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Wind Energy Conversion Systems Based On a DFIG Controlled By Indirect Vector Using PWM and SVM

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ABSTRACT

This work presents consideration and use of the asynchronous generator in the production of wind energy. To do this, a model of the wind turbine has been established, the mathematical model of the doubly fed induction generator (DFIG) variable speed is presented and the control quantities used when integrated with a wind system. A modeling in a diphasic reference mark related to the stator field and a strategy vector control active and reactive power are offered with a PWM and SVM technique for inverter control is considered in our work.

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1. INTRODUCTION

This paper is to study the indirect control power of doubly fed induction generator (DFIG) operation generator for this, our work is organized as follows:

- The first part is dedicated to the description and modeling of wind turbines based on physical equations responsive operation.
- The second part, we present a mathematical model of the (DFIG) will simulate the model in generator mode.
- The third is devoted to the study of the technique of indirect control power to realize the conversion DC-AC inverter using two voltage levels with technical using the PWM controller (Pulse Width Modulation) and SVM (space vector modulation)

2. MODEL OF THE TURBINE

A wind turbine, commonly called wind is a device which transforms a part of the kinetic energy of wind into mechanical energy available on a shaft and then into electrical energy via a generator (DFIG) [1].

Mechanical power available on the shaft of a wind turbine is expressed as:

$$P_m = \frac{P_m}{P_{mt}} P_{mt} = C_p . P_{mt} = \frac{1}{2} C_p(\lambda) \rho \pi R^2 V_1^3 \quad (1)$$

With

$$\lambda = \frac{\Omega_1 R}{V_1} \tag{2}$$

Ω_1: Rotation speed before multiplier.
R: rotor radius 35.25 m.
ρ: air density,1.225 kg.m^{-3}.

$$C_p = f(\lambda, \beta) = C_1\left(\frac{C_1}{\lambda_i} - C_3\beta - C_4\right)\exp\left(\frac{C_5}{\lambda_i}\right) + C_6\lambda \tag{3}$$

With:

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$

C_1=0.5176; C_2=116; C_3=0.4; C_4=5; C_5=21; C_6=0.0068 [1], [2].
Characteristics of C_p in terms of λ for different values of the pitch angle are shown in Figure 1. The maximum value of C_p (C_{pmax}=0.4353) is reached of β=2° and λ=10.01. This particular value of λ is defined as the nominal value [1], [3].

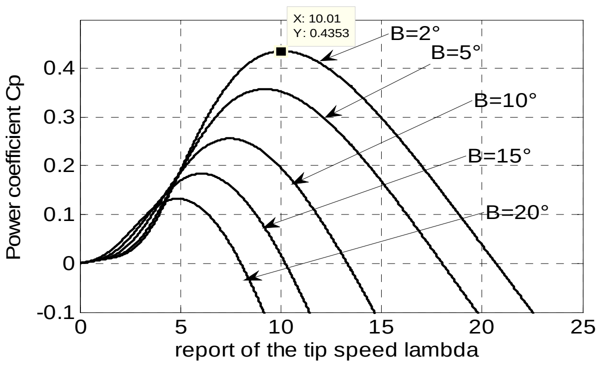

Figure 1. The power factor for different angles of stalls

3. MODEL OF THE DOUBLY FED INDUCTION GENERATOR

A commonly used model for the doubly fed induction generator (DFIG) is the Park model. The electrical equations of the DFIG in the Park reference frame are given as follows [4], [5]:

$$\begin{cases} v_{sd} = R_s i_{sd} + \frac{d\varphi_{sd}}{dt} - \omega_s \varphi_{sq} \\ v_{sq} = R_s i_{sq} + \frac{d\varphi_{sq}}{dt} + \omega_s \varphi_{sd} \end{cases} \tag{4}$$

$$\begin{cases} v_{rd} = R_r i_{rd} + \frac{d\varphi_{rd}}{dt} - \omega_r \varphi_{rq} \\ v_{rq} = R_s i_{rq} + \frac{d\varphi_{rq}}{dt} + \omega_r \varphi_{rd} \end{cases} \tag{5}$$

The stator and rotor flux are given as:

$$\begin{cases} \varphi_{sd} = L_s i_{sd} + L_m i_{rd} \\ \varphi_{sq} = L_s i_{sq} + L_m i_{rq} \end{cases} \tag{6}$$

$$\begin{cases} \varphi_{rd} = L_r i_{rd} + L_m i_{sd} \\ \varphi_{rq} = L_r i_{rq} + L_m i_{sq} \end{cases} \tag{7}$$

In these equations, R_s,R_r,L_s and L_r are respectively the resistances and the inductances of the stator and the rotor windings, L_m is the mutual inductance.

$V_{sd}, V_{sq}, V_{rd}, V_{rq}, i_{sd}, i_{sq}, i_{rd}, i_{rq}, \varphi_{sd}, \varphi_{sq}, \varphi_{rd}, \varphi_{rq}$ are the d and q components of the stator and rotor voltages, currents and flux, whereas ω_r is the rotor speed in electrical degree.

The electromagnetic torque is expressed as:

$$C_{em} = p(\varphi_{sd}.i_{sq} - \varphi_{sq}.i_{sd}) \quad (8)$$

Stator and rotor variables are both referred to the stator reference Park frame. With the following orientation, the d component of the stator flux is equal to the total flux whereas the q component of the stator flux is null Figure 2. [6].

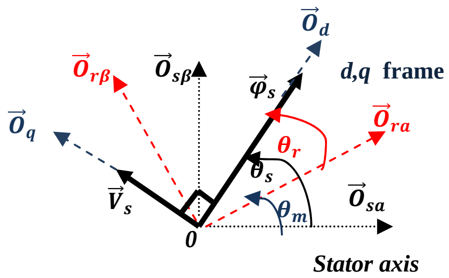

Figure 2. Determination of the electrical angles in Park reference frame

$$\varphi_{sd} = \varphi_s, \varphi_{sq} = 0 \quad (9)$$

By replacing (9) in (6) and (8), the electromagnetic torque can be given as follows:

$$C_{em} = -p\frac{L_m}{L_s} i_{rq}\varphi_{sd} \quad (10)$$

Assuming that the resistance of the stator winding R_s is neglected, and referring to the chosen reference frame, the voltage equations and the flux equations of the stator winding can be simplified in steady state as follows:

$$\begin{cases} v_{sd} = 0 \\ v_{sq} = v_s = \omega_s\varphi_s \end{cases} \quad (11)$$

$$\begin{cases} \varphi_{sd} = L_s i_{sd} + L_m i_{rd} \\ 0 = L_s i_{sq} + L_m i_{rq} \end{cases} \quad (12)$$

From (12), the equations linking the stator currents to the rotor currents are deduced below:

$$\begin{cases} i_{sd} = \frac{\varphi_s}{L_s} - \frac{L_m}{L_s} i_{rd} \\ i_{sq} = -\frac{L_m}{L_s} i_{rq} \end{cases} \quad (13)$$

The active and reactive powers at the stator side are defined as:

$$\begin{cases} P_s = v_{sd} i_{sd} + v_{sq} i_{sq} \\ Q_s = v_{sq} i_{sd} - v_{sd} i_{sq} \end{cases} \quad (14)$$

Taking into consideration the chosen reference frame, the above power equations can be written as follows:

$$\begin{cases} P_s = v_s i_{sq} \\ Q_s = v_s i_{sd} \end{cases} \quad (15)$$

Replacing the stator currents by their expressions given in (15), the equations below are obtained:

$$\begin{cases} P_s = -v_s \frac{L_m}{L_s} i_{rq} \\ Q_s = \frac{v_s \varphi_s}{L_s} - \frac{v_s L_m}{L_s} i_{rd} \end{cases} \quad (16)$$

The block diagram of the DFIG model in Park reference frame is depicted in Figure 3, assuming a constant stator voltage (v_s) [7].

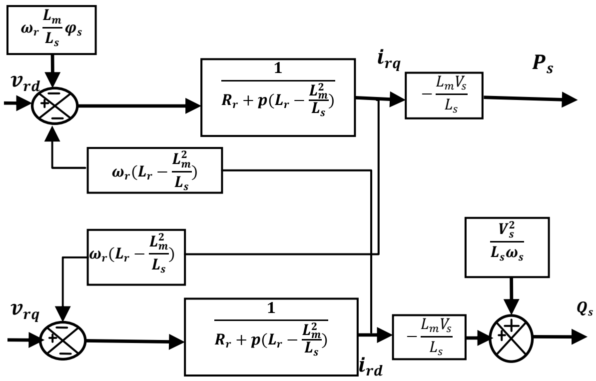

Figure 3. Block diagram of the DFIG model

4. REGULATION WITH BUCKLE OF POWER

to improve the control system the DFIG, we will introduce an additional loop control of active and reactive power in the block diagram of the control loop without power so that each axis controller contains two PI control, one to control the power and the other rotor current (figure 4) [8].

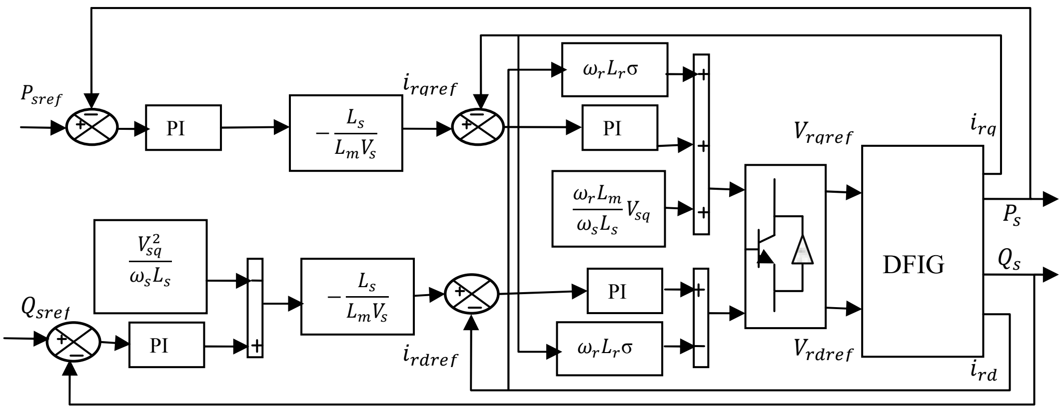

Figure 4. Schema block indirect regulation with loop power

5. MODELLING OF VOLTAGE INVERTERS TWO LEVELS

The three-phase voltage inverter at two levels, is composed of three independent arms, comprising two switches each. each switch comprises an IGBT or GTO thyristors and a diode connected in antiparallel. can be replaced group each transistor-diode switches by kj with (j = 1, 2, 3, 4, 5, 6), we obtain the simplified diagram for each inverter as shown in Figure 5. [9].

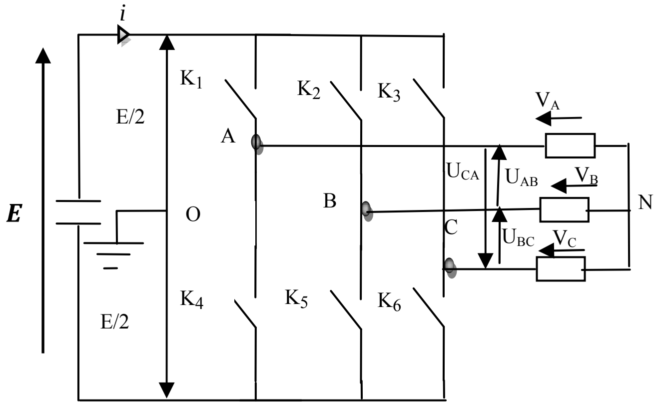

Figure 5. Simplified diagram of the three-phase inverter

The equations of simple voltage applied to the three phases are:

$$\begin{cases} V_A = V_{AO} + V_{ON} \\ V_B = V_{BO} + V_{ON} \\ V_C = V_{CO} + V_{ON} \end{cases} \quad (17)$$

Knowing that the system is symmetrical stator phase voltages:

so: $$V_A + V_B + V_C = 0 \quad (18)$$

The voltage converter can be modeled by a matrix [T] providing passage DC to AC.

$$[V_{AC}] = [T].[V_{dc}] \quad (19)$$

such that:

$$\begin{cases} [V_{AC}] = [V_A \;\; V_B \;\; V_C]^T \\ [V_{dc}] = [V_{AO} \;\; V_{BO} \;\; V_{CO}]^T \\ [V_{dc}] = E[S_1 \;\; S_2 \;\; S_3]^T \end{cases} \quad (20)$$

So, for each arm there are two independent states, these states can be considered as Boolean variables. Supposed ideal switching: S_i=(1ou 0) {i=1,2,3}.
The transfer matrix is:

$$[T] = \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \quad (21)$$

In our work, the switches of the inverter are made by using the PWM controller (Pulse Width Modulation) and SVM (space vector modulation).

6. PULSE WIDTH MODULATION (PWM)

The most widely used method of pulse width modulation is based carrier. this method is also known as the sinusoidal (SPWM), triangulation, subharmonic, or method suboscillation [10], [11]. Sinusoidal modulation is based on a triangular carrier signal as shown in Figure 6. In this method, three reference signals U_{AC}, U_{BC}, U_{CC} comparing with triangular carrier signal U_t which is common to all three phases. In this way, the logic signals Sa, Sb, Sc are generated, which define the switching times of the power transistors.

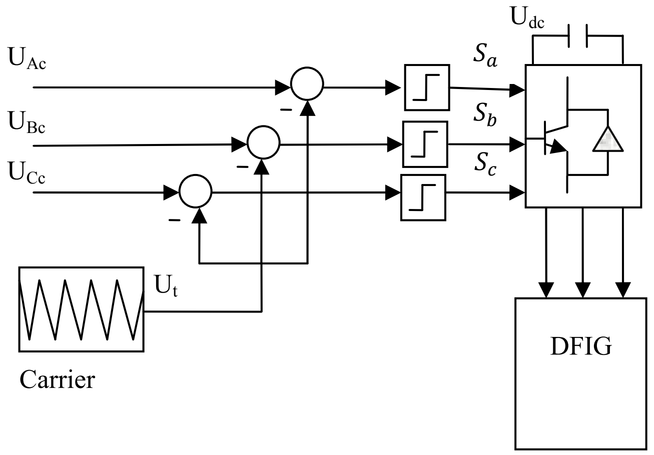

Figure 6. Block scheme of carrier based sinusoidal PWM

7. THE SIMULATION RESULTS OF THE INDIRECT CONTROL WITH PWM

The simulation is performed by imposing the active and reactive power reference (P_{ref}, Q_{ref}), while the DFIG is driven at variable speed Pref varies between –300000 and -1000000watts and Qref varies between -100000 and -400000 100000 VAR and de Isabc varies between 1000 A and 2500 A

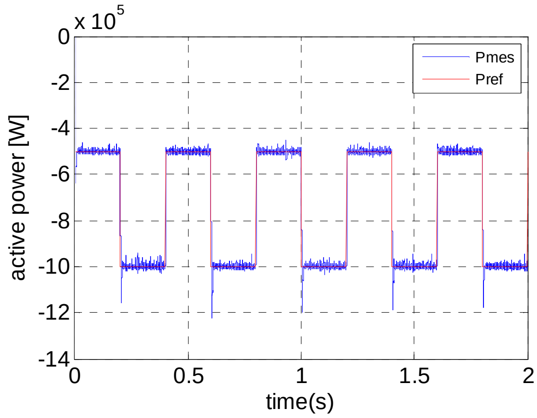

Figure 7. Electrical active power produced with PWM

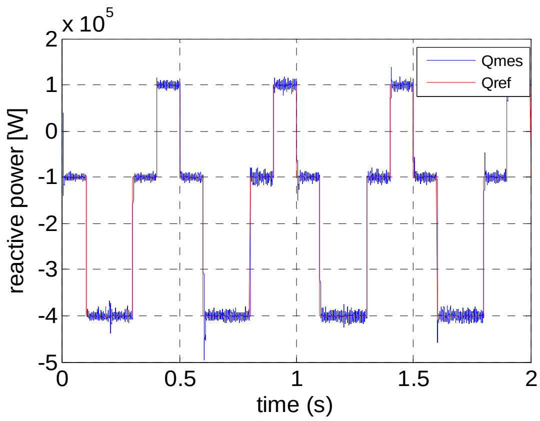

Figure 8. Electrical reactive power produced with PWM

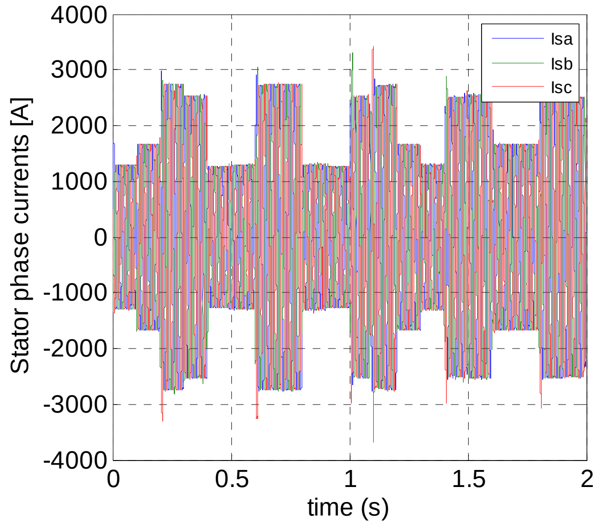

Figure 9. Stator phase currents with PWM

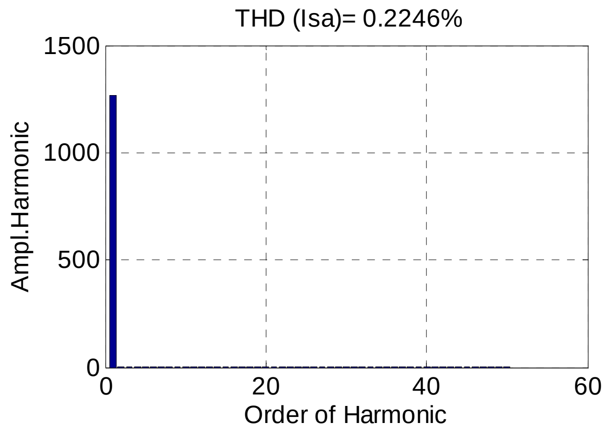

Figure 10. THD of current Isa with PWM

8. SPACE VECTOR MODULATION (SVM)

Modulation techniques different spatial vectors of the carrier on the basis of this manner, there is no separate modulators used for each of the three phases. Instead of them, the reference voltages are supplied by the voltage vector of the space and the output voltages of the inverter are considered space vectors [12]:

$$V_i = \begin{cases} \frac{2}{3} U_{dc} e^{\frac{j(i-1)\pi}{3}} & i = 1..6 \\ 0 & i = 0,7 \end{cases} \quad (22)$$

There is a possible eight vectors output voltage, six active vectors $V_1 - V_6$, and two zero vectors V_0,V_7 figure 10. The reference voltage vector is performed by sequentially switching the active and zero vectors.

In Figure 10 shows voltage vector reference voltage V_c and eight vectors, which corresponds to the possible states of the inverter. The six active vectors divide a plane for the six sectors 1- 6. In the sector of each of the voltage reference vector V_c is obtained by switching on, for a suitable time, two adjacent vectors. Shown in Figure 10 reference vector V_c can be implemented by switching vectors V_1, V_2 and zero vectors V_0, V_7 [13], [14].

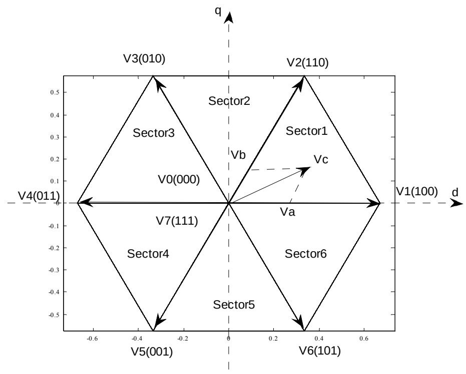

Figure 10. Principle of the space vector modulation

The reference voltage vector V_c is sampled with the fixed clock frequency f_s=1/T_s,and next a sampled value $V_c(T_s)$ is used for calculation of times t_1, t_2, t_0 and t_7. The signal flow in space vector modulator is shown in Figure 11.

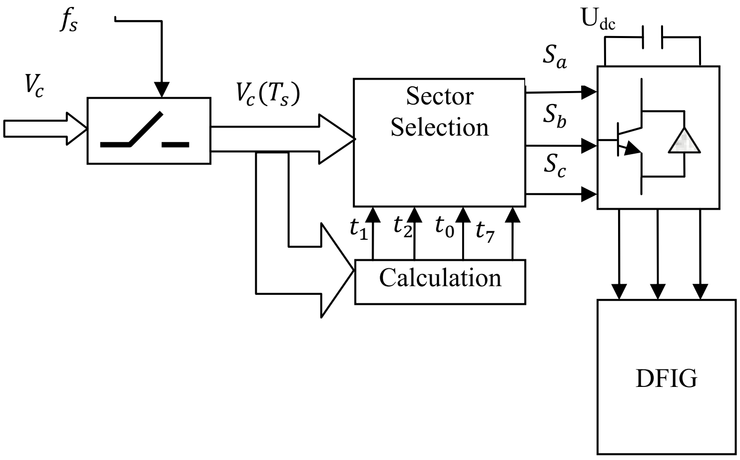

Figure 11. Block scheme of the space vector modulator

9. THE SIMULATION RESULTS OF THE INDIRECT CONTROL WITH SVM

The rotor of the DFIG is powered by a three-phase balanced system, and by a voltage to SVM inverters. To simulate the behavior of the DFIG, we opted for the MATLAB / Simulink software, the simulation results are given by the following figures

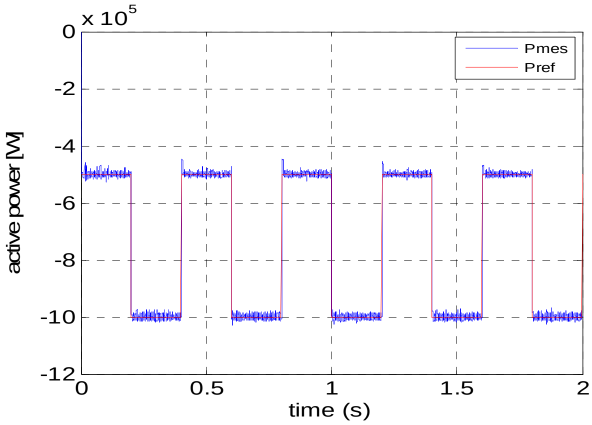

Figure 12. Electrical active power produced with SVM

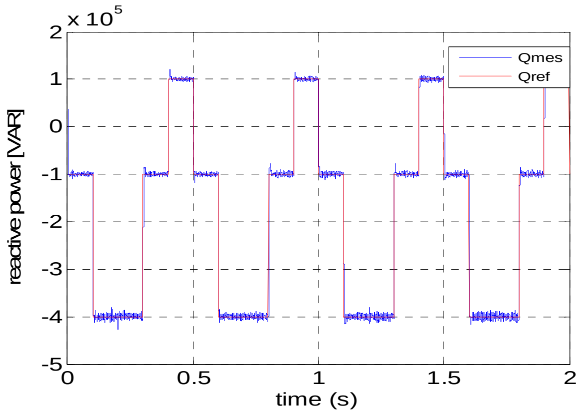

Figure 13. Electrical reactive power produced with SVM

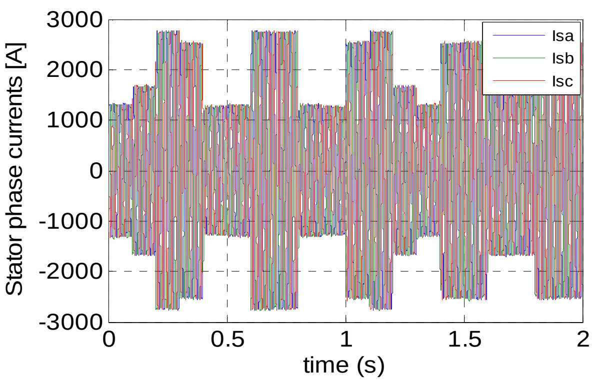

Figure 14. Stator phase currents with SVM

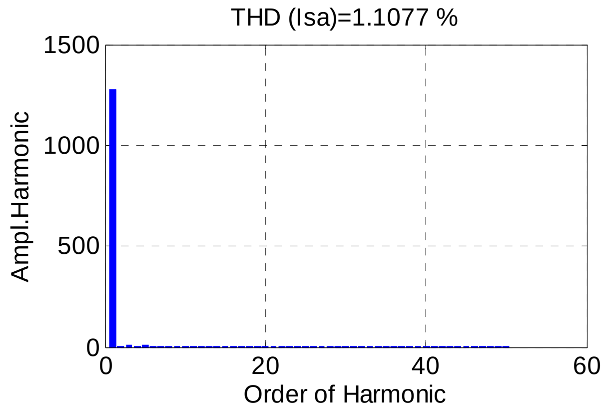

Figure 11. THD of current Isa with SVM

10. CONCLUSION

In our work, we have established the model the machine with its electric equations in axis linked to the d-q synchronous system. We have also developed the method of vector control power of the machine to know the order and dedicated to the study of the art of the power of indirect control to achieve the DC-AC conversion using two voltage levels with technical PWM controller Pulse Width Modulation and SVM Modulation Vector Space. Indeed we have seen that the control indirectly allows us, together with the closure powers, to have an efficient system and robust. It is certainly more complex to work, but will have an operation optimal system of electric generation minimizing potential problems related to changes in machine parameters and the wind system.

APPENDIX A

- Nominal Power =1.5(Mw)
- Stator Per Phase Resistance =0.012 (Ω)
- Rotor Per Phase Resistance=0.021 (Ω)
- Stator Leakage Inductance= $2.0372.10^{-004}$ (H)
- Rotor Leakage Inductance= $1.7507.10^{-004}$ (H)
- Magnetizing Inductance= 0.0135 (H)
- Number Of Poles Pairs=2
- Moment Of Inertia= 1000 ($Kg.M^2$)
- Friction Coefficient =0.0024

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Djallel Kerdoun received the B. Sc. Degree and M. Sc. degree in electrical drive and automation of industrial and technological complexes from the Technical University, Institute of Energy of Moscow, Russia, in 1995 and 1997, respectively. And he received the Ph.D. degree in electrical engineering from the Technical University, Institute of Energy of Moscow, Russia, in 2001 for his work on Asynchronous Electric Drive of Spherical Drum-Type Mills with use of Voltage Regulator.
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