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Three-phase Induction Motor SVPWM-FOC Control Based on PLC Matlab Translation Approach

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Abstract. Industries have been moved from conventional control to programmable logic control (PLC). System control, protection and maintenance for 3-induction motor have to be used in safe controlling process rather than human continuous control. This paper simulates a PLC control system for three- phase induction motor through Matlab simulation. The motor is driven by a space vector pulse with modulation (SVPWM), a three-phase voltage source inverter through a PLC controller. PLC control can employ speed and current control besides initiating a protection signal for abnormal current, voltage and temperature. Moreover, it can be used as a helpful tool for continuous monitoring of any quantity corresponding to the controlled motor. To emulate the control program in Matlab/Simulink software, a translation approach is used. It translates the PLC control program into m-file function block. The results reflect a successful PLC translation control through the results of speed, current and torque during load and no- load conditions.

Nomenclature.

SVPWM	Space Vector Pulse Width Modulation.
FOC	field- oriented control.
N*	Actual speed.
n	Reference speed.
iq*	Reference quadrature axis current.
iq	Quadrature axis current.
id*	Reference direct axis current.
id	Direct axis current.
vq	Quadrature axis voltage.
vd	Direct axis voltage.
PID	Proportional, Integral and Derivative control.

1. Introduction

The three-phase induction motor is the most used in the industrial facilities because of its simple and rugged structure, good self-starting capability, low cost, and reliability. The emulation is one of the main stages in the crediting of the designing special operations for the IM-drive system, by eliminating the designing errors and the resulting errors in the construction of the first model and testing it. The dynamic model of the induction motor in direct, quadrature and zero axes can be derived from

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fundamental equations of the transformation. It is adequate for the induction motor simplification model [1].
VSI is an approach to transfer from DC to AC quantity, used to supply a controllable voltage provenance to provision three-phase induction motor. Three-phase voltage source inverters are extensively used in changing the speed of AC motor drives. They provide high changing frequency and changing voltage supply. The control policy used for controlling the VSI is the sinusoidal pulse width modulation (SPWM). The major disadvantage of SPWM is lower dc bus voltage utilization, and the greatest output voltage from VSI is limited to 0.5V dc (peak) or 0.353 Vrms. SVPWM improves DC bus utilization by 15.15%, therefore the digital implementation of SVPWM is efficient. The space vector pulse width modulation is the superior technique to supply sine wave voltage with lower THD to the motor [1,2]. This technique is used to control electric motors and has become available with the employment of programmable logic controllers (PLCs) [3].
PLC are extensively utilized in manufacturing control because they are cheap, simple to install and extremely pliable in applications [1-3]. To get exact industrial electric drive systems, it is useful to use PLC device, which is connected to power converters, subjective computers, and other electric paraphernalia. The cons of this procedure are that this makes the equipment more developed, complicated, and high-priced. In the beginning, the tenet of flux control was used and called 'field-oriented control' or 'vector control' for squirrel cage induction motors and thereinafter for synchronous machines [4]. In the 'vector control' method the stator current of the motor is divided into two parts (i_d) and (i_q), part one (i_d) is the (flux-producing) stator current, and another (i_q) is the (torque-producing) stator current. After dismantling both components, they will be controlled independently and the induction motor can be controlled such as a separately excited direct current motor.
In this paper, the PLC controller is used to simulate the FOC strategy. Since this work is related with simulation rather than the real-time implementation, the translation approach is used to represent the PLC controller in m-file. The references V_d and V_q which are obtained from the PLC are used to drive the SVPWM inverter. The controlled 3-phase induction motor shows a better performance response compared to the corresponding operation from open- loop control. When using the open-loop control method to control the speed of three-phase induction motor, the settling time and rise time are high compared to the filed-oriented control method. In addition, the starting current time of the open-loop control method is greater than the FOC method under the same operation condition. therefore, the use of the FOC method is very useful to maintain the induction motor and increase its efficiency.

2. Motor Control via FOC Strategy and PLC Control

A direct field- oriented control for a 3-phase induction motor generates direct and quadrature reference voltages V_d and V_q. These values have to be used to drive the SVPWM inverter as shown in Figure 1.

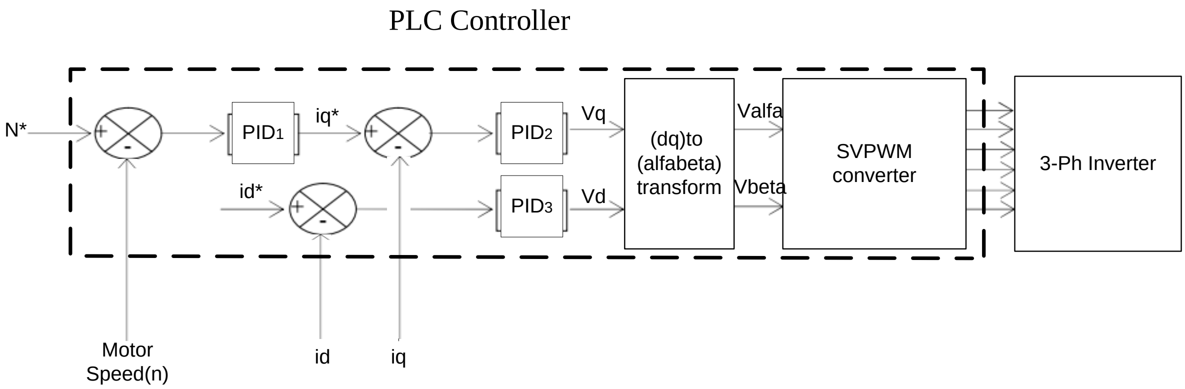

Figure 1. FOC controlled SVPWM inverter.

The three-PID controllers can be represented in the PLC controller. The parameters of PID controllers can be chosen either by trial and error method or any other optimization method. Figure 2. shows a schematic diagram for the induction motor PLC-FOC-SVPWM induction motor control interfaced with PC and human- machine interface (HMI).

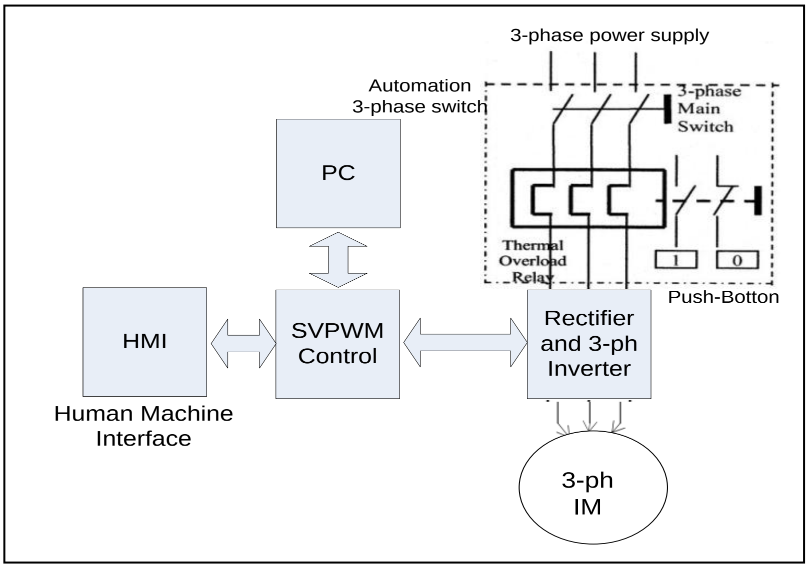

Figure 2. Configuration of complete PLC-FOC-SVPWM, 3-phase induction motor control.

2.1. Technique for Space Vector Pulse Width Modulation (SVPWM).
The SVPWM technique is the generality main technique used for controlling the voltage source inverter, which is used to supply the AC motors like the induction motor, because of the space vector pulse width modulation mechanism generate less THD in the VSI and utilizes DC bus voltage over efficiently. This inverter consists of three legs with six controlled switches (S_1 to S_6). The idea is to generate a vector with amplitude V_{ref} which moves with an angle (α) across six sectors, as shown in Figure 3. [5,6]. The SVPWM can be performed in three steps:
-Step 1. The calculation of V_{ref} , and the angle (α) from V_d and V_q
-Step 2. The calculation of the time period T_1, T_2, and T_0 according to the time division that represent this technique as follows [6,7].

$$T_1 = \frac{\sqrt{3}\,T_z\,|\bar{V}_{ref}|}{V_{dc}} \sin\left(\frac{n}{3}\pi - \alpha\right) \tag{1}$$

$$T_2 = \frac{\sqrt{3}\,T_z\,|\bar{V}_{ref}|}{V_{dc}} \sin\left(\alpha - \frac{n-1}{3}\pi\right) \tag{2}$$

$$T_0 = T_z - (T_1 + T_2) \tag{3}$$

where: n represents the number of sectors (from 1 to 6), the angle (α) is $0 \le \alpha \le 60°$ and T_z is the switching time ($T_z = 1/f_z$). Figure 4 shows the timing period for sector 1.
-Step 3. Calculation of the alteration time of each switching device (S_1 to S_6). The time period T_z is divided into seven sub-periods, applying zero state vector in the first part for $1/4^{\text{th}}$ the total zero state vector time. In the second and third parts applying active state vectors for $1/2^{\text{th}}$ of the total time of their vectors, then applied zero state vector again for $1/4^{\text{th}}$ the total zero state vector time. This process is repeated in the second half of the switching period. [7,8,9].

2.2. The Programmable Logic Controller (PLC).
PLC is a digital electronic device uses a programmable memory to store orders and performs certain logical sequential tasks in time to control industrial machines and processes in factories. PLC programming is concerned with various logical processes (AND, OR, XOR), the processes of

connecting or separating components and designing circuits within the device to withstand vibration, heat, humidity and noise. PLC devices are available in different shapes and sizes and some can be programmed directly using the LCD screen without the need for a computer. The PLC consists of; input and out modules, memory and central processing unit (CPU), power supply unit and programming device [10].

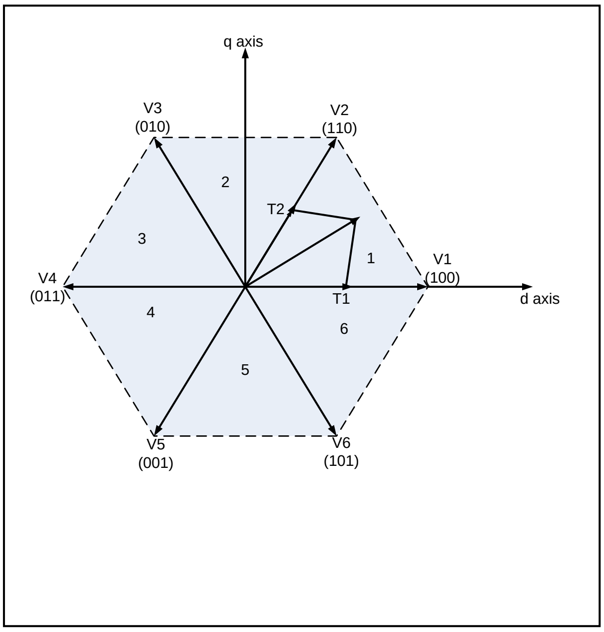

Figure 3. The switching vectors and sectors.

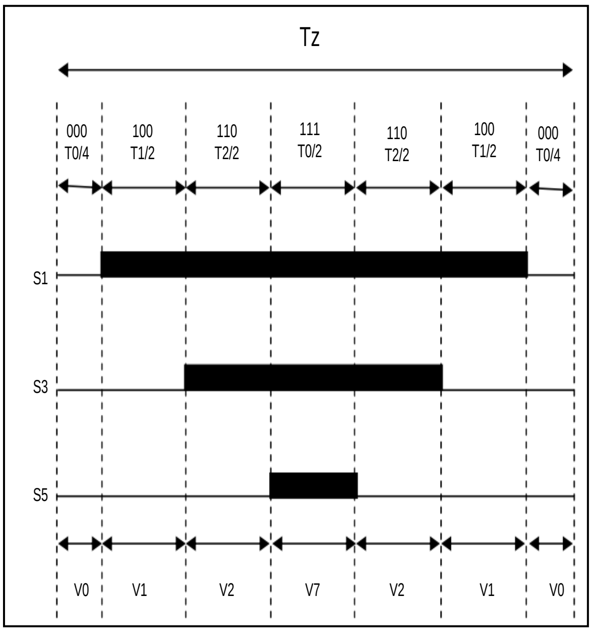

Figure 4. Timing periods for sector 1

The advantages of PLC are; flexible, has low cost, its implementation program can be carried out before the PLC unit is installed on the industrial equipment, fast execution of the program, protection from tampering with the program and ease of handing, correct errors and locate the error and has small size. Figure 5 shows the main block of PLC device [11].

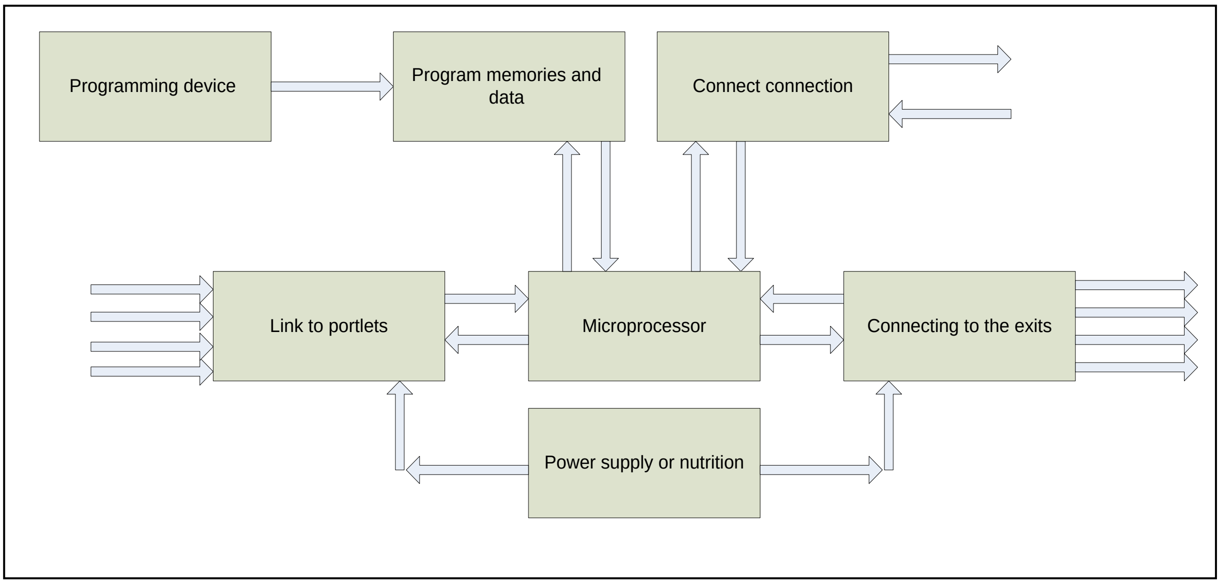

Figure 5. Block Diagram of PLC device

3. PLC Translation Approach.

The PLC program that controls the induction motor can be implemented by Matlab/Simulink. which automatically translate the control program in PLC as its instruction list in Matlab software language.

The PLC controller for an industrial process is simulated in Matlab/Simulink as a block called "Industrial Process Simulation Block". A block called "PLC control program" emulates the PLC operation. The inputs are taken from drive sensors and detectors such as i_d, i_q and rotor speed while the output (speed and torque) affects the actuator (inverter and induction motor).

The translation algorithm depends on type of PLC, number of inputs and outputs. The arguments are defined and created in a text m-file. For example, "d_{i1} to d_{in} denote the PLC's digital inputs, a_{i1} to a_{im} denote the PLC's analog inputs, d_{o1} to d_{op} denote the PLC's digital outputs and a_{o1} to a_{oq} denote the PLC's analog outputs. n, m, p and q denote, respectively, the PLC's number of digital inputs, analog inputs, digital outputs and analog outputs" [12].

The control approach is represented using a schematic language such as ladder diagram or in a text-oriented programming language with a set of translation rules like Math, Timer, Moving, Program control, etc.

4. Simulink Model of Proposed FOC-SVPWM with PLC Controller.

In this work, the FOC strategy is represented in PLC through the m-file function in Matlab/Simulink. The rotor speed is compared with its reference and the error is passed through PID_1 controller to obtain reference i_q as shown in Figure 1. The last is compared with motor i_q and used to obtain the controlled V_q through a PID_2 controller. The controlled voltage V_d is obtained from a PID_3 controller which is input is the error difference between reference and actual motor i_d.

The SVPWM technique is implemented in MATLAB according to the description given in section 2.1. Six pulses will be generated and applied to the VSI. The motor used is 1hp, 380V, 50Hz, 3-ph., Y connected, 2 poles, 3-ph induction motor. The overall Simulink model is shown in Figure 6.

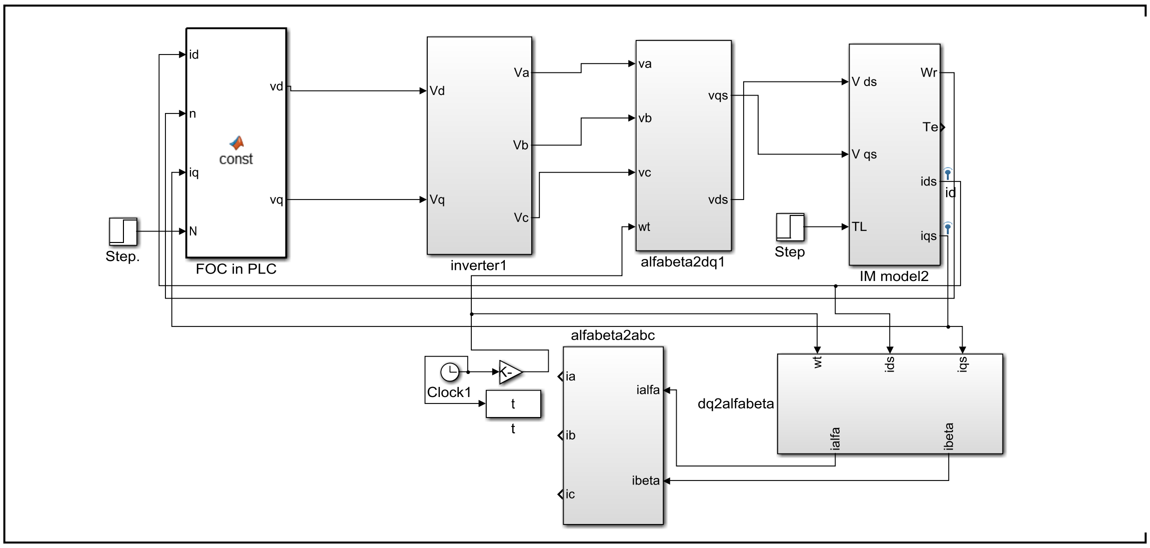

Figure 6. Simulink model using FOC-SVPWM 3-phase induction motor drive

5. Simulation Results.

Motor signatures have been taken for analysis study, these are line currents (ia), rotor speed and electromagnetic torque. The load torque is taken at the rated value at 1 N.m. The three-PID controller parameters are tuned by trial and error method and their parameters are given in Table 1.

Table 1 PID controller parameters

	K_I	K_p	K_D
PID_1	0.1358	10.1244	0.1721
PID_2	0.1358	10.1244	0.1721
PID_3	0.1358	10.1244	0.1721

The motor response has been reached to the stable condition after 0.9 second in an open- loop control condition while it reaches its state speed 2977 rpm, after 0.2 sec. in FOC control. The electromagnetic torque wave shows that it is reached in the steady condition in the same above time as shown in Figure 7. A full load torque is applied at 5 sec. and removed at 7 sec. The motor speed remains constant at rated speed with a small disturbance during 0.05 sec. Figure 8 describes the mentioned case.

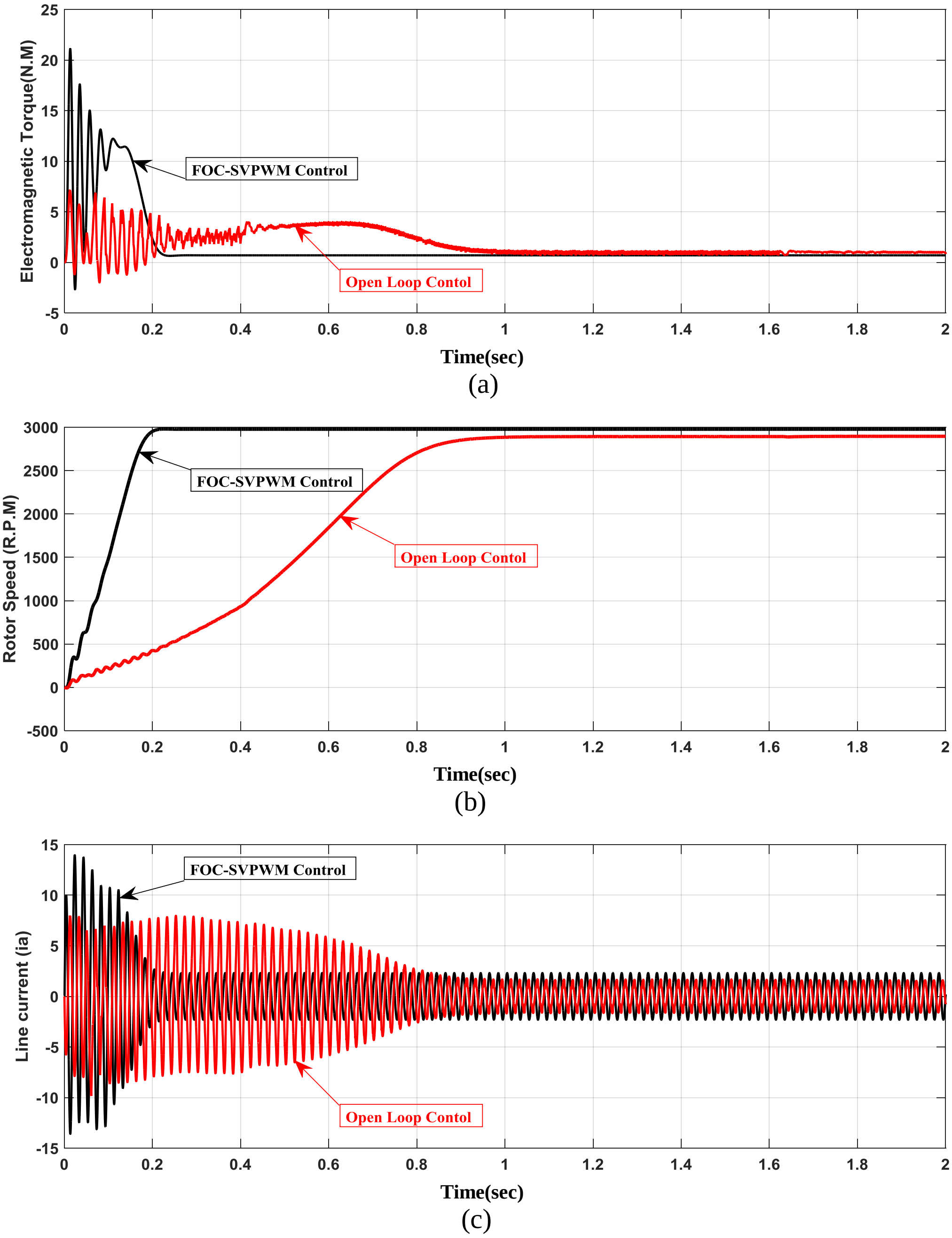

Figure (7). (a) Electromagnetic Torque, (b) Rotor Speed and (c) the line current.

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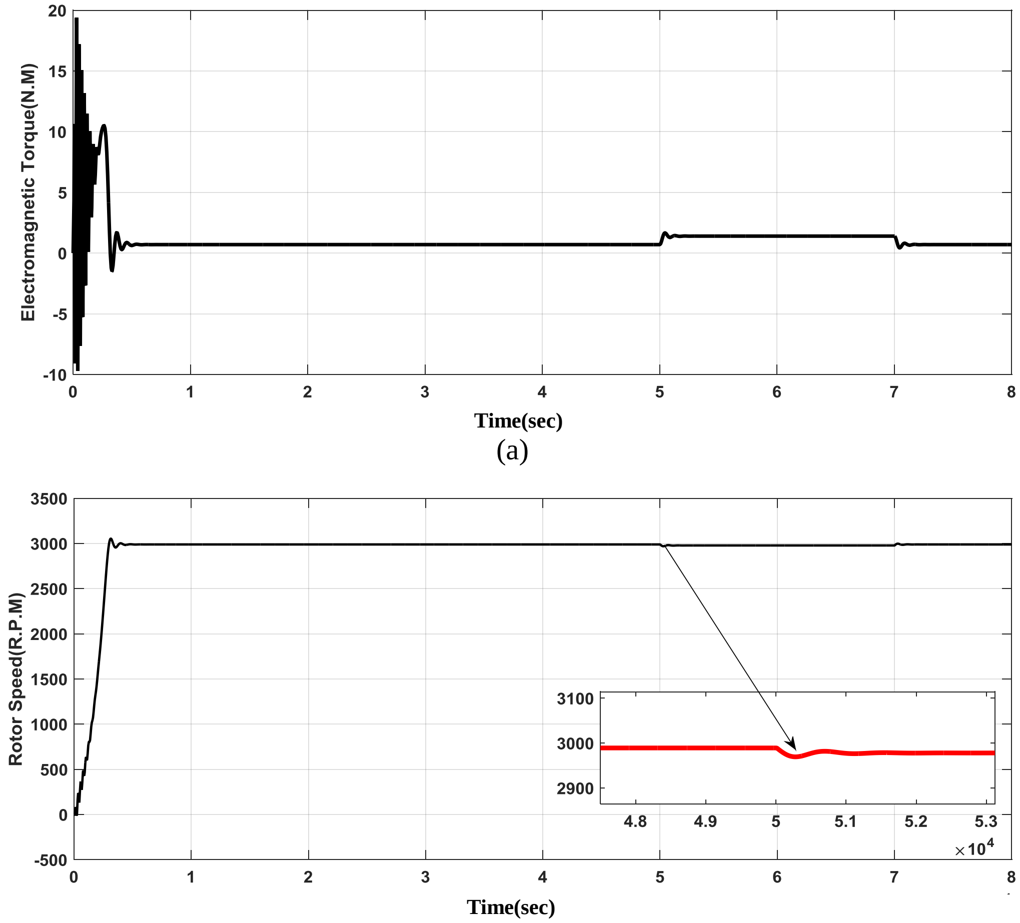

(b)

Figure (8). (a) Electromagnetic Torque, (b) Rotor Speed

6. Conclusion.

This paper presents FOC method to control the speed of induction motor based on SVPWM technique by using a translation approach to emulate the PLC control program Matlab/Simulink software. A FOC method is applied to SVPWM inverter to achieve the required speed and flux tracking of IM. The PID-controller has been employed for regulating the fluctuation of the motor current and torque, due to the parametric variation of an induction motor. A translation methodology to emulate PLC control program in the Matlab/Simulink environment. The translation package automatically translates the PLC control program into Matlab/Simulink software language. The PLC control program is transferred into a Matlab function. The subtitle package results a m-file function, obtained by implementing a set of translation base that transformation the PLC instructions listing into Matlab language. All the results agreed with the motor response operation.

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