P-Q Control Matrix Converter Based UPFC By Direct Power Control Method

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Abstract **- In the recent years, due to economics and environment problems, build of new power planet and transmission line become more difficult. Hence it is advisable to enhance power transfer capability of the existing transmission lines up to thermal limit instead of constructing new one. For enhancing the power capability, FACTS controller like SSC, TCSC, SVC are developed. But these controllers cannot compensate the real and reactive power separately. For this a controller called, Unified Power Flow Controller (UPFC) is developed which uses both the series and shunt controller with a common DC capacitor link. This capacitor brings several disadvantages such as affecting the reliability, high cost etc. This paper proposes a new topology for UPFC based on the Matrix converter design. 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 power control (DPC) 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.**

I.INTRODUCTION

The original UPFC concept, introduced in the nineties by L.Gyugyi [1], consists of two AC-DC converters using Gate-Turn Off thyristors (GTO), back to back connected through their common DC link using large high-voltage DC storage capacitors. This arrangement can be operated as an ideal reversible AC-AC switching power converter, in which the power can flow in either direction between the AC terminals of the two converters The DC link capacitors provide some energy storage capability to the back to back converters that help the power flow control. Replacing the two three-phase inverters by one matrix converter the DC link (bulk) capacitors are eliminated, reducing costs, size, maintenance, increasing reliability and lifetime. The AC-AC matrix converter, also known as all siliconconverter, processes the energy directly without large energy storage needs. This leads to an increase of the matrix. In [2] an UPFC-connected power transmission network model was proposed with matrix converters and in [3] was used to synthesize both active (P) and reactive (Q) power controllers using a modified Venturini high-frequency PWM modulator.

In this paper a Matrix Converter based UPFC-connected power transmission network model is proposed, using a Direct Power Control approach (DPC-MC). This control method is based on sliding mode control techniques [5] and allows real time selection of adequate state-space vectors to control input and output variables.

II. MODELING OF UPFC POWER SYSTEM

A. General architecture

A simplified power transmission network of DPC technique applied to the three phase Matrix Converter (MC) operated as UPFC is presented in Fig. 1, where *VS* and *VR* are the sending-end and receiving-end sinusoidal voltages of the *GS* and *GR* generators respectively. The MC is connected to the inductive transmission line, represented by inductance and series resistance (*L*2 and *R*2), through coupling transformers *T*1 and *T2.*

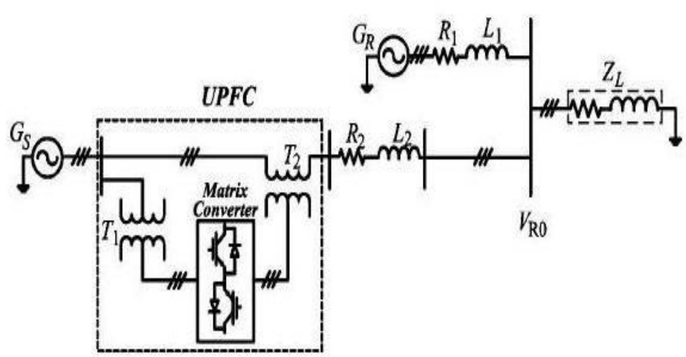

Fig.1.Transmission Network with Matrix Converter UPFC

Fig. 2 shows the simplified three-phase equivalent circuit of the matrix UPFC transmission system model. For System modelling, the power sources and the coupling transformers are all considered ideal

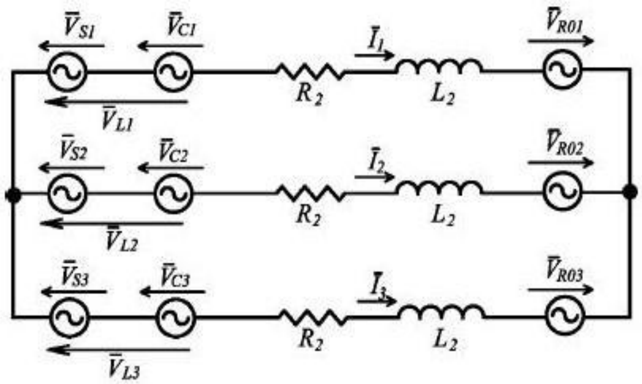

Fig. 2.Three-phase equivalent circuit of the matrix UPFC
and transmission line.

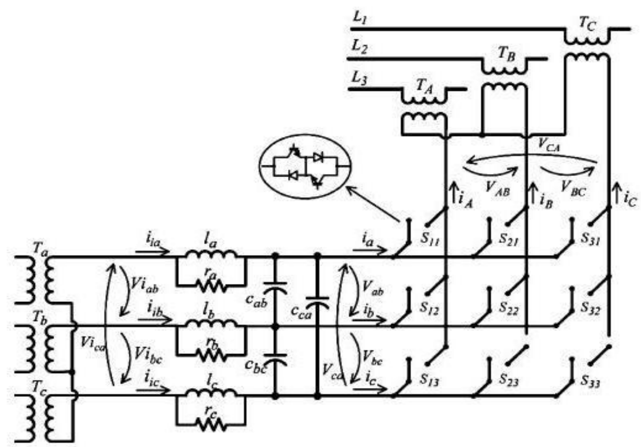

Fig. 3.Transmission network with matrix converter UPFC.

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 DPC-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.

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

$$\frac{dI_q}{dt} = -\omega I_d - \frac{R_2}{L_2} I_q + \frac{1}{L_2}(V_{Lq} - V_{Roq}) \quad (2)$$

The active and reactive power of sending end generator [19] are given in coordinates by

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

Assuming V_{Rod} and $V_{sd}=V_d$ as constants and a rotating reference frame synchronized to the V_s source so that $V_{sq}=0$,active and reactive power P and Q are given by(4) and (5) ,respectively.

$$P = v_d i_d \, (4)$$

$$Q = -v_d i_q \, (5)$$

B. Matrix Converter Output Voltage and Input Current Vector

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 TA, TB, TC) and the three-phase matrix converter, represented as an array of nine bidirectional switches Skj 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.

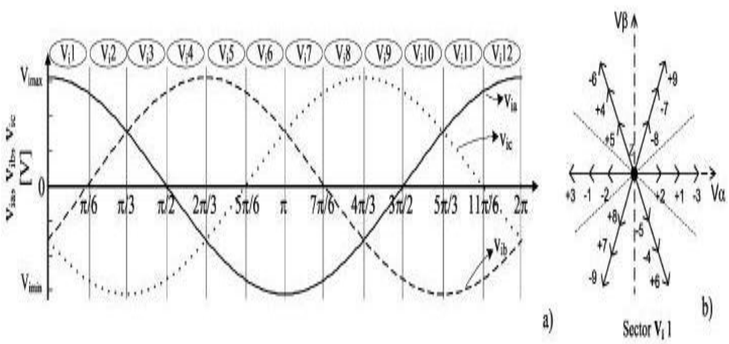

Fig.4. (a) Input voltages and their corresponding sector (b) Output voltage state-space vectors when theinput Voltagesare located at sector

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.

$$\frac{di_d}{dt} = \omega i_{iq} - \frac{1}{2l} v_d - \frac{1}{2\sqrt{2l}} v_q + \frac{1}{l} v_{id}$$

$$\frac{di_{iq}}{dt} = -\omega i_{id} + \frac{1}{2\sqrt{2l}} v_d - \frac{1}{2l} v_q + \frac{1}{l} v_{iq} \qquad (6)$$

$$\frac{dv_d}{dt} = \omega v_q - \frac{1}{2\sqrt{3}C} i_{iq} + \frac{1}{2C} i_{id} - \frac{1}{2\sqrt{3}C} i_q$$

$$\frac{dv_d}{dt} = -\omega v_d + \frac{1}{2\sqrt{3}C} i_{id} + \frac{1}{2C} i_{iq} - \frac{1}{2\sqrt{3}C} i_d - \frac{1}{2C} i_q$$

Assuming ideal semiconductors, each matrix converter bidirectional switch can assume two possible states: " Ski=1" if the switch is closed or "Ski=0 " if the switch is open .The nine matrix converter switches can be represented as a 3x3 matrix

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

The matrix converter topological constrains implies $\sum_{j=1}^{3} S_{kj} = 1$

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. 4.2]. The active and reactive power DPC-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 DPC controllers for line power flow are here derived based on the sliding mode control theory. From 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, 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).

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

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$$e_P = P_{ref} - P \; (8)$$

$$e_Q = Q_{ref} - Q \; (9)$$

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

$$S_P(e_{p,} t) = K_p (P_{ref} - P) = 0$$

$$S_Q(e_{Q,} t) = K_Q (Q_{ref} - Q) = 0$$

The proportional gains kp and kq 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 Ep and Eq 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 (12) and (13) must be verified

$$S_p(e_p, t)\dot{S}(e_P, t) < 0 \; (12)$$

$$S_Q(e_Q, t)\dot{S}(e_Q, t) < 0 \; (13)$$

According to (10) and (12),

The criteria to choose the matrix Vector should be

$$S_p(e_p, t) > 0 \Rightarrow \dot{S}(e_P, t) < 0 \Rightarrow \dot{S}(e_P, t) < 0$$

$$\Rightarrow P < P_{ref}$$

Then choose a vector suitable to increase p

$$S_p(e_p, t) < 0 \Rightarrow \dot{S}(e_P, t) > 0 \Rightarrow \dot{S}(e_P, t) > 0$$

$$\Rightarrow P > P_{ref}$$

Thenchoose a vector suitable to decrease P.

$S_p(e_p, t) = 0$

Then choose a vector which does not significantly change the active power (15).

The same procedure should be applied to the reactive power error applied to the reactive power error .to choose a vector from(4)and (11), and considering $P_{ref}$and in steady state ,the following can be written the following Table. I. shows the Switching Combinations and Output Voltage / Input Current State-Space Vectors

TABLE I
SWITCHING COMBINATIONS AND OUTPUT VOLTAGE/INPUT CURRENT STATE-SPACE VECTORS

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

$$\dot{S}(e_P,t) = K_P\left(\frac{dP_{pref}}{dt} - \frac{dP}{dt}\right) = -K_P\frac{dP}{dt} = -K_P\frac{d(V_d I_d)}{dt} = -K_P V_d\frac{dI_d}{dt}$$

from (13) considering V_d and P_{ref} constants,

if $S_P(e_P,t)>0$, then it must be $\dot{S}_P(e_P,t)>0$.

From (14) if $K_P V_d$ is positive, then $\frac{dI_d}{dt}>0$, meaning that

P must increase from theequilen tmodel in dq coordinates present in (1),if the choosen vector has $V_{Ld} > V_{Rod} - \omega L_2 I_q + R_2 I_d$ then $\frac{dI_d}{dt}>0$ then selected vector being suitable to increase the active powerSimilarly from (5) and (13), with reactive power Qref and V_d in steady state

$$\dot{S}(e_Q,t)=K_Q(\frac{dP_{Qref}}{dt}-\frac{dQ}{dt})=-K_Q\frac{dQ}{dt}=-K_Q\frac{d(-V_dI_d)}{dt}=-K_QV_d\frac{dI_Q}{dt}$$

From(13), if $S_Q(e_Q$, t)>0,then $\dot{S}_Q(e_Q$, t) <0, which still implies $\frac{dQ}{dt}$>0,meaning that $\frac{dI_q}{dt}$ Qmust increase .Also,from(15) if k_QV_d $(\frac{dI_q}{dt})$< 0 which means that if k_QV_d is positive then must be negative .considering the Iq current dynamics written in dq cordinates (2)then ,to ensure the reaching condition,then choosen vector must have

$V_{Ld} < V_{Roq} + \omega L_2 I_d + R_2 I_q$ to gurantee $\frac{dI_q}{dt} < 0$

,meaning the voltage vector has a q component suitable to increase the reactive power.Should be transformed to αβ coordinates S_P (e_P, t) and $S_Q(e_Q$, t) should be Transformed to αβ coordinates $S_\alpha(e_P,t)\, S_\beta(e_Q,t)$.

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 nextsubsection. 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.The same procedure should be applied to the reactive power error.To choose a vector, from (4) and (12), and consideringP$_{ref}$ and V$_d$in steady state, the following can be written. The following table II shows the state-space vectors selection for different error combination.

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

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 thematrix 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.

$$\dot{S}(e_Q,t)=(Q_{ref}-Q_i)+K_{Qi}\frac{d(Q_{ref}-Q_i)}{dt}$$

The time derivative can be approximated by a discrete time difference, as has been chosen to obtain a suitable witching frequency, since as stated before, this sliding surface. Fig. 5.(a) Output currents and their corresponding sector. (b) Input current state-space vectors, when output currents are located at sectorVi1

$$\dot{S}(e_Q,t)=V_{id}\left(\frac{di_{iq}}{dt}+K_{Qi}\frac{d^2i_{iq}}{dt^2}\right)=V_{id}\left(-\omega i_{id}+\frac{1}{2\sqrt{3}l}V_d-\frac{1}{2l}V_q\right)+$$

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

From (17) it is seen that the control input ,the iq matrix input current ,must have enough amplitude ,(16) and (17) are used to establishe the criteria (18) to choose the adequate matrix input current vector that impose the needed sign of the matrix input phase current iq related to the out put-phase currents by

$S_Q(e_Q,t)>0\Rightarrow\dot{S}_{Qi}(e_{Qi},t)<0\ \dot{S}(e_P,t)<0$ then select vector with current $i_q<0$ to increase Q_i

$S_Q(e_Q,t)<0\Rightarrow\dot{S}_{Qi}(e_{Qi},t)>0\ \dot{S}(e_P,t)>0$ then select vector with current $i_q>0$ to decrease Q_i

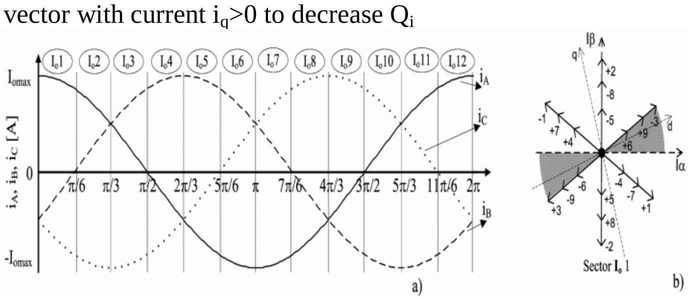


Fig.5. (a) Output currents and their corresponding sector
(b) Input current state-space vectors

The sliding mode is reached when vectors applied to the converter have the necessary current amplitude to satisfy stability conditions. 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). From (17), it is seen that the control input, the matrix input current, must have enough amplitude to impose the sign of Supposing that there is enough amplitude, (16) and (17) are used to establish the criteria (18) to choose the adequate matrix input current vector that imposes the needed sign of the matrix input-phase current related to the output-phase currents.

IV. IMPLEMENTATION OF THE DPC-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 currents measurement is also used to determine the location of the input currents component. The control of the matrixconverter 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. A simplified power transmission network of DPC technique applied to the three phase Matrix Converter (MC) operated as UPFC is presented in Fig. 1,is used for this study.

Table III
STATE-SPACE VECTORS SELECTION, FOR INPUT VOLTAGES LOCATED AT SECTOR V_{I1}

C_α	C_β	Sector: I_012 ; I_01 C_{Qi}		I_02 ; I_03 C_{Qi}		I_04 ; I_05 C_{Qi}		I_06 ; I_07 C_{Qi}		I_08 ; I_09 C_{Qi}		I_010; I_011 C_{Qi}	
		+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1
-1	+1	-9	+7	-9	+7	-9	+7	+7	-9	+7	-9	+7	-9
-1	0	+3	-1	+3	-1	-1	+3	-1	+3	-1	+3	+3	-1
-1	-1	-6	+4	+4	-6	+4	-6	+4	-6	-6	+4	-6	+4
0	+1	-9	+7	-9	+7	-9	+7	+7	-9	+7	-9	+7	-9
0	0	-2	+2	+8	-8	-5	+5	+2	-2	-8	+8	+5	-5
0	-1	-7	+9	-7	+9	-7	+9	+9	-7	+9	-7	+9	-7
+1	+1	-4	+6	+6	-4	+6	-4	+6	-4	-4	+6	-4	+6
+1	0	+1	-3	+1	-3	-3	+1	-3	+1	-3	+1	+1	-3
+1	-1	-7	+9	-7	+9	-7	+9	+9	-7	+9	-7	+9	-7

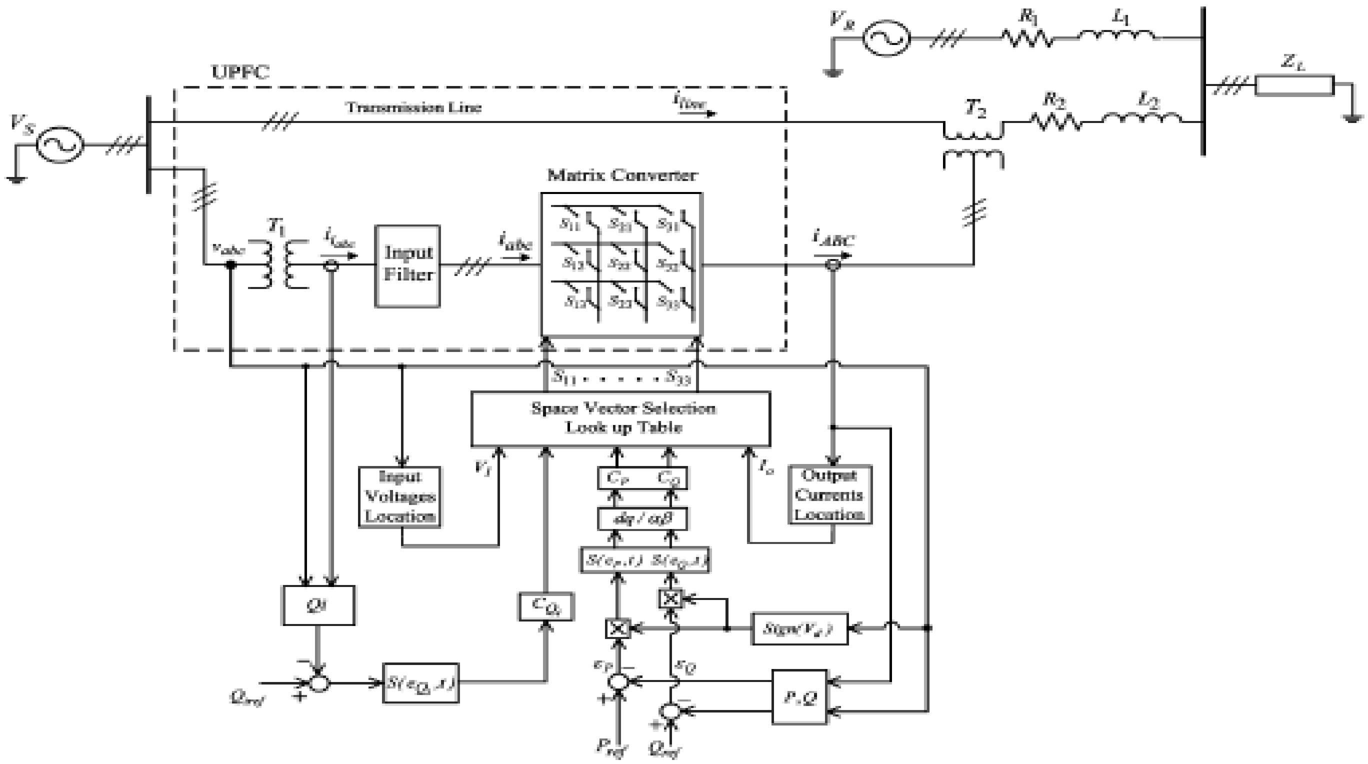


Fig. 6. Control scheme of direct power control of the three-Phase matrix converter operating as a UPFC

The performance of the proposed direct controlsystem was evaluated with a detailed simulation model using the MATLAB/Simulink. The load power is 1.5kW (1 p.u.) and transmission lines 1 and 2 are simulated as inductances L1=12 mH L2 =15 mH, and series resistances R1=R2 = 0.2_, respectively for line 1 and 2. Sliding mode DPC gains are KP = KQ = KQi =1selected 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 response to changes in Pref and Qref references (Δ Pref and Δ Qref).Fig. 7(a) and (b) shows, respectively, the simulation results for the active and reactive power step response (Δ Pref = +0.4 p.u. and Δ Qref =+ 0.2 p.u.) and shunt reactive power, considering initial reference values: Pref = 0.4 p.u., Qref = 0.2 p.u., and Qref = -0.07 p.u. Both results clearly show that there is no cross-coupling between active and reactive power

A. Waveforms for without matrix converter

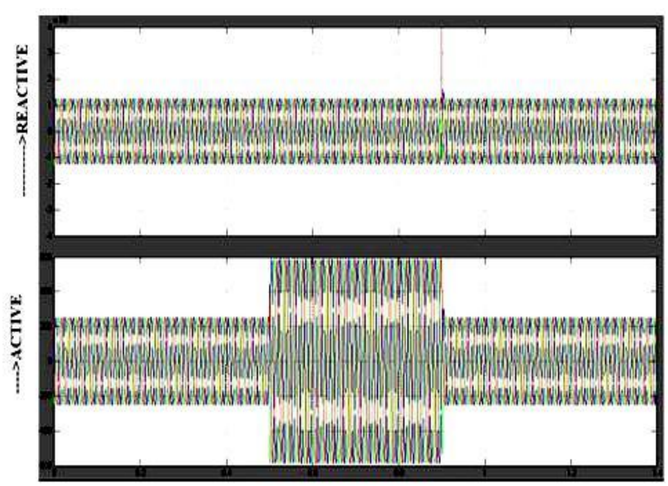
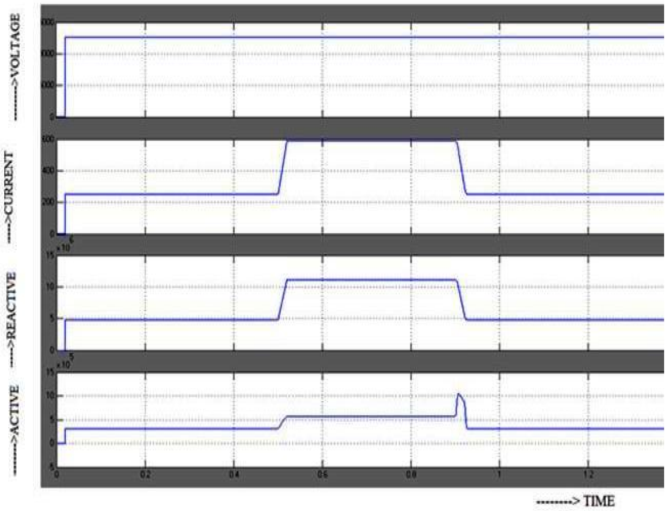


Fig.7. (a)



(b)

Fig.7. (a) Active and reactive series power response and reactive shunt power, for P and Q steps
(b) Active and reactive power response and linecurrents for a P and Q step

B. Wave Forms for With Matrix Converter

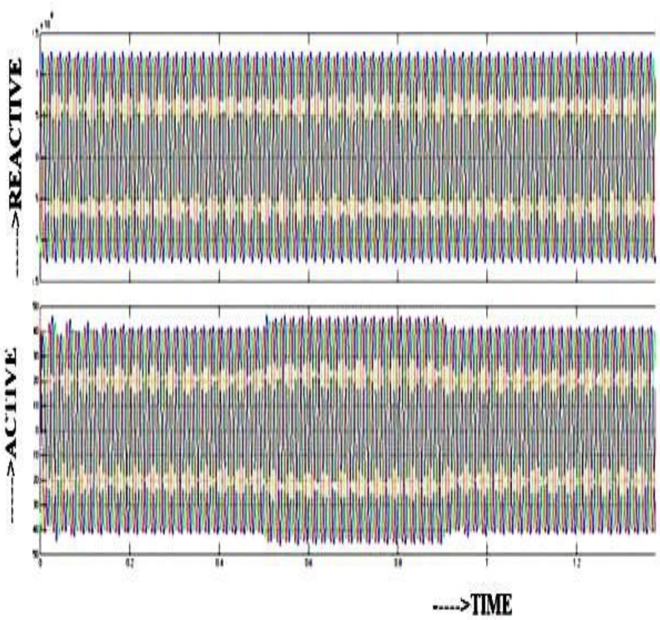
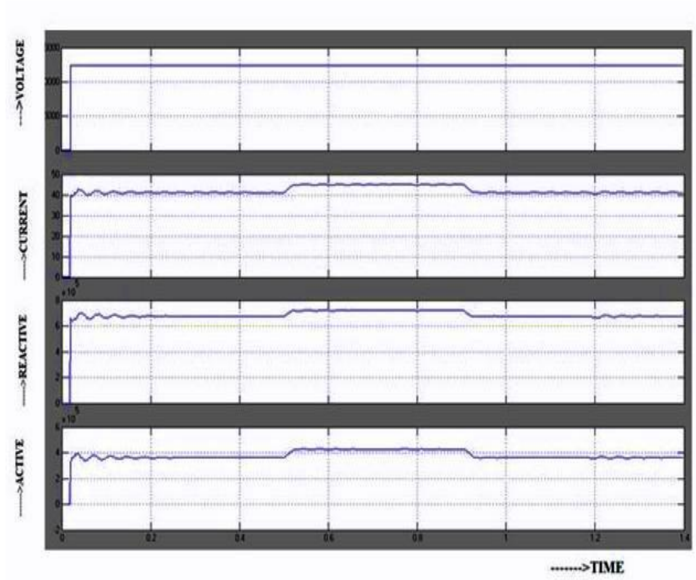


Fig.8. (a)



(b)

Fig.8. (a) Active and reactive series power response and reactive shunt power, for P and Q steps
(b) Active and reactive power response and line currents for a P and Q step

DPC simulation results presented in Fig. 8(a) and (b), showing the claimed DPC faster dynamic response to step active and reactive power reference change.

VI CONCLUSION

The proposed UPFC is able to control the full range of power flow and the power coefficient as is a conventional power flow controller. A UPFC based on a matrix converter is suitable for application where supply voltages are symmetrical. Presented simulation and experimental resultsshow that active and reactive power flow can be advantageously controlled by using the proposed DPC. 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 DPC methodology.

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