An Intelligent Techniques for Facts Device with Matrix Converter using Large Bus System

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***Abstract*- A direct power control (DPC) 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. principles of direct power control (DPC) based on sliding mode control techniques are established for an MC-UPFC dynamic model including the input filter. Experimental results of DPC controllers for MC-UPFC show decoupled active and reactive power control, zero steady-state tracking error, and fast response times.**

This paper presents a direct power control (DPC) 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.

The existence of a dc capacitor bank originates additional losses, decreases the converter lifetime, and increases its weight, cost, and volume. Results show no steady-state errors, no cross-coupling, insensitivity to non modeled dynamics and fast response times, thus confirming the expected performance of the presented nonlinear DPC methodology. The performance of the proposed direct control system was evaluated with a detailed simulation model using the MATLAB/Simulink

Index terms — Direct power control (DPC), AC/AC converter, matrix converter (MC), unified power-flow controller (UPFC), MATLAB/ SIMULINK.

NOMENCLUTURE

K_p,K_q	proportional gains
e_p	active power error
e_q	reactive power error
V_d,V_q	matrix converter voltage in dq components
i_d,i_q	input current in dq component

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.

This paper presents a direct power control (DPC) 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[1]. 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. Experimental results of DPC 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 Venturini high-frequency [3] PWM modulator, the experimental results of the advanced DPC-MC guarantee faster responses without overshoot and no steady-state error, presenting no cross-coupling in dynamic and steady-state responses. 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. In the dependence of the matrix converter output voltage on the modulation coefficient was investigated, concluding that MC-UPFC is able to control the full range of power flow. In the last few years, direct power control techniques have been used in many power applications, due to their simplicity and good performance.

In order to design UPFCs, presenting robust behavior to parameter variations and to disturbances, the proposed DPC-MC control method, 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 DPC-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 Venturini high-frequency PWM modulator.

II. DIRECT POWER CONTROL OF MC-UPFC

A. Line Active And Reactive Power Sliding Surfaces

In this section The DPC controllers for line power flow are here derived based on the sliding mode control theory. In steady state, Vd is imposed by source Vs. the transmission-line currents can be considered as state variables with first-order dynamics dependent on the sources and time constant of impedance L 2 / R 2.

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 .Therefore, define the active power error e P and the reactive power error e Q as the difference between the power references the actual transmitted powers pref ,Qref and the actual transmitted powers P,Q respectively.

$$e_p = P_{ref} - P \qquad (1)$$

$$e_Q = Q_{ref} - Q \qquad (2)$$

Then, the robust sliding surfaces $S_p\left(e_p,t\right)$ an $S_Q\left(e_Q,t\right)$ must be proportional to these errors, being zero after reaching sliding mode

$$S_p\left(e_p,t\right) = K_p\left(P_{ref} - P\right) = 0 \quad (3)$$

$$S_Q\left(e_Q,t\right) = k_Q\left(Q_{ref} - Q\right) = 0 \quad (4)$$

converter sides, while guaranteeing that the active power exchanged on the UPFC series connection is always supplied/absorbed by the shunt connection .The proportional gain K_p and k_Q are chosen to impose appropriate switching frequencies.

B.LINE ACTIVE AND REACTIVE DIRECT SWITCHING LOSS

The DPC uses a nonlinear law, based on errors eQ and eP 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 (5.5) and (5.6) must be verified.

$$S_P\left(e_P,t\right)\dot{S}_P\left(e_P,t\right) < 0 \qquad (5)$$

$$S_Q\left(e_Q,t\right)\dot{S}_Q\left(e_Q,t\right) < 0 \qquad (6)$$

These conditions mean that if $S_P(e_P,t)$ >0.then the $S_P(e_P,t)$ value must be decreased meaning that its time derivative should be negative $S_Q\left(e_Q,t\right) < 0$. According to (3) and (5), the criteria to choose the matrix vector should be

1.If $S_P\left(e_P,t\right) > 0 \Rightarrow \dot{S}_p\left(e_p,t\right) < 0 \Rightarrow P < P_{ref}$ then

choose a vector suitable to increase P

2.If $S_P\left(e_P,t\right) > 0 \Rightarrow \dot{S}_p\left(e_p,t\right) < 0 \Rightarrow P > P_{ref}$ then

choose a vector suitable to decrease P

3. If $S_P(e_P,t) = 0$ then choose a vector which does not significantly change the active power.

The same procedure should be applied to the reactive power error.

To design the DPC control system, the six vectors of group I will not be used, since they require extra algorithms to calculate their time-varying phase [6]. 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 V_{Lq} and V_{Lq} 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 e_p and e_q are quantized using two hysteresis comparators, each with three levels (-1.0 and +1), 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.

Using the same reasoning for the remaining eight active and reactive power error combinations and generalizing it for all other input voltage sectors, Table I 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

III.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 dynamics has a strong relative degree of two, then a suitable sliding surface $SQ\left(eQ,t\right)$ will be a linear combination of the desired reactive power error $eQi = Qiref - Qi$ and its first order time derivative The time derivative can be approximated by a discrete time difference, KQi as has been chosen to obtain a suitable switching frequency, since as stated

$$S_{Qi}\left(eQi,t\right)=\left(Q_{iref}-Q_i\right)+k_{Qi}\frac{d}{dt}\left(Q_{iref}-Q_i\right) \qquad (7)$$

Supposing that there is enough i_q amplitude, (7) are used to establish the criteria (8) to choose the ad- equate matrix input current vector that imposes the needed sign of the matrix input-phase current i_q related to the output-phase current by

1. If $S_{Qi}\left(e_{Qi},t\right) > 0 => S_{Qi}\left(e_{Qi},t\right) < 0$ then choose a vector current $i_q < 0$ to increase Q_i
2. If $S_{Qi}\left(e_{Qi},t\right) < 0 => S_{Qi}\left(e_{Qi},t\right) > 0$ then choose a vector current $i_q > 0$ to decrease Q_i

Before, this sliding surface needs to be quantized only in two levels (-1 and +1) using one hysteresis comparator. The sliding mode is reached when vectors applied to the converter have the necessary iq current amplitude to satisfy stability conditions. Therefore, to choose the most adequate vector in the chosen dq reference frame, it is necessary to know the output currents location since the iq input current depends on the output currents (Table I). Considering that the dq–axis location is synchronous with the input voltage (i.e., dq reference frame depends on the input voltage location), the sign of the matrix reactive power Qi can be determined by knowing the location of the input voltages and the location of the output current.

IV.MATRIX CONVERTER

The Matrix Converter is a forced commutated converter which uses an array of controlled bidirectional switches as the main power elements to create a variable output voltage system with unrestricted frequency. It does not have any dc-link circuit and does not need any large energy storage elements .

The key element in a Matrix Converter is the fully controlled four-quadrant bidirectional switch, which allows high-frequency operation. The early work dedicated to unrestricted frequency changers used thyristors with external forced commutation circuits to implement the bidirectional controlled Each output phase can be connected to any input phase at any timeSwitching pattern and commutation control must avoid line to line short circuits at the input Switching pattern and commutation control must avoid open circuits at the output (assuming inductive load) Switch duty cycles are modulated so that the “average” output voltage follows the desired reference (for example a sinusoidal reference) “Average” input current is sinusoidal when the input voltage, output reference and output current are sinusoidal .

The introduction of power transistors for implementing the bidirectional switches made the matrix converter topology more attractive .However, the real development of matrix converters starts with the work of Venturini and Alesina published in 1980. They presented the power circuit of the converter as a matrix of bidirectional power switches and they introduced the name “matrix converter.” One of their main contributions is the development of a rigorous mathematical analysis to describe the low-frequency behavior of the converter, introducing the “low-frequency modulation matrix” concept. In their modulation method, also known as the direct transfer function approach, the output voltages are obtained by the multiplication of the modulation (also called transfer) matrix with the input voltages.

B.INPUT FILTERS

Filters must be used at the input of the matrix converters to reduce the switching frequency harmonics present in the input current.

- To have a cutoff frequency lower than the switching frequency of the converter;
- To minimize its reactive power at the grid frequency
- To minimize the volume and weight for capacitors and chokes
- To minimize the filter inductance voltage drop at rated current in order to avoid a reduction in the voltage transfer ratio

It must be noticed that this filter does not need to store energy coming from the load. Several filter configurations like simple *LC* and multistage *LC* have been investigated [2]. It has been shown that simple *LC* filtering is the best alternative considering cost and size.

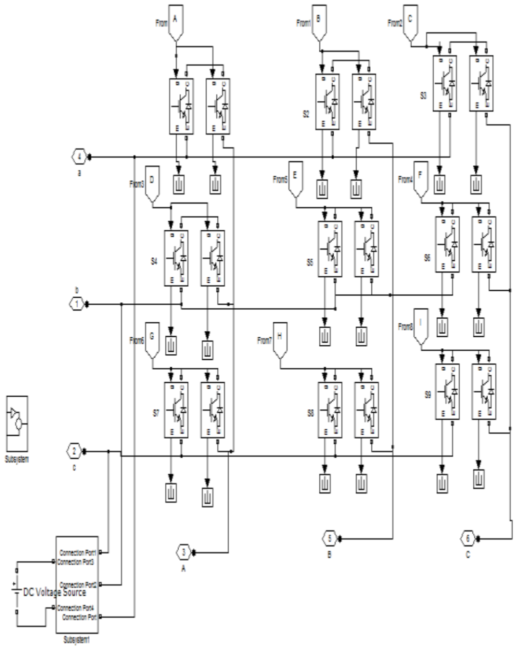

Fig 1. Modeling of matrix converter

Due to the *LC* configuration of the input filter, some problems appear during the power-up procedure of the matrix converter. It is well known that an *LC* circuit can create overvoltage during transient operation. The connection of damping resistors ,to reduce over voltages is proposed in [3].The damping resistors are short circuited when the converter is running. The use of damping resistors connected in parallel to the input reactors is proposed in [3].

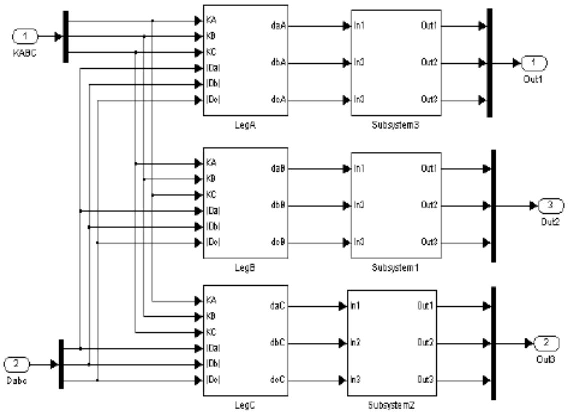

Fig 2.Modeling of vector selection block

The control of the instantaneous active and reactive powers requires the measurement of voltages and output currents necessary to calculate sliding surfaces. The output currents 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 I and II for all voltage sectors.

C_α	C_β	***Sector*** $I_0 12 ; I_0 1$ C_{Qi}		$I_0 2 ; I_0 3$ C_{Qi}		$I_0 4 ; I_0 5$ C_{Qi}		$I_0 6 ; I_0 7$ C_{Qi}		$I_0 8 ; I_0 9$ C_{Qi}		$I_0 10; I_0 11$ 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

TABLE I : State-Space Vectors Selection, For Input Voltages Located At Sector

Using the same reasoning for the remaining eight active and reactive power error combinations and generalizing it for all other input voltage sectors, Table I 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 .

V. SIMULATION RESULTS

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

Matrix converter was built by using three semiconductor modules from DANFOSS, each one with six 1200-V 25-A insulated-gate bipolar transistors (IGBTs) with an anti parallel diode in a common collector arrangement. To input filter parameter variation, the ability to operate at low switching frequencies, and insensitivity to switching nonlinearity. The 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.

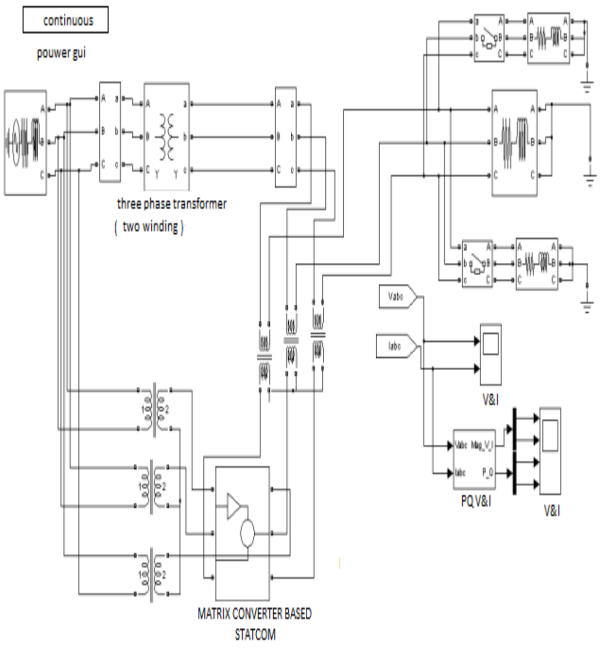

Fig 6.1 Modeling of UPFC with matrix converter

Digital Simulations are carried out in MATLAB 7.11.0 (R2010b) & was run for 10s with the controller. The step size for 3 simulations was taken to be very small so that we get very accurate results. For the software implementation purposes, a 3 generator 9 bus system with 220 KV line and 100 MVA generators is considered.

DPC controller ability to operate at lower witching frequencies, the DPC gains were lowered and the input filter parameters were changed accordingly to lower the switching frequency to nearly 1.4 kHz.

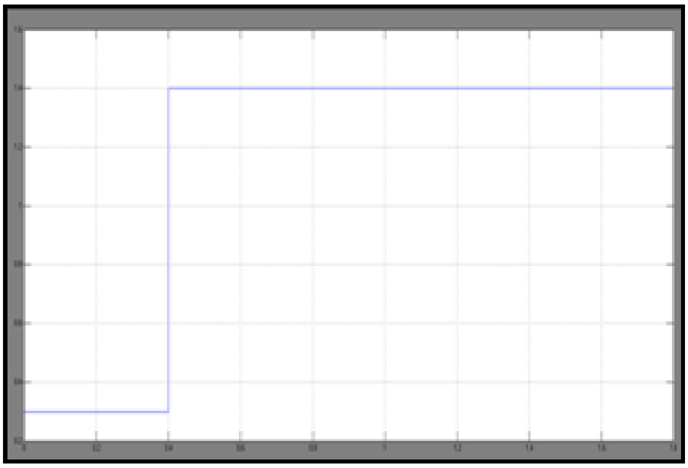

Fig 4. Active power response for Matrix converter .

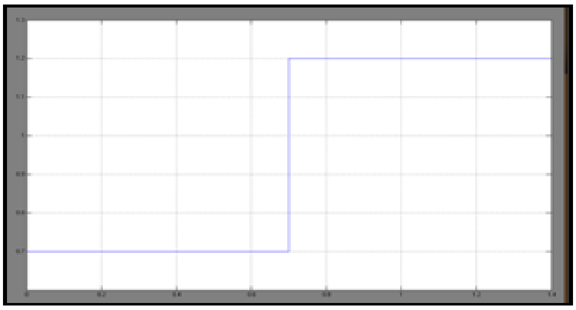

Fig 5. Reactive power response for Matrix converter.

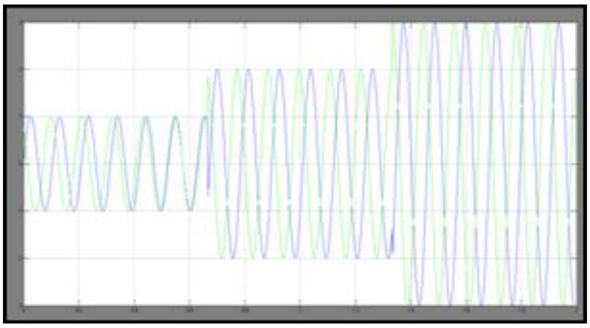

Fig 6. Line current for P and Q

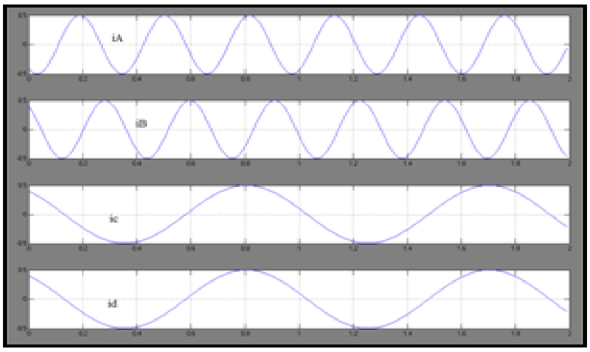

Fig 7. Line current (iA,iB) and input matrix converter current (ic,id).

VI. CONCLUSION

In the present method the Matrix Converter based UPFC was implemented in the single bus system where as in this paper it is implemented in three bus system and derived advanced nonlinear direct power controllerswas derived 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 DPC. Results show no steady-state errors, no cross-coupling, insensitivity to non modeled dynamics and fast response times, thus confirming the expected performance of the presented nonlinear DPC methodology. The obtained DPC-MC results were compared to PI linear active and reactive power controllers using a modified Venturini high-frequency PWM modulator. Despite showing a suitable dynamic response, the PI performance is inferior when compared to DPC. Furthermore, the PI controllers and modulator take longer times to compute. Obtained results show that DPC is a strong nonlinear control candidate for line active and reactive power flow. It ensures transmission-line power control as well as sending end reactive power or power factor control.

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