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AN INTELLIGENT TECHNIQUE FOR UNIFIED POWER FLOW CONTROLLER WITH MATRIX CONVERTER

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Abstract **-** The Matrix Converter is an array of controlled semiconductor switches that connects directly the three phase source to three phase load. In the Matrix Converter there is no dc link for ac/ac conversion. MC-based UPFC (MC-UPFC) has reduced capacitor loss, volume, cost. sliding mode control techniques is used in the principles of direct power control (DPC) which is established for an MC-UPFC model as consists of input filter. Simulation results of DPC controllers for MC-UPFC provide no cross coupling in dynamic and steady state response, fast response time and decoupled active and reactive power control. The Proposing System matrix converter- based UPFC using a direct power control approach (DPC-MC) based on an MC-UPFC dynamic model. The design UPFCs, presenting robust behavior to parameter variations and to disturbances.

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

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 recent years, with ever-increasing demand for electricity, the power transfer grows, the power system becomes increasingly more complex to operate and the system can become less secure for riding through the major outages. [1]. 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. UPFCs can occur over line impedance due to sending and receiving end voltage amplitudes and phase differences. Unified power-flow controllers (UPFC) enable the operation of power transmission networks near their maximum ratings, by enforcing power flow through well-defined lines[1]. In dc-link capacitance of the UPFC increase its losses, weight, cost, and volume and decreasing the lifetime.

In the last few decades, an increasing interest in new converter types, are performing the same functions but with reduced storage needs, has arisen. Matrix converter is highly applicable for ac to ac conversion, allowing bidirectional power flow, assurance of near sinusoidal input and output currents, voltages with variable amplitude, and adjustable power factor [8].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.

Conventional UPFC controllers do not guarantee robustness. 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. Presented simulation and experimental results show that active and reactive power flow can be advantageously controlled by using the proposed DPC. Simulation and experimental results confirm the performance of the proposed controllers, showing no cross-coupling, no steady-state error (only switching ripples), and fast response time for different changes of power references. In dc-link capacitance of the UPFC increase its losses, weight, cost, and volume and decreasing the lifetime. These matrix converters are capable of performing the same ac/ac conversion, allowing bidirectional power flow, assurance of 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[8].

II. DIRECT POWER CONTROL OF MC-UPFC

A. Line Active and Reactive Power Sliding Surfaces

In DPC method have the steady state, v_d is imposed by source v_s. 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).

In the DPC control ,sliding mode control theory is used, 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 p_{ref}, Q_{ref} and 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 the 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

Direct power control must ensure that the sending end power follows power references .The nonlinear law, based on errors e_Q and e_P is selected in the real time by using DPC in the matrix converter switching states. High control speed is achived because where there are no modulators and pole zero-based approaches. To maintain stability for active and reactive power controllers, the conditions of sliding-mode stability (5) and (6) should 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 a vector is chosen for the real power to not be changed.

The same procedure is applied for the reactive power error. The six vectors of group I cannot not be used to design the DPC control system, that is why 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 assure the previously discussed required levels of V_{Lp} and V_{Lq} required, to satisfy their conditions. In group III the lowest amplitude voltages vectors, and three null vectors, could be used for near zero errors[2].

If the control errors ep and eq are quantized using two hysteresis comparators, each with three levels (-1, 0 and +1), combinations of nine output voltage error are obtained. The shunt reactive power is controlled by using two-level comparator (-1 and 1) then 18 error combinations will be defined, then enabling the selection of 18 vectors. selecting one out 18 vectors is sufficient so for the three zero vectors have a minor influence on the shunt reactive power control.

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, and dependent only on the errors of the controlled output to ensure robustness to parameter variations, operating conditions, allow system order reduction, and minimizing response time.

III. DIRECT CONTROL OF MATRIX CONVERTERS INPUT REACTIVE POWER

The minimum or a certain desired reactive power is obtained at the matrix converter UPFC can be controlled to ensure a at the matrix converter input. In the same way 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, a suitable switching frequency is given by choosing KQi, 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 $S_{Qi}\left(e_{Qi},t\right) > 0 \Rightarrow S_{Qi}\left(e_{Qi},t\right) < 0$ 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 i_q 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 i_q 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 Q_i can be determined by knowing the location of the input voltages and the location of the output current.

IV. MATRIX CONVERTER

The matrix converter (MC) is an AC to AC conversion and development of the fully controlled converter based on bi-directional fully controlled switches, PWM voltage control, as mentioned earlier. With the initial progress made by Venturing it has received considerable attention in recent years as it provides a good alternative to the double-sided PWM voltage source rectifier inverters having the advantages of being a single stage converter with only nine switches for three-phase to three-phase conversion and inherent bi-directional power flow, sinusoidal input/output waveforms with moderate switching frequency, possibility of a compact design due to the absence of dc link reactive components, and controllable input power factor independent of the output load current. They presented the power circuit of the converter as a matrix of bidirectional power switches and they introduced the matrix converter and the low-frequency modulation matrix concept. In their modulation method, as the direct transfer function approach, the output voltages are obtained using multiplication of the *modulation matrix with the input voltages*

A.. Input Filters

Filters must be used at the input of the matrix converters to reduce the switching frequency harmonics present in the input current. The requirements for the filter are as follows: 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. One should be noticed that this filter does not need to store energy coming from the load. Some filter configurations like simple LC and multistage *LC* have been investigated . It has been shown that simple *LC* filtering is the best alternative considering cost and size.

B. Venturini Method

Given a set of three-phase input voltages with constant amplitude Vi and frequency f= ωi/2∏, this method calculates a switching function involving the duty cycles of each of the nine bi-directional switches and generate the three-phase output voltages by sequential piecewise sampling of the input waveforms. These output voltages follow a predetermined set of target voltage waveforms and with a three-phase load connected, a set of input currents Ii and angular frequency ωi should be in phase for unity.

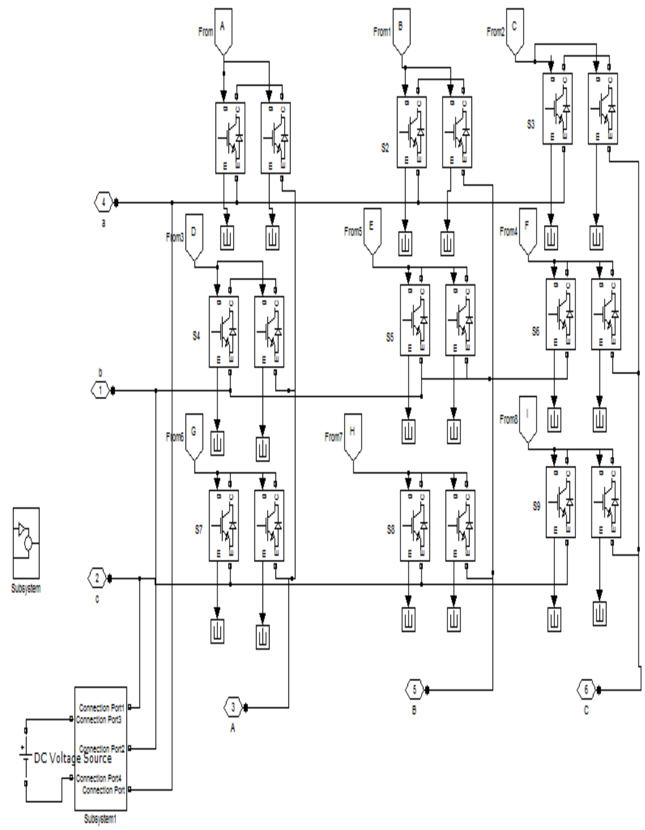

Fig 1. Modeling of matrix converter

Some problems appear during the power-up procedure of the matrix converter in the *LC* configuration of the input filter. *LC* circuit can create overvoltage during transient operation. The connection of damping resistors, to reduce over voltages is proposed in [5]. when the converter is running the damping resistors are short circuited. The use of damping resistors connected in parallel to the input reactors is proposed in [5].

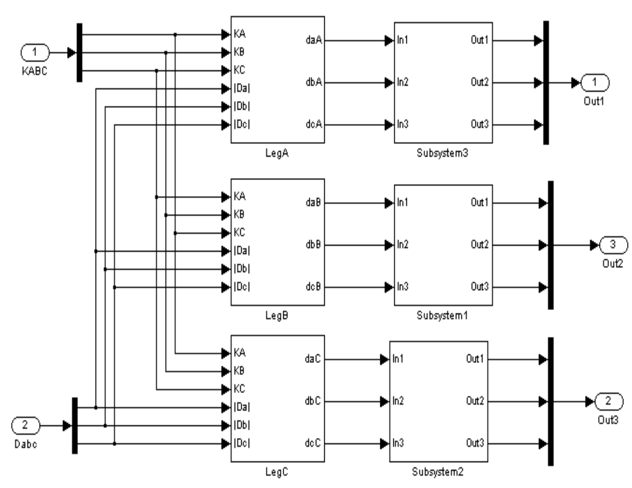

Fig 2. Modeling of vector selection block

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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.

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

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

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 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 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 and fast response times for different changes of power references.

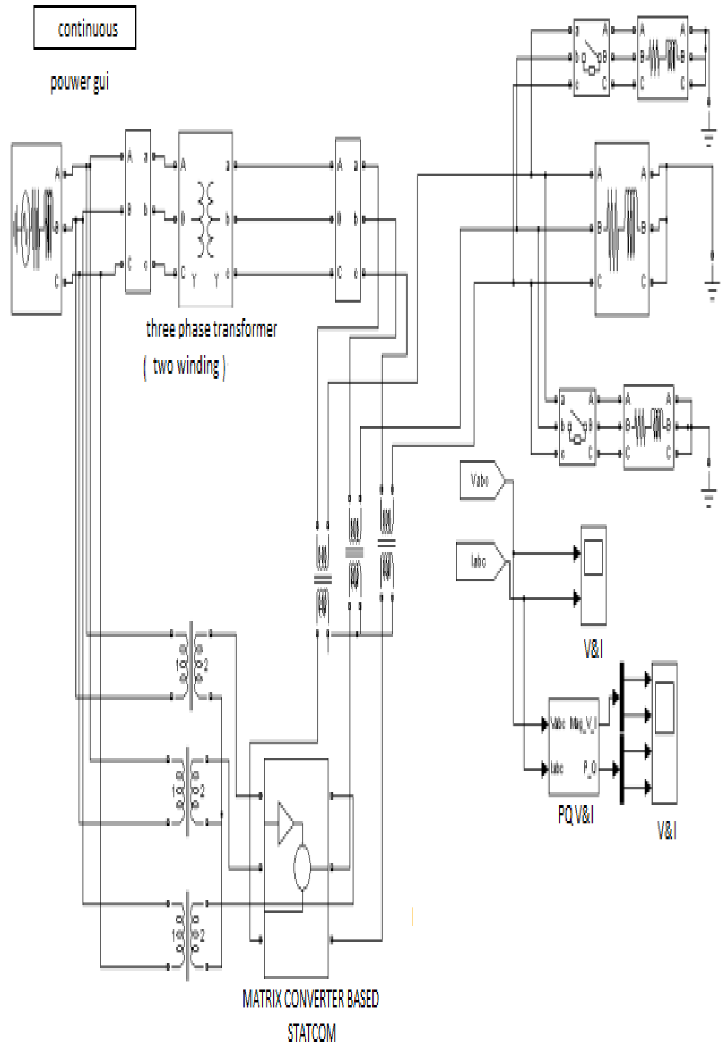

Fig 6.1 Modeling of UPFC with matrix converter

Digital Simulations are carried out in MATLAB 7.11.0 (R2010b) & was run for 10s with the controller. To get very accurate results, the step size for 3 simulations was taken to be very small. 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.

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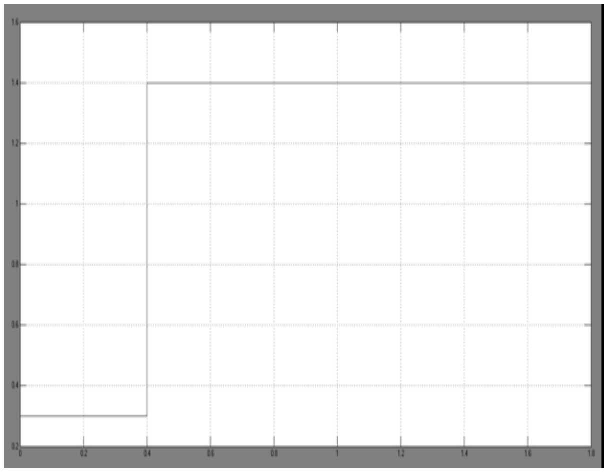
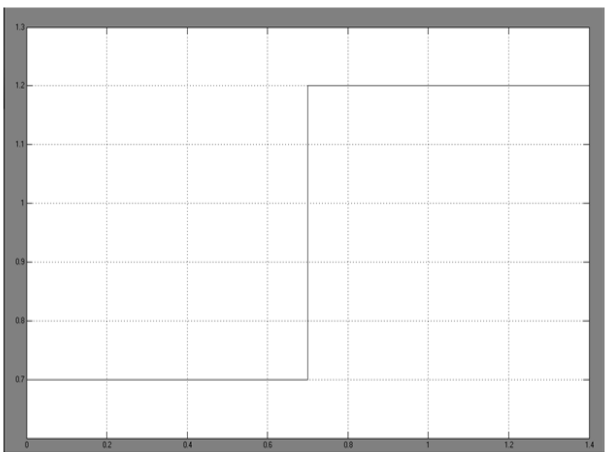
P



Time(s)

Fig 4. Active power response for Matrix converter.

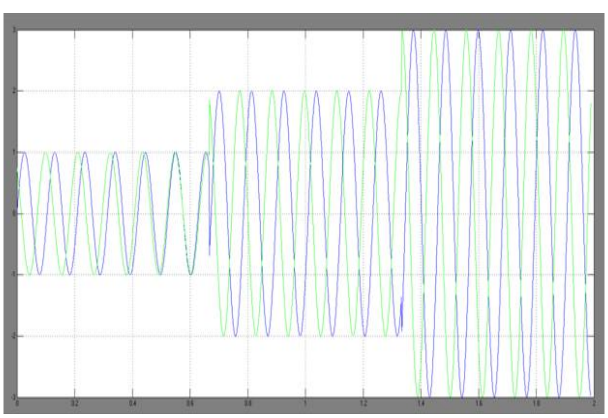
Q



Time(s)

Fig 5. Reactive power response for Matrix converter

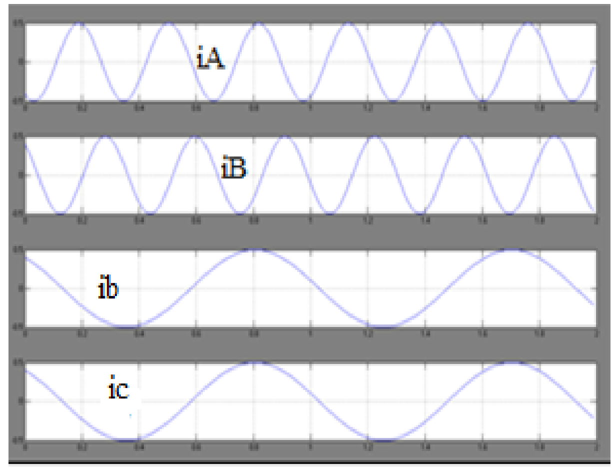
C
U
R
R
E
N
T



Time(s)

Fig 6. Direct Power Controller

C
U
R
R
E
N
T



Time(s)

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

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 controllers were 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 time, 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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