Modeling and Control of Three-Phase Pulse Width Modulation Rectifier

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Abstract—This **work proposes the use of hysteresis band current to control a pulse width modulation three phase rectifiers. This strategy is used to eliminate the harmonics current almost to maintain the power factor at unity. The main objective is to maintain the DC capacitor voltage at the required level, while the line of currents drawn from the power supply should be sinusoidal and in phase with respective phase voltages to satisfy the unity power factor operation of the PWM rectifier. The simulation results prove the efficiency of the proposed control system.**

Keywords— *PWM* ***rectifier; controller; line current; power factor.***

I. INTRODUCTION

The distortion harmonic in the power electrical system causes a number of problems. However, the use of the nonlinear loads such as AC/DC conventional rectifiers such as diode rectifier bridge has become a serious problem, , the input current of this rectifier contains a large number of harmonics, which has become to the main source of grid and consequently low power factor [1]. To solve this problem in the power systems, a number of solutions have been developed and put into practice. The use of the active power filters and PWM rectifiers are two typical examples of these solutions. The active power filter and PWM rectifier have basically the same circuit configuration and can operate based on the same control principle.

The PWM rectifier has six power transistors with anti-parallel diodes. These diodes are mainly used to carry out the PWM generation as well as the power bidirectional conversion. The converter is supplied by three-phase source in series with coupling inductance (L_c), and is the inductance between the grid and the PWM rectifier [2, 3]. This converter have some important advantages: does not produce harmonic distortion in line current, bi-directional power flow, regulation the power factor to unity, adjustment and stabilization of DC-link voltage and reduced the size of DC filter capacitor [4]. In particular, several standards have introduced important and stringent limits on harmonics that can be injected into the power supply [5, 6]. In recent years different strategies have been proposed for controlling PWM converter.

In this paper, hysteresis band current based on PI controller is proposed to control the three-phase PWM rectifier. The performances of the converter are evaluated using Matlab/Simulink. Fig.1 show the basic circuit topology of the PWM rectifier converter:

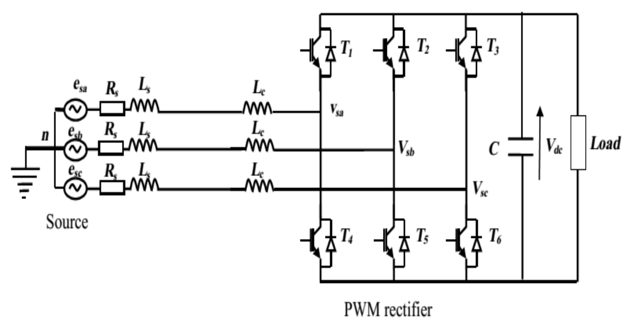

Fig. 1. Three-phase PWM rectifier converter

II. ANALYTICAL MODEL OF THREE-PHASE PWM RECTIFIERS

Three phase voltage source fed PWM rectifier and the lines current are given by (1) and (2), respectively:

$$\begin{cases} e_a(t) = E_{\max}\sin(\omega t) \\ e_b(t) = E_{\max}\sin(\omega t - \frac{2\pi}{3}) \\ e_c(t) = E_{\max}\sin(\omega t - \frac{4\pi}{3}) \end{cases} \quad (1)$$

$$\begin{cases} i_a(t) = I_{\max}\sin(\omega t + \varphi) \\ i_b(t) = I_{\max}\sin(\omega t - \frac{2\pi}{3} + \varphi) \\ i_c(t) = I_{\max}\sin(\omega t - \frac{4\pi}{3} + \varphi) \end{cases} \quad (2)$$

Where, E_{max}, I_{max}, $w=2.pi.f$ and φ are, respectively, amplitude of the phase voltage, maximum current, angular frequency, and angular phase.

With assumption:

$$i_a(t) + i_b(t) + i_c(t) = 0 \quad (3)$$

In α, β stationary system, the equations (1) can be expressed by:

$$\begin{cases} e_{s\alpha}(t) = \dfrac{\sqrt{3}}{2} E_{\max} \sin(\omega t) \\ e_{s\beta}(t) = \dfrac{\sqrt{3}}{2} E_{\max} \cos(\omega t) \end{cases} \quad (4)$$

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

$$\begin{cases} e_{sd}(t) = \dfrac{\sqrt{3}}{2} E_{\max} = \sqrt{e^2{}_{sd} + e^2{}_{sq}} \\ e_{sq}(t) = 0 \end{cases} \quad (5)$$

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

$$\begin{cases} u_{ab} = (S_a - S_b) * V_{dc} \\ u_{bc} = (S_b - S_a) * V_{dc} \\ u_{ca} = (S_c - S_a) * V_{dc} \end{cases} \quad (6)$$

And phase voltages are equal:

$$\begin{cases} v_a = f_a * V_{dc} \\ v_b = f_b * V_{dc} \\ v_c = f_c * V_{dc} \end{cases} \quad (7)$$

Where the switching states of the PWM rectifier are:

$$\begin{cases} f_a = \dfrac{2S_a - (S_b + S_c)}{3} \\ f_b = \dfrac{2S_b - (S_a + S_c)}{3} \\ f_c = \dfrac{2S_c - (S_a + S_b)}{3} \end{cases} \quad (8)$$

The f_a, f_b and f_c are assume 0 , ± 1/3 and ± 2/3.
The voltage equations for balanced three-phase system without the neutral connection can be written as [6, 7]:

$$\begin{cases} e_a = v_a + Ri_a + L\dfrac{di_a}{dt} \\ e_b = v_b + Ri_b + L\dfrac{di_b}{dt} \\ e_c = v_c + Ri_c + L\dfrac{di_c}{dt} \end{cases} \quad (9)$$

And, additionally for currents is:

$$C\frac{dv_{dc}}{dt} = S_a i_a + S_b i_b + S_c i_c - i_{dc} \quad (10)$$

A block diagram of PWM rectifier corresponding to equations (10 and 11) is shown in Fig. 2.

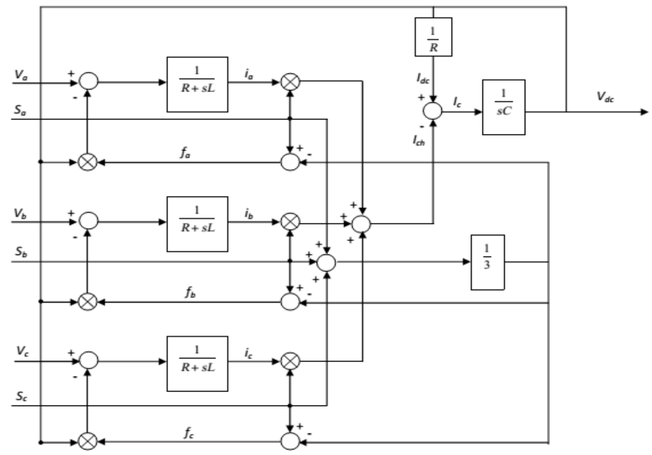

Fig. 2 Block diagram of voltage source PWM rectifier

III. HYSTERESIS BAND CURRENT CONTROL

In order to improve the line current waveform, with power factor equal to unity, hysteresis band current control is based on feedback loops with hysteresis comparators, which used to generate directly the switching states for the PWM rectifier when the error between the reference and the actual value exceeds an assigned tolerance band [8-10]. Fig.3. Show the basic circuit topology of proposed system.

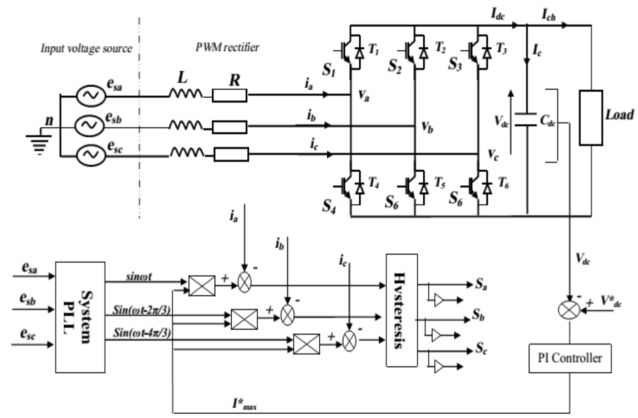

Fig. 3 Hysteresis control current of PWM

Phase current references are generated using the PLL system taken from three phase AC source and by multiplying them by the output signal of the DC voltage controller [11]. The DC voltage controller is implemented by using a conventional proportional-integral (PI) controller whose output is the amplitude of the current reference I_m and transfer function is given by:

$$G(p) = K_p + \frac{K_i}{s} \quad (12)$$

Where K_p and K_i are the proportional and the integral control gain of PI controller respectively.

IV. SIMULATION RESULTS

To show the effectiveness of hysteresis band current based on PI controller for PWM rectifier, numerical simulation of the proposed system was carried out by using MAtlab/Simulink, the line to line input voltage source take the value of 380V, the initial value of the DC link voltage V_{dc} is regulated at 600V. To validate the effectiveness of the control strategy studied in this paper, all spectrum analysis harmonic figures are under the levels imposed by international standards recommendation IEEE 519-1992, in terms of total distortion harmonic (THD). The load value is R =45Ω.
It can be seen in Fig.4 and Fig.5, the input voltage and the line currents of PWM rectifier, presents a clear improvement in the line currents waveforms. In the Fig. 5 the line input currents are sinusoidal and the spectrum harmonics analysis shown in Fig. 6, gives a THD of 2.64% that is within the limit of the harmonic standard [5].

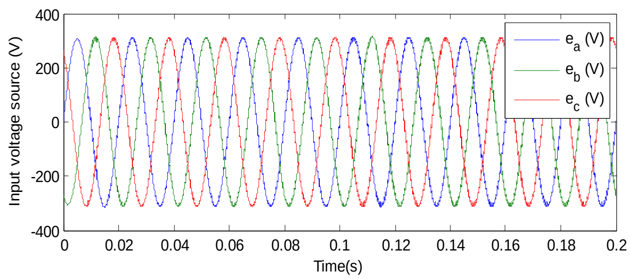

Fig.4 The input voltage of PWM rectifier

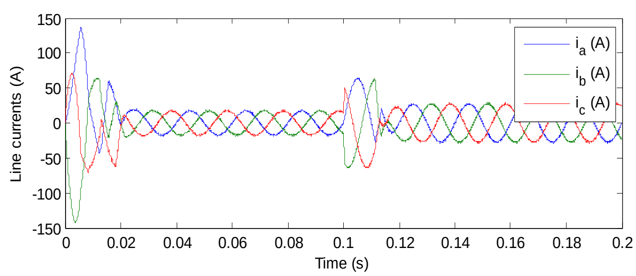

Fig.5 Line input current of PWM rectifier

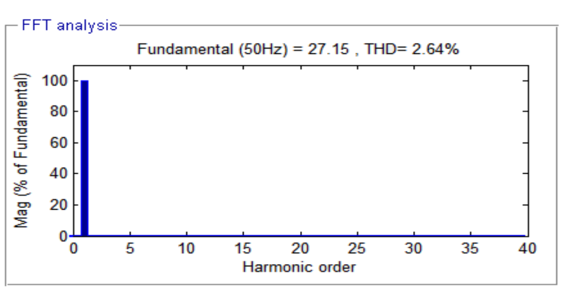

Fig.6 Spectrum harmonic of line current

Fig.7 shows the line current and the input voltage. In the presence of PWM rectifier, It can be seen that the linee current is sinusoidal and nearly in-shape with the respective phase voltages.

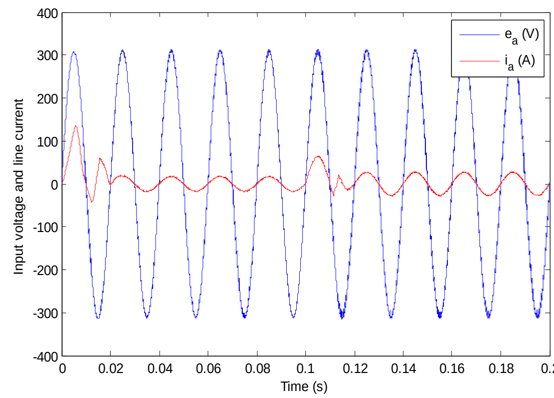

Fig.7 Input voltage and line current superposition

In order to implement the control algorithm of a PWM rectifier, the DC capacitor voltage (V_{dc}) is sensed and compared with the reference value (V_{dc} reference). Fig.8 shows the DC capacitor voltage variation with and without PI controller, can be seen that his value follows up its initial reference value fixed at 600V only with presence of PI controller.

In order to test the robustness an effectiveness of PI controller, the reference value have been changed to 750V at t= 0.1s, the capacitor voltage source keeps tracking his reference with good dynamic performance.

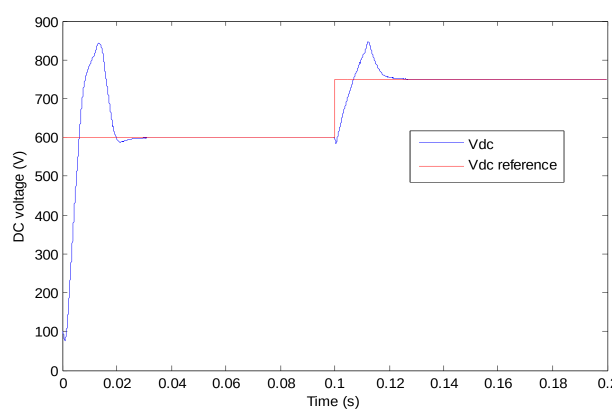

Fig.8 Source current and the input voltage of PWM rectifier

The evolution of the instantaneous three-phase active and reactive powers and power factor are presented respectively in Fig.9 and 10. It can be clearly shown that the reactive power flow is zero consumption, which is very favorable for the system performances and so the power-factor is almost equal to unity.

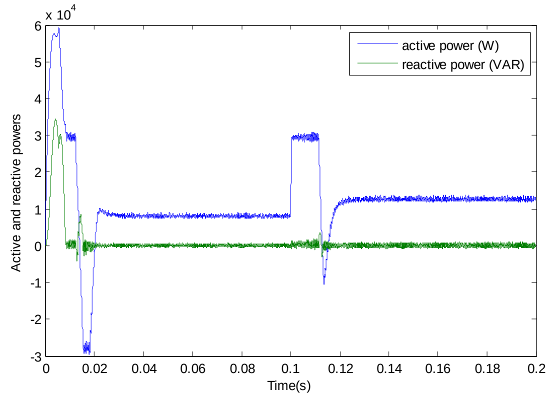

Fig.9 Active and reactive powers of PWM rectifier

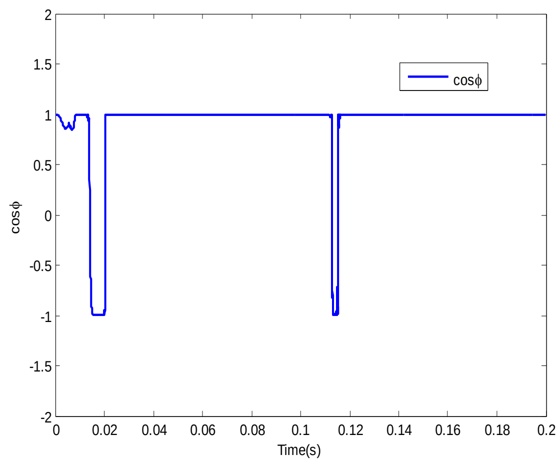

Fig.10 Power factor of PWM rectifier

V. CONCLUSION

In this paper, we have presented a new improved control structure for PWM rectifier. It depends on the use of the hysteresis band current based on PI controller. The simulation results presented in this paper confirm that the PI controller improves the system performances. These improvements affect the performances of the system response on the power-factor correction and the THD of the line sinusoidal current. The use of the hysteresis band current with PI controller has an extremely simple and robust structure and excellent dynamic performance.

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