



ROBUST DIRECT POWER CONTROL OF PWM RECTIFIER FOR POWER QUALITY IMPROVEMENT IN DISTORTED SUPPLY NETWORK

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ABSTRACT

The widespread integration of nonlinear loads in modern power systems has significantly exacerbated power quality issues, particularly current and voltage harmonic distortion and reactive power imbalance. These effects adversely affect system efficiency, stability, and compliance with grid standards and customer requirements. To mitigate these challenges, this study proposes a novel and effective control strategy based on Direct Power Control (DPC) for a three-phase Pulse Width Modulated (PWM) rectifier. The proposed DPC approach enables direct control of instantaneous active and reactive power, resulting in a simplified control structure and reduced computational burden. Voltage vector selection is carried out using a predefined switching table governed by hysteresis controllers acting on active and reactive power errors. This control mechanism ensures fast dynamic response, accurate power regulation, and stable DC-link voltage control. The effectiveness of the proposed strategy is validated through simulation results. The simulations demonstrate a substantial reduction in input current harmonics, achieving a low total harmonic distortion (THD) in compliance with power quality standards. Furthermore, the input power factor is significantly improved and approaches unity, indicating near-zero reactive power consumption. The controller also exhibits robust regulation of active and reactive power while maintaining a stable DC-link voltage with low ripple and accurate reference tracking.



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I. INTRODUCTION

Despite significant progress in power electronic converter technologies, the widespread use of nonlinear loads particularly diode and thyristor Rectifiers Bridge to pose serious challenges to power quality in electrical distribution networks [1]. These challenges are primarily manifested through harmonic current distortion, reduced power factor, and increased stress on network components, which may lead to equipment malfunction, efficiency degradation, and non-compliance with international power quality standards such as IEEE 519 [2, 3]. Conventional harmonic mitigation techniques, including passive filters and traditional rectification schemes, often suffer from drawbacks such as bulky components, fixed compensation characteristics, and limited adaptability to dynamic operating conditions [4]. PWM rectifiers have emerged as an effective alternative due to their ability to achieve sinusoidal input currents and unity power factor operation. However, the performance of PWM rectifiers is highly dependent on the adopted control strategy. Existing linear control approaches, such as Voltage Oriented Control (VOC) and classical Direct Power Control (DPC), exhibit limitations in terms of robustness, dynamic response, and sensitivity to parameter variations and grid disturbances. Moreover, while advanced control techniques such as PI and fuzzy logic control have been investigated independently, their systematic integration into established PWM rectifier control frameworks remains insufficiently explored [5-9].

The scientific problem addressed in this research lies in the need for a robust and efficient control strategy capable of improving power quality while maintaining stable operation of PWM rectifiers [10, 11]. The topicality of this research is reinforced by the increasing penetration of power electronic interfaces in industrial systems and the growing demand for compliance with stringent power quality standards. The primary objective of this work is to enhance the performance of PWM rectifiers through the incorporation of nonlinear control techniques using DPC control. Specifically, the study aims to develop and analyze both adaptive control approaches that ensure regulated DC-link voltage, unity power factor, and reduced harmonic distortion. By addressing the identified limitations of existing control methods, this research fills a gap in scientific knowledge related to the practical application of control strategies for power quality improvement in grid-connected PWM rectifier systems.

II. THEORETICAL ANALYSIS

The presence of current harmonics in electrical networks degrades power factor and causes various operational issues. To address these problems, rectifier technologies have progressively evolved in both topology and control strategies to reduce harmonic injection into the grid [12, 13]. This evolution has led to the development of sinusoidal current absorption rectifiers, which operate with high power factors and exhibit quasi-resistive behavior from the grid perspective. These converters share a common objective: shaping and regulating the input current waveform through appropriate architecture and control, making them an effective solution for harmonic mitigation [14]. Among these technologies, the PWM voltage rectifier stands out due to its ability to operate in both rectification and regeneration modes while maintaining near-unity power factor. Its key advantage lies in the bidirectional control of active and reactive power across a wide harmonic range. Consequently, PWM rectifiers are particularly suitable for applications involving frequent regenerative operation, such as variable-speed AC drives, where they are commonly integrated into frequency converters. They are also widely used as DC power supplies for various loads [15, 16]. Despite their higher cost and control complexity, PWM rectifiers offer superior performance by enabling output voltage regulation, harmonic current compensation, and reactive power control at the grid interface. As a result, they have become one of the most widely adopted static converters in modern industrial applications and harmonic pollution mitigation systems [17].

II.1 PMW RECTIFIER

PWM rectifiers employ forced-commutation semiconductor devices such as IGBTs, MOSFETs, or GTO. Based on a voltage-source inverter topology, each switch consists of a controlled semiconductor device with an anti-parallel diode. As shown in Figure 1, allowing unidirectional voltage blocking and bidirectional current flow [18-21]. This configuration enables reversible current operation and precise control of input current waveforms. The rectifier supplies a DC load from an AC source while ensuring sinusoidal input currents that can be maintained in phase with the supply voltage. As a result, the system achieves near-unity power factor and allows controlled absorption or injection of reactive power. However, a notable limitation is the reactive power demand of the DC-link capacitors, which must be supplied internally to maintain voltage stability.

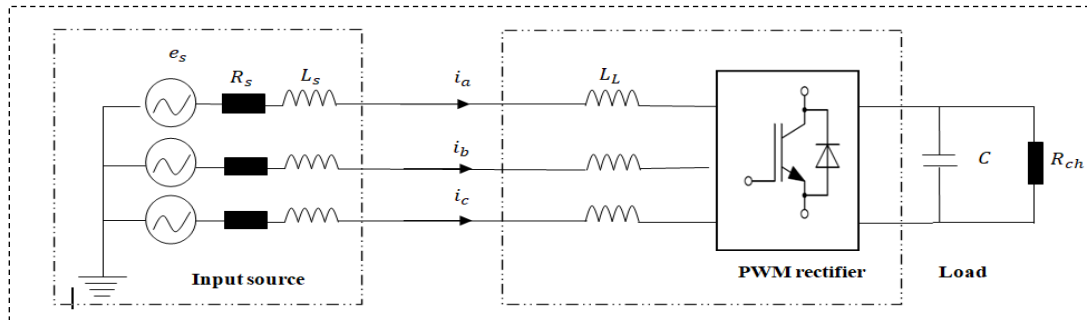


Figure 1: PWM rectifier circuit diagram.

Source: Authors, (2026).

The source voltages and line currents are expressed as follows:

$$e_{si} = E_m \begin{bmatrix} \sin(\omega t - 0) \\ \sin(\omega t - \frac{2\pi}{3}) \\ \sin(\omega t - \frac{4\pi}{3}) \end{bmatrix} \quad (1)$$

$i = a, b, c$

Let V_a , V_b , and V_c denote the phase-to-neutral voltages at the output terminals of each phase. From Fig.1, the system of differential equations governing the current in each phase can be derived [20, 21]. We have:

$$\frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & 0 & 0 \\ 0 & -\frac{R_s}{L_s} & 0 \\ 0 & 0 & -\frac{R_s}{L_s} \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{1}{L_s} \begin{bmatrix} e_a - v_a \\ e_b - v_b \\ e_c - v_c \end{bmatrix} \quad (2)$$

Knowing the state of each switch, the connection matrix of the bridge can be defined. The expressions of the input quantities can then be derived as functions of the output quantities [22-24]. The rectifier input voltages, expressed as functions of the output voltage and the switch states are given by system.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \cdot \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \cdot [V_{dc}] \quad (3)$$

Similarly, the output current (I_{dc}) can be expressed as a function of the input currents through the following relationship:

$$i_{dc} = [S_a \quad S_b \quad S_c] \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (4)$$

The voltage V_{dc} across the load is given by the following equation:

$$\begin{aligned} \frac{dv_{dc}}{dt} &= \frac{i_{dc} - i_{ch}}{C} \\ \frac{di_{ch}}{dt} &= \frac{v_{dc} - R_{ch}i_{ch}}{L_{ch}} \end{aligned} \quad (5)$$

II.2 DC VOLTAGE CONTROL

PI controller is used for the error between the measured DC voltage and its reference value. The product of the reference DC current and the DC voltage yields the reference active power. The time-domain equation of this controller is given as follows [25, 26]:

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau) d\tau \quad (6)$$

Where $e(t)$, $u(t)$, k_p , k_i are respectively denote the error at time t , the generated control signal, and the controller gains. The corresponding transfer function is given by:

$$R(s) = k_p + \frac{k_i}{s} \quad (7)$$

The following diagram illustrates the DC voltage regulation using a PI controller. As shown in Figure 2.

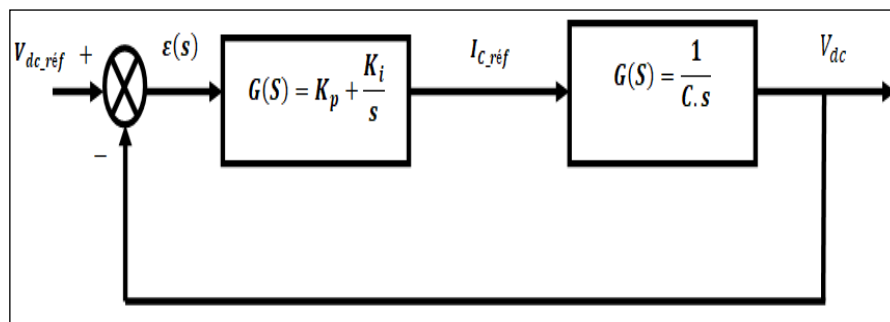


Figure 2: DC voltage control.
Source: Authors, (2026).

The closed-loop transfer function is given by:

$$H(s) = \frac{R(s).G(s)}{1 + R(s).G(s)} \quad (8)$$

We obtain:

$$H(s) = \frac{k_p \cdot s + k_i}{C \cdot s^2 + k_p \cdot s + k_i} \quad (9)$$

To control the system in closed loop, it is necessary to properly select the coefficients k_p and k_i . In this case, the pole placement method is used [27]. The closed-loop transfer function of a second-order system is characterized by:

$$F(s) = \frac{1}{s^2 + 2 \cdot \xi \cdot \omega_n s + \omega_n^2} \quad (10)$$

By comparing the previous expressions, we obtain:

$$\begin{aligned} k_p &= 2 \cdot C \cdot \xi \cdot \omega_n \\ k_i &= C \cdot \omega_n^2 \end{aligned} \quad (11)$$

The reference DC current is expressed as follows:

$$I_{dc_ref} = i_{c_ref} + I_{ch} \quad (12)$$

Where:

I_{ch} : Load current ;

I_{ref} : Measured load current;

I_{dc_ref} : DC reference current.

$$P_{ref} = v_{dc_ref} \cdot I_{dc_ref} \quad (13)$$

The product of the reference DC current and the DC voltage yields the reference active power. As shown in Figure 3:

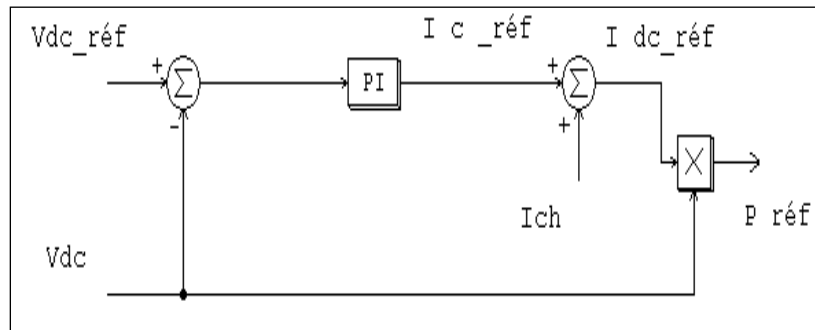


Figure 3: Calculation of the reference power.
Source: Authors, (2026).

II.3 DPC STRATEGY CONTROL

A variety of control strategies have been proposed for PWM rectifiers, which are generally classified into Voltage-Oriented Control (VOC) and Direct Power Control (DPC). This paper focuses on DPC, which can be defined in two ways: a broader definition that includes DPC with modulation using instantaneous power variables in place of current loops, and a stricter definition where instantaneous powers are directly controlled without modulation, relying on a switching table [28, 29]. This study adopts the broader definition, implying that DPC operates without internal current loops. DPC for PWM rectifiers is inspired by direct torque control in electric drives. It directly regulates active and reactive power using hysteresis comparators and a switching table, based on the sector of the grid voltage. The DC-link voltage is controlled by a PI controller, while the reactive power reference is set to zero to achieve sinusoidal input currents and unity power factor. The overall DPC scheme is illustrated in Figure 4. Direct Power Control (DPC) selects an appropriate switching vector using a predefined switching table [30]. This selection is based on the digitized error signals, which are constrained within hysteresis bands, and on the angular position of the supply voltage at the load connection point, as illustrated in Figure 5. To determine the operating region, the stationary (α, β) plane is divided into twelve sectors.

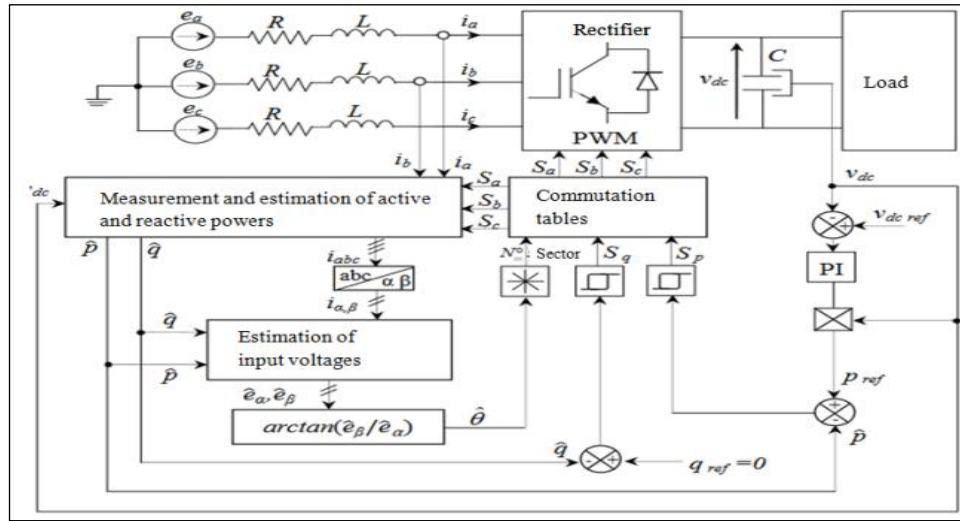


Figure 4: DPC control of PWM rectifier.

Source: Authors, (2026).

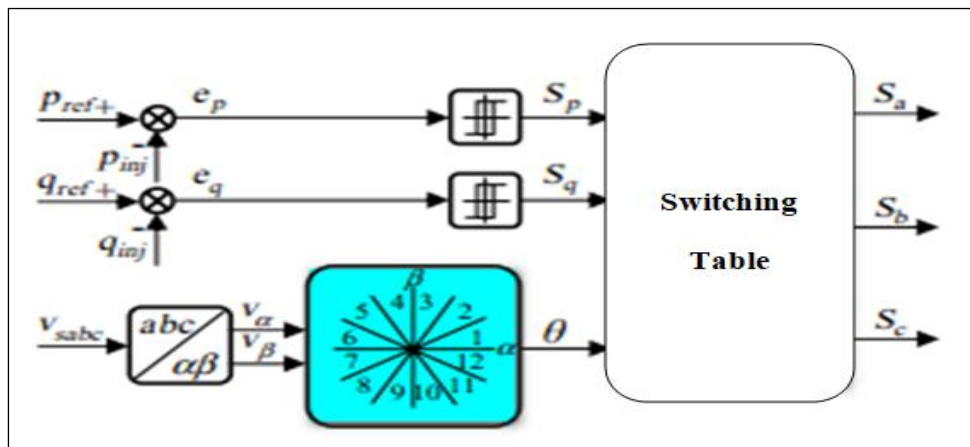


Figure 5: General Configuration of DPC.

Source: Authors, (2026).

The switching mode of the rectifier is chosen so that the error between the reference value of the instantaneous active power and the measured value remains within the hysteresis band δp . similarly, the error of the reactive power must remain within the hysteresis band δq . to achieve this, the errors of the instantaneous active and reactive powers are processed by two two-level hysteresis comparators, whose outputs (h_p and h_q) are set to 1 when the control variable (p or q) needs to be increased, and to 0 when the control variable must remain unchanged or decrease [31, 32].

$$\begin{aligned} dp = 1 & \quad p \leq p_{ref} - \Delta p \\ dp = 0 & \quad p \geq p_{ref} + \Delta p \\ dq = 1 & \quad q \leq q_{ref} - \Delta q \\ dq = 0 & \quad q \geq q_{ref} + \Delta q \end{aligned} \quad (14)$$

Knowledge of the estimated mains voltage is necessary to determine optimal switching states. For this, the work plan (α, β) is divided into 12 sectors as show in Figure 6, the latter can be determined by the following relationship:

$$(n-2)\frac{\pi}{6} < \theta_n < (n-1)\frac{\pi}{6} \quad (15)$$

$$n = 1, 12$$

The sector corresponding to the instantaneous voltage vector is determined as:

$$\theta = \text{Arctg}\left(\frac{v_\beta}{v_\alpha}\right) \quad (16)$$

θ : is the angular position of the estimated voltage vector in the (α, β) reference frame.

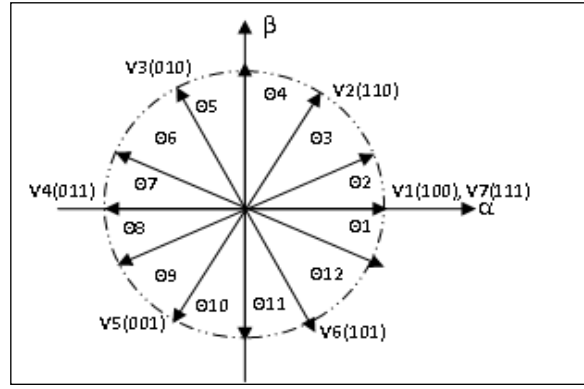


Figure 6: all Sectors in α - β stationary coordinate.
Source: Authors, (2026).

II.3.1 Switching Table

Once the Boolean outputs of the hysteresis comparators are obtained, the control voltage vector for the rectifier switches is selected from a predefined switching table according to the sector in which the voltage vector $V_{\alpha\beta}$ lies. This table maps the digitized power errors and the operating sector to the corresponding switching states S_a , S_b , and S_c of the PWM rectifier. At each switching instant, the optimal switching state is chosen based on the combination of the comparator outputs and the sector number, ensuring that the instantaneous active and reactive power errors are maintained within the prescribed hysteresis bands [33]. A two-level PWM rectifier generates eight distinct voltage vectors, each corresponding to a unique combination of the switching states and the DC-link voltage. The selection of the output voltage vectors for inclusion in the switching table is based on the active and reactive power errors, as well as the angular position of the voltage vector. The currents expressed in the (α, β) reference frame are given by:

$$\frac{di_{\alpha}}{dt} = \frac{1}{L}(e_{\alpha} - u_{e\alpha} - Ri_{\alpha}) \quad (17)$$

$$\frac{di_{\beta}}{dt} = \frac{1}{L}(e_{\beta} - u_{e\beta} - Ri_{\beta}) \quad (18)$$

The line current vector can be regulated by selecting the suitable voltage vector at the rectifier input. The variation in line current is contingent upon the network voltage $e_{\alpha\beta}$, the selected voltage vector at the rectifier input $V_{\alpha\beta}$, and the recorded currents $i_{\alpha\beta}$. The parameter L is essentially disregarded; it serves as a preliminary approximation of equation (5), which so transforms into:

$$\frac{di_{\alpha}}{dt} = \frac{1}{L}(e_{\alpha} - v_{\alpha}) \quad (19)$$

$$\frac{di_{\beta}}{dt} = \frac{1}{L}(e_{\beta} - v_{\beta}) \quad (20)$$

The derivatives of the active and reactive powers in the (α, β) coordinate are given by:

$$\begin{aligned} \frac{dp}{dt} &= \frac{de_{\alpha}}{dt}i_{\alpha} + e_{\alpha}\frac{di_{\alpha}}{dt} + \frac{de_{\beta}}{dt}i_{\beta} + e_{\beta}\frac{di_{\beta}}{dt} \\ \frac{dq}{dt} &= \frac{de_{\beta}}{dt}i_{\alpha} + e_{\beta}\frac{di_{\alpha}}{dt} - \frac{de_{\alpha}}{dt}i_{\beta} - e_{\alpha}\frac{di_{\beta}}{dt} \end{aligned} \quad (21)$$

If the switching frequency is high enough, the change in grid voltage can be neglected [34, 35]. The dynamics of active and reactive power can be given as follows:

$$\begin{aligned} \frac{dp}{dt} &= e_{\alpha}\frac{di_{\alpha}}{dt} + e_{\beta}\frac{di_{\beta}}{dt} \\ \frac{dq}{dt} &= e_{\beta}\frac{di_{\alpha}}{dt} - e_{\alpha}\frac{di_{\beta}}{dt} \end{aligned} \quad (22)$$

So, the power dynamics becomes:

$$\begin{aligned}\frac{dp}{dt} &= \frac{1}{L}(e_\alpha^2 + e_\beta^2) - \frac{1}{L}(e_\alpha \cdot u_{e\alpha} + e_\beta \cdot u_{e\beta}) \\ \frac{dq}{dt} &= \frac{1}{L}(e_\alpha \cdot u_{e\beta} - e_\beta \cdot u_{e\alpha})\end{aligned}\quad (23)$$

The term $(e_\alpha^2 + e_\beta^2)$ represents the square of the module of the network voltage in the reference frame, then:

$$(e_\alpha^2 + e_\beta^2) = \frac{3}{2} E_m^2 \quad (24)$$

The tensions are given by:

$$\begin{cases} e_\alpha = E \cos \theta \\ e_\beta = E \sin \theta \end{cases} \quad (25)$$

Using the outputs of the hysteresis comparators S_p and S_q , and according to the sector in which the voltage vector is located as show in figure 6, the voltage vector to be applied to the rectifier is selected based on the switching Table 1.

Table 1: Switching table for all sectors.

S_p	S_q	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6	γ_7	γ_8	γ_9	γ_{10}	γ_{11}	γ_{12}
1	0	V ₅	V ₅	V ₆	V ₆	V ₁	V ₁	V ₂	V ₂	V ₃	V ₃	V ₄	V ₄
1	1	V ₃	V ₃	V ₄	V ₄	V ₅	V ₅	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

Source: Authors, (2026).

II.3.2 Calculation of Instantaneous Powers

The total instantaneous active and reactive powers are calculated as follows:

$$\begin{aligned}p &= e_a \cdot i_a + e_b \cdot i_b + e_c \cdot i_c \\ q &= \frac{1}{\sqrt{3}} [(e_b - e_c) i_a + (e_c - e_a) i_b + (e_a - e_b) i_c]\end{aligned}\quad (26)$$

The calculation of instantaneous active and reactive powers is given by the following equations:

$$\begin{aligned}p &= V_{dc} (S_a i_a + S_b i_b + S_c i_c) - L \left(\frac{di_a}{dt} i_a + \frac{di_b}{dt} i_b + \frac{di_c}{dt} i_c \right) \\ q &= \frac{1}{\sqrt{3}} \left\{ -U_{dc} [S_a (i_b - i_c) + S_b (i_c - i_a) + S_c (i_a - i_b)] - 3L \left(\frac{di_a}{dt} i_c - \frac{di_c}{dt} i_a \right) \right\}\end{aligned}\quad (27)$$

The virtual flow, in addition to being present for synchronization, is also used for calculating instantaneous powers. Thus, integrating the network voltage generates a virtual flux vector in the coordinates [36-39]. The voltage drop across the resistor has also been neglected.

$$\begin{aligned}\psi_\alpha &= \int e_\alpha dt = \int \left(v_\alpha - L \frac{di_\alpha}{dt} \right) dt \\ \psi_\beta &= \int e_\beta dt = \int \left(v_\beta - L \frac{di_\beta}{dt} \right) dt\end{aligned}\quad (28)$$

Thus, the instantaneous powers are calculated as follows:

$$\begin{aligned}p &= e_\alpha i_\alpha + e_\beta i_\beta \\ q &= e_\beta i_\alpha - e_\alpha i_\beta\end{aligned}\quad (29)$$

Knowing that for almost sinusoidal and balanced voltages the derivatives of the flux amplitude are zero, the instantaneous active and reactive powers are calculated by the equation below.

$$\begin{aligned} p &= \omega(\psi_{\alpha} \cdot i_{\beta} - \psi_{\beta} \cdot i_{\alpha}) \\ q &= \omega(\psi_{\alpha} \cdot i_{\alpha} + \psi_{\beta} \cdot i_{\beta}) \end{aligned} \quad (30)$$

This method has advantages compared to the voltage estimation method and consequently it allows working with a lower sampling frequency (discontinuities in the estimation of the converter voltage are filtered by the integrator which behaves like a low-pass filter) and obtain better performance when the network voltage is disturbed.

III. RESULTS AND DISCUSSIONS

The simulation of the overall system was carried out using the Matlab/Simulink environment. The main objective is to provide an objective and quantitative analysis of the simulation results in order to validate the theoretical study under steady-state conditions and to assess the dynamic performance of the power control strategy. The block diagram of PWM rectifier based on DPC control is shown in Figure 7.

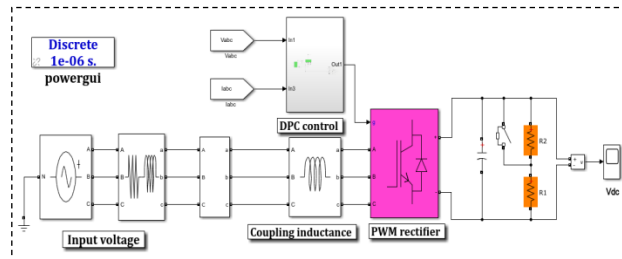


Figure 7: Bloc diagram of PWM rectifier based on DPC control.

Source: Authors, (2026).

To validate the implementation of the proposed DPC control strategy for the PWM rectifier, three distinct case studies were conducted. The first case study aims to demonstrate the effectiveness of the PI-based DPC control under a constant DC-bus voltage condition. The second case study evaluates the controller's capability to effectively manage transient operation in response to a change in the DC-bus voltage reference. Finally, the third case study illustrates the controller's proficiency in achieving active and reactive power tracking while simultaneously regulating the DC-link voltage under load variations. Table 2 presents the simulation results of the proposed system.

Table 2: Simulation parameters.

System	Values
Input voltage	$V_s=220V$, $f=50Hz$ $R_s = 0.1\Omega$; $L_s = 0.1\text{ mH}$
Load	$C=2\text{ mF}$ $V_{dc-ref} = 600\text{ V}$ $R_L= 100\ \Omega$ and 200
PWM rectifier	$L=14\text{ mH}$, $R=1\text{ m}\Omega$
Simulation conditions	$T_s=1e-6\text{ s}$

Source: Authors, (2026).

III.1 UNDER A CONSTANT DC-BUS VOLTAGE CONDITION

All the following figures show the response of the proposed system when the DC-bus voltage reference is set to 600 V.

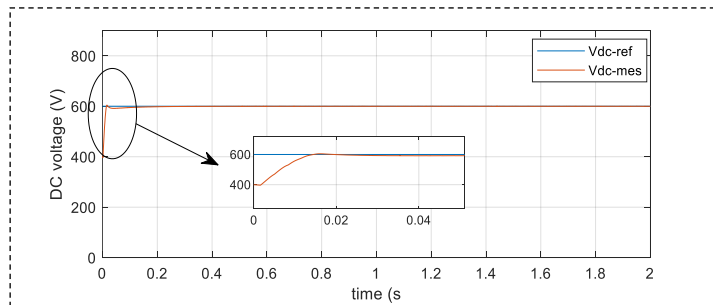


Figure 8: DC bus voltage and its reference.

Source: Authors, (2026).

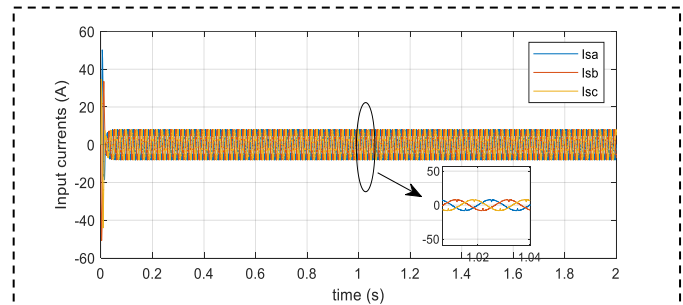


Figure 9: Input currents.

Source: Authors, (2026).

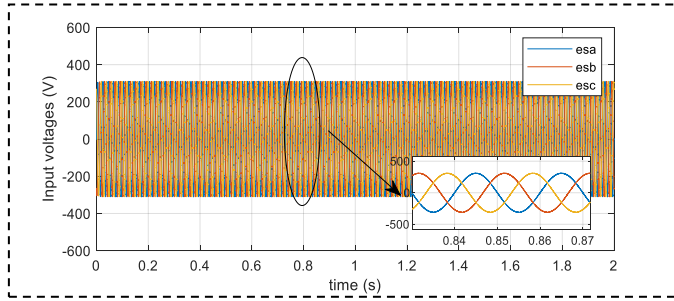


Figure 10: Input voltages.
Source: Authors, (2026).

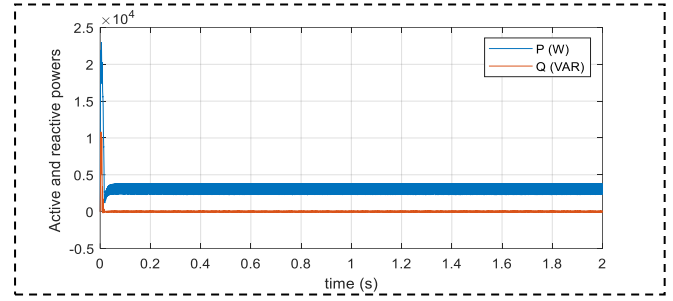


Figure 11: Instantaneous active and reactive powers.
Source: Authors, (2026).

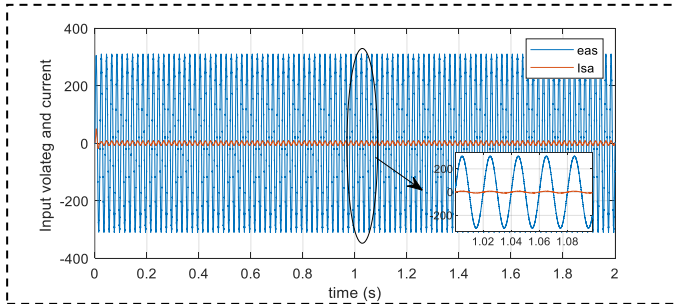


Figure 12: Zoom of input voltage and input current.
Source: Authors, (2026).

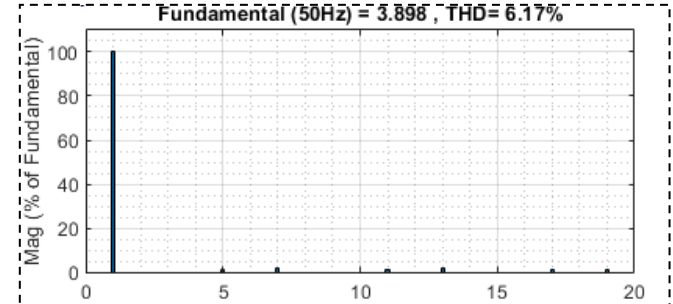


Figure 13: Total harmonic distortion of current.
Source: Authors, (2026).

The analysis of the obtained results demonstrates that, when the DC-bus voltage is maintained constant at $V_{dc}=600V$ and accurately tracks its reference value, as shown in Figure 8, the proposed control strategy ensures high operational efficiency of the PWM rectifier. Specifically, the ripples in both the input current and voltage are significantly reduced, and their waveforms are nearly sinusoidal, as illustrated in Figures. 9 and 10, respectively. Moreover, the input current and voltage are sinusoidal and exhibit zero phase shifts, as shown in Figure 12, indicating unity power factor operation. The active power varies in magnitude, whereas the reactive power remains equal to zero throughout the operation, as depicted in Figure 11. The resulting total harmonic distortion in term of THD (Figure 13) is very low at 6.17%, confirming that the input voltage and current are practically sinusoidal. Additionally, it is observed that the conventional DPC strategy ensures effective regulation of instantaneous power, with reactive power maintained at zero. These results clearly highlight the high performance of the proposed DPC approach. Consequently, the main control objectives namely, the absorption of sinusoidal input currents with unity power factor—are successfully achieved.

III.2 PERFORMANCES OF THE DPC UNDER DC BUS VOLTAGE CHANGE

The same performance results as previously observed are obtained when the response of the proposed system is evaluated under a step change in the DC-bus voltage reference from 600 V to 700 V at $t=1$ s.

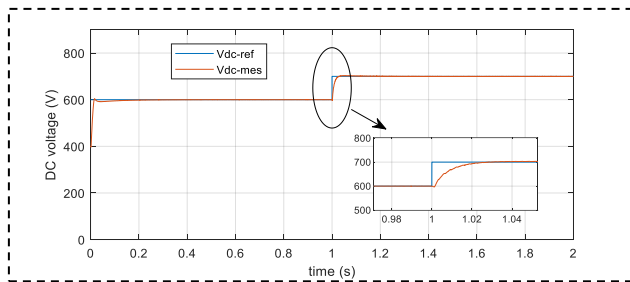


Figure 14: DC-bus voltage during the change of the reference at $t = 1$ s.
Source: Authors, (2026).

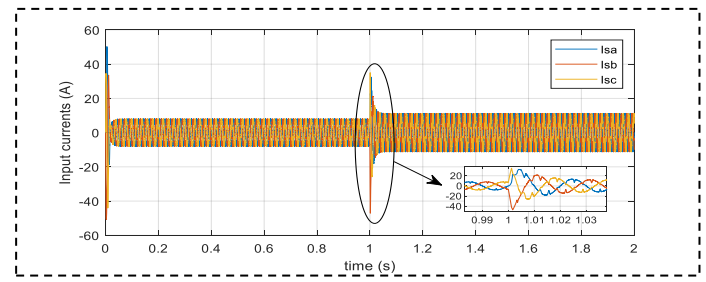


Figure 15: Input current during the change of the reference at $t = 1$ s.
Source: Authors, (2026).

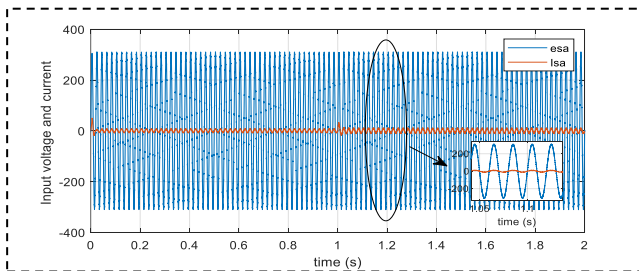


Figure 16: Input voltage and input current during the change of the reference at $t = 1$ s.
Source: Authors, (2026).

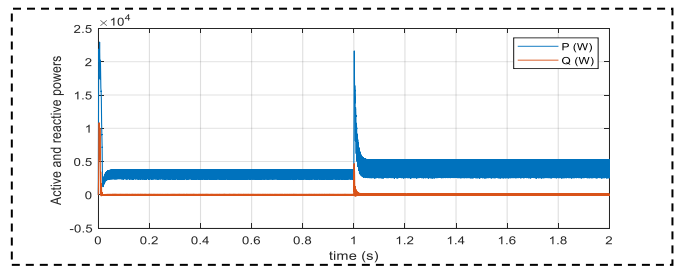


Figure 17: Instantaneous reactive and reactive powers during the change of the reference at $t = 1$ s.
Source: Authors, (2026).

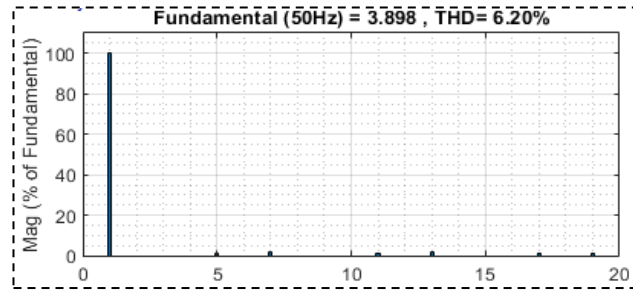


Figure 18: Total harmonic distortion THD of current during the change of the reference at $t = 1$ s.
Source: Authors, (2026).

Figure 14 show that, after a short transient period, the DC-bus voltage and the active power accurately track their new reference values with good stability. As illustrated in Figure 15 and 16 respectively the input voltage and current are in phase, indicating unity power factor operation. Furthermore, the input current is nearly sinusoidal, with a total harmonic distortion (THD) of 6.20%, which is well below the 10% (THD_i) limit imposed by international standards, see Figure 18. The DPC strategy ensures accurate tracking of the active power reference generated by the PI controller, while maintaining the reactive power close to zero, as shown in Figure 17. This confirms that the DPC approach provides effective decoupling between instantaneous active and reactive power control.

III.3 PERFORMANCES OF THE DPC UNDER VARIATION OF THE DC BUS AND THE LOAD

In the final case study, the proposed system is evaluated under a step change in the DC-bus voltage reference from 600 V to 700 V at $t=1$ s, followed by the introduction of an additional 100 Ω load at $t=1.5$ s.

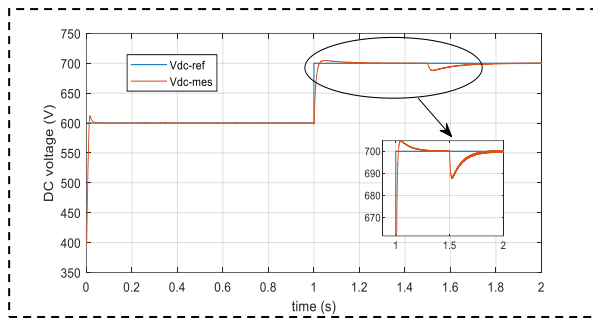


Figure 19: DC-bus voltage during the change of its reference and load at 1.5s.
Source: Authors, (2026).

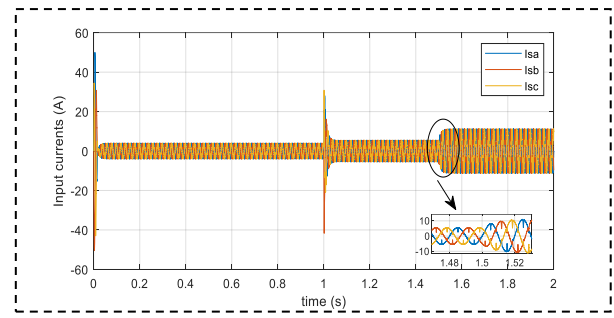


Figure 20: Input currents during the change DC voltage and load at 1.5s.
Source: Authors, (2026).

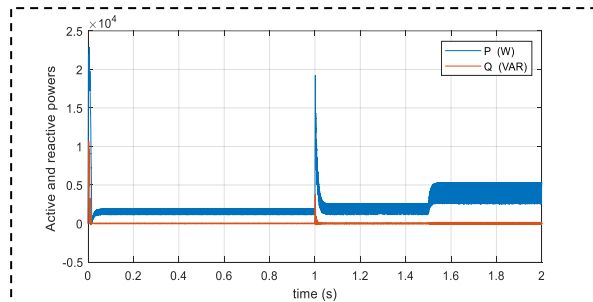


Figure 21: Instantaneous active and reactive powers during the change DC voltage and load at 1.5s.
Source: Authors, (2026).

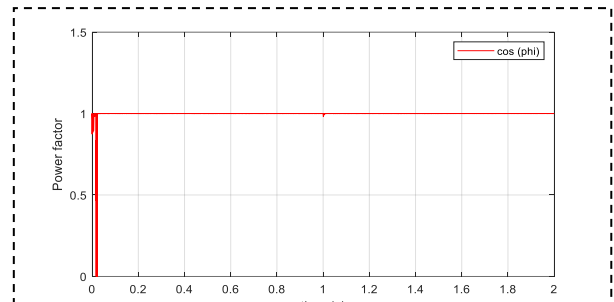


Figure 22: Power factor at unity.
Source: Authors, (2026).

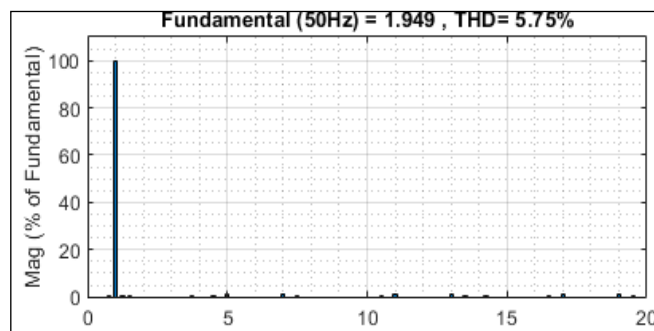


Figure 23: Total harmonic distortion THD of current during the change DC voltage and load at 1.5s.
Source: Authors, (2026).

The results presented in the figures correspond to a load variation test in which the load connected to the DC bus experiences a decrease in resistance at $t=1.5t = 1.5t=1.5$ s, while the voltage reference remains constant. It is observed that the DPC control strategy exhibits stable behavior during the load change. As shown in Figure 19, the DC-bus voltage converges to its reference value after a short transient period and then returns to steady-state operation following an increase in active power, which accurately tracks its reference generated by the PI controller of the DC bus. The instantaneous reactive power is maintained at zero, confirming unity power factor operation, as illustrated in Figure 22. Furthermore, the phase current is nearly sinusoidal and remains in phase with the grid voltage, as shown in Figure 20. The resulting total harmonic distortion (THD) of 5.75% demonstrates excellent power quality performance as shown in Figure 22. This test, involving a sudden load variation, confirms the effectiveness and robustness of the proposed DPC control strategy. Overall, the results are highly promising, demonstrating good stability and high accuracy under the applied disturbances

VI. CONCLUSIONS

This study investigated the behavior and performance of a Direct Power Control (DPC) strategy applied to a three-phase PWM rectifier, with particular emphasis on power quality improvement under nonlinear load conditions such as thyristor and Diode Bridge. Extensive simulation results demonstrated that the proposed DPC approach effectively regulates the DC-bus voltage, ensures accurate tracking of the active power reference, and maintains the reactive power close to zero, thereby achieving unity power factor operation. The control strategy successfully compensates for harmonic distortion and reactive power generated by nonlinear loads, resulting in a significant reduction of input current distortion. The obtained total harmonic distortion (THD) values, reaching as low as 5.75% and remaining well below the 10% limit imposed by international standards for harmonic currents, confirm the excellent power quality performance of the system. A key advantage of the DPC strategy lies in its simple control structure. By eliminating inner current control loops, coordinate transformations, and modulation stages, the proposed approach offers fast dynamic response, reduced computational complexity, and reliable operation without the need for additional voltage or current sensors. The harmonic spectrum analysis further validates the effectiveness of the DPC method, showing strong attenuation of undesirable harmonics and improved grid current quality. The robustness of the DPC strategy was also confirmed through various variation tests, during which the system maintained stable operation and high dynamic performance. These features make the proposed control technique particularly suitable for high-power and high-voltage applications, such as electric traction and grid-connected converters supplying nonlinear loads. Despite its advantages, a major limitation of conventional DPC is the variable switching frequency, which may lead to increased switching losses and electromagnetic interference. Consequently, future research should focus on enhanced DPC schemes, such as DPC combined with Space Vector Modulation (SVM), predictive DPC, or intelligent control techniques, to further improve system efficiency, power quality, and industrial applicability.

V. AUTHOR'S CONTRIBUTION

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Investigation: Abla Bouguerne, Aziz Boukadoum.

Discussion of results: Abla Bouguerne, Aziz Boukadoum, Dris Idris, Tahar Bahi.

Writing – Original Draft: Abla Bouguerne, Aziz Boukadoum.

Writing – Review and Editing: Abla Bouguerne, Aziz Boukadoum.

Resources: Abla Bouguerne.

Supervision: Abla Bouguerne, Aziz Boukadoum, Tahar Bahi.

Approval of the final text: Abla Bouguerne, Aziz Boukadoum, Dris Idris, Tahar Bahi.

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VII. REFERENCES

- [1] J. Yaghoobi, A. Abdullah, D. Kumar, F. Zare and H. Soltani, "Power Quality Issues of Distorted and Weak Distribution Networks in Mining Industry: A Review," in IEEE Access, vol. 7, pp. 162500-162518, 2019, doi: 10.1109/ACCESS.2019.2950911.
- [2] W. K. Chang, W. M. Grady and M. J. Samotyj, "Meeting IEEE-519 harmonic voltage and voltage distortion constraints with an active power line conditioner," in IEEE Transactions on Power Delivery, vol. 9, no. 3, pp. 1531-1537, July 1994, doi: 10.1109/61.311214.
- [3] "IEEE recommended practice and requirements for harmonic control in electric power systems," IEEE Std 519-2014 (Revision of IEEE Std 519-1992), , 2014, pp. 1–29
- [4] G. Yang, Z. Li, T. Li, J. Chang, "Fractional-Order Complementary Terminal Sliding Mode Control of Active Power Filter Based on Improved Reptile Search Algorithm", Jordan Journal of Electrical Engineering, vol. 11, no. 2, pp. 413-429, 2025, DOI: <https://doi.org/10.5455/jjee.204-1734527692>
- [5] P. Sarafrazi , S. Abbas Taher, A. Akhavan, "A Robust Backstepping Controller Based on Nonlinear Observer for Shunt Active Filters to Improve Power Quality in Four-Wire Distribution Systems", Jordan Journal of Electrical Engineering, vol. 10, no. 4, pp. 520-540, 2024, DOI: <https://doi.org/10.5455/jjee.204-1700421844>
- [6] A. Boukadoum, T. Bahi, A. Bouguerne , "Power quality improvement using fuzzy logic controlled voltage source PWM rectifiers" International Journal of Intelligent Engineering Informatics, Vol. 5, No. 3, 2017pp 242-252, <https://doi.org/10.1504/IJIEI.2017.086611>
- [7] P. -H. Huang, F. C. Lin and P. Enjeti, "A Simplified Three Phase PWM Current Source Rectifier for Hydrogen Electrolyzers," 2025 IEEE Energy Conversion Conference Congress and Exposition (ECCE), Philadelphia, PA, USA, 2025, pp. 1-7, doi: 10.1109/ECCE58356.2025.11260302.

- [8] X. Meng, L. Dong and J. Lai, "Dual-Objective Model Predictive Control for Three-Phase PWM Rectifier with Series-Stacked Buffer Under Unbalanced Grid," 2025 IEEE Energy Conversion Congress & Exposition Asia (ECCE-Asia), Bengaluru, India, 2025, pp. 1-6, doi: 10.1109/ECCE-Asia63110.2025.11112192.
- [9] Z. Boudries, D. Rekioua Ziani, "Study on Decoupling Direct Power Control of PWM Rectifier Using Space Vector Modulation". Arab J Sci Eng 38, 875–882 (2013). <https://doi.org/10.1007/s13369-012-0425-9>
- [10] T. Shi, J. Wang, C. Zhang, et al. "Direct power control for three-level PWM rectifier based on hysteresis strategy. Sci. China Technol. Sci. 55, 3019–3028 (2012). <https://doi.org/10.1007/s11431-012-4999-y>
- [11] A. Chebabhi, M.F. Benkhoris, N. Debdouche, et al. Enhanced grid current and DC voltage regulations for three level four leg rectifier DC microgrid under uncertainty and disturbances", Scientific Reports 15, 23938, 2025. <https://doi.org/10.1038/s41598-025-09603-w>
- [12] F. Chouaf, Y. Djeghader, C. Bousnoubra, "Power Quality Enhancement Using Hybrid Power Filters with nonlinear controller", PRZEGLĄD ELEKTROTECHNICZNY, ISSN 0033-2097, R. 100 NR 10/2024, doi:10.15199/48.2024.10.21
- [13] O. Abdalla, S. Elmasry, M. El Korfolly, I. Htita, "Harmonic analysis of an arc furnace load based on the IEEE 519-2014 standard," 23rd International Middle East Power Systems Conference, 2022, doi: 10.1109/MEPCON55441.2022.10021725.
- [14] Ö. Ergen and E. Bekiroğlu, "Analyzing Effects of Current Harmonics on Distribution Transformers," 2025 IEEE 19th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Antalya, Türkiye, 2025, pp. 1-6, doi: 10.1109/CPE-POWERENG63314.2025.11027279.
- [15] E. M. Kuyumani, A. N. Hasan and T. Shongwe, "Harmonic current and voltage monitoring using artificial neural network," 2020 International Conference on Artificial Intelligence, Big Data, Computing and Data Communication Systems (icABCD), Durban, South Africa, 2020, pp. 1-5, doi: 10.1109/icABCD49160.2020.9183805.
- [16] Sait, O., Latreche, S., Sait, B., Khemliche, M., & Khemliche, H. (2025). Enhanced Control and Analysis of a Five-Leg Inverter Using PWM Strategies for Dual Asynchronous Motor Drives. ITEGAM-JETIA, 11(56), 296-309. <https://doi.org/10.5935/jetia.v11i56.2772>
- [17] X. Yuan, X. Huang, L. Guo, D. Zhuo, M. Chen, T. Wang, "Implementation of a control strategy for harmonic suppression and dynamic voltage compensation in series active power filter," 23rd International Conference on Electrical Machines and Systems (ICEMS), 2020, doi: 10.23919/ICEMS50442.2020.9290862.
- [18] Okuo, M., Adebisi, O., & Akinola, O. (2025). Assessment of the effect of series passive filter on harmonic distortion-power losses relationship in an electricity distribution network. ITEGAM-JETIA, 11(52), 156-164. <https://doi.org/10.5935/jetia.v11i52.1565>
- [19] M. A. H. Mujammal, A. Moualdia, G. Lorenzini, S. Boulkhrachef, P. Wira, M.A. Albasheri, "Three-phase PWM rectifier control: Enhanced direct power control with neural networks from theory to superior reality performance". Journal Européen des Systèmes Automatisés, Vol. 57, No. 6, pp. 1743-1752. 2024, <https://doi.org/10.18280/jesa.570622>
- [20] Y. Sato and T. Kataoka, "A current-type PWM rectifier with active damping function," in IEEE Transactions on Industry Applications, vol. 32, no. 3, pp. 533-541, May-June 1996, doi: 10.1109/28.502164.
- [21] M.A.H. Mujammal, A. Moualdia, G. Lorenzini, S. Boulkhrachef, P. Wira, M.A. Albasheri, "Three-phase PWM rectifier control: Enhanced direct power control with neural networks from theory to superior reality performance". Journal Européen des Systèmes Automatisés, Vol. 57, No. 6, pp. 1743-1752. 2024, <https://doi.org/10.18280/jesa.570622>
- [22] P. -H. Huang, F. C. Lin and P. Enjeti, "A Simplified Three Phase PWM Current Source Rectifier for Hydrogen Electrolyzers," 2025 IEEE Energy Conversion Conference Congress and Exposition (ECCE), Philadelphia, PA, USA, 2025, pp. 1-7, doi: 10.1109/ECCE58356.2025.11260302.
- [23] S. Shila, S. P. Biswas, M. R. Islam, M. M. Rahman, G. Shafiullah and O. A. Sadaba, "A New PWM Scheme to Improve the Input Power Quality of 18-Pulse Rectifier Fed 3-level NPC Inverter Based Induction Motor Drive," 2021 31st Australasian Universities Power Engineering Conference (AUPEC), Perth, Australia, 2021, pp. 1-6, doi: 10.1109/AUPEC52110.2021.9597803.
- [24] Y. Li, S. Zhao, M. Novak, Y. Liu, H. Wang and F. Blaabjerg, "Differentiable Predictive Control for Power Electronic Systems," in IEEE Transactions on Power Electronics, vol. 41, no. 1, pp. 7-12, Jan. 2026, doi: 10.1109/TPEL.2025.3598178.
- [25] Lokman H. Hassan & all. Takagi-Sugeno, "Fuzzy Gains Scheduled PI Controller for Enhancement of Power System Stability", American Journal of Applied Sciences 7 (1): 145-152, 2010
- [26] M. Malinowski, M. Jasinski, M.P. Kazmierkowski, "Simple Direct Power Control of Three-Phase PWM Rectifier Using Space Vector Modulation", IEEE Transaction Industrial Electronics, vol. 51, no 2, p. 447-454, April 2004.
- [27] E. Z. Peng and J.-S. Lai, "Generalized instantaneous reactive power theory for three-phase power systems," IEEE Trans. Instrum. Meas., vol. 45, no. 1, 1996, pp. 293–297, doi: 10.1109/19.481350.
- [28] J. Hu, L. Shang, Y. He, and Z. Zhu, "Direct active and reactive power regulation of grid-connected DC/AC converters using sliding mode control approach," IEEE Trans. Power Electron., vol. 26, no. 1, 2011, pp. 210–222, doi: 10.1109/TPEL.2010.2057518.
- [29] T. Noguchi, H. Tomiki, S. Kondo and I. Takahashi, "Direct power control of PWM converter without power-source voltage sensors," in IEEE Transactions on Industry Applications, vol. 34, no. 3, pp. 473-479, May-June 1998, doi: 10.1109/28.673716
- [30] A. Boukadoum, T. Bahi, A. Bouguerne, Y. Soufi and S. Oudina, "Hysteresis band current and fuzzy logic control for active power filter," 2013 Eighth International Conference and Exhibition on Ecological Vehicles and Renewable Energies (EVER), Monte Carlo, Monaco, 2013, pp. 1-6, doi: 10.1109/EVER.2013.6521538.
- [31] A. Rath and G. Srungavarapu, "New Model Predictive & Algorithm DPC based Shunt Active Power Filters (SAPFs)," 2021 1st International Conference on Power Electronics and Energy (ICPEE), Bhubaneswar, India, 2021, pp. 1-6, doi: 10.1109/ICPEE50452.2021.9358550.
- [32] K. Sayahi and B. Faouzi, "STATCOM/APF Control Using Two Proposed DPC Strategies For Power Quality Improvement," 2021 IEEE 2nd International Conference on Signal, Control and Communication (SCC), Tunis, Tunisia, 2021, pp. 270-275, doi: 10.1109/SCC53769.2021.9768395.

- [33] A. Boukadoum, A. Bouguerne, T. Bahi, M.S. Djebbar, & A. Khechekhouché. "Four-Leg Inverter Based on Three-Dimensional Space Vector Modulation Method for Desired Output Frequency". *Tehnički vjesnik*, 31 (3), 688-695. 2024, <https://doi.org/10.17559/TV-20230421000555>
- [34] Y. Zhang and C. Qu, "Direct Power Control of a Pulse Width Modulation Rectifier Using Space Vector Modulation Under Unbalanced Grid Voltages," in *IEEE Transactions on Power Electronics*, vol. 30, no. 10, pp. 5892-5901, Oct. 2015, doi: 10.1109/TPEL.2014.2371469.
- [35] A. Kolli, O. Béthoux, A. De Bernardinis, E. Labouré and G. Coquery, "Space-Vector PWM Control Synthesis for an H-Bridge Drive in Electric Vehicles," in *IEEE Transactions on Vehicular Technology*, vol. 62, no. 6, pp. 2441-2452, July 2013, doi: 10.1109/TVT.2013.2246202.
- [36] I. N. El Badsì, B. El Badsì and A. Masmoudi, "Space Vector PWM Techniques for B3-VSI Fed Three-Phase IM Drives," 2016 IEEE Vehicle Power and Propulsion Conference (VPPC), Hangzhou, China, 2016, pp. 1-6, doi: 10.1109/VPPC.2016.7791779.
- [37] Monteagudo, F. E., Ramos, J., Guerrero, E., Ruedas, F., Varela, R., Rivas, C., Olvera, C. A., Barraza, S., & Sánchez, L. O. (2022). Design of a multi-level inverter for applications in distributed generation. *ITEGAM-JETIA*, 8(33), 4-12. <https://doi.org/10.5935/jetia.v8i33.803>
- [38] Mudhavath, S., Gopikrishna, K., & Kumar G, V. A. (2024). DTC of a 5-Level MMC Fed 3- Φ Induction Motor with PI and FLC Using CBAPOD PWM Technique. *ITEGAM-JETIA*, 10(50), 40-45. <https://doi.org/10.5935/jetia.v10i50.1295>
- [39] Luján, J. C., Monteagudo, F. E., Ramos, J., & Rodríguez, L. del C. (2024). Characterization of a low power wind turbine prototype for interconnection to the grid. *ITEGAM-JETIA*, 10(46), 22-26. <https://doi.org/10.5935/jetia.v10i46.1110>