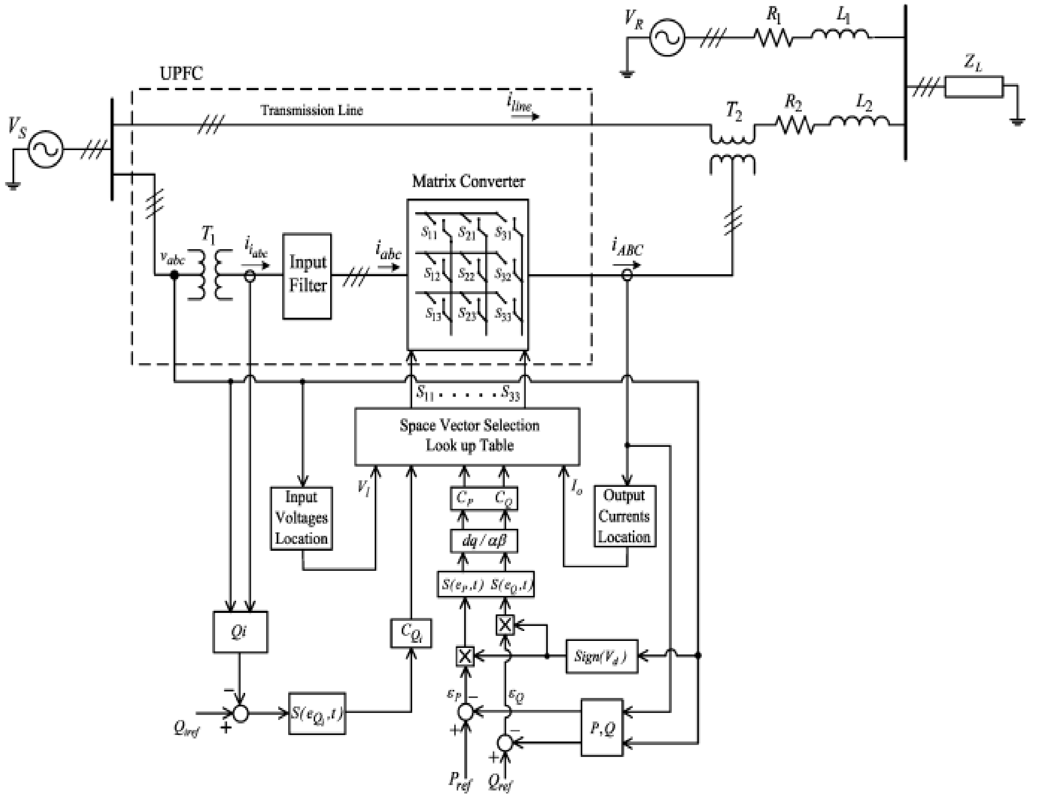


Fig. 6. Control scheme of direct power control of the three-phase matrix converter operating as a UPFC.

A. Simulation Modeling

The performance of the proposed direct control system was evaluated with a detailed simulation model using the*-MATLAB/Simulink Sim Power Systems to represent the matrix converter, transformers, sources and transmission lines, and Simulink blocks to simulate the control system. Ideal switches were considered to simulate matrix converter semiconductors minimizing simulation times.

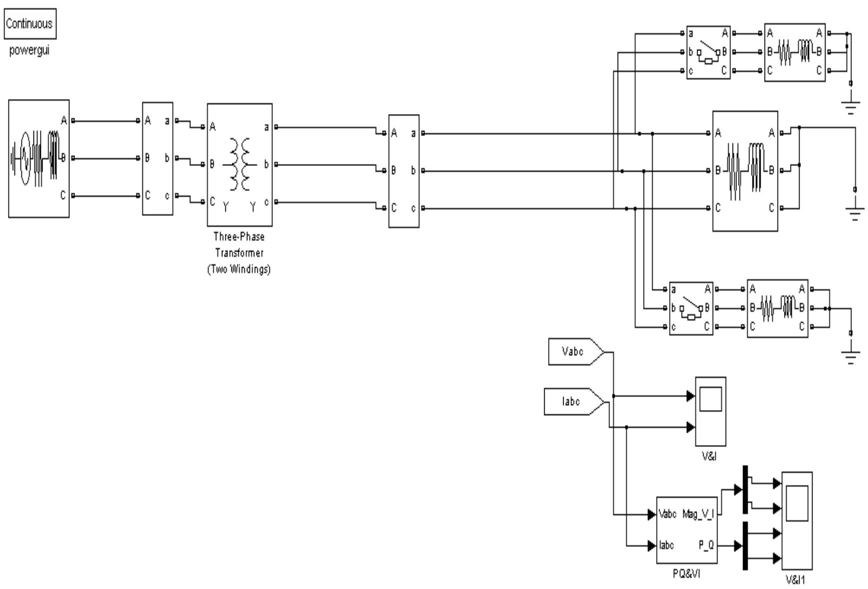


Fig 7: Modeling of UPFC without Matrix Converter.

To the simulations, a low-power prototype matrix converter was built [14] by using three semiconductor modules each one with six 1200-V 25-A insulated-gate bipolar transistors (IGBTs) with an anti parallel diode in a common collector arrangement, driven by optical isolated drives. The second-order input filter is 4.2 mH, 6.6 F, This prototype was connected to the laboratory low-voltage network operating as UPFC, (Fig.5.1) by using three-phase transformers T_1 and T_2 (2-KVA transformers with voltage ratio 220/115 V and 66.5/66.5 V, respectively). Current sensors were used to measure the matrix converter input and output currents and voltage sensors were used to measure the power network phase-to-phase voltages.

To achieve safe commutation between matrix converter bidirectional switches, the four-step output current commutation strategy [18] was implemented in a field-programmable gate array

Algorithm was implemented in a digital signal processor Power PC with a sampling time approximately equal to 17-sec. The load power is 1.5kw (1 p.u.) And transmission lines 1 and 2 are simulated as inductances 15 mH, and series resistances, respectively for line 1 and 2. Sliding mode DSPC gains are 1, selected to ensure the highest switching frequencies around 2.5 kHz. Simulation results of the active and reactive direct power UPFC controller are obtained from the step remote retio.

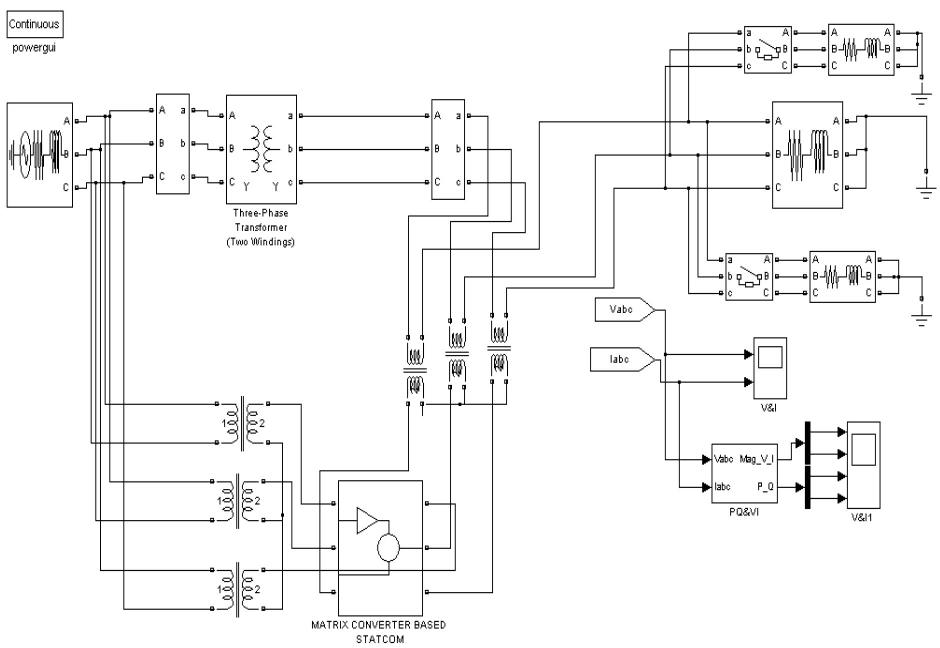


Fig 8; Modeling of UPFC with matrix convertor

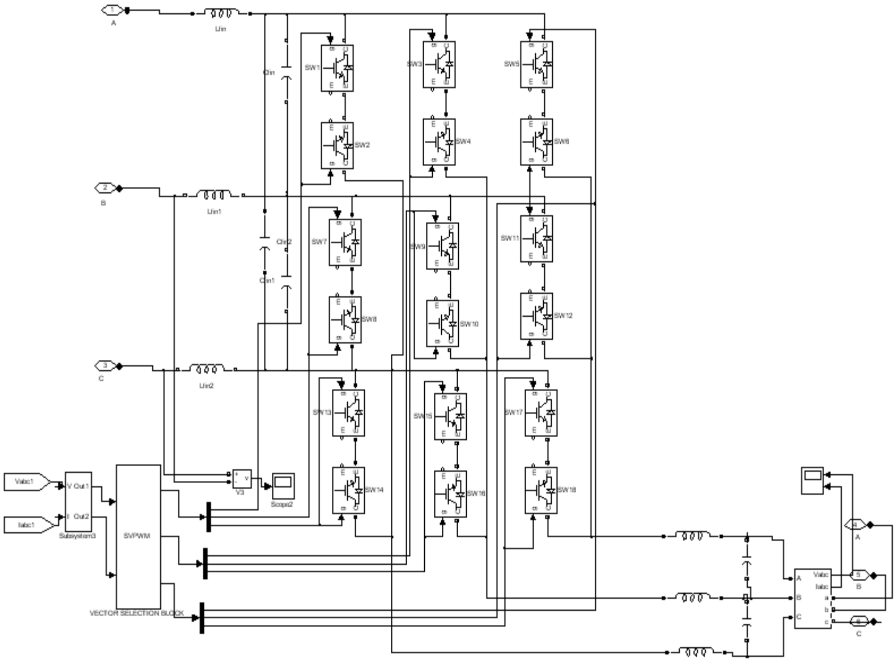


Fig 9;.Modeling of matrix convertor

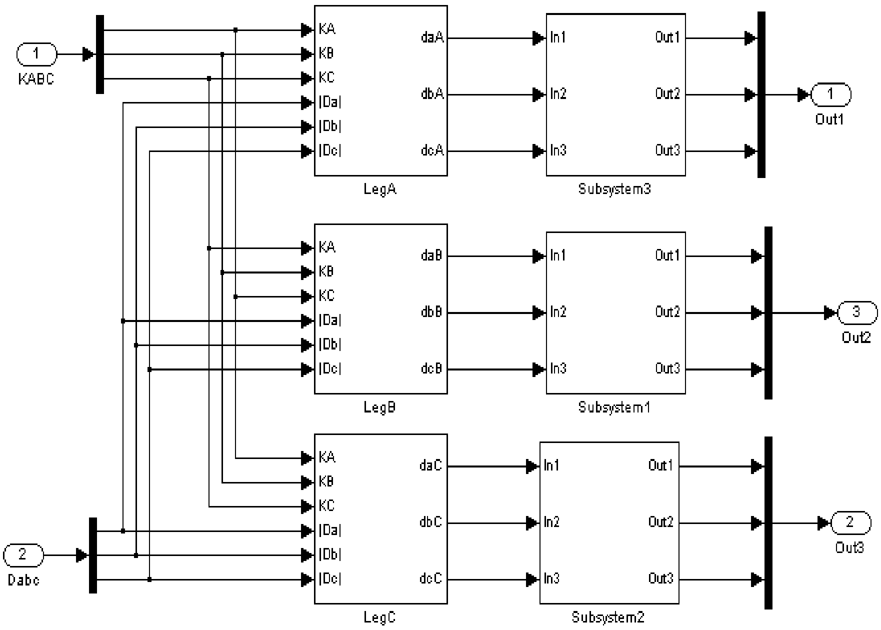


Fig 10; Modeling of vector selection block

The simulation power spectral density of transmission line and matrix converter current respectively, Fig. 5.3 shows that the main harmonics are nearly 30 db below the 50-Hz fundamental for the line current, and 22 db below the 50-Hz fundamental for the matrix converter current. The power spectral density shows switching frequencies mainly below 2.5 kHz as expected. Simulation results confirm the performance of the proposed controllers, showing no cross-coupling, no steady-state error (only switching ripples), and fast response times for different changes of power references. DSPC active and reactive power step response and line currents results were compared to active and reactive power linear PI controllers [11] using a Aventurine high-frequency PWM modulator [17], working at 5.0-khz switching frequency.

Simulation results for 0.4 p.u. And 0.2 p.u. Show cross-coupling between active and reactive power control, which introduces a slowly decaying error in the response. Longer response times are also present, when compared to DSPC simulation results presented showing the claimed DSPC faster dynamic.

Response to step active and reactive power reference change To test the DSPC controller ability to operate at lower switching frequencies, the DSPC gains were lowered and the input filter parameters were changed accordingly (5.9 mH) to lower the switching frequency to nearly 1.4 kH. The results also show fast response without cross coupling between active and reactive power's This confirms the DSPC-MC robustness to input filter parameter variation, the ability to operate at low switching frequencies, and insensitivity to switching non linearity.

B. Simulation Results

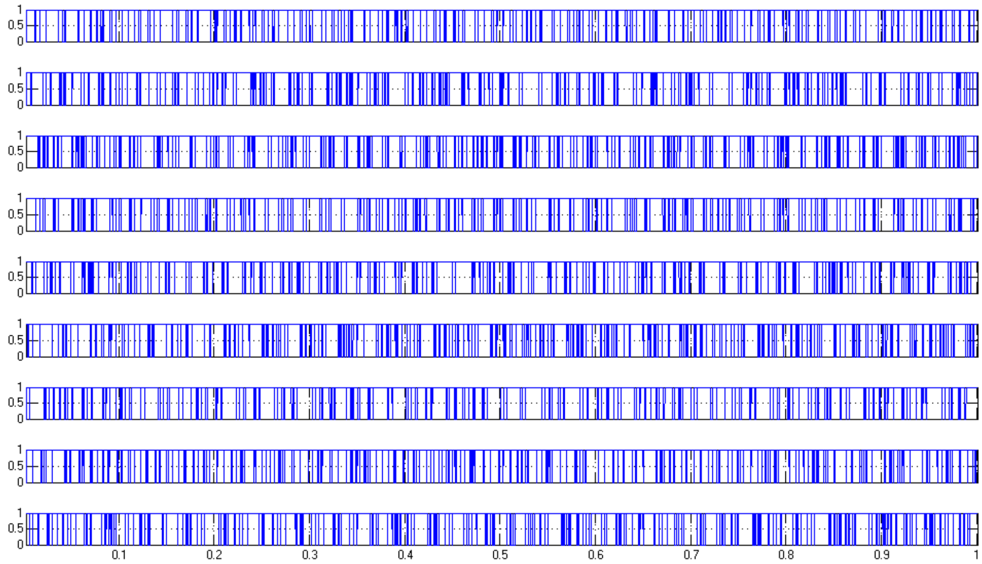


Fig 11: SVPWM Pulse wave forms

In SVPWM Pulse wave forms as shown Fig 11 the pulse gives to nine bi-directional on matrix converter and it works the switches turn ON & turn OFF

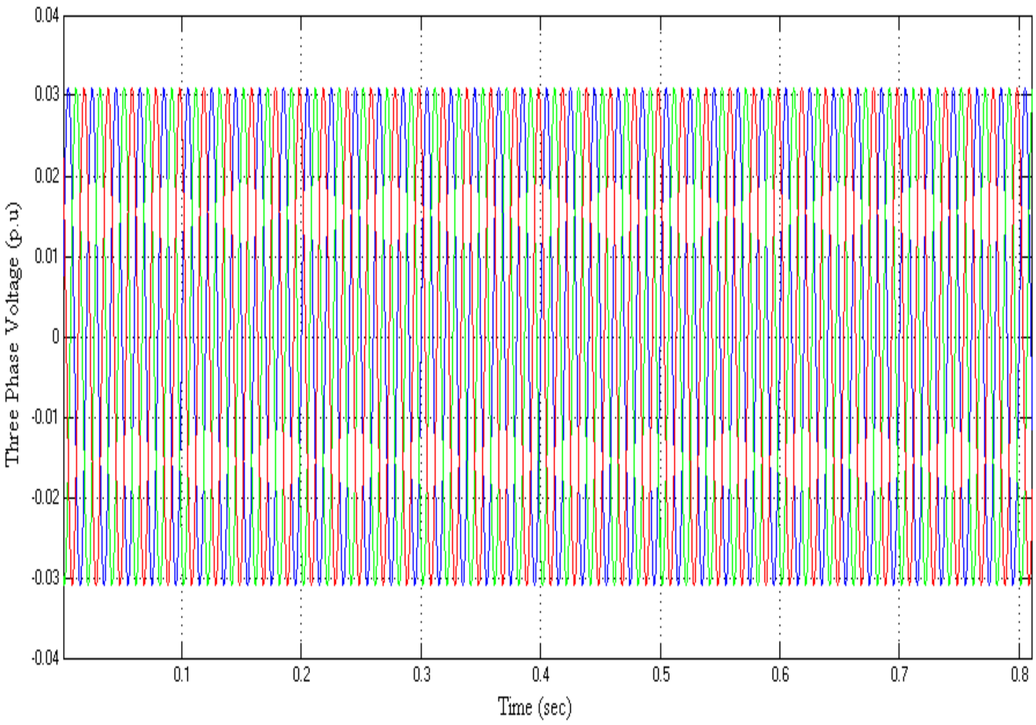


Fig 12: Output 3-Phase Voltage of UPFC without Matrix Converter.

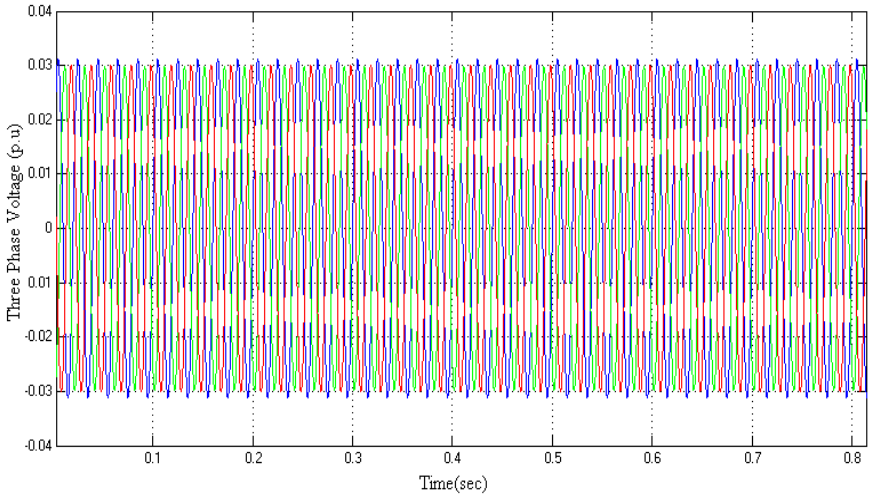


Fig 13: Output 3-Phase Voltage of UPFC with Matrix Converter

In Output 3-Phase Voltage of UPFC with and without Matrix Converter as shown in above (fig 12&13) those are output wave forms do not change why because all the loads connected are parallels

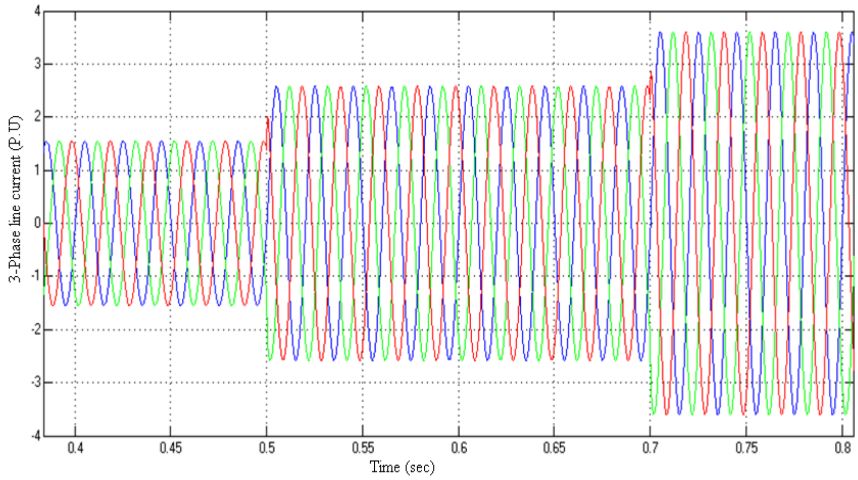


Fig 14: Output 3-Phase Line Current of UPFC without Matrix Converter.

In 3-Phase line current (i_A,i_B,i_C) as shown in above (fig 14) the current will be increased with respect to time and doesn't control the output current in without Matrix converter of UPFC.

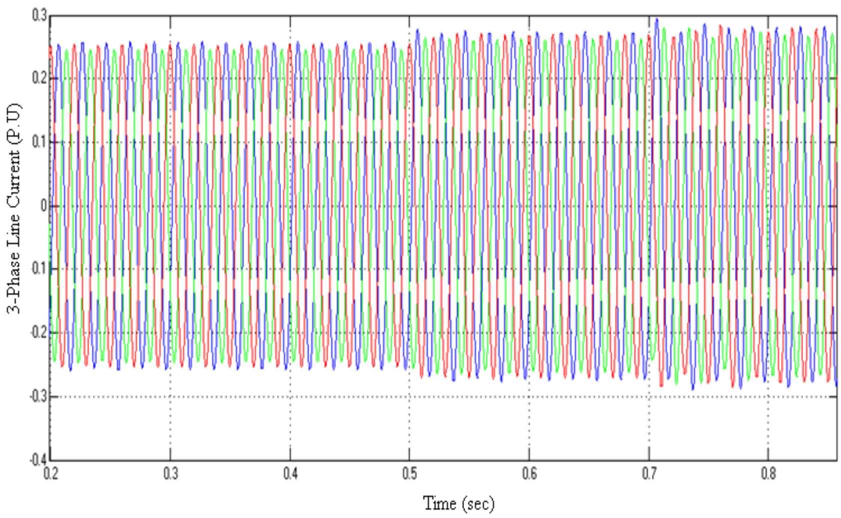


Fig 15: Output 3-Phase Line Current of UPFC with Matrix Converter.

In 3-Phase line current (i_A,i_B,i_C) as shown in above (fig 15) the current will be increased with respect to time and we can control the output current with Matrix converter of UPFC

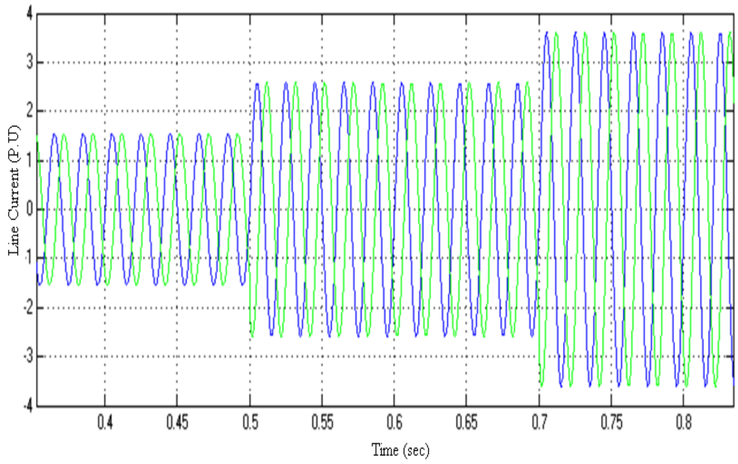


Fig 16: Output Line Current (i_A,i_B) of UPFC without Matrix Converter.

In line current (i_A,i_B) as shown in above (fig 16) the current will be increased with respect to time and doesn't control the current in without Matrix converter of UPFC

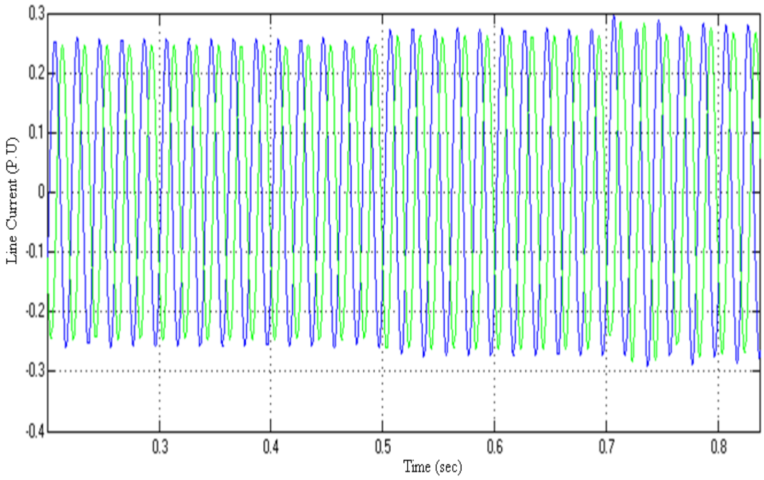


Fig 17: Output Line Current (i_A,i_B) of UPFC with Matrix Converter.

In line current (i_A,i_B) as shown in above(fig 17) the current will be increased with respect to time and we can control the output current with Matrix converter of UPFC

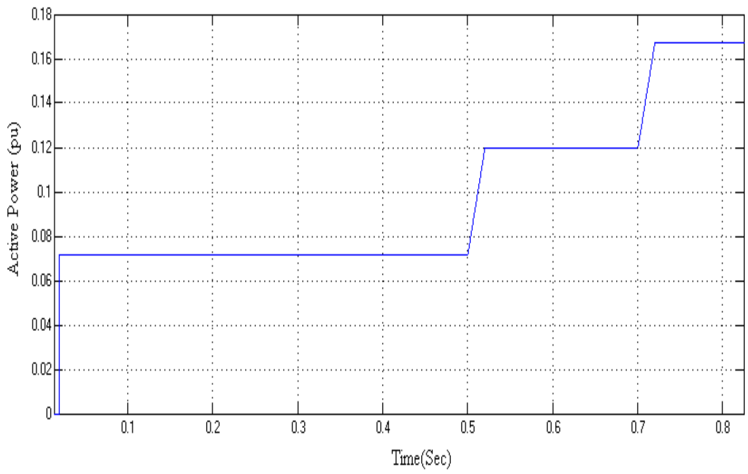


Fig 18: Magnitude of output Active Power without Matrix Converter.

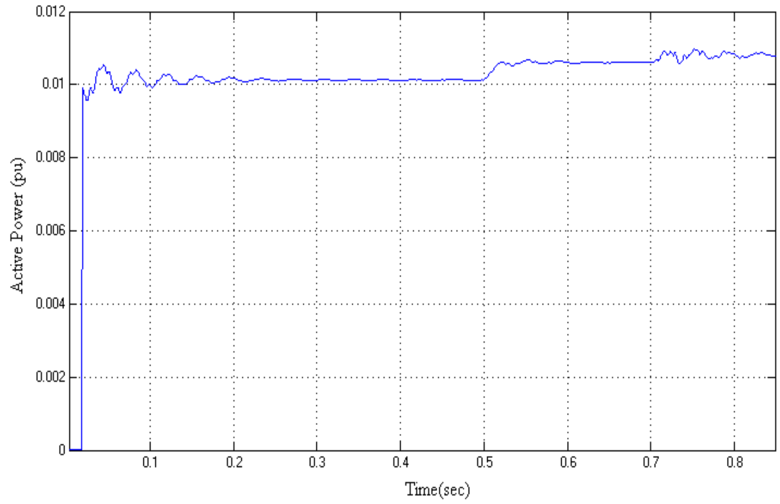


Fig 19: Magnitude of output Active Power with Matrix Converter.

The magnitude of output active power of UPFC without Matrix Converter as shown in above (fig 18) gets reached to the not steadystate with more time where as with matrix converter the active power as shown in above (fig 19) gets reached the steadystate with less time.

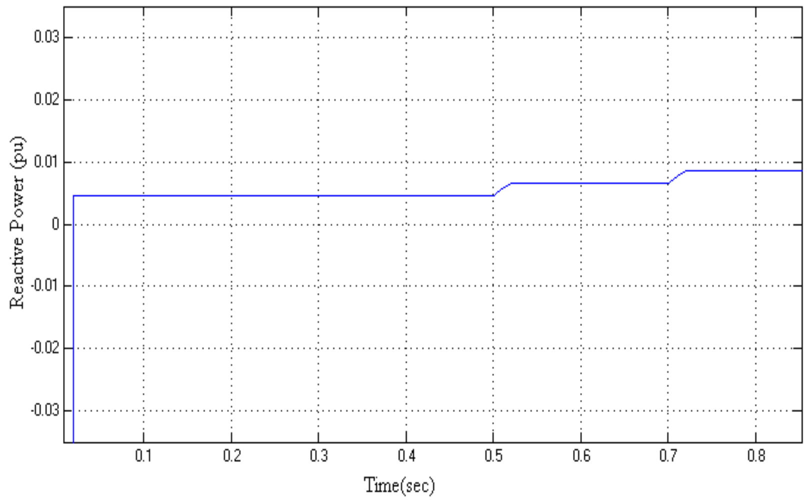


Fig 20: Magnitude of output Reactive Power without Matrix Converter.

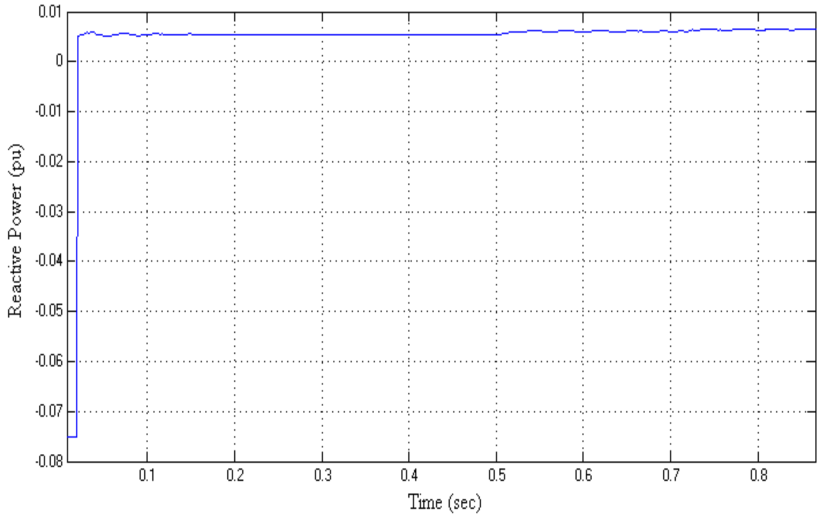


Fig 21: Magnitude of output Reactive Power with Matrix Converter.

The magnitude of output reactive power of UPFC without Matrix Converter as shown in above (fig 20) gets reached to the not steadystate and controlabul where as with matrix converter the active power as shown in above (fig 21) gets reached the steadystate and controlabul.

V. Conclusion

This paper derived advanced nonlinear direct power controllers, based on sliding mode control techniques, for matrix converters connected to power transmission lines as UPFCs. Presented simulation and experimental results show that active and reactive power flow can be advantageously controlled by using the proposed DSPC. Results show no steady-state errors, no cross-coupling, insensitivity to no modeled dynamics and fast response times, thus confirming the expected performance of the presented nonlinear DSPC methodology. The obtained DSPC-MC results were compared to PI linear active and reactive power controllers using a modified Venturing.

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