



A NEW COMPARATIVE STUDY OF THE CONTROL METHODS USED TO REGULATE DC VOLTAGE, POWER FACTOR AND HARMONIC DISTORTION IN A THREE-PHASE RECTIFIER

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ABSTRACT

In order to achieve effective unit power factor control, harmonic distortion rate reduction, and direct current (DC) voltage regulation, a three-phase pulse width modulation (PWM) rectifier is subjected to a novel scientific study that compares two efficient control techniques: direct power control (DPC) and dq reference frame's current control. The simulations were conducted using the Matlab/Simulink software. In the DQ reference frame, DPC appears to be more effective than current control, as evidenced by the results. For both control methods, the DC voltage adheres to its new reference, and the DPC technique has a lower rate of harmonic distortion. However, it should be noted that there are discrepancies in the transient domain's mistakes' exponential convergence and during setpoint changes, as well as in the reaction times, overshoots, and oscillations of the controlled quantities. The application of DPC, widely regarded as the most effective and best-performing control, has been demonstrated to yield optimal results.



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I. INTRODUCTION

Three-phase PWM rectifiers are essential components in a wide range of industries and emerging fields, including smart microgrids, renewable energy generation and active power filtering. They are commonly used in quadrature for AC/DC power conversion and generator speed control, particularly in wind power systems. In addition, these rectifiers play a crucial role as an interface between electric vehicles (EVs) and the electricity grid, enabling EVs to store energy from the grid and return it using vehicle-to-grid (V2G) technology [1],[2]. Today, the use of the PWM rectifier, not only to produce a stable and variable DC voltage in relation to the load demand from an AC network and to ensure bidirectional power flow, but also to reduce the rate of harmonic distortion and to ensure an input current close to sinusoidal shape, with a power factor equal to unity, has led to extensive research in the field to improve the efficiency of these converters through the development of suitable control techniques, which will be considered [3],[4]. The dq reference frame's current control has some disadvantages.

The hysteresis corrector generates a changeable switching frequency, while the PI corrector is not ideal for AC signal control applications. However, this approach calls for two or three current sensors and three or two voltage sensors in addition to the DC bus voltage sensor. To avoid the first problem, a solution has been proposed for three-phase systems using PI correctors in a rotating frame of reference (with the Park transformation) [5],[6]. Direct Power Control, or DPC, is the name of this power-related control. In order to replace traditional control based on current loop regulation, it was first proposed in 1991 and developed in 1998 for use in rectifier control. Instantaneous active and reactive power are the controlled variables in this novel control method [7-9]. In order to accomplish instantaneous control of the DC voltage, control of the unit power factor, and reduction of the harmonic distortion rate, we develop two control techniques in this article: direct power control (DPC) and current control of the DQ reference frame applied to a three-phase PWM rectifier.

In the first part we presented the modelling of our rectifier. The second part presents the control techniques that will allow us to control and optimise the energy flow converted by our PWM rectifier. To this end, we will develop the following controls: I: current control of the PWM rectifier in the DQ reference frame based on three PI regulators to converge these errors towards zero; II: the second control algorithm is a direct power control based on a switching table. Finally, the work is concluded with a general conclusion, as well as suggestions and some perspectives for future research work in this field.

II. MODELLING OF THE OUR THREE-PHASE RECTIFIER

The converter structure consists of two switches per arm. The switches are bi-directional and fully controllable for opening and closing. They can be MOSFETs for low power and very high frequency, IGBTs for high power and high frequency or GTOs for very high power and low frequency. To ensure that current flows in both directions, the switch must be placed in anti-parallel with a diode [10].

II.1 THE POWER SOURCE

This is a three-phase voltage, assumed to be perfectly sinusoidal, and connected in series with a resistance R and an inductance L representing the total resistance and inductance of the line respectively. The line voltages are given by [10],[11]:

$$\begin{cases} V_1 = R \cdot i_1 + L \frac{di_1}{dt} + V_{an} \\ V_2 = R \cdot i_2 + L \frac{di_2}{dt} + V_{bn} \\ V_3 = R \cdot i_3 + L \frac{di_3}{dt} + V_{cn} \end{cases} \quad (1)$$

Where:

V_{an} , V_{bn} and V_{cn} are the simple voltages with respect to the neutral of the source at the input of the converter. And the currents of each phase are then given by the following system of differential equations:

$$\frac{d}{dt} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & 0 & 0 \\ 0 & -\frac{R}{L} & 0 \\ 0 & 0 & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} + \frac{1}{L} \begin{bmatrix} V_1 - V_{an} \\ V_2 - V_{bn} \\ V_3 - V_{cn} \end{bmatrix} \quad (2)$$

II.2 THE CONVERTER STAGE

The rectifier structure is identical to that of the inverter and the bridge connection matrix is similar to the following equation:

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \frac{U_C}{3} \cdot \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix} \quad (3)$$

II.3 THE LOAD

This part consists of a capacitor C in parallel with a resistor R, which is a DC load. It is governed by the following two electrical equations:

$$\begin{cases} \frac{dU_C}{dt} = \frac{1}{C} (i_s - i_{ch}) \\ U_C = R_{ch} \cdot i_{ch} \end{cases} \quad (4)$$

$$\frac{U_C}{i_s} = \frac{R_{ch}}{1 + R_{ch} \cdot C \cdot p} \quad (5)$$

III. THE DQ REFERENCE FRAME'S CURRENT CONTROL

This control consists of a fast internal current loop that controls the current through the mains filter and a slower external loop that controls the DC bus voltage [12],[13].

III.1. EXTERNAL VOLTAGE REGULATION LOOP

The purpose of the external control loop is to maintain the voltage across the capacitor at a reference voltage. A regulator is used to generate the reference current in the capacitor. According to the following equation, we can write a 1st order system as follows:

$$\frac{V_{dc}}{i_{con}} = \frac{1}{C \cdot s} \quad (6)$$

Regulating the DC bus voltage using PI type regulators gives us the reference current i_{con_ref} in the capacitor. The power for the capacitor is given by:

$$P_{con_ref} = i_{con_ref} V_{dc} \quad (7)$$

III.2 INTERNAL CURRENT REGULATION LOOP

The purpose of the internal control loop is to maintain a power factor close to the unit at the point of connection to the mains. Two line voltage regulators are used to decouple the control of reactive and active power. The equations governing the line voltages in the (d,q) reference frame are:

$$\begin{cases} V_{pd} = V_d - R \cdot i_d - L \frac{di_d}{dt} + L\omega i_q \\ V_{pq} = V_q - R \cdot i_q - L \frac{di_q}{dt} - L\omega i_d \end{cases} \quad (8)$$

III.3 SIMULATION RESULTS

The results of the simulation for the different tests are shown below:

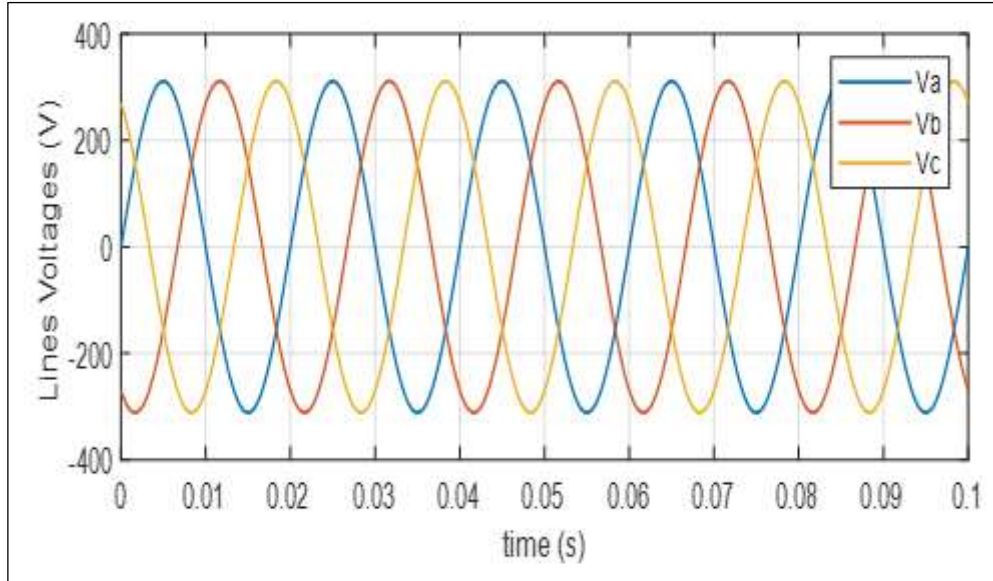


Figure 1: Lines Voltages.
Source: Authors, (2026).

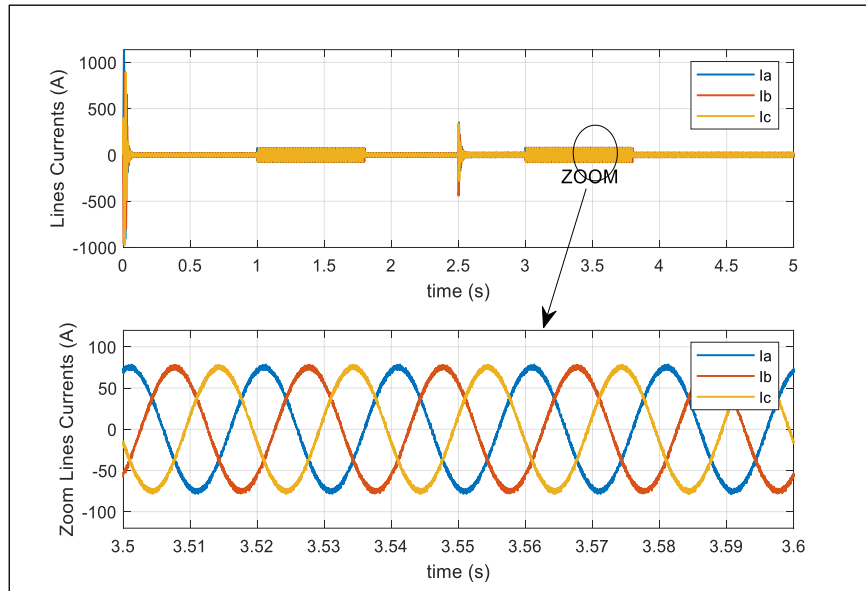


Figure 2: Lines currents.
Source: Authors, (2026).

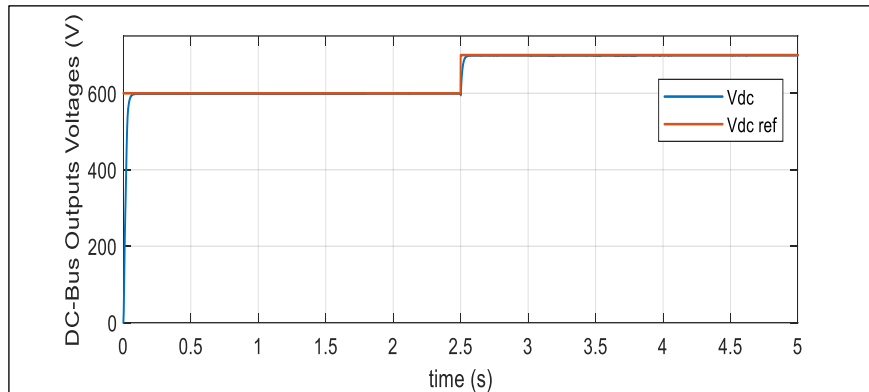


Figure 3: DC- Bus output voltages.

Source: Authors, (2026).

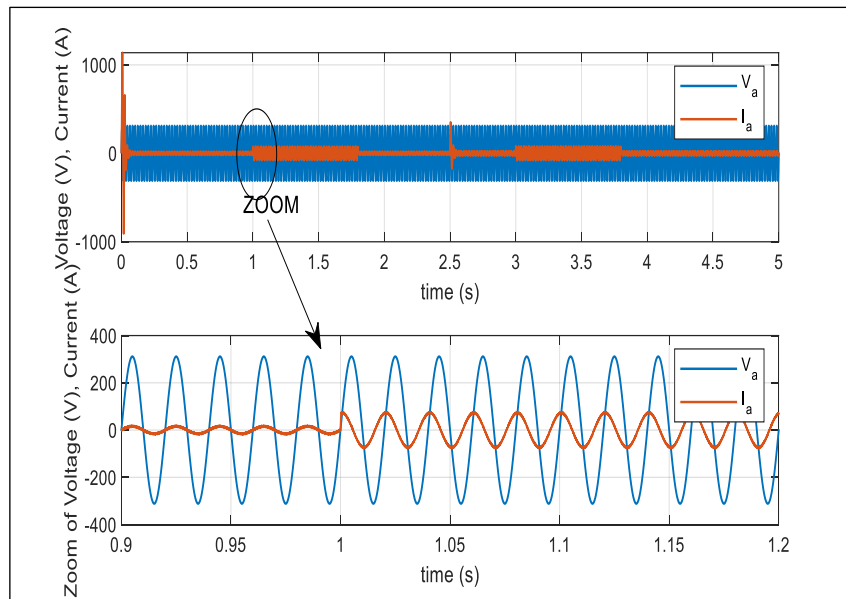


Figure 4: The load current and lines voltages.

Source: Authors, (2026).

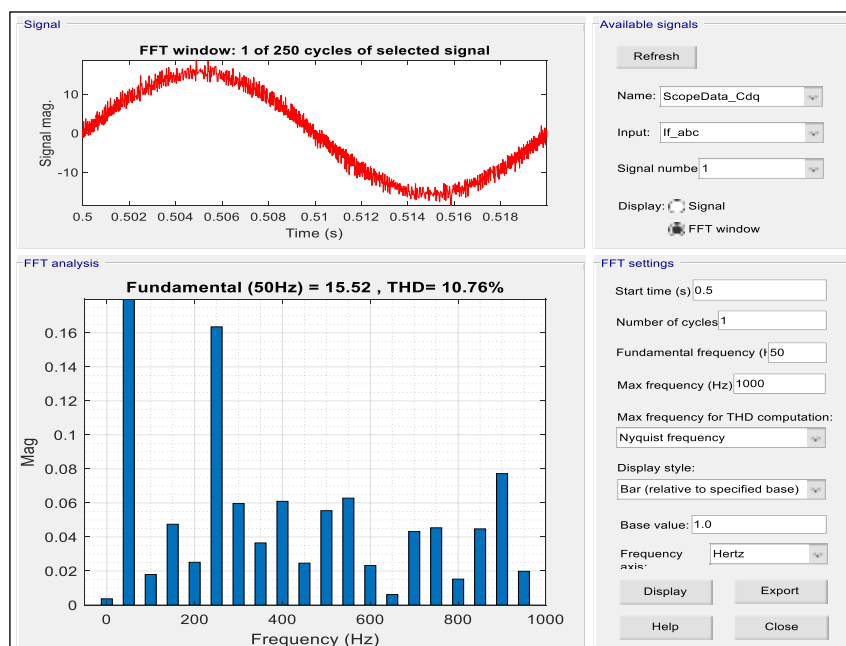


Figure 5: Harmonic spectrum of the line current.

Source: Authors, (2026).

IV THE DIRECT POWER CONTROL

Using a switching table, the DPC principle chooses a series of switching orders (S_a , S_b , and S_c) for the semiconductors that make up the PWM rectifier. The digitalised errors, S_p and S_q , between the active and reactive power references (P^* and q^*) are used to make the selection. A PI regulator is used to control the DC voltage in order to reach the active power setpoint. In order to guarantee a consistent power factor, the reactive power is brought to zero, and two two-stage hysteresis comparators supply the actual values (P and q) along with the angular position of the mains voltage vector ($\alpha\beta$). The α - β plane is split into twelve (12) equal sections of 30° for the latter [14, 15].

IV.1 SECTOR DETERMINATION

The expected voltage in the sector must be known in order to determine the best switching conditions. The following relationship can be used to calculate the 12 sectors that make up the working plane (α , β):

$$(n - 2) \frac{\pi}{6} < \gamma n < (n - 1) \frac{\pi}{6} \quad n = 1, 2 \dots 12 \quad (9)$$

Where:

n is the sector number.

The position of the voltage vector, which can be found instantly using the following formula, determines the sector number:

$$\hat{\theta} = \text{Arctg} \left(\frac{v_{s\beta}}{v_{s\alpha}} \right) \quad (10)$$

Sectors choose adjacent vectors to maximise converter switching. The plan is separated into 12 sectors for increased accuracy and to prevent issues at the limits of each control vector.

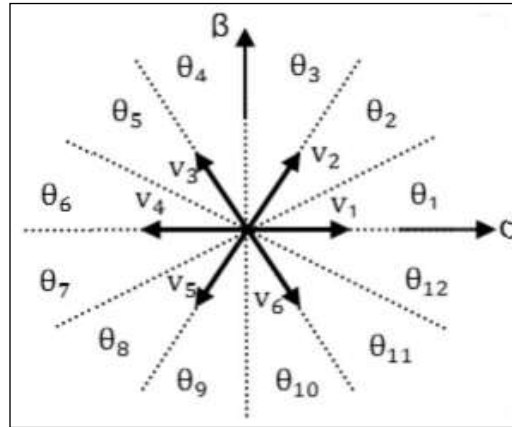


Figure 6: Determination of the 12 sectors.

Source: Authors, (2026).

IV.2 SWITCHING TABLE

The operational sector and the digital error signals S_p and S_q are fed into the switching table, which records the PWM rectifier's switching states. At each switching step, the combination of the digital signals S_p , S_q , and the sector number determines the converter's ideal switching state. This reduces the reactive power error in a 2Hz and the active power error in a 2Hz wide hysteresis region.

IV.3 SIMULATION RESULTS

The results of the simulation for the different tests are shown below:

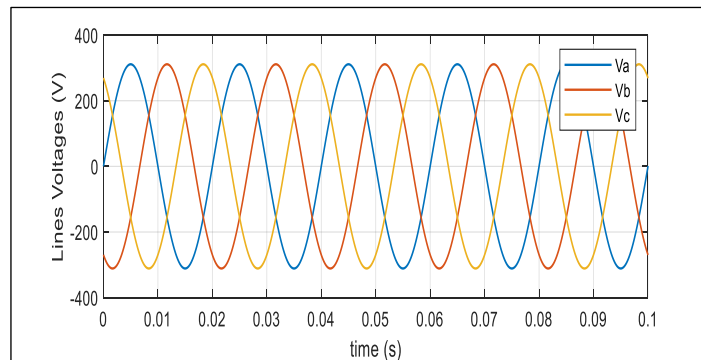


Figure 7: Lines Voltages (DPC).

Source: Authors, (2026).

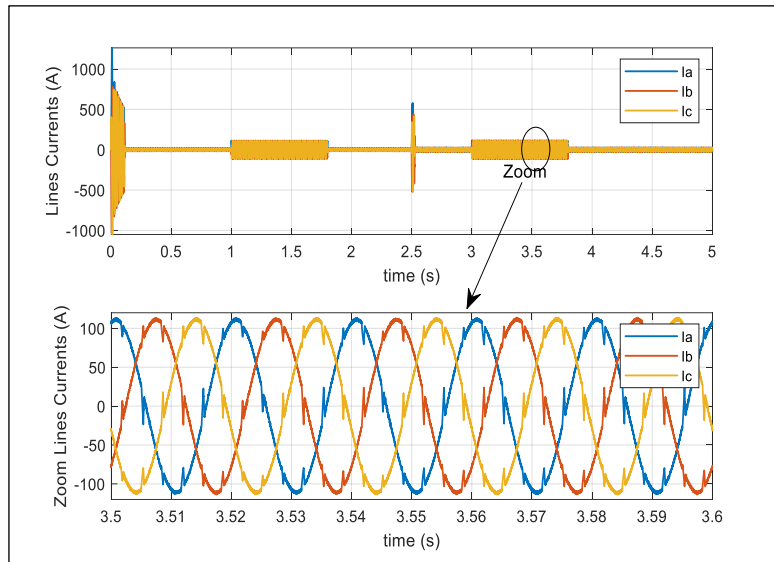


Figure 8: Lines currents (DPC).
Source: Authors, (2026).

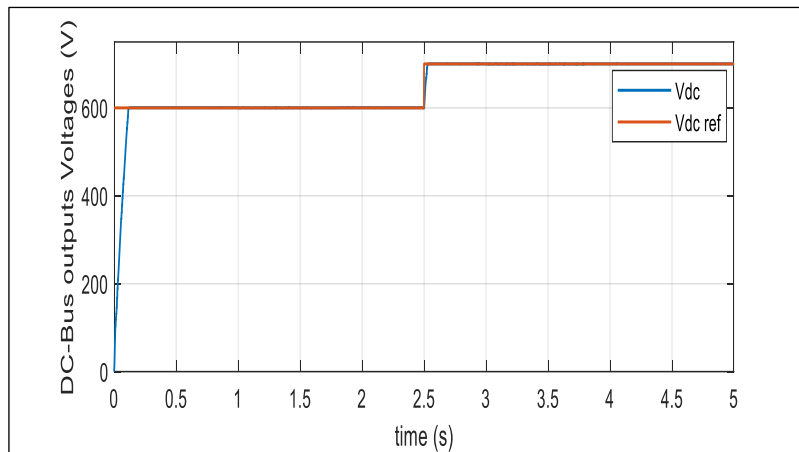


Figure 9: DC- Bus output voltages (DPC).
Source: Authors, (2026).

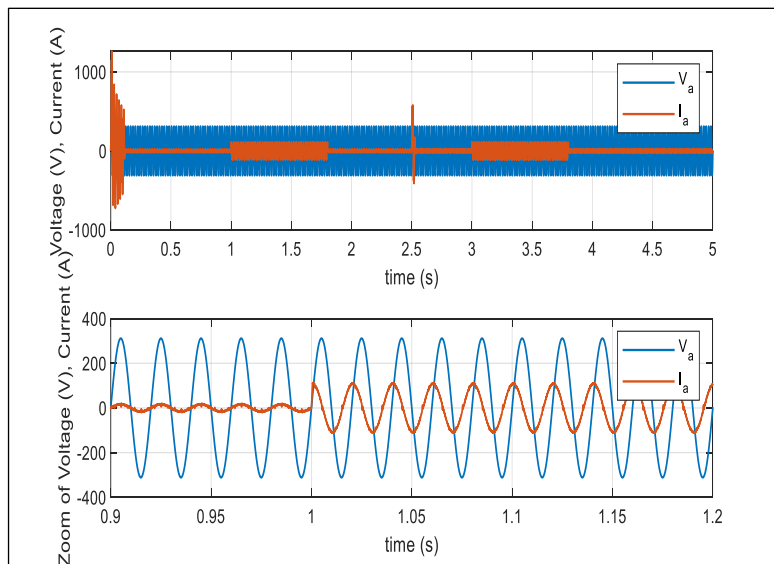


Figure 10: DC- The load current and lines voltages (DPC).
Source: Authors, (2026).

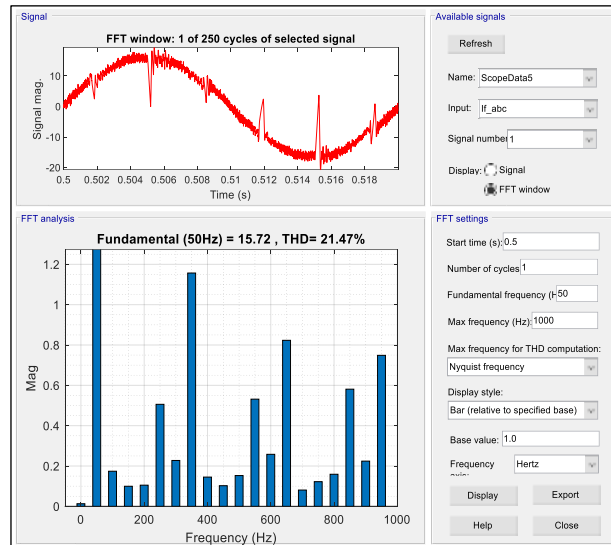


Figure 11: Harmonic spectrum of the line current (DPC).
Source: Authors, (2026).

V. CONCLUSION

In the present article, the authors develop and propose two novel control techniques with the objective of regulating the energy exchange between the rectifier and the electrical network. The employment of these techniques facilitates the operation at unity power factor, while imposing zero reactive power, converting the voltage to DC, and thereby reducing harmonic problems. In the subsequent phase of the research project, a simulation was conducted using the MATLAB software (SIMULINK) to test the three-phase PWM rectifier with these controls. In addition to its simplicity, direct power control (D.P.C.) has been demonstrated to provide enhanced control of instantaneous active and reactive power. However, it is evident that the current and voltage distortion rates are marginally higher than those obtained with current control in the DQ reference frame.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Zouggar Eloulid, Rouabhi Riyadh, Herizi Abdelghafour and Abed Ahcene.

Methodology: Zouggar Eloulid, Rouabhi Riyadh, Herizi Abdelghafour and Abed Ahcene.

Investigation: Zouggar Eloulid and Rouabhi Riyadh.

Discussion of results: Zouggar Eloulid, Rouabhi Riyadh, Herizi Abdelghafour and Abed Ahcene.

Writing – Original Draft: Zouggar Eloulid and Rouabhi Riyadh..

Writing – Review and Editing: Zouggar Eloulid, Rouabhi Riyadh, Herizi Abdelghafour and Abed Ahcene.

Resources: Zouggar Eloulid and Herizi Abdelghafour.

Supervision: Zouggar Eloulid and Rouabhi Riyadh.

Approval of the final text: Zouggar Eloulid, Rouabhi Riyadh, Herizi Abdelghafour.

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