Experimental results of vector control for an asynchronous machine

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Article Info	ABSTRACT
	The aim of this article is contribute to the advanced vector control strategy of asynchronous machines. Analyzes of experimental of indirect field-oriented control are presented. In this context, we propose vector control algorithms to provide solutions to the disadvantages of field-oriented control field-oriented control (FOC). The results obtained from various methods of determining the parameters for asynchronous machine are compared. We calculate the various parameters and then we present the technical characteristics of each element of the asynchronous machine; finally, we implement the vector control used as basis of comparison between the simulation under Matlab/Simulink software and experiments. The simulation and experimental tests show that the proposed controller is suitable for medium and high-performance applications. *This is an open access article under the CC BY-SA license.*

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1. INTRODUCTION

The field oriented control for an asynchronous motor is mainly categorized into two types: indirect and direct. In indirect field oriented control, the slip estimate with measured or estimated rotor velocity is required to calculate the synchronous velocity [1]. For direct control, the synchronous velocity is calculated based on the available flux angle from the flux estimator or flux sensors. The indirect field control technology (IFOC) is very useful for the implementation of high performance induction motor drive systems.

Simulations for vector control are performed to validate control theories [2]. The feasibility of monitoring strategies using simulation is necessary before laboratory measurements. Thus, the simulation models of the field-oriented control (FOC) Field oriented control are based on Simulink and blocks. A 1.5 kW induction motor is used, the parameters of this motor are determined from various tests. The experimental implantation of an asynchronous machine training system is an important step for the validation of the algorithms tested and validated in simulation [3]. In this article, we present the experimental configuration used to perform the vector control tests. Finally, the comparison of experimental results and simulations is illustrated.

2. IDENTIFYING PARAMETERS OF THE ASYNCHRONOUS MACHINE

We started the identification of the parameters for an asynchronous machine 1.5 kW mechanically coupled to a direct current (DC) motor and the measuring devices (voltmeter, ammeter and oscilloscope). A diagram of the experimental test bench in the laboratory is shown in Figure 1. In aims to determine the elements of the equivalent diagram of this machine, we carry out two series of tests: the no-load test and the blocked rotor test:

− Resistance of a stator phase Rs.
− Equivalent resistance of a rotor phase brought back to the stator R'r.
− Stator leakage inductance: Ls and rotor Lr.
− Magnetizing inductance Lm.
− The stator losses due to the no-load current Pf+v.

Figure 1. Experimental bench

2.1. Continuous current test

This test is used to evaluate the value of the stator resistance by the voltametric method. In this test, we give a very low DC voltage at the terminals of phases a and b. In fact, vary the value of this voltage while measuring the current flowing through them as shown in Table 1. The tests for measuring the resistance of the stator per phase Rs must be carried out in the vicinity of the nominal current by the voltametric method, only the last two values of the table will be considered. Therefore, their average value is calculated, which gives Rs = 10.82 Ohm.

Table 1. DC test

Voltage (V)	Current (A)	Resistance (ohm)
4	0.525	7.62
10	0.95	10.53
15	1.35	11.11

2.2. Blocked rotor test

The advantage of this test is to keep the rotor speed (mechanical) equal to 0. That is to say that the sliding g of the machine is always 1, so we neglect the parallel branch of the machine which contains the magnetizing inductance X and the resistance modelling iron losses Rfer. In aims to determine the rotor resistance and the sum of the two cyclic inductances, the asynchronous machine is star-coupled and supplied with balanced three-phase voltage. By gradually increasing the voltage value [4] while keeping the rotor locked. The voltage, stator current and active powers are shown in Table 2. The operating results of the blocked rotor test are Rr =3.12 ohm, Xs+Xr=13.5 ohm et Q=168 Var.

$$R_r = \frac{P}{3.I^2} - R_s \qquad (1)$$

$$X_s + X_r = \frac{Q}{3.I^2} \qquad (2)$$

Table 2. Blocked rotor test of the asynchronous machine

Power (W)	Stator current (A)	Voltage (V)	Rotor current (A)	Reactive Power (Var)	Cos(φ)
100	1.95	45.6	6.42	168	0.56

2.3. Blocked rotor test

When the motor runs at no load (no load coupled to the motor), its rotation speed No is close to the synchronous speed Ns. We consider that g = 0 and No = Ns. We have Rr /g tends to infinity, so we can consider that the rotor branch is open circuit [2, 3]. The aim of this test is to determine the constant losses in the steady state, that is to say the mechanical losses and the iron losses. The value of R and X can also be found [5].

No mechanical load is applied and a voltmeter is placed on the mechanical arm to keep the synchronous velocity [6, 7]. The value of the compound voltage between two stator phases is varied from 40 Volts to 190 Volts and the rotor voltage, stator current and active power are also noted. Below is the data table as shown in Table 3.

Table 3. No-load test of the asynchronous machine

V_{s0}(V)	V_r(V)	I_{s0}(A)	P_{s0}(W)	Q_{s0}(Var)
198	79.76	1.67	34.9	331.3
160	64.73	1.24	21	198
120	47.97	0.90	11.8	107
80	32.36	0.60	5.6	48.6
40	15.95	0.30	1.6	12.2

In aims to obtain the static losses, the curve Pfer + Pmeca (=Ptotal-Plosses) must be plotted as a function of Vs2 as shown in Figure 2. It is known that it is possible to use a linear equation to approach the curve. It is known that when there is no voltage, the iron losses are systematically zero [8]. Thus, at the point Vs = 0, there are mechanical losses.

Once the values of the mechanical losses and the value of Pfer + Pméca are obtained at nominal voltage (380 Volts), the value of Pfer in nominal voltage is found. At rated voltage, it is also necessary to find the reactive power. To calculate the magnetic inductance X and the resistance modeling the iron losses Rfer by the following expressions and gives the following value:

$$X = \frac{Q_0}{3.I_{S0}^2} = 149.87 ohm \quad Rref = \frac{Pfero}{3.I_S^2} = 2472.64 ohm \tag{3}$$
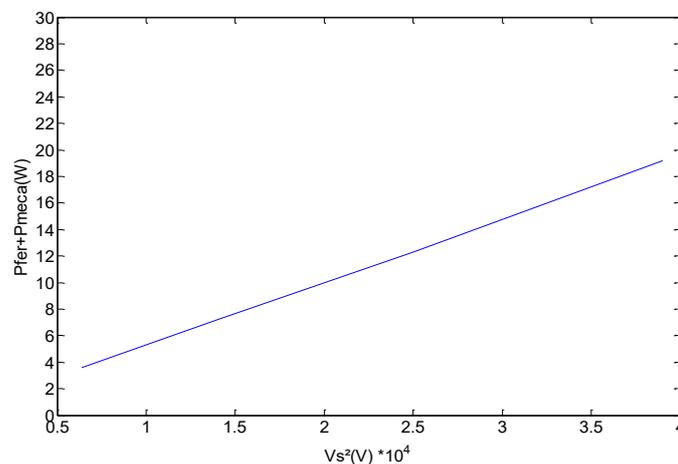
Figure 2. No-load result of Pfer+Pmeca

3. DESCRIPTION OF THE EXPERIMENTAL SETUP

The Figure 3 shows the experimental based on a vector control speed variator implemented for the development of an experimental bench dedicated to open loop and closed-loop vector control of the asynchronous machine [9]. This bench allows developing and test a multitude of control algorithms, in particular the various techniques for controlling the speed of the asynchronous machine. It should be noted that with simple modifications, it is also possible to use this bench for the control of other electrical machines.
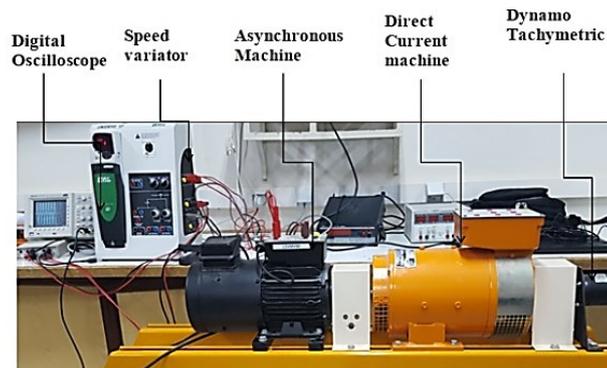
Figure 3. Experimental Bench for the no-load and loaded vectorcontrol with variable speed drive

3.1. Characteristics of the Asynchronous motor

The asynchronous motor has a power of 1.5 KW, with electricals parameters: nominal current In = 3.4, stator resistance Rs= 10.82 Ω, stator inductance Ls = 22 mH, rotor resistance Rr= 3.12 Ω, rotor inductance Lr =22 mH, and with the following characteristics presented in Table 4.

Table 4. Characteristic of the asynchronous machine

Power	1.5 KW
Mark	LEROY SOMER
Protection sign	IP55
Maximal Voltage	380V
Maximal speed	1425 tr/mn
Nominal current	3.40 A
pole pairs number	4
Stator resistance	10.82 ohm
Rotor resistance	3.12 ohm
Longitudinal Inductance	22 mH
Quadratic Inductance	22 mH
Nominal moment	9.4 kg.m2

3.2. Resolver

It is powered by an AC voltage and consists of a stator and a wound rotor, it produces two voltages whose combination makes it possible to determine the position of the rotor. The robustness (no electronics) and its high reliability in severe environments (high temperature, and vibration) are of interest.

3.3. Dynamo tachometer and optical encoder

The tacho generator is an electric generator which provides a DC voltage proportional to the speed. We offer as standard the type KTD3 hollow shaft Ø14 mm 20V/1000 min-1. Triques ". The number of steps per revolution is determined by an optical disc. A shaft rotation generally has 8192 steps, which corresponds to 13 bits. At the end of a complete shaft revolution of the encoder, the same values are repeated.

3.4. Speed drive controllers

The Figure 4 present the Variable speed drives intended to be incorporated into electrical installations or machines. In the case of incorporation into a machine, their entry into service is prohibited until the machine has been checked for conformity with the provisions of Directive 2006/42/EC (machine directive). Observes-EN 60204, which stipulates in particular that electrical actuators (of which variable speed drives are part) cannot be regarded as cut-off devices and even less for cutting.

3.5. Mechanical load (DC machine + resistance)

The mechanical load is constituted by a DC generator with separate excitation flowing over a resistor [10, 11]. This makes it possible to generate a torque that is resistant in both directions of rotation of the asynchronous machine. It also allows the image of the resistive torque applied and the rotation speed of the group to be taken in Figure 5. The DC machine has the following characteristics:
− Generator : LEROY-SOMER
− Power : 1.25 KW
− Nominal speed : 1500 tr/min

Figure 4. Speed drive controllers unidrive SP LEROY SOMER

Figure 5. Direct current machine

4. RESULTS AND DISCUSSIONS

The vector control tests are carried out with an alternate drive for supplying asynchronous motors. We present in detail the different parts of the experimental setup, specifying the role of each element, as well as the problems encountered, and we will review some experimental results of flux vector vector control. By parameterizing, the vector control can therefore be configured in the following operating modes:

− Vector control of open loop flux

Thanks to its computing power, the vector control separately controls the magnetizing current and the active current with an asynchronous motor. The speed and position of the rotor are calculated to control the torque and speed of the motor.

− Closed loop vector control

The use of this mode on an asynchronous motor allows better control of the torque and the speed of the motor over a greater range of speed (including zero speed) with increased dynamic performance. The objective of a speed control loop is to maintain the actual speeds measured at the electrical asynchronous machine as close as possible to their references on the vector control.

The aims of simulate the behavior of the electrical and mechanical quantities of the asynchronous machine, the no-load machine is started and a load torque is inserted at time t = 0.18 s. The Figure 6 shows the evolution and regulation of the rotor speed control is when a resistive torque step is applied the speed returns to its initial value after the application of a load torque profile 10 Nm. At start-up, the convergence of the velocity towards the reference values (157rad s-1500 rpm) and at the application of the load the speed decreases and returns to its initial value. Low torque and velocity oscillations are observed due to the use of vector control.

A ramp signal is used to simulate the starting behavior of the asynchronous machine, after the rotor speed of the motor reaches the target value of 400 rpm, it has been maintained as a constant [3]. At the same time, when the engine was started from the stop with a ramp load torque of 0 to 5 Nm at the steady state speed of 400 rpm. Then, during the period of constant speed. Experimental tests of the vector control on the test bench gave satisfactory results.
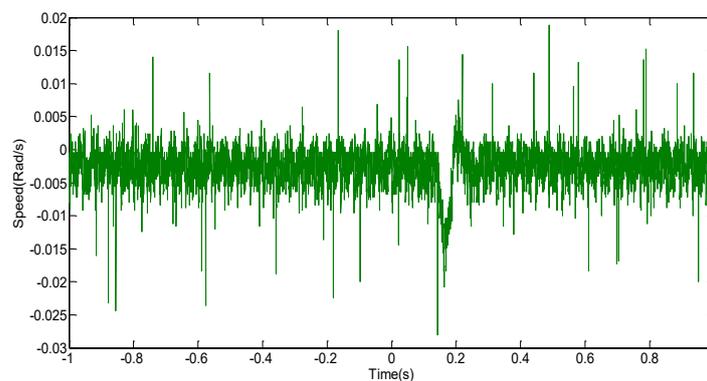
Figure 6. Evolution of speed

4.1. Open loop and closed-loop vector simulation results

The Figure 7 shows an approximate view of the mechanical part of the experimental test bench. This test shows the performance of vector control by open loop and closed loop flux direction. The Figure 8 shows the evolution of the compound voltage and experimental current, in a steady state, we apply a torque of nominal load 10 Nm at time t = 0.8s, the control reacts to this disturbance to bring back [8, 9] the rotation

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speed to the reference value after a transient time delay. During this test the electromagnetic torque is maintained equal to the nominal torque in simulation. The electromagnetic torque to be increased to the maximum value defined by (15 Nm), then to stabilize to 10 Nm once the speed is finished and the engine reaches 1500 rpm. The electromagnetic torque developed by the motor increases to the nominal value 10 Nm to satisfy the load torque demand with a proportional increase in the stator current [12, 13]. Indeed this allows us to guarantee the correct choice of the coefficients of the speed regulator. The experimental results are similar to those of the simulation as shown in Figure 9.

Figure 7. Test bench for closed loop and open loop vector control

(a)

(b)

(c)

(d)
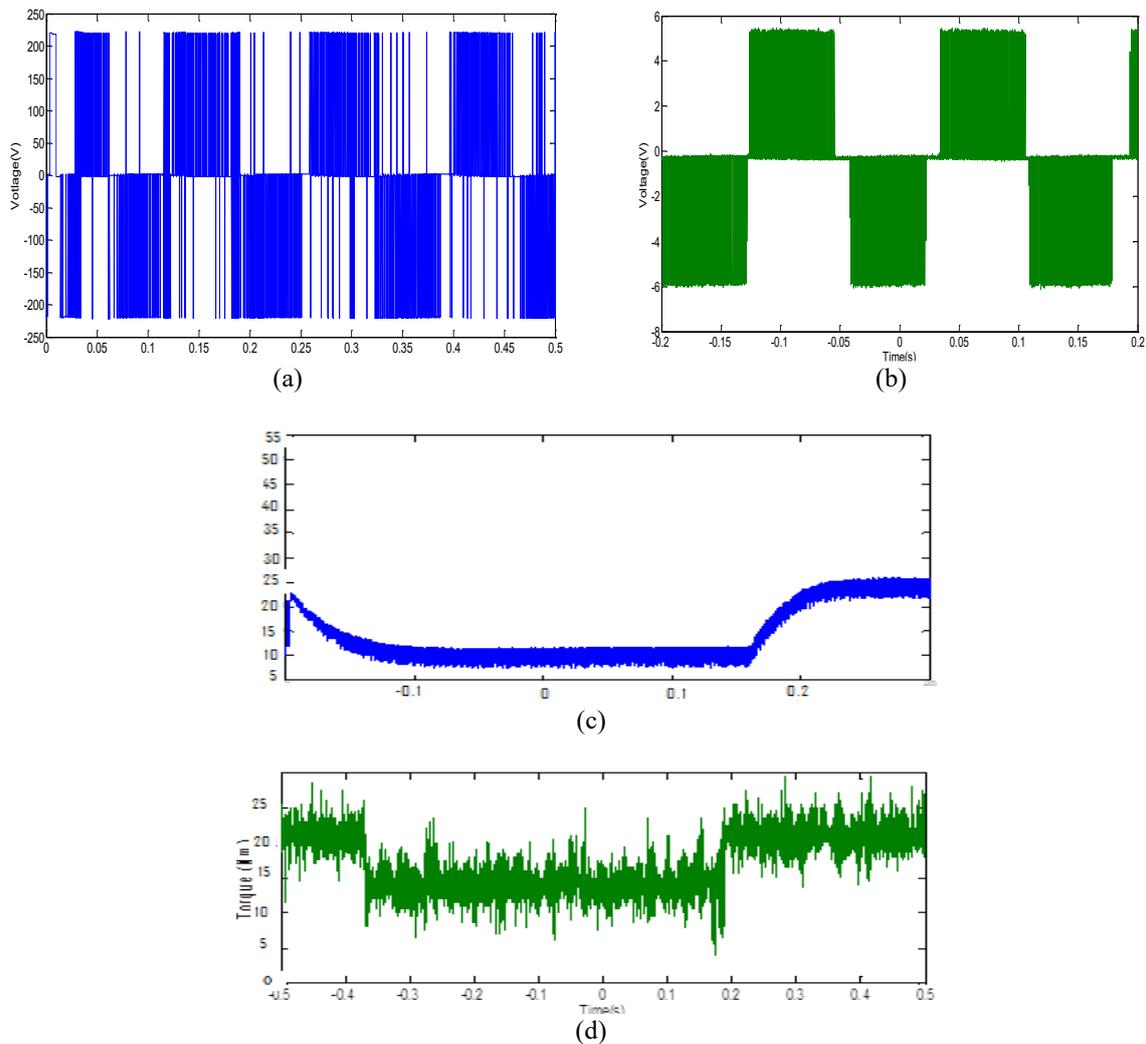
Figure 8. (a) Experimental voltage at 20 rad / s, (b) simulation voltage at 20 rad / s
(c) experimental current at 20 rad / s, (d) simulation torque at 20 rad /s
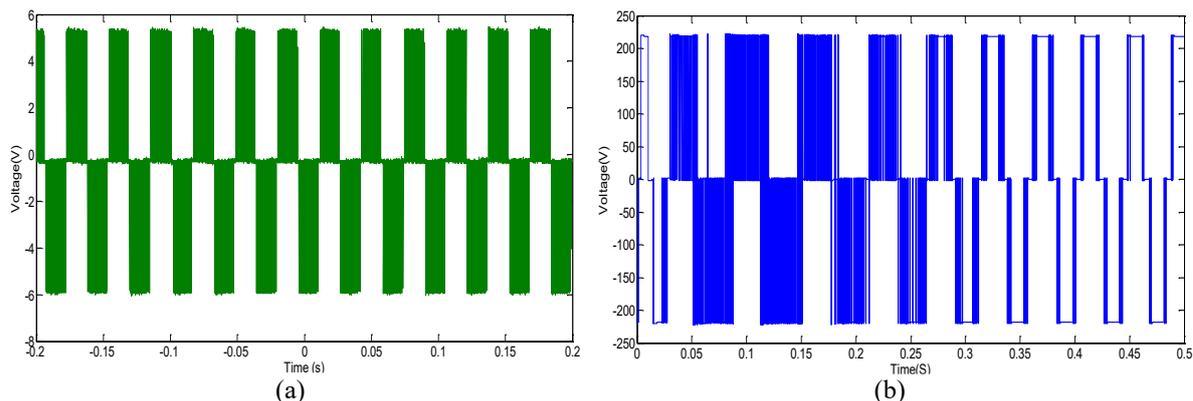
Figure 9. (a) Experimental voltage at 100 rad /s, (b) Voltage simulation at 100 rad/s

For torque responses, in the first step, a high torque is generated to accelerate the engine [14, 15]. After reaching target speed. It is clear to see that the torque response is decent and fast. The experimental curves of the tensions and compound torques are similar to those of the simulation (same amplitude and same period) [16, 17]. This proves the correct identification of the mechanical and electrical parameters of the asynchronous machine as shown in Figure 10.
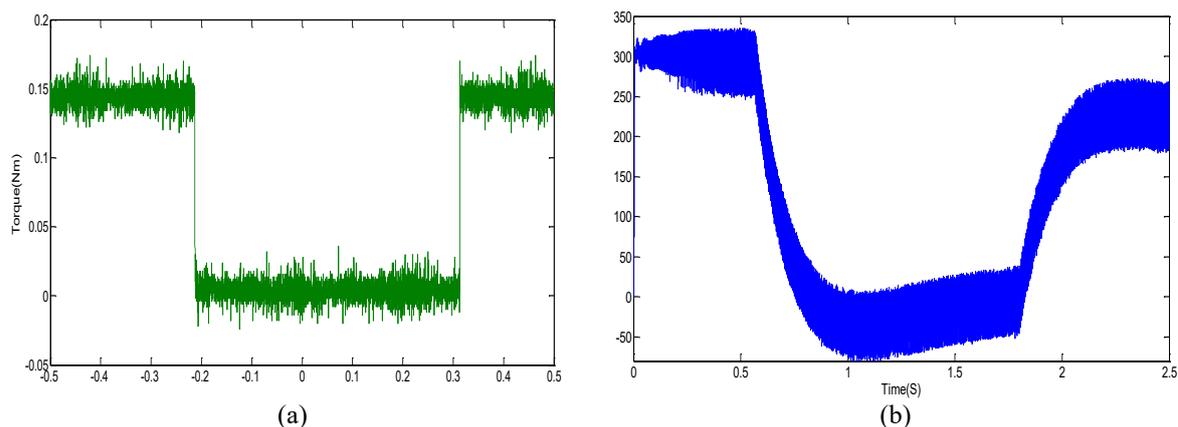
Figure 10. (a) Experimental current at 100 rad /s, (b) Torque simulation at 100 rad/s

5. COMPARISON STUDY

In order to evaluate the advanced vector control strategy of asynchronous machines, the following comparison is introduced [18, 19]. The results obtained from various methods of determining the parameters for asynchronous machine are compared. We calculate the various parameters and then we present the technical characteristics of each element of the asynchronous machine; this proves the correct identification of the mechanical and electrical parameters of the asynchronous machine [20]. In Figure 10, during this test the electromagnetic torque is maintained equal to the nominal torque. The [9] presents a large ripple in the torque; this can be remarked from the response of our method, which is maintained constant [21-25].

6. CONCLUSION

A detailed description of the experimental device used for the control of an asynchronous machine was given. This device is based on the use of a variable speed drive which will serve to control the asynchronous machine through the speed control. Experiments are an important step in the engineering study. It has been shown that simulation results for asynchronous motors operating with FOC will have good stability. In order to demonstrate the feasibility and verify the theoretical analysis, experiments were carried out under different conditions to test the control strategies. The experimental results of field oriented control of an induction motor are obtained and compared with simulation findings and validate the model developed.

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