

A New Control Strategy for Three-Phase PWM Boost-Rectifier

M. Kesler

Abstract – This paper presents a new control strategy for 3-phase PWM boost rectifiers that has the step-up characteristics of output DC-link voltage. The boost rectifier draws sinusoidal AC current from the AC line with active filtering and a unity power factor. In this study, the dynamics and steady-state operation of the PWM rectifier are analyzed; computer simulations and experimental results are used to validate the operating features of the proposed control strategy. Both simulations and experimental results show that the proposed control method operates successfully. As shown in the results, the proposed control strategy provides good dynamic response under DC-link load variation, and so the stability of the PWM rectifier control is enhanced. As a result, the proposed method is very effective and successful in harmonic compensation. **Copyright (c) 2012 Praise Worthy Prize S.r.l. - All rights reserved**

Keywords: AC-DC converters, PWM rectifier, VSI, Inverter, 3-phase rectifiers

Nomenclature

i_{abc}	3-phase source currents
v_{abc}	3-phase source voltages
L_{Fabc}	3-phase line inductances
v_{DC}	DC-link voltage
v_{DCref}	DC-link reference voltage
ωt	Transformation angle, output signal of the PLL
i_d, i_q, i_0	Instantaneous source currents at d-q-0 coordinates
i'_0, i'_q	Zero and negative sequence components of the source current reference.
i_a, i_b, i_c	Measured source current signals
i'_a, i'_b, i'_c	Reference current signals
\tilde{i}_d, \tilde{i}_q	d-q coordinates oscillating component
\bar{i}_d, \bar{i}_q	d-q coordinates average component

I. Introduction

The AC-DC rectifiers are used increasingly in many industrial applications, such as motor drives, power supply, home devices, electronic ballast, battery charging, and power conversion, because of their advantages of high efficiency and small size. Until recent years, uncontrolled diode and phase controlled thyristor

rectifiers were used very often. However, the uncontrolled diode rectifier does not adjust DC-link voltage, and phase controlled thyristor rectifiers inherently causes many power factor issues. High power AC-DC rectifiers constitute an important enabling technology in the industry where high power and efficiency energy conversions are required. The recent developments in power electronics technology and rapid growth in computers and industrial equipments requires this type of power converters [1-4].

Recently, due to power-quality and power-factor which active research topic in power electronics, the PWM (Pulse With Modulation) based rectifier must be employed. Typically, PWM rectifier topologies always include controllable switches, such as MOSFET/IGBT. The PWM rectifier has a very high performance in the power quality and control flexibility. However, they are expensive due to the high cost of power electronics and complex fault protection [5].

Most techniques developed in the inverter area can be used in industrial applications, especially when high performance is required; the PWM boost rectifier is preferred, because of its high efficiency, good current quality, and low EMI emissions. The basic topology of three-phase PWM boost rectifiers, which consists of a voltage-source inverter (VSI), is shown in Fig.1. The rectifier can have excellent control characteristics, if output voltage is higher than the input line voltage amplitude. It is controlled by an output DC-link voltage loop for output regulation and inner current loops which shape the source currents according to their sinusoidal references [6].

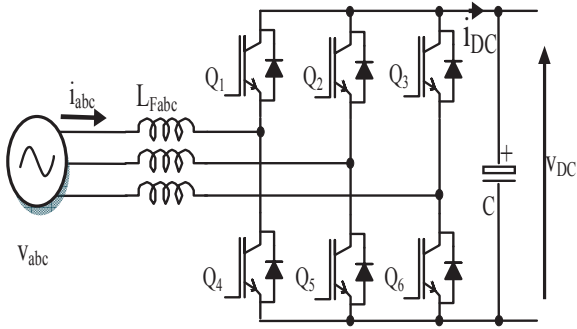


Fig.1. The basic configuration of a PWM boost rectifier.

In this study, a new simplified control strategy is proposed for 3-phase a PWM boost rectifier that has the step-up characteristics of output DC-link voltage. The dynamic and steady-state operation of the proposed PWM rectifier control strategy is analyzed. As a result, both the simulations and the experimental studies show that the proposed strategy works well and unity power factor can be achieved with load variations. These results are in accordance with the IEC 61000-3-2 standard [7].

II. The Proposed Control Strategy for the PWM Rectifier

A PWM rectifier can offer advantages of reduced low order source current harmonics and the unity input power factor when compared to a conventional uncontrolled diode or phase controlled thyristor rectifier. Typically, two rectifier topologies are possible: a boost-type topology [8–11] or a buck-type topology [12–16]. Also in some studies [17] buck-boost-type topologies have been investigated. In addition, there are several PWM rectifier control methods presented in the literature [8-22]. The proposed control strategy based on the d-q-0 coordinates using the PLL algorithm for PWM boot type rectifier. It is simple, easy to implement and offers reduced current measurement; therefore it can be run efficiently in DSP platforms. A PLL algorithm is widely used for some control methods [5, 23] in PWM rectifiers and power applications. The aim of the PLL algorithm is to detect the phase angle of the source voltage for grid synchronization. If the phase angle of the source voltage is not detected or the output of the PLL is unsteady, the PWM rectifier system can be damaged. For this reason, the PLL algorithm is a very important part of the PWM rectifier.

In this paper, the PLL algorithm, given in Fig. 2, is employed for determination of the positive sequence components of the source voltage. To calculate the transformation angle (ωt) as output signal of the PLL, v_{ab} and v_{bc} line voltages are measured and multiplied by i_a and i_b feedback currents, which have unity amplitude and a phase difference of 120° to other, to obtain three-phase auxiliary instantaneous active power (p_{ax}). The reference fundamental angular frequency (ω_0) is added to the

output of the PI controller to stabilize the output. The PLL circuit arrives to the stable operating point; in other words, the transformation angle (ωt) reaches the fundamental positive sequence components of the source voltage, when three-phase auxiliary instantaneous active power (p_{ax}) comes to zero or in low frequency oscillation. As a result, the PLL output is in the same phase angle as the fundamental positive sequence components of the measured (v_a) source voltage [23].

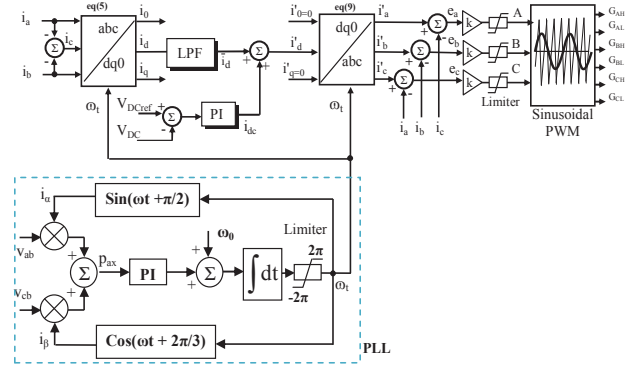


Fig.2. the proposed PWM rectifier control block diagram.

In this study, the PWM rectifier is connected to a three-phase system with balanced source voltage conditions. Thus, the sums of both the instantaneous source voltages and currents of the three phases are zero. Consequently, measuring only two source currents (i_a and i_b) is adequate and the other current (i_c) is calculated as given in (1).

$$i_c = -i_a - i_b \quad (1)$$

The proposed control method uses only source currents and DC-link voltage to calculate reference current signal. So, the source currents (i_a , i_b and i_c) are transformed from a-b-c coordinates to d-q-0 coordinates as given in (4) using (ωt) coming from the PLL circuit. Since the rectifier acts as a nonlinear system, the instantaneous source currents at d-q-0 coordinates, given in (2) and (3), include both oscillating (\tilde{i}_d, \tilde{i}_q) and average (\bar{i}_d, \bar{i}_q) components.

$$i_d = \bar{i}_d + \tilde{i}_d \quad (2)$$

$$i_q = \bar{i}_q + \tilde{i}_q \quad (3)$$

The oscillating components of the source currents at d-q-0 coordinates consist of the harmonic and the negative sequence components. The average components of the source currents at d-q-0 coordinates consist of the positive sequence components and correspond to reactive currents. The negative sequence component of the source current (i_0) appears under unbalanced conditions. The proposed method uses the positive sequence average component (\bar{i}_d) in “d” axes of the source currents; the oscillating and the negative sequence component (\tilde{i}_q and

i_0) are set to zero; in order to compensate reactive power, harmonics and unbalances [23].

$$\begin{bmatrix} i_0 \\ i_d \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ \sin(\omega t) & \sin(\omega t - 2\pi/3) & \sin(\omega t + 2\pi/3) \\ \cos(\omega t) & \cos(\omega t - 2\pi/3) & \cos(\omega t + 2\pi/3) \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (4)$$

To compensate the active power losses of the PWM rectifier circuit, the DC-link voltage is compared to its reference value (V_{DCref}) and the required active current (i_{dc}) is obtained by a PI controller as given in (5).

$$i_{dc} = K_p * (V_{DCref} - V_{DC}) + K_i * \int (V_{DCref} - V_{DC}) dt \quad (5)$$

The source current average component (\bar{i}_d) is obtained by a low-pass filter (LPF). A two-order Bessel type LPF is implemented in DSP platform to eliminate higher frequency than the cutoff frequency. In Fig.3, step and impulse response in the frequency domain is shown alongside magnitude and phase response of the PLL in time domain.

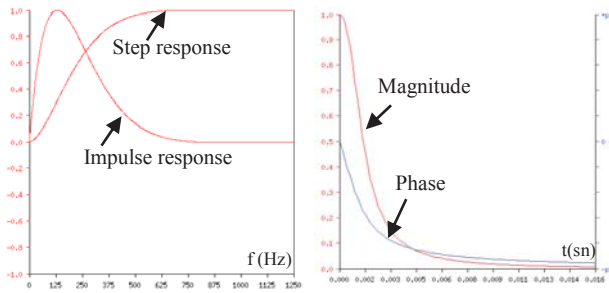


Fig.3. Step and impulse response in frequency domain, magnitude and phase response of the LPF in time domain.

In the proposed method, the zero and the negative sequence components of the source current reference (i'_0 and i'_q) in “0 and q” axes are set to zero in order to compensate harmonics, unbalance, distortion and the reactive power in the source current. The source current references are calculated as given in (6) and (7) to compensate harmonics, unbalance and reactive power by regulating DC-link voltage.

$$i'_d = i_{dc} + \bar{i}_d \quad (6)$$

$$\begin{bmatrix} i'_a \\ i'_b \\ i'_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & \sin(\omega t) & \cos(\omega t) \\ 1/\sqrt{2} & \sin(\omega t - 2\pi/3) & \cos(\omega t - 2\pi/3) \\ 1/\sqrt{2} & \sin(\omega t + 2\pi/3) & \cos(\omega t + 2\pi/3) \end{bmatrix} \begin{bmatrix} 0 \\ i'_d \\ 0 \end{bmatrix} \quad (7)$$

The measured source currents (i_a , i_b and i_c) are compared with the reference current signals (i'_a , i'_b and i'_c). Then the differences are multiplied a constant value k as given in (8) and (9).

$$\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} = \begin{bmatrix} i'_a \\ i'_b \\ i'_c \end{bmatrix} - \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} A \\ B \\ C \end{bmatrix} = k * \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (9)$$

The produced references values (A, B and C) are applied to the Sinusoidal PWM controller to produce IGBT switching signals for reactive power, current harmonic and the DC-link voltage regulation.

III. Simulation Results

The PWM rectifier system parameters used in this study are given in Table I. In the simulation studies, the results are specified before and after the operation of the PWM rectifier system. In addition, while PWM rectifier system was operated, load was changed and the dynamic response of the system was tested. Then, the proposed control method was examined under load variation conditions during simulation.

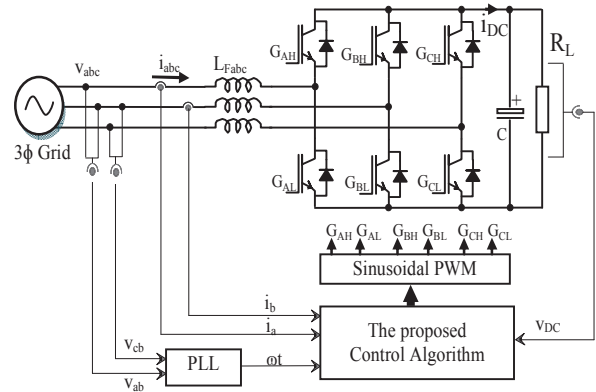


Fig.4. The proposed PWM rectifier control block diagram.

TABLE I.
THE PWM RECTIFIER SYSTEM PARAMETERS.

Parameters		Value
Source	Voltage	V_{Sabc} 92 $V_{L-L,rms}$
	3-Phase Filter Inductance	L_{Fabc} 4.0 mH
	Frequency	f 50 Hz
DC-link	Voltage	V_{DCref} 130 V
	V_{DC} Capacitor	C 3300 μ F
	V_{DC} Load Resistor	R_L 25 Ω
Switching Frequency		f_{pwm} 20 kHz

Fig.5. shows the simulation results for DC-link voltage and the source currents before and after the PWM rectifier operation. As given in the figure, the

source current harmonics were eliminated and DC-link voltage increases the offset value after the PWM rectifier operation. The current harmonic compensation capability of the proposed PWM rectifier control method is shown in Fig. 6 as total harmonic distortion (THD) levels given before and after rectifier operation. The obtained results show that the proposed control method produce a THD level of 0.9 % currents by mitigating all harmonic components. In addition, the proposed control algorithm has the ability to compensate for harmonics and reactive power of the source currents. In Fig.7. the simulation results for reactive power compensating are given.

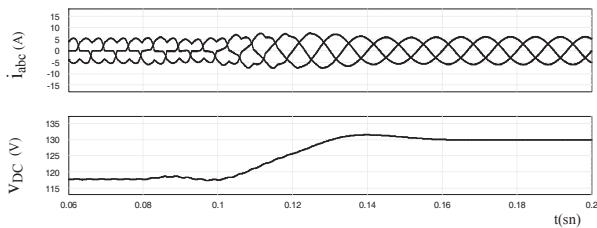


Fig.5. The simulation results for dc link voltage and source currents before and after PWM rectifier operation.

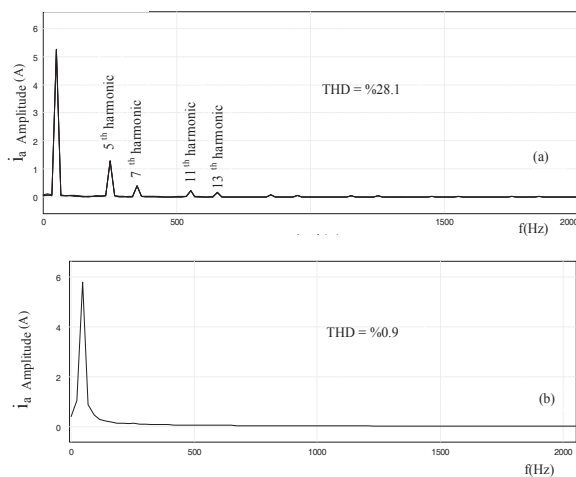


Fig. 6. The simulation results for THD levels of source current (a) before and (b) after PWM rectifier operation.

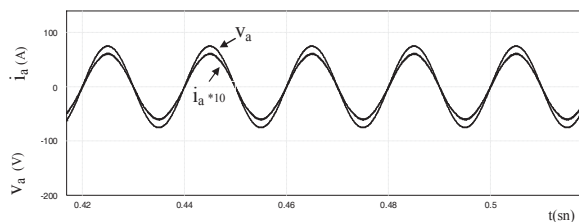


Fig.7. The simulation results for reactive power compensating.

The proposed control method has been evaluated and tested under dynamic and steady-state load conditions. Simulation results for under load changes are shown in Fig. 8. In this case, the PWM rectifier system is operated in 0.19 s and load current amplitudes increase approximately 100% at 0.2 s. The DC-link voltage

shows an almost invisible transient during 100% load change (step-up). In addition, it has better response time capability than the standard control topology proposed in [8].

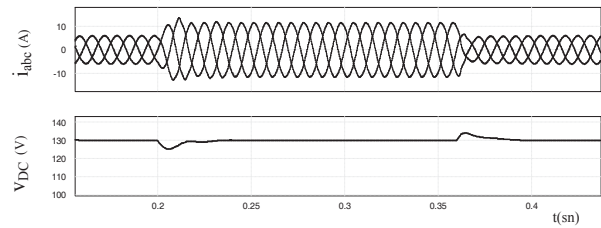


Fig.8. The simulation results for DC-link voltage and source current before and after load variation.

The results show that the proposed control strategy compensates to harmonic components as well as most of the other current distortions. Also it has good compensating characteristics in grid power systems.

IV. Experimental Results

All parameters and experimental conditions are set up nearly the same as the simulation conditions. The control strategy is implemented by using a floating-point DSP (TMS320F28335 of Texas Instruments). The control and switching frequency are set at 20 kHz. In experimental study, results for DC-link voltage and source current (i_{abc}) before and after load variation (load step-up) are shown in Fig. 9. To evaluate steady-state and the dynamic performance of the proposed control strategy, the transient responses of the PWM rectifier are illustrated in Fig. 10. and Fig. 11. Fig. 10 shows that when the load is changed (100% step-up) the PWM rectifier quickly responds to the load change to mitigate harmonics in source currents and to guarantee that the source currents always sinusoidal. In addition, Fig. 11 shows that when the load is changed (100% step-down) the PWM rectifier also quickly responds against the load change to mitigate harmonics in source. These experimental results show that the compensation features of the PWM rectifier are done effectively. The experimental prototype about the proposed PWM rectifier is shown in Fig. 12.

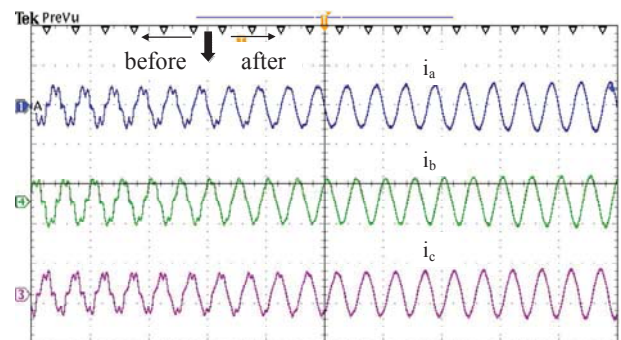


Fig.9. The experimental results for source currents before and after the PWM rectifier operation. 10 A/div, 40.0 ms/div.

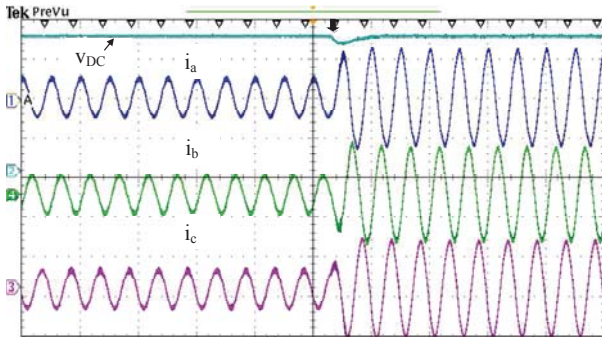


Fig. 10. The experimental results for DC-link voltage and source current before and after load variation (load step-up). 10A/div, 40.0ms/div

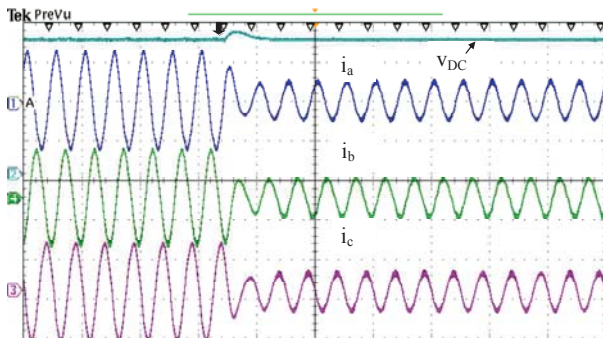


Fig. 11. The experimental results for DC-link voltage and source current before and after load variation (load step-down). 10 A/div, 40.0 ms/div

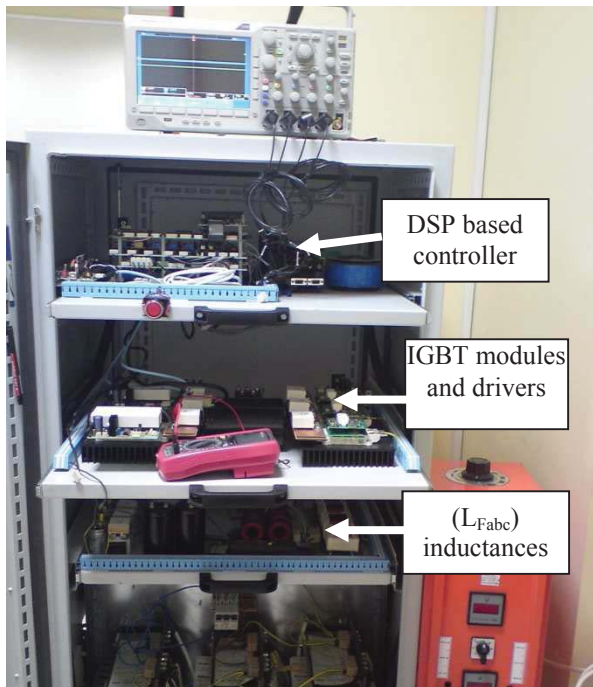


Fig. 12. The photograph of the experimental prototype of the proposed PWM rectifier

V. Conclusion

In this study presents a new control strategy for 3-phase boost type PWM rectifiers which has the step-up characteristics of output DC-link voltage. The proposed method is simple, easy to implement and offers reduced current measurement; so it can be run efficiently in DSP platforms. Along with a good steady-state performance, a fast dynamic response is also an important factor of the PWM rectifier performance because the source current should be compensated to be sinusoidal as soon as possible during load variations. Relating to the experimental study verifies the effectiveness of the proposed control scheme. Finally, both simulations and experimental results show that the proposed control method operates successfully and improves compensating characteristics of both harmonics and reactive power of the 3-phase grid systems.

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Authors' information

Department of Computer Engineering, Engineering Faculty, Bilecik Şeyh Edebali University, Bilecik, Turkey



Metin Kesler was born in Gumushane, Turkey. He received the M.Sc. and Ph.D. degrees in electrical education from Kocaeli University, Kocaeli, Turkey, in 2005 and 2010, respectively. In 2012, he was a Visiting Professor at the University of Tennessee, Knoxville, where he was also working on a project at the CURENT National Laboratory, Knoxville, TN, USA. He has been an Assistance Professor with

the Computer Engineering Department, Faculty of Engineering, Bilecik Şeyh Edebali University, Bilecik, Turkey. His research interests are renewable energy system and power electronics interface, DSP-based design and control systems, active power filters, and power quality.

E-mail: metin.kesler@bilecik.edu.tr