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Engineering

PI CONTROLLER BASED DIRECT POWER CONTROL FOR PULSE WIDTH MODULATED VSC CONVERTERS

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ABSTRACT The Proportional and Integral controller based Direct Power Control strategy is proposed to control Pulse Width Modulated voltage source converters under various load conditions. This technique is used to reduce the harmonics distortions in the current, to maintain the DC bus capacitor voltage at the required level, while the input currents drawn from the supply mains should be sinusoidal and in phase with respective phase voltages to satisfy the unity power factor condition. Simulation results are presented and interpreted.

KEYWORDS : Direct Power Control, Proportional and Integral controller, Pulse Width Modulation, VSC, UPF

INTRODUCTION

There are number of reasons which cause severe harmonic distortion problems in electrical networks and grid when line side rectifiers are used. They have negative influence on the control and automatic power electronic equipments, protection systems, and other electrical loads. The commonly used method of harmonic compensation for current involves passive filters. These used to eliminate 5th, 7th, 11th, and 13th, however, these passive present many disadvantages such as series and parallel resonances [1, 2]. The use of the active power filters is one of the most attractive modern solutions to suppressing harmonic pollution, enhance power quality, and ensure the better quality power distribution system. there are two types of (APFs) as series active power filter and shunt active power filter [3]. The conventional AC/DC rectifiers converter such as diodes bridge have nonlinear loads nature, which absorb a non-sinusoidal input current, consume sometimes reactive energy, and they generate harmonic currents in to the AC line power [4]. Researches and application show that the PWM voltage source converters are used in several industrial applications, the performance of the PWM converters depends upon the design of the structure and the types of controllers to obtain the high performances. In this paper, DPC strategy is proposed to control PWM voltage source converters rectifiers. The PWM rectifiers have bidirectional power flow capability. The converter is supplied by a 3-phase source in series with coupling inductance (**L**$_c$); the PWM rectifier is supplying various loads connected in parallel with DC capacitor voltage. The advantage of PWM voltage source converter rectifier as non-polluting equipment, it has sinusoidal input currents with unity power factor (UPF) with bi-directional power flow and the stabilization of output DC voltage[5]. Several control strategies were proposed in recent works for the PWM rectifier, DPC strategy based on PI controller provides sinusoidal line current and lower harmonic distortion in to the AC line power [6]. This paper is dedicated to this specific type of rectifiers using DPC strategy, shown in Figure. 1.

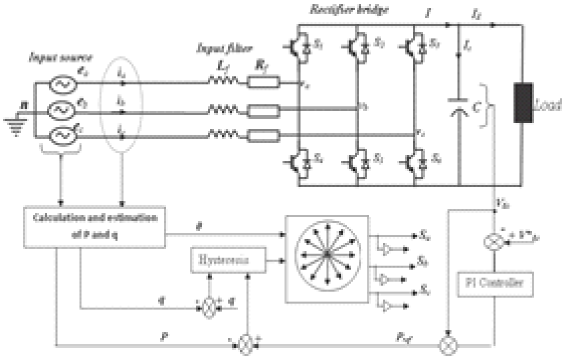

Figure 1: Three-phase PWM voltage source converter

The instantaneous voltages of AC source and the fundamental line current [5, 7] are expressed as:

$$v_{an}(t) = V_m \cos(\omega t) \tag{1}$$
$$v_{bn}(t) = V_m \cos(\omega t - \tfrac{2\pi}{3}) \tag{2}$$
$$v_{cn}(t) = V_m \cos(\omega t - \tfrac{4\pi}{3}) \tag{3}$$
$$i_a(t) = I_m \cos(\omega t + \varphi) \tag{4}$$
$$i_b(t) = I_m \cos(\omega t - \tfrac{2\pi}{3} + \varphi) \tag{5}$$
$$i_c(t) = I_m \cos(\omega t - \tfrac{4\pi}{3} + \varphi) \tag{6}$$

V_m: is the amplitude source voltage,
I_m: is the amplitude of the phase current,
φ: is the angular phase

with assumption:

$$i_{AN} + i_{BN} + i_{CN} = 0 \tag{7}$$

α–β input voltages are:

$$v_{s\alpha}(t) = \frac{\sqrt{3}}{2} V_m \sin(\omega t) \tag{8}$$

$$v_{s\beta}(t) = \frac{\sqrt{3}}{2} V_m \cos(\omega t) \tag{9}$$

Similarly, the input voltages in the synchronous d-**q** coordinates are expressed by

$$v_{sd}(t) = \frac{\sqrt{3}}{2} = \sqrt{\mathrm{v}_{\mathrm{sd}}^2 + \mathrm{v}_{\mathrm{sq}}^2} \tag{10}$$

$$v_{sq}(t) = 0 \tag{11}$$

Line to Line input voltages of PWM rectifier can be described as:

$$V_{AB}(t) = (S_A - S_B) * V_{dc} \tag{12}$$

$$V_{BC}(t) = (S_B - S_A) * V_{dc} \tag{13}$$

$$V_{CA}(t) = (S_C - S_A) * V_{dc} \tag{14}$$

$$v_{sa} = v_{ca} + Ri_{ca} + L\frac{di_{ca}}{dt} \tag{15}$$

$$v_{sc} = v_{cc} + Ri_{cc} + L\frac{di_{cc}}{dt} \tag{16}$$

$$v_{sb} = v_{cb} + Ri_{cb} + L\frac{di_{cb}}{dt} \tag{17}$$

And additionally for currents

$$C\frac{du_{dc}}{dt} = S_a\, i_{Ca} + S_b\, i_{Cb} + S_c\, i_{Cc} \tag{18}$$

DIRECT POWER CONTROL

The basic principle of the Direct Power Control (DPC) was proposed by Noguchi [8], this strategy was inspired from DTC is based on the concept of the direct torque control (DTC) applied to electric motors. The DPC strategy was developed for controlling PWM rectifiers connected to the network [9-11]. In this case, active and reactive instantaneous powers represent the controlled variables. In this technique, there are no internal current control loops and no PWM modulator block [6], because the PWM voltage source converters switching states are appropriately selected by a lookup table based on the instantaneous errors between the commanded and measured values of the active and reactive powers are defined as:

$$p = v_{an}(t).\, i_a(t) + v_{bn}(t).\, i_b(t) + v_{cn}(t).\, i_c(t) \tag{19}$$

$$q = \frac{1}{\sqrt{3}}((\, v_{bn}(t) - v_{cn}(t)).\, i_a(t) + (\, v_{cn}(t) - v_{an}(t)).\, i_b(t) + (\, v_{an}(t) - v_{bn}(t)).\, i_c(t)) \tag{20}$$

Figure.2 shows the configuration of the direct instantaneous active and reactive power controller for the PWM converter.

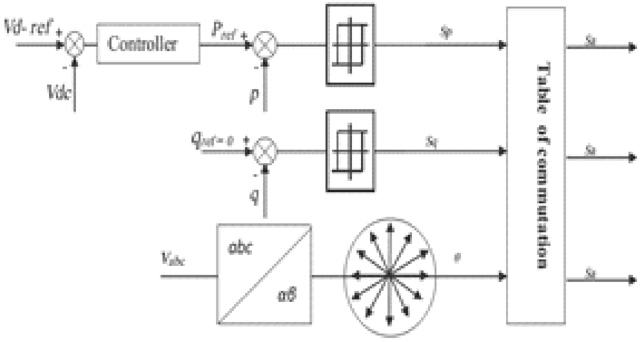

Figure 2: DPC based on the instantaneous active and reactive power control

HYSTERESIS CONTROL

The regulators used in hysteresis comparators for errors instantaneous active and reactive power. The output switches determine the switching states of the converter, indicate higher or lower limits of power errors according to the below logic.

$$S_p = 1\ p_{ref} - p > \square_p \tag{21}$$

$$S_p = 0\ p_{ref} - p < \square_p \tag{22}$$

$$S_q = 1\ q_{ref} - q > \square_q \tag{23}$$

$$S_q = 0\ q_{ref} - q < \square_q \tag{24}$$

Where h_p and h_q designate the hysteresis band.

Figure.3 shows the block diagram of the PWM rectifier state selection.

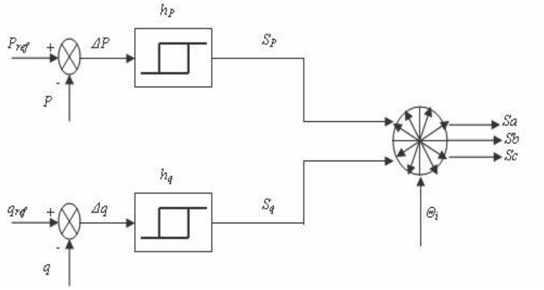

Figure 3: Block diagram of the PWM converter state selection

SWITCHING TABLE

The principle of DPC is to select a sequence of switching commands **(Sa, Sb, Sc),** from a switching table, according to the errors between of the active and the reactive powers as well as the angular position of the source voltage vector. This position is defined by the following relationship [6,]. The input voltage can be estimated by the following equation:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \frac{1}{i_\alpha^2 + i_\beta^2} \begin{bmatrix} i_\alpha & -i_\beta \\ i_\beta & i_\alpha \end{bmatrix} \begin{bmatrix} p^\wedge \\ q^\wedge \end{bmatrix} \tag{25}$$

The knowledge of the estimated voltage sector is necessary to determine optimal switching states. Determination of the number sector is given by:

$$(n-1)\frac{\pi}{6} < \theta_n < (n-1)\frac{\pi}{6} \tag{26}$$

Where n is the sector number n=1, 2…12.

$\boldsymbol{\theta_{n:}}$ is the voltage vector position is obtained as follows, is shown in Figure. 4.

Where:

$$\theta_n = arctg(\frac{v_\alpha}{v_\beta}) \tag{27}$$

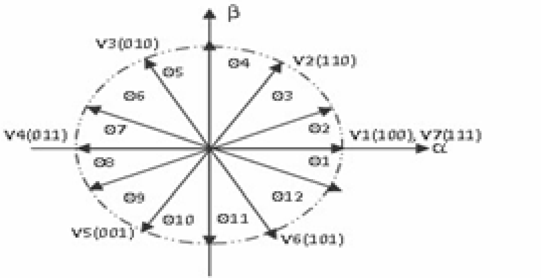

Figure 4: Voltage vectors generated in α-β coordinate

The switching table was determined in order to minimize the errors between the commanded and measured powers in each sampling period. Also to achieve a better performance, they proposed to divide the vector space into twelve sectors and then determine the position of the source voltage vector corresponding. Switching table for direct instantaneous power control illustrated by Table 1.

TABLE- I: SWITCHING TABLE FOR THE DPC TECHNIQUE

S_p	S_q	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	θ_{10}	θ_{11}	θ_{12}
1	0	V_5	V_5	V_6	V_6	V_1	V_1	V_2	V_2	V_3	V_4	V_4	V_4
1	1	V_3	V_3	V_4	V_4	V_5	V5	V_6	V_6	V_1	V_1	V_2	V_2
0	0	V_6	V_1	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5	V_5	V_6
0	1	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5	V_5	V_6	V_6	V_1

CONTROL OF DC VOLTAGE

The advantage control of DC voltage source of PWM converter arises suitable transit of supply power necessary added to power active fluctuate. The storage capacity 'C' absorbs the power fluctuations caused by the compensation of the reactive power. In the normal conditioner, the real power supplied by the source should be equal to the real power demand of the load plus a small power to compensate the losses in the active filter [8-11]. Thus, the DC capacitor voltage can be kept at constant value and confirmed at a reference value. However, in the abnormal conditioner, In the presence of harmonics current, when the load changes, the real power balance between the source and the load will be disturbed. In this case, the real power poured most is compensated by the DC capacitor of inverter constructor of (SAPF). The changes of DC capacitor voltage from its reference most is regulate.

Proportional and Integral Regulator
(PI Regulator)

The functional diagram of *VDC* voltage regulation based on a classical PI regulator [12-13] is given by Figure. 4. The closed loop transfer function is given by:

$$H(s) = \frac{R(s)G(s)}{1+R(s)G(s)} \tag{28}$$

We have:

$$H(s) = \frac{k_p s+k_i}{Cs^2+k_p s+k_i} \tag{29}$$

To order the closed loop system, it is necessary to choose the coefficients $\boldsymbol{k_i}$and $\boldsymbol{k_p}$. The transfer of a system of second order function is given by

$$F(s) = \frac{\omega_C^2}{s^2+2\xi\,\omega_C\,s+\omega_C^2} \tag{30}$$

So,

$$k_p = 2C\xi\omega_C \tag{31}$$

$$k_i = C\omega_C \tag{32}$$

The reference dc current is

$$I_c = I_{dc} - I_l \tag{33}$$

And the referenced active power is given by

$$P_{ref} = I_{dc}.V_{dc} \tag{34}$$

The control loop of the DC voltage is represented by the diagram of Figure 5.

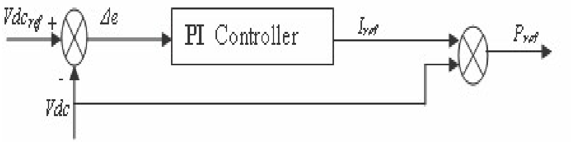

Fig.5. DC capacitor voltage regulation

SIMULATION AND DISCUSSION

To validate the effectiveness of the control strategy discussed in this paper, The PWM rectifier was observed through simulations using MATLAB/Simulink. All spectrum analysis of harmonic distortion figures are mentioned below and the levels imposed by international standards recommendation IEEE 519-1992, in terms of total distortion harmonic (THD). The system parameters studied in this paper are given in Table II.

TABLE-II SYSTEM PARAMETERS

RMS supply phase voltage source	380 V, 50Hz
coupling inductance	R=0.1 Ω, L=12mH
Load rectifier bridge	R=100Ω, R=50 Ω, L=30mH
DC voltage	600V and 750V

Figure. 6 show the superposition of the input current and the input voltage. We can see that the input current is sinusoidal and nearly in-shape with the respective phase voltages due the presence of DPC technique based on PI controller. Figure. 7 shows, the evolution of line current phase. The THD at 1.73 %, that is within the limit of the harmonic standard, shown as Figure. 8.

The DC voltage control system is tested as well as the DPC method following a DC voltage step variation occurred at t=0.5s from 600V to 750V and at 0.7. Here a load is introduced named author load (see Figure. 9).The effectiveness of the DC voltage PI controller is illustrated by Figure.10. We can see that the DC value follows up its reference at 600V.We have changed the reference value in t= 0.5s at 750V, the DC voltage pursue its reference that system became more stable and more robust.

Figure.11 presents the evolution of the instantaneous active and reactive power. We can observe that the reactive power flow is small, what is very beneficial for the system performances and thus the power-factor is almost equal to unity, shown in Figure. 12.

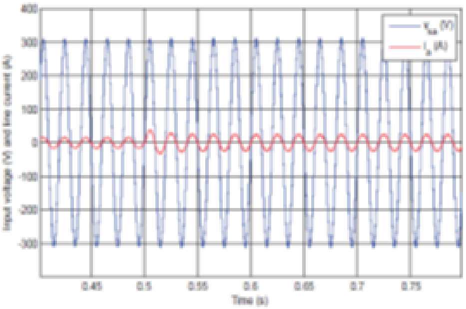

Figure 6: Line current in phase with input voltage

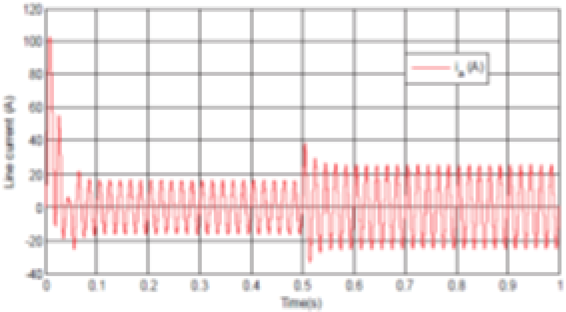

Figure 7: Line sinusoidal current

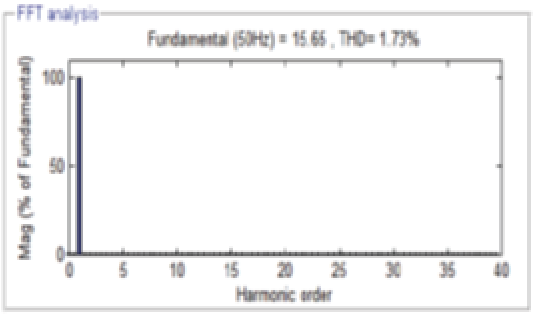

Figure 8: Line current spectrum harmonic

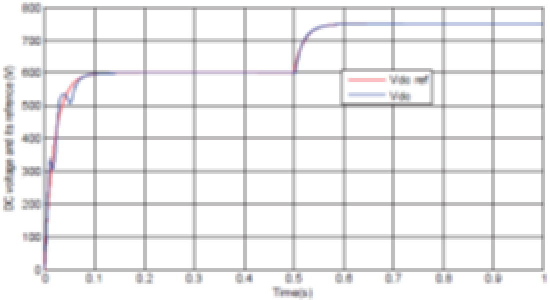

Figure 9: DC capacitor voltage and its reference

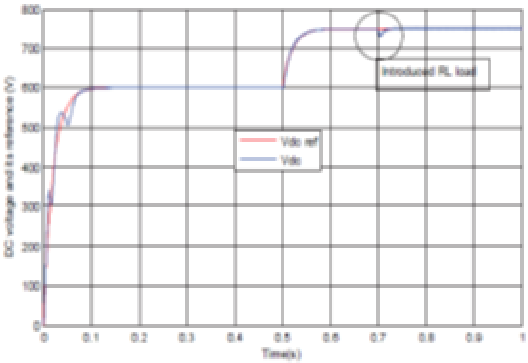

Figure 10: DC capacitor voltage and its reference at various load

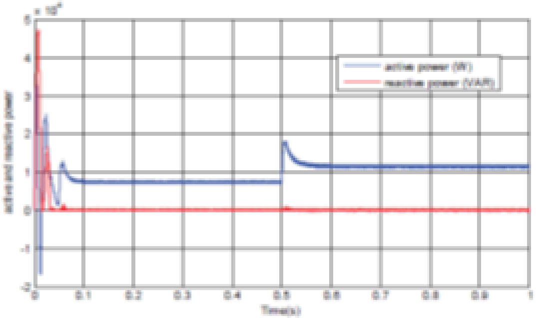

Figure 11: Active and Reactive Powers

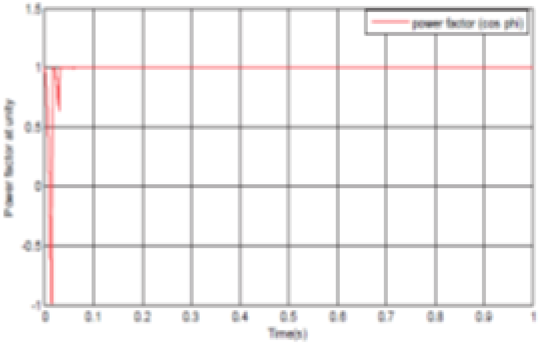

Figure 12: Power factor correction

CONCUSION

In this article we presented a control strategy for a PWM rectifier. It concerns the use of the direct power control based on PI controller. The simulation results obtained showed that the DPC technique improves the system performances. These improvements affect the performances of the system response on the DC side capacitor voltage, power-factor correction, sinusoidal line current and power quality improvement.

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