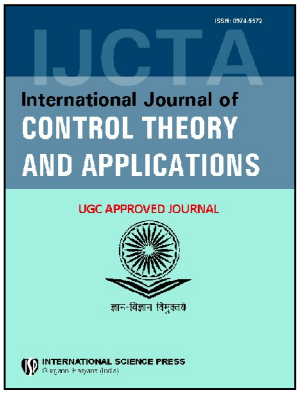


International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 34 • 2017

Improvement of the Performances of the Direct Power Control Using Space Vector Modulation of Three Phases PWM-Rectifier

Arezki Fekik, HakimDenoun[*1], M. Zaouia[*2], N. Benyahia[*3], Naceredine Benamrouche[*4], A. Badji[*5] and Sundarapandian Vaidyanathan[#]

[*] *Arezki Fekik is with the Electrical and Computer Engineering Department at Mouloud Mammeri University of Tizi-Ouzou, Algeria, P.O. Box 17 , Tizi-Ouzou, Algeria, E-mail arezkitdk@yahoo.fr*
[*1] *Hakim Denoun is with the Electrical and Computer Engineering Department at Mouloud Mammeri University of Tizi-Ouzou, Algeria, P.O. Box, 17, Tizi-Ouzou, Algeria E-mail: akim_danoun2002dz@yahoo.fr.*
[*2] *Nacereddine Benamrouche is with the Electrical and Computer Engineering Department at Mouloud Mammeri University of Tizi-Ouzou, Algeria University, P.O. Box 17, Tizi-Ouzou, Algeria, E-mail: benamrouchen@yahoo.fr.*
[#] *Sundarapandian Vaidyanathan, Professor & Dean R & D Centre, Vel Tech University #42, Avadi-Vel Tech Road, Avadi Chennai-600062, Tamil Nadu, India, E-mail: sundarcontrol@gmail.com*

Abstract: In this work, a method of control of three-phase PWM-rectifiers will be studied, in order to remedy the drawback of the conventional direct power control with variable switching frequency, called direct power control with Space vector modulation. In the direct Power control the switching states are selected from a switching table based on the digitized errors between the estimated active and reactive powers and their references respectively, and thus the angular position of the voltage. In the direct power control with Space vector modulation, the hysteresis regulators are replaced by PI regulators and the switching table with a vector modulation block to have a constant switching frequency, and in order to improve the quality of the current absorbed by the PWM-rectifier. The simulation results show that when using DPC-SVM method is better those obtained by a conventional DPC

Keywords: Direct power control (DPC), instantaneous active and reactive power, pulse width modulated (PWM) rectifier, switching table, Space Vector Modulation (SVM), Switching frequency, Total Harmonics Distortion (THD)

1. INTRODUCTION

Static converters know for a long time, a considerable development, and offer huge potential for the conversion of electrical energy. Research in the field of converters, considers several aspects including the topologies of these converters, the structures and performances of power switches and the control techniques[1],[2].

Static converters can induce a very high total harmonic distortion (THD) under certain operating conditions[1],[2]. For this reason, international standards are adaptedsuch as IEEE standard 519 and IEC 61000 which impose limits to current and voltage THDs within the power supply network. In order to limit the harmonic perturbation rate caused by non-linear loads or power electronics connected to the grid, a more interesting method of harmonic reduction is proposed. It is based on the use of rectifiers with PWM either with current or voltage structure. Among the most common and the most attractive structures is the PWM voltage rectifier. It has the capacity to control the currents absorbed and to operate under a unit power factor, it also ensures a bidirectional transfer of the power flow. In recent years, technical variants were proposed in the literature for controlling the AC / DC converters with PWM strategy, all of these strategies aim to achieve the same objectives namely the power factor and a current wave form close to a sinusoid. A various control strategies have been proposed in recent works[3],[4]. They can be classified according to their use of current loop controllers [5], or active/reactive power controllers[4],[6], Voltage-oriented control (VOC), which provides a good dynamic response by an internal current control loop [7]. An interesting emerging control technique, direct power control (DPC), was developed analogously with the well-known direct torque control (DTC) [4].In DPC scheme, there are no internal control loops and the converter switching states are appropriately selected by a switching table based on the instantaneous errors between the controlled and estimated values of instantaneous active and reactive powers and the voltage vector position[4], [7]. However, among the well-known disadvantages of the DPC scheme, we can enumerate: variable switching frequency .To eliminate the above difficulties and drawbacks, space vector modulated direct power control (DPC-SVM), is presented in recent works [4] in DPC–SVM method, the switching states of the converter are generated by a SV-PWM modulator block operating with constant switching frequency.

This paper presents Improvement of the performances of the Direct Power control using the Space vector Modulation of three phases PWM-Rectifier, which achieves a unity power factor, by the direct control of the instantaneous active and reactive powers.

This strategy is compared to the classical direct Power control with switching table, both strategies are modeled and then a simulation is undertaken under Matlab environment. The comparative analysis shows that the performances using the Space vector modulation are slightly better that those obtained using a simple direct power control. In fact, the output voltage contains fewer harmonic reducing the THD ratio.

2. MODELING OF THREE PHASESRECTIFIER

2.1. General Structure

The power circuit of the PWM rectifier contains a bridge of six power transistors with anti-parallel diodes, which is used to carry out the PWM generation as well as the power bidirectional conversion, the general diagram of the PWM rectifier is shown in Figure 1. The converter is supplied by a voltage source in series with an inductance and a resistance, which model the network. Generally, the network inductance is insufficient to eliminate all the harmonics present in the current and voltage [8], [9], [11].

To attenuate the ripples due to the switching operation of the PWM rectifier, a series filter having a more significant inductance is needed. A load and a capacitor are connected simultaneously at the output of the converter. The capacitor is used as a voltage source and allows the rectifier to also operate as an inverter [8], [9], [11].

The logical states impose the rectifier input voltages, are given as:

$$\begin{aligned} u_{ea} &= S_a.V_{dc} \\ u_{eb} &= S_b.V_{dc} \\ u_{ec} &= S_c.V_{dc} \end{aligned} \tag{1}$$

Thus the operation principle of the rectifier is illustrated by the following matrix system:

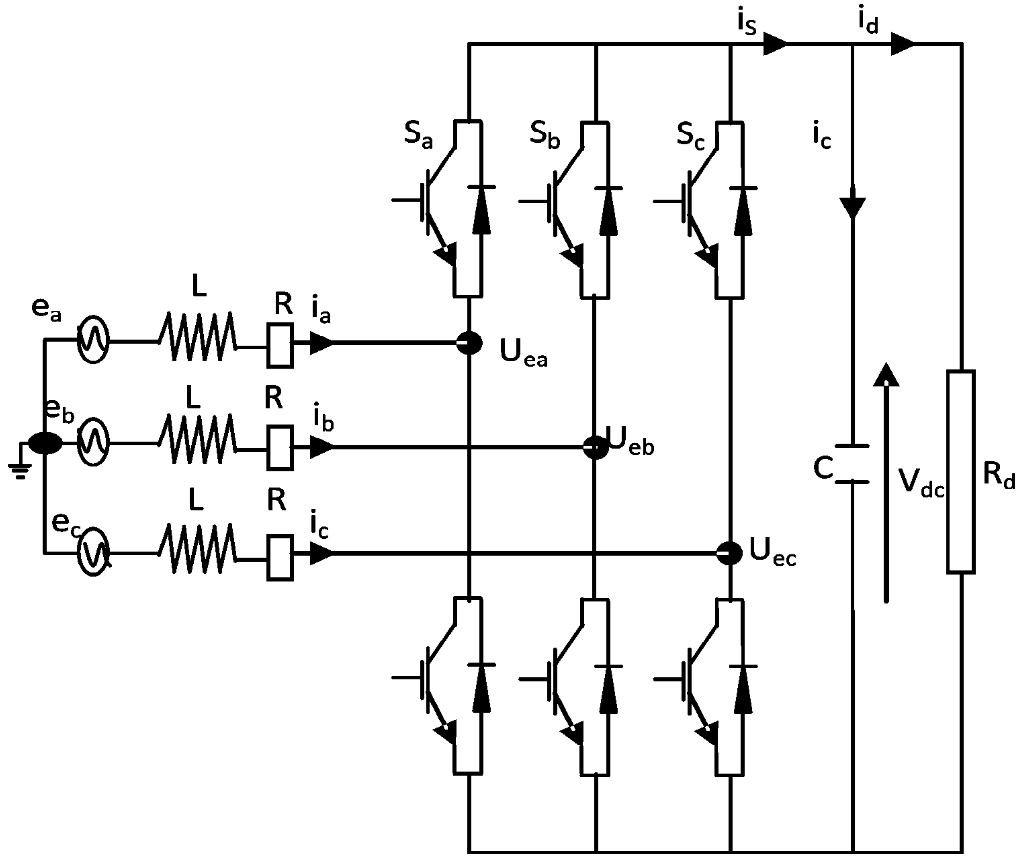


Figure 1: General Diagram of the PWM rectifier

$$\begin{bmatrix} u_{ea} \\ u_{eb} \\ u_{ec} \end{bmatrix} = V_{dc} \begin{pmatrix} \frac{2}{3} & -\frac{1}{3} & -\frac{1}{3} \\ -\frac{1}{3} & \frac{2}{3} & -\frac{1}{3} \\ -\frac{1}{3} & -\frac{1}{3} & \frac{2}{3} \end{pmatrix} \begin{pmatrix} S_a \\ S_b \\ S_c \end{pmatrix} \tag{2}$$

The AC side can be modelled by the following equations [12].

$$\begin{cases} u_{ea} = e_a - Ri_a - L\dfrac{di_a}{dt} \\ u_{eb} = e_b - Ri_b - L\dfrac{di_b}{dt} \\ u_{ec} = e_c - Ri_c - L\dfrac{di_c}{dt} \end{cases} \tag{3}$$

AC currents i_a, i_b and i_c are generated by voltage drops at impedances network boundaries (e_a-u_{ea}), (e_b-u_{eb}) and (e_c-u_{ec}), and then these currents will be modulated through the switches to provide the D.C.current i_s such as:

$$i_s = S_a i_a + S_b i_b + S_c i_c \tag{4}$$

The voltages vectors generated by the rectifier can be given by Table 1:

Table 1
Different switches configurations and the corresponding voltage vectors

S_a	S_b	S_c	U_{ea}	U_{eb}	U_{ec}	V_i
0	0	0	0	0	0	V_0
0	0	1	$-\frac{V_{dc}}{3}$	$-\frac{V_{dc}}{3}$	$\frac{2V_{dc}}{3}$	V_5
0	1	0	$-\frac{V_{dc}}{3}$	$\frac{2V_{dc}}{3}$	$-\frac{V_{dc}}{3}$	V_3
0	1	1	$-\frac{2V_{dc}}{3}$	$\frac{V_{dc}}{3}$	$\frac{V_{dc}}{3}$	V_4
1	0	0	$\frac{2V_{dc}}{3}$	$\frac{V_{dc}}{3}$	$\frac{V_{dc}}{3}$	V_1
1	0	1	$\frac{V_{dc}}{3}$	$-\frac{2V_{dc}}{3}$	$\frac{V_{dc}}{3}$	V_6
1	1	0	$\frac{V_{dc}}{3}$	$\frac{V_{dc}}{3}$	$-\frac{2V_{dc}}{3}$	V_2
1	1	1	0	0	0	V_7

i_d is the current absorbed by the load, its equation depends on the nature of this load [14].

No load

$$i_d = 0 \tag{5}$$

For a resistive load (R_d)

$$i_d = \frac{V_{dc}}{R_d} \tag{6}$$

For passive inductive load (L_d, R_d,)

$$\frac{di_d}{dt} = \frac{V_{dc} - R_d i_d}{L_d} \tag{7}$$

For an active inductive load (L_d, R_d, E)

$$\frac{di_d}{dt} = \frac{V_{dc} - R_d i_d - E}{L_d} \tag{8}$$

In our the study load is considered to be purely resistance

2.2. Direct Power Control

DPC is based on the instantaneous active and reactive power control loops. In DPC there are no current control loops. As shown in Figure 2, and for the classical DPC, the converter switching states are selected by a predefined switching table based on the digitized signals S_p and S_q, of instantaneous errors of active and reactive power, respectively, provided by a fixed band hysteresis comparators and the power source voltage vector position θ_n [13], [16], [17].

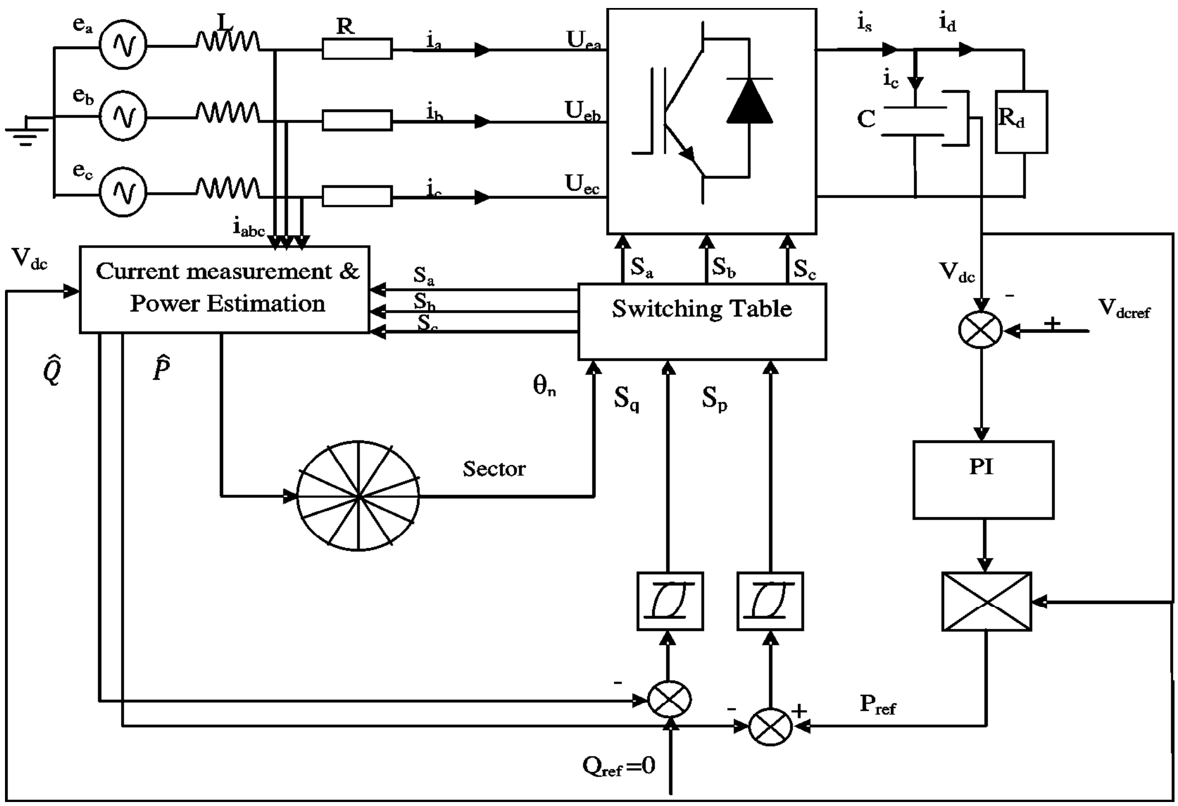


Figure.2: Configuration of DPC with switching table of PWM rectifier

2.2.1. Instantaneous Power Estimation

The estimation of instantaneous active and reactive powers is carried out by equation (9):

$$\hat{P} = L\left(\frac{di_a}{dt} + \frac{di_b}{dt} + \frac{di_C}{dt}\right) + V_{dc}(S_a i_a + S_b i_b + S_c i_c) \tag{9}$$

$$\hat{Q} = \frac{1}{\sqrt{3}}\left[L\left(\frac{di_a}{dt} i_c - \frac{di_c}{dt} i_a\right) + V_{dc}(S_a(i_b - i_c) + S_b(i_c - i_a) + S_c(i_a - i_b))\right]$$

2.2.2. Voltage Estimation

To achieve voltage sensor less operation, using the following equation:

$$\begin{bmatrix} \hat{e}_\alpha \\ \hat{e}_\beta \end{bmatrix} = \frac{1}{i_\alpha^2 + i_\beta^2} \begin{bmatrix} i_\alpha & -i_\beta \\ i_\beta & i_\alpha \end{bmatrix} \begin{bmatrix} \hat{P} \\ \hat{Q} \end{bmatrix} \tag{10}$$

2.2.3. Line Voltage Vector Position

The phase of the power-source voltage vector is converted to the sector signal. For this purpose, the stationary coordinates are divided into 12 sectors, as shown in Figure.3 and the angle can be deduced from equation (11).

$$\theta_n = arct\left(\frac{e_\beta}{e_\alpha}\right) \tag{11}$$

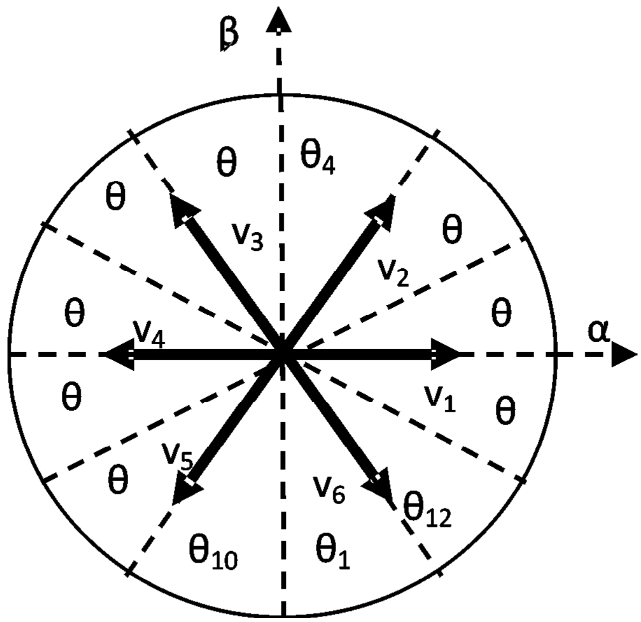


Figure 3: Voltage vector in stationary coordinates with twelve sectors

2.2.4. Switching Table

The selection of the adequate vector is determined by the following table according to the variation in the active and reactive power with the position of voltage vector.

Table 2
Switching table of DPC

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}
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
1	0	V_6	V_7	V_1	V_0	V_2	V_7	V_3	V_0	V_4	V_7	V_5	V_0
1	1	V_7	V_7	V_0	V_0	V_7	V_7	V_0	V_0	V_7	V_7	V_0	V_0

V_1(100), V_2(110), V_3(010), V_4(011), V_5(001), V_6(101), V_0(000), V_7(111)

2.3. Direct Power Control with Space Vector Modulation

The DPC-SVM with constant switching frequency uses closed-loop power control, as shown in Figure 4. The control reactive power Q_{ref} set to zero for unity power factor operation and delivered from the outer PI dc-voltage controller. The reference active power P_{ref} and reactive power Q_{ref} which are in the DC frame and flowing between the supply and the dc link are compared with the calculated $\hat{p}$ and $\hat{Q}$ respectively. The errors are delivered to a PI controller to eliminate steady-state error, and the output signals are transformed to the fixed frame and used for switching signals generation by the space-vector modulator (SVM)[10], [15].

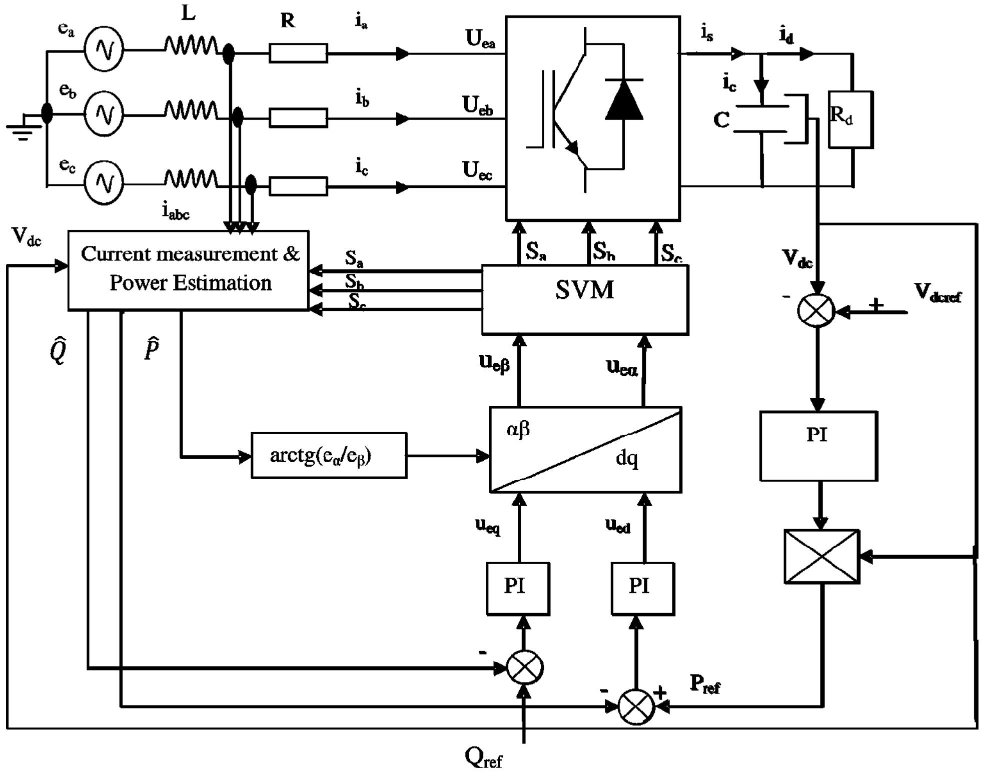


Figure 4: Configuration of DPC with space vector modulation of PWM rectifier

2.3.1. Synthesis of Active and Reactive Power Controllers

The synthesis of active and reactive power controllers can be done analytically using a simplified model of PWM rectifier.The active and reactive power in (d-q) coordinates has the form after the orientation of the frame [4]

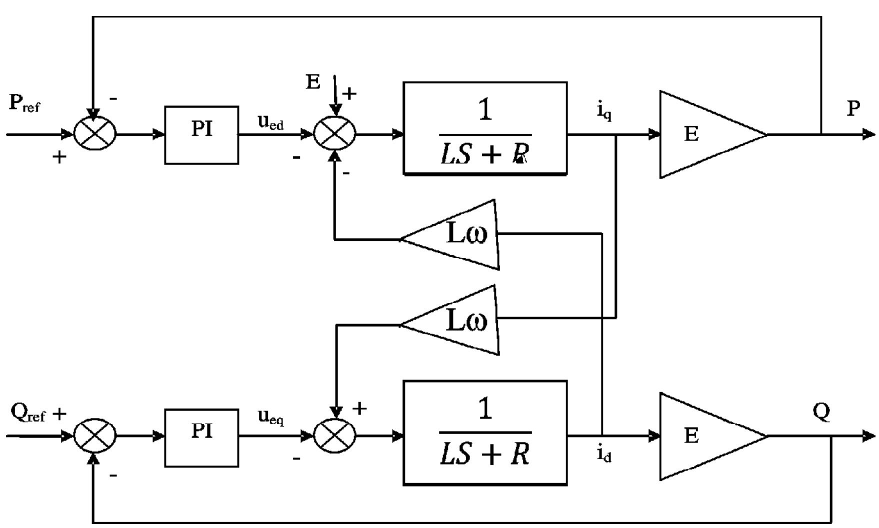


Figure 5: Simplified block diagram

$$e_d = E = \sqrt{\frac{3}{2}} E_m \qquad e_q = 0 \tag{12}$$

And

$$e_d = Ri_d + L\frac{di_d}{dt} - wLi_q + u_{ed} \qquad 0 = Ri_q + L\frac{di_q}{dt} + wLi_d + u_{eq} \tag{13}$$

The expressions of active and reactive powers in synchronous coordinates are:

$$P = Ei_q \qquad Q = Ei_d \tag{14}$$

The parameters of the PI Controller can be adjusted based on the superposition theorem. The figure.6. Shows the simplified block diagram of the instantaneous active power control loop

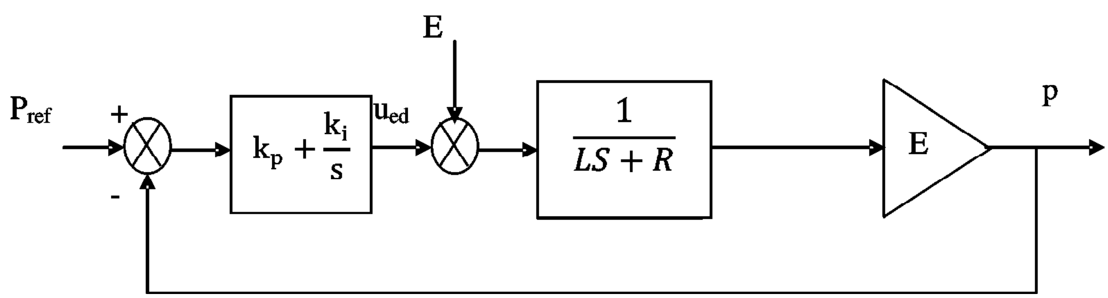


Figure 6: Active power controller

The line voltage is considered as a constant disturbance and must be compensated for by the integral part of the corrector PI. The closed loop transfer function of the system is given by:

$$FTBF = \frac{E(k_p s + k_i)}{Ls^2 + (Ek_p + R)s + Ek_i} \tag{15}$$

The transfer functions of a second order system in a closed loop:

$$F(s) = \frac{1}{s^2 + 2z_n\omega_n s + \omega_n^2} \tag{16}$$

By analogy between expressions (15) and (16), we find:

$$k_p = \frac{2Lz_n\omega_n - R}{E} \quad k_i = \frac{L\omega_n^2}{E} \tag{17}$$

It should be noted that equation (17) is valid for both regulators

3. SIMULATION RESULTS

Both strategies, was simulated using Matlab / Simulink software. The parameters used are shown by table.3. The DC voltage control system for both strategies is tested as well as the DPC and DPC-SVM method following a DC voltage step variation occurred at t=0.5s from 300V to 350V (parameters given in table.3).

Table 3
System Parameters

R	line resistance	0.25	Ω
L	line inductance	0.0016	H
C	DC-capacitor	0.0047	F
R_d	Load resistance	100	Ω
e_{abc}	Voltage line	120	V
f	Source voltage frequency	50	Hz
f_c	Switching frequency(DPC-SVM)	30	KHz
V_{dcref}	DC-Voltage Reference	300	V

Figure 7-A and Figure 8-A show the DC link capacitor voltage, when a step voltage is applied at t=0.5s, we can see, that the DPC-SVM structure need 0.1s to attend the references value. Figure 7-B and Figure 8-B show the behaviours of the instantaneous active under step variation, between 0.9 and 1.2 kW we can see that the responses of both structure provides an excellent performances.

Figure 7-C and Figure.8-C show that the quick variation of the active power does not affect the reactive power which is keep at its reference (value 0 VAR), thus, decoupled control between active and reactive power is achieved. To compare the DPC and the DPC-SVM strategie the harmonic spectrums of the current are given in Figure 7-E and Figure.8-E. It is shown that the DPC-SVM is better than the DPC strategy as far as the harmonic content is concerned (THD= 2,05 with a DPC-SVM compared to THD=4,29 with a DPC)

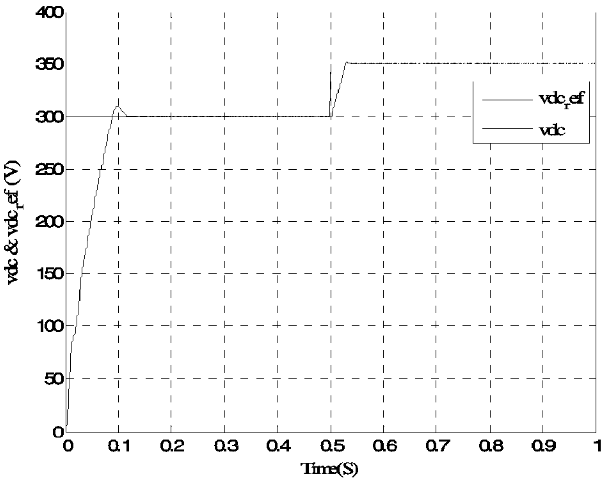
4. CONCLUSION

This paper present improvement of the performances of the Direct Power control using Space vector Modulation of three phases PWM-Rectifier, which achieves a unity power factor by the direct control of the instantaneous active and reactive powers. This strategy is compared to the classical direct Power control with switching table.

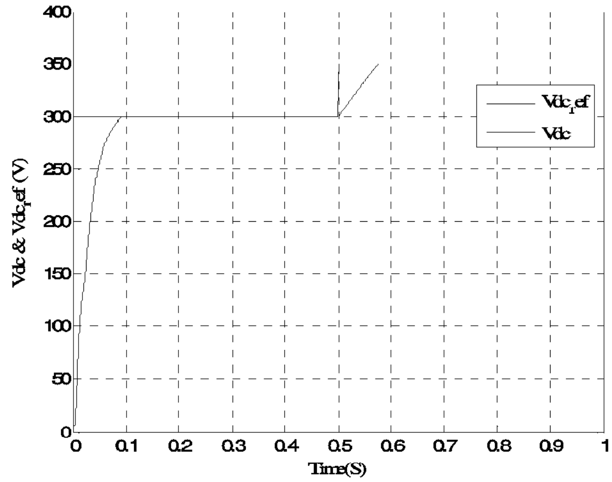
In DPC the active and reactive power can be regulated directly by hysteresis comparators of the power.In this configuration, the errors between the power control signal and the feedback signals are compared by the hysteresis elements, and the specific switching state of the converter is appropriately selected by the switching table, so that the errors can be restricted within the hysteresis bands. In DPC–SVM method, the switching states of the converter are generated by a SV-PWM modulator block operating with constant switching frequency.

The DPC-SVM has proven excellent performances and verifies the validity of the proposed control system. The DPC-SVM system has the advantages having a lower sampling frequency,a lower THD, and constant switching frequency those obtained by classical DPC.

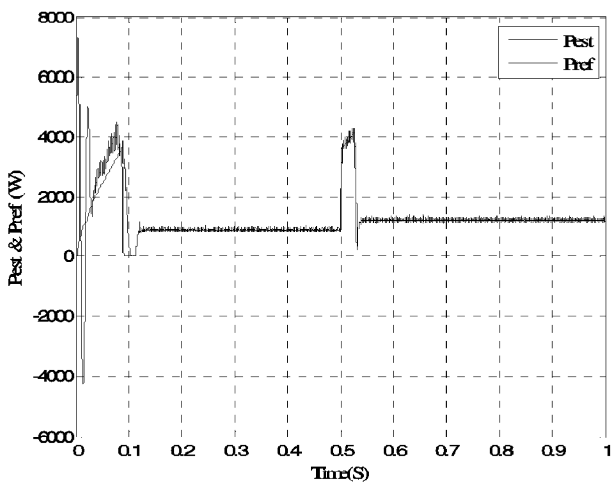
DPC **SVM-DPC**



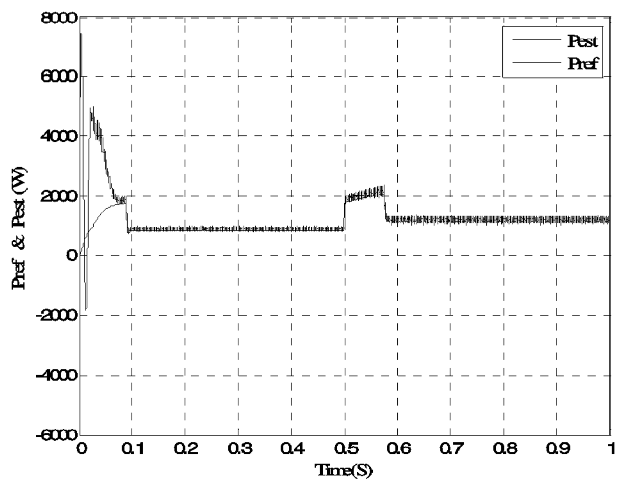
(A)



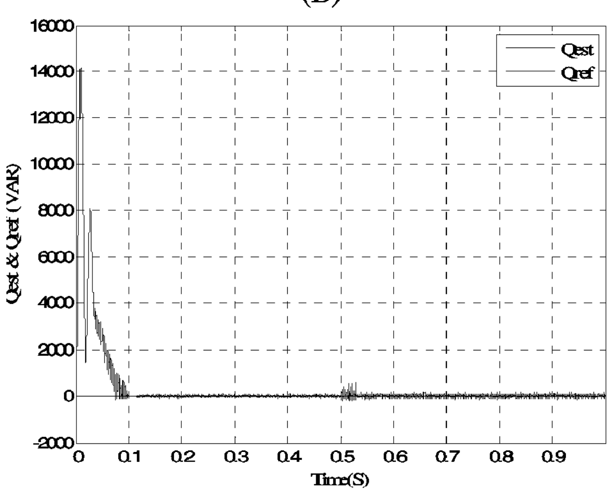
(A)



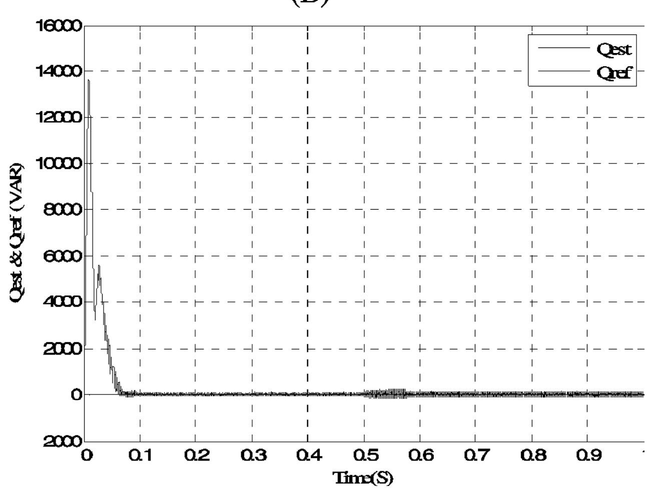
(B)



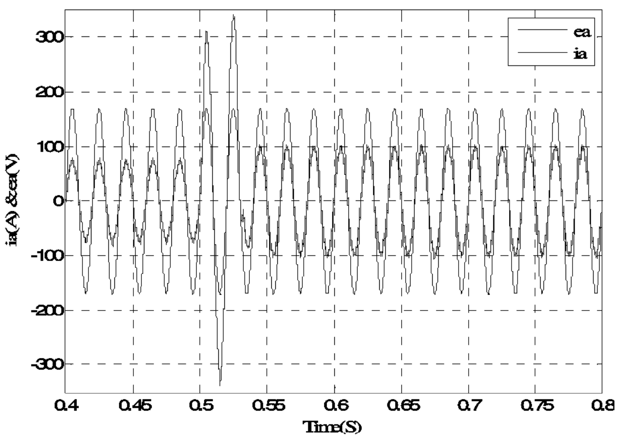
(B)



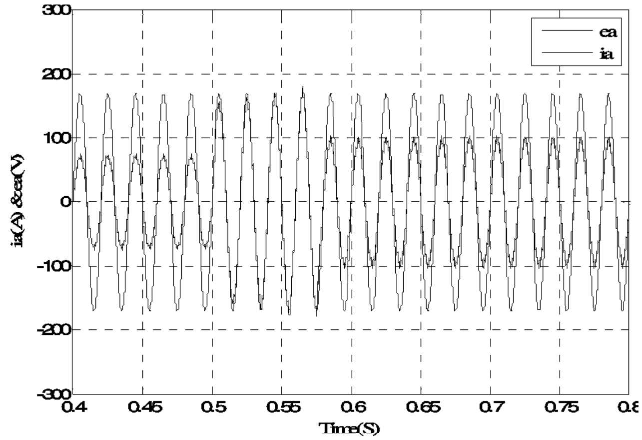
(C)



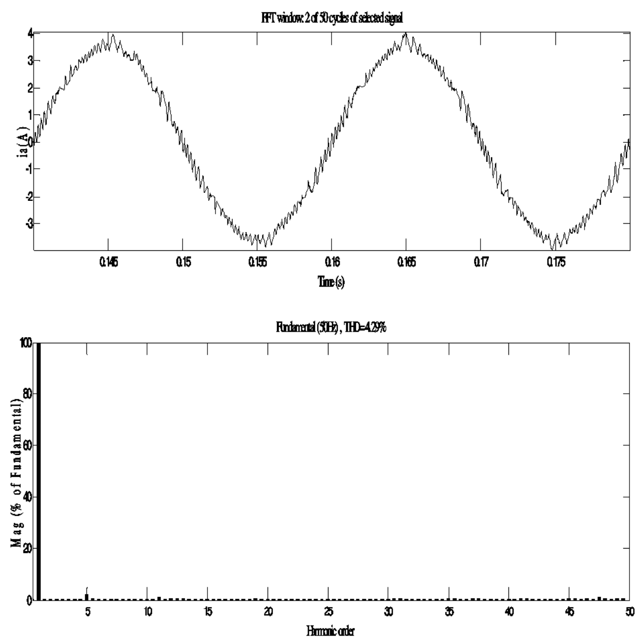
(C)



(D)

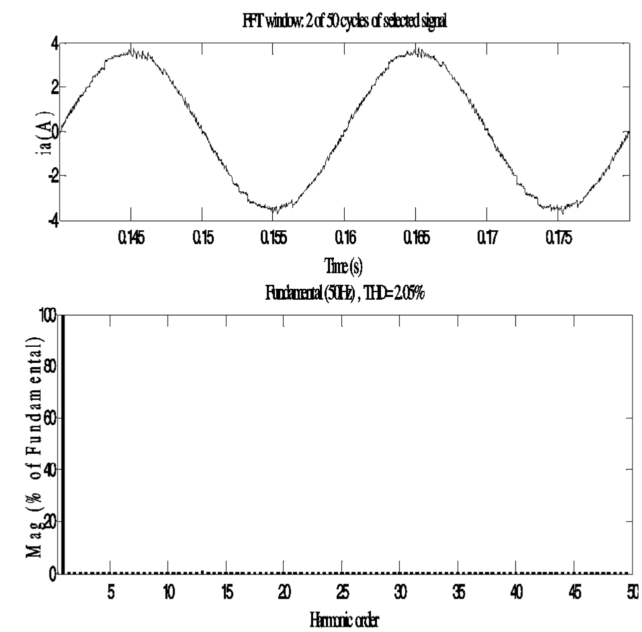


(D)



(E)

Figure 7: (A, B, C, D, E):Simulated basic signal waveforms and line current harmonic spectrum under purely sinusoidal line voltage for DPC. From the top: instantaneous active and reactive power, DC link voltage, line current, and harmonic spectrum of the line current (THD = 4.29%)



(E)

Figure 8: (A, B, C, D, E):Simulated basic signal waveforms and line current harmonic spectrum under purely sinusoidal line voltage for DPC-SVM. From the top: instantaneous active and reactive power, DC link voltage, line current, and harmonic spectrum of the line current (THD = 2.05%)

This work was supported in part by LATAGE research laboratory, University Mouloud Mammeri, of Tizi-Ouzou, 15000 Algeria.

REFERENCES

[1] B.Zhang, K.Zhou and Y. Wang, "Performance improvement of repetitive controlled PWMinverters: A phase-lead compensation solution,"*International Journal of Circuit Theory and Applications,* **38**, 453–469, 2010.

[2] G. Kishor, T.Sudha Rani and P. Vijaya,"Analysis and simulation of AC to DC boost converter by using IC Uc3854a", *International Journal of Circuit Theory and Applications*, **8**, 277-287, 2015.

[3] A. Fekik, H. Denoun, N. Benamrouche, N. Benyahia and M. Zaouia,"A fuzzy logic based controller for three phase PWM rectifier with voltage oriented control strategy", *International Journal of Circuits, Systems And Signal Processing*, **9**, 412-419, 2015.

[4] Z.Boudries and D.R. Ziani,"Study on decoupling direct power control of PWM rectifier using space vector modulation,"*Arabian Journal for Science and Engineering*, **38** (4), 875–882,2013.

[5] A. Fekik, H.Denoun, N.Benamrouche, N.Benyahia, M.Zaouia and S.Haddad,"Comparative study of PI and fuzzy DC-voltage control for voltage oriented control-PWM rectifier,"WSEAS 14th International Conference on Circuits, Systems, Electronics, Control & Signal Processing 103-110, Konya,Turkey, CSECS, 2015.

[6] L. Zhang, G. Zheng and G.Li, "Direct power control strategy of three-phase PWM rectifier,"*Journal of Information & Computational Science,* 10 (9), 2807-2813, 2013.

[7] A.Chaoui, J.P.Gaubert and A.Bouafia, "Direct power control switching table concept and analysis for three-phase shunt active power filter,"*J. Electrical Systems*,9 (1), 52-65, 2013.

[8] S. Lechat, "Voltage orientedcontrol ofthree phase boost PWM converters design, simulation and implementation of a 3 phase boost battery Charger", Master of Science Thesis in Electric Power Engineering,ChalmersUniversity,2010.

[9] A.Bouafia and A.Krim,"A fuzzy-logic-based controller for three-phase PWM rectifier with unity power factor operation", *J.Electrical Systems*,4 (1), 36-50, 2008.

[10] A.Berzoy and M.Strefezza 'Optimized fuzzy variable structure for a three-phase rectifier with power factor correction," WSEAS Transactions on Power Systems, 4, 275-284, 2009.

[11] D. Carmona and J.Mandiola, "Design and implementation of a three-phase boost battery charger with PFC using compact RIO control system," Master of Science Thesis, Electric Power Engineering,ChalmersUniversity, 2012.

[12] P. Karuppanan and M. Kamalakanta, "PI, PID and fuzzy logic controlled cascaded voltage source inverter based active filter for power line conditioners,"*WSEAS Transactions on Power Systems*, 6, 100-109, 2011.

[13] A. Semmah, A.Massoum, H.Hamdaoui and P.Wira,"Comparative study of PI and fuzzy DC voltage control for a DPC-PWM rectifier', *Electrical Review*, 87, 355-359, 2011.

[14] H. Denoun, N.Benamrouche, S.Haddad, S.Meziani and S.Ait Mamar,"A DSP (TMS320LF2407) based implimentation of PWM for single – phase AC-DC bipolar converter with a unity power factor", *WSEAS International Journal of Circuits, Systems and Signal Processing*, 5, 354-361, 2011.

[15] J. Restrepo, J. Viola, J.M. Aller and A. Bueno,"A simple switch selection state for SVM direct power control," 2006 IEEE International Symposium on Industrial Electronics, July 9-13, 1112–1116, 2006.

[16 M.Malinowski, M.Jasinski and M.Kazmierkowski,"Simple direct power control of three phase PWM rectifier using space vector modulation (DPC-SVM)", *IEEE Transactions on Industrial Electronics*, 51, 447-454, Apr. 2004.

[17] A.Mehdi, S.Rezgui, H.Medouce and H.Benalla 'A Comparative Study between DPC and DPC-SVM Controllers Using dSPACE (DS1104)' International Journal of Electrical and Computer Engineering (IJECE) 4, 322 – 328, 2014.

[18] A.T. Azar and S. Vaidyanathan, *Chaos Modeling and Control Systems Design,* Springer, Berlin, Germany, 2015.

[19] A.T. Azar and S. Vaidyanathan, *Advances in Chaos Theory and Intelligent Control*, Springer, Berlin, Germany, 2016.

[20] S. Vaidyanathan and C. Volos, Advances and Applications in Nonlinear Control Systems, Springer, Berlin, Germany, 2016.

[21] S. Vaidyanathan and C. Volos, *Advances and Applications in Chaotic Systems*, Springer, Berlin, 2016.

[22] S. Vaidyanathan and C. Volos, *Advances in Memristors, Memristive Devices and Systems*, Springer, Berlin, 2017.

[23] S. Vaidyanathan and C.H. Lien, *Applications of Sliding Mode Control in Science and Engineering*, Springer, Berlin, 2017.

[24] S. Vaidyanathan, "A novel 3-D conservative chaotic system with sinusoidal nonlinearity and its adaptive control", *International Journal of Control Theory and Applications*, 9 (1), 115-132, 2016.

[25] S. Vaidyanathan and S. Pakiriswamy, "A five-term 3-D novel conservative chaotic system and its generalized projective synchronization via adaptive control method", *International Journal of Control Theory and Applications,* 9 (1), 61-78, 2016.

[26] V.T. Pham, S. Jafari, C. Volos, A. Giakoumis, S. Vaidyanathan and T. Kapitaniak, "A chaotic system with equilibria located on the rounded square loop and its circuit implementation," *IEEE Transactions on Circuits and Systems-II: Express Briefs*, 63 (9), 2016.

[27] S. Vaidyanathan and S. Sampath, "Anti-synchronisation of identical chaotic systems via novel sliding control and its application to a novel chaotic system," *International Journal of Modelling, Identification and Control,* 27 (1), 3-13, 2017.

[28] S. Vaidyanathan, K. Madhavan and B.A. Idowu, "Backstepping control design for the adaptive stabilization and synchronization of the Pandey jerk chaotic system with unknown parameters," *International Journal of Control Theory and Applications*, 9 (1), 299-319, 2016.

[29] R.K. Goyal, S. Kaushal and S. Vaidyanathan, "Fuzzy AHP for control of data transmission by network selection in heterogeneous wireless networks," *International Journal of Control Theory and Applications*, 9 (1), 133-140, 2016.

[30] C.K. Volos, D. Prousalis, I.M. Kyprianidis, I. Stouboulos, S. Vaidyanathan and V.T. Pham, "Synchronization and anti-synchronization of coupled Hindmarsh-Rose neuron models," *International Journal of Control Theory and Applications*, 9 (1), 101-114, 2016.

[31] S.M.B. Mansour and V. Sundarapandian, "Design and control with improved predictive algorithm for obstacles detection for two wheeled mobile robot navigation," *International Journal of Control Theory and Applications,* 9 (38), 37-54, 2016.

[32] A. Ouannas, A.T. Azar and S. Vaidyanathan, "A robust method for new fractional hybrid chaos synchronization," *Mathematical Methods in the Applied Sciences*, 40 (5), 1804-1812, 2017.

[33] S. Vaidyanathan and S. Sampath, "Anti-synchronisation of identical chaotic systems via novel sliding control and its application to a novel chaotic system," *International Journal of Modelling, Identification and Control,* 27 (1), 3-13, 2017.

[34] A. Ouannas, A.T. Azar and S. Vaidyanathan, "New hybrid synchronisation schemes based on coexistence of various types of synchronisation between master-slave hyperchaotic systems," *International Journal of Computer Applications in Technology*, 55 (2), 112-120, 2017.

[35] S. Vaidyanathan, "A conservative hyperchaotic hyperjerk system based on memristive device," *Studies in Computational Intelligence*, 701, 393-423, 2017.

[36] S. Vaidyanathan, V.T. Pham and C. Volos, "Adaptive control, synchronization and circuit simulation of a memristor-based hyperchaotic system with hidden attractors," *Studies in Computational Intelligence,* 701, 101-130, 2017.

[37] B. Raj and S. Vaidyanathan, "Analysis of dynamic linear memristor device models," *Studies in Computational Intelligence,* 701, 449-476, 2017.

[38] S. Vaidyanathan, "A highly chaotic system with four quadratic nonlinearities, its analysis, control and synchronization via integral sliding mode control," *International Journal of Control Theory and Applications*, 9 (1), 279-297, 2016.

[39] S. Vaidyanathan, "Analysis, adaptive control and synchronization of a novel 4-D hyperchaotic hyperjerk system via backstepping control method", *Archives of Control Sciences*, 26 (3), 311-338, 2016.

[40] S. Vaidyanathan, "A novel 3-D jerk chaotic system with two quadratic nonlinearities and its adaptive backstepping control", *International Journal of Control Theory and Applications*, 9 (1), 199-219, 2016.