Performance of an Indirect Field-Oriented Control for Asynchronous Machine

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***Abstract*—This paper presents an analysis method for achieving control torque and speed with indirect field oriented control for asynchronous motors, by the three-axis to two-axis current transformation. But the drive performance often degrades for the machine parameter variations. The aim is to apply two techniques for controlling independently the induction machines; the performance of this system is tested and compared by simulation in terms of reference tracking. A PI controller is used to control the rotor speed of the induction machine and a hysteresis current controller is applied for controlling the output voltage of the PWM inverter. To achieve desired speed and torque performance, these two models controls are implemented in Matlab Simulink.**

Keyword- Asynchronous machine, Indirect Field Oriented, Hysteresis current, Speed controller

I. INTRODUCTION

Asynchronous motors are widely used as actuators in many industrial and research applications. Along the last decades the evolution of digital processing systems and power electronics made possible the extended use of high-performance induction motor control systems such as field oriented control (FOC).

The main difficulty in the asynchronous machine control resides in the fact that complex coupling exists between the field and the torque. Conversely, induction motors inherently have complex, non-linear, and highly interacting multi-variable control structure [1]. The space vector control in FOC ensures decoupling between these variables, and the torque is made similar to that of a DC machine [2].

Theoretically, the field oriented control for the induction motor drive can be mainly categorized into two types; indirect and direct. The field to be oriented could be rotor, stator, or flux linkage. In the indirect field oriented control, the slip estimation with measured or estimated rotor speed is required in order to compute the synchronous speed. There is no flux estimation appearing in the system. For the direct scheme, the synchronous speed is computed basing on the flux angle which is available from flux estimator or flux sensors. The indirect field oriented control (IFOC) technique is very useful for implementing high performance induction motor drive systems [3].

These two methods of vector control, direct and indirect, are different in the angle calculation of Park (teta) (essential magnitude in the control , representing the phase of the field directed in the reference related to the stator and in the indirect control [4], this angle is calculated from the stator pulsation it (ws) even reconstituted using the autopilot relationship addition the electric speed (w) and (wg) slip pulse, while direct control, directly calculates this angle from quantities, measured or estimated [5], in this paper, we treat indirect field oriented control of induction machine with two types of regulators.

The proposed control strategy is that of Indirect Field control that incorporates the control circuits of the current Isd and Isq and the speed; with a supply voltage and controlled current. Different regulators have been dimensioned from the parameters of the machine that have been identified. Here in this study, an indirect field oriented control is modeled by a system generator in Matlab/Simulink and with appropriate simulations, and the results are analyzed [6].

II. THEORETICAL STUDY OF AN INDIRECT FIELD-ORIENTED CONTROL

The Field Orientated Control consists of controlling the stator currents represented by a vector. This control is based on the three-phase to two-axis current transformation system into a two coordinate (d and q axes). These projections lead to a structure similar to that of a DC machine control. The FOC machines need two constants as input references: the torque component (aligned with the q coordinate) and the flux component (aligned with d coordinate) [7].

The objective of space vector control is to assimilate the operating mode of the asynchronous machine at the one of a DC machine with separated excitation, by decoupling the torque and the flux control. Starting from the operating equations of the asynchronous machine [8], the first model was developed taking into account certain simplifying assumptions; model describing the operation of the MAS is given by:

$$\frac{diqs}{dt}=\frac{1}{\partial Ls}\left[-Rsr.iqs-\omega s.\partial.Ls.ids+\frac{M.Rr}{Lr^2}.\phi qr-\frac{M}{Lr}.\omega.\phi dr+Vsq\right] \quad (1)$$

$$\frac{dids}{dt}=\frac{1}{\partial Ls}\left[-Rsr.ids+\omega s.\partial * Ls.ids+\frac{M.Rr}{Lr^2}\phi dr+\frac{M}{Lr}.\omega.\phi qr+Vsd\right] \quad (2)$$

$$\frac{d\phi dr}{dt}=\frac{M*Rr}{Lr}ids-\frac{Rr}{Lr}\phi dr+\omega g.\phi qr \qquad \frac{d\phi qr}{dt}=\frac{M.Rr}{Lr}*isq-\frac{Rr}{Lr}.\phi qr-\omega g.\phi dr \quad (3)$$

$$Te=np\frac{M}{Lr}(\phi rd.iqs-\phi rq.ids) \quad (4)$$

$$J\frac{d\omega}{dt}+f\omega=Ce-Cr \quad (5)$$

$$Rsr=Rs+Rr\frac{M^2}{Lr^2} \qquad \omega g=\omega s-\omega \qquad \partial=(1-\frac{M^2}{Ls*Lr}) \quad (6)$$

- ids, iqs (A): d-axis and q-axis components of the stator current vectors is.
- idr, iqr (A): d-axis and q-axis components of the rotor current vectors ir.
- Vds, Vqs (A): d-axis and q-axis components of the stator voltage vectors Vs.
- Rr (Ω): Rotor resistance.
- Rs (Ω): Stator resistance.
- $\omega s, \omega r$ (rad / s): Stator and rotor electrical heartbeat.
- ϕs , ϕr (Web): Stator and rotor fluxes linkage.
- $\phi dr, \phi qr$: d-axis and q-axis components of the rotor fluxes linkage.
- Ls (H): Stator inductance.
- Lr (H): Rotor inductance.
- M (H): Mutual Inductance between the stator and the rotor.
- Ce (Nm): Electromagnetic torque.
- $\tau s, \tau r$: Stator and rotor time constant.
- ∂ : Coefficient leakage blondel.
- J : Moment of inertia.
- Cr (Nm) : Mechanical torque.
- Te (Nm) : Electromagnetic torque.
- F : Coefficient of viscous friction.
- θ s (rad / s): Stator angular electrical frequency.
- ω g (rad / s): Slip pulse.
- ω (rad / s): Electric rotor speed.
- ωr (rad / s): Mechanical rotor speed.
- P: Pole number.
- s : Laplace operator.

The IFOC consists in making Φqr=0 while the rotor direct flux Φdr converges to the reference Φr* [3]. The drawback of the indirect flow estimate is that its precision is affected by the variation in rotor resistance due to temperature variation. It is immediately apparent that any error on the relative value of the rotor time constant Tr direct impact on the estimated quantities [4]. The equations of the indirect field oriented control strategy are defined from the equations that link the rotor flux vector to stator current vector:

-Flux calculation :
$$\phi r = \frac{M}{1 + Tr * s} Ids \tag{7}$$

- Angle calculation of Park (teta) :
$$\theta s = \int \omega s * dt \qquad \omega s = \omega + \omega g \qquad \omega = \frac{M}{Tr.\phi r *} Iqs \tag{8}$$

- Id* calculation :
$$Ids* = \frac{\phi r *}{M} \tag{9}$$

-Iq* calculation :
$$Iqs* = \frac{2}{3} \frac{2}{p} \frac{Lr}{M} \frac{Te *}{\phi r} \tag{10}$$

The current control methods play an important role in power electronic circuits particularly in current regulated PWM inverter switch are widely applied of an induction machine [9], The Basic implementation of hysteresis current control is based on deriving the switching signals from the comparison of the current error with tolerance band. This control is based on the comparison of the actual phase current with the tolerance band around the reference current associated with that phase [10].

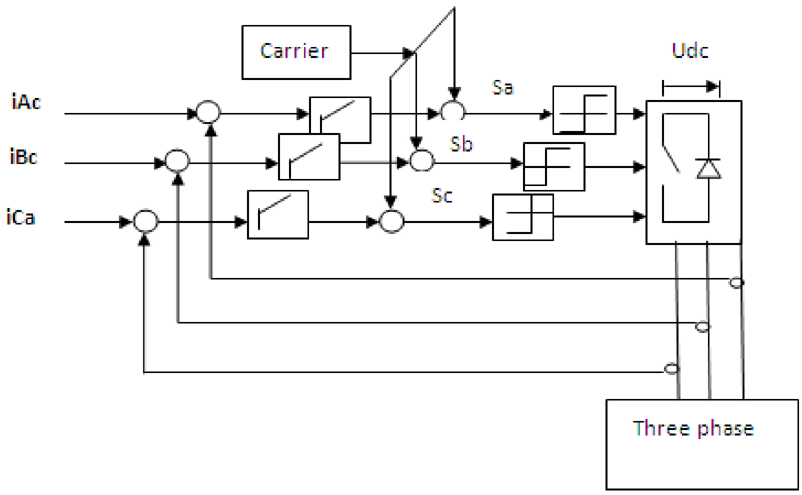

Figure 1. The model of PWM inverter [3]

III. MODEL OF AN INDIRECT FIELD ORIENTED CONTROL

The effectiveness of the proposed system model is validated using Matlab/Simulink utilized for the indirect field orientation control of induction machine. This control system includes the realization of the mathematical model to represent the natural behaviour of the system controlled.

The rotor speed ω is compared to rotor speed command $\omega *$ and the resulting error is process in the controller. The controller generates the q-axis reference current Iqs. For hysteresis current controller in figure 3, both stator reference current in d-axis and q-axis are converted to three phase stationary reference frame through Inverse Park Transformation and compared to the current from the feedback of the motor. Then the current errors are fed to hysteresis current controllers which generate switching signal for the voltage source inverter [10].

In this section, it is basically designed in the Matlab, the various blocks and then assembles them to build the simulation block-diagram of the indirect field oriented control of an induction machine. Thus, the work will begin in a first time, by the design of the various sub blocks.

The block diagram of complete system model including the controller in Matlab Simulink developed for the indirect field oriented controlled induction machine is shown in Figure 2 and the general view of vector control in Figure 3.

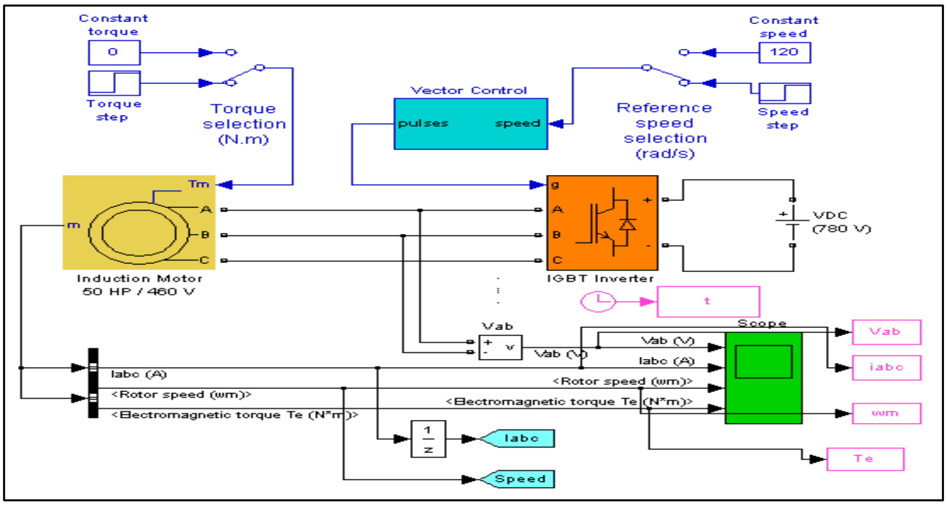

Figure2. The block diagram of complete system model including the controller of an indirect field oriented controlled induction machine

The induction motor is fed by a current-controlled PWM inverter which is built using a block. The motor drives a mechanical load characterized by inertia J, and load torque Tr .The speed control loop uses a proportional-integral controller to produce the two-axis current reference iq* which controls the motor torque. The motor flux is controlled by the direct-axis current reference id*. The block dq-abc is used to convert id* and iq* into current references ia*, ib*, and ic* for the current regulator. The current and voltage measurement blocks provide signals for visualization purpose in figure 3.

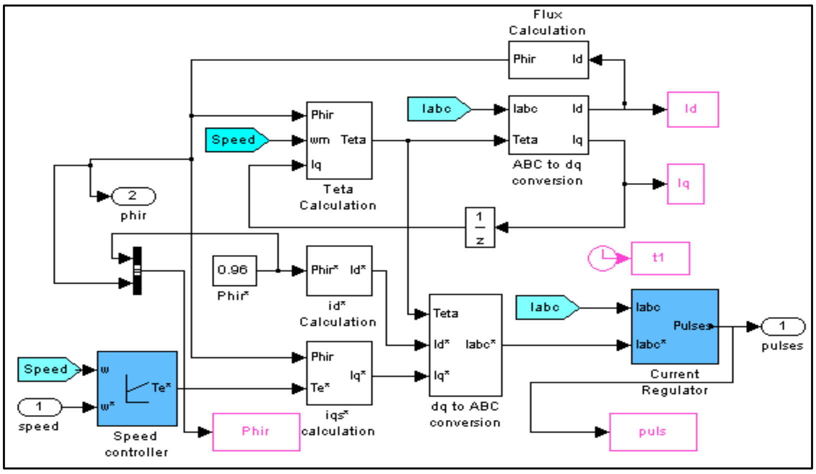

Figure3. The sub block diagram of an indirect field oriented controlled induction machine

A. Hysteresis current controller block

A simplified diagram of the proposed three-phase PWM current controller is shown in Figure 4. The current controller involves three independent hysteresis comparators and three logic gates with NOT function. The drive signals for the inverter power switches are derived from the output signals other controller. In the current controller, the three-phase current commands (ias*,ibs* , and ics *) are compared with the actual stator currents (ias ibs,and ics), and then the resulting errors are fed into the two-level hysteresis comparators, respectively.

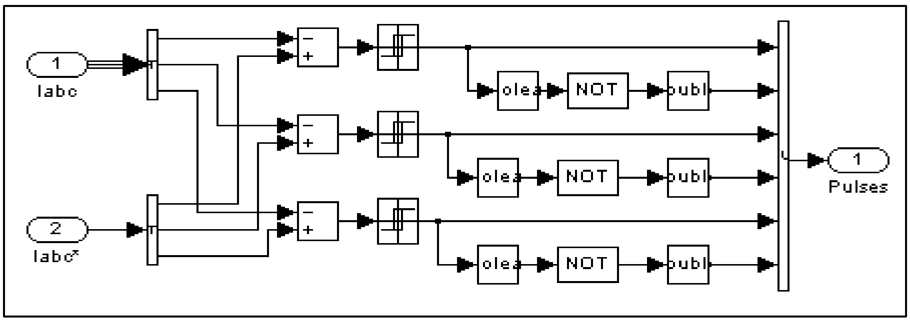

Figure 4. The hysteresis current controller

B. speed controller block

The indirect field orientation control of the induction machine is realized with a speed regulator. A speed controller block is a straight forward block where the difference between the reference speed and measured speed is calculated. Inputs of this block are reference speed and the measured speed. The output of this block is the torque reference as shown in figure 5.

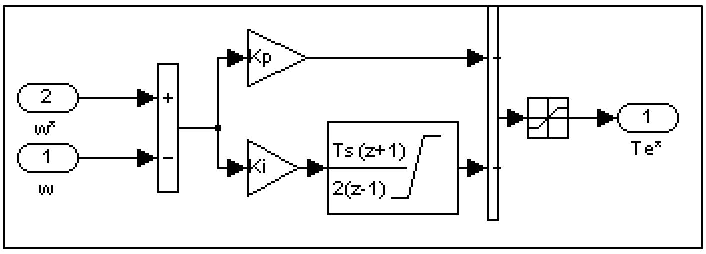

Figure 5. The speed controller block

C. Rotor field angle generation block

In the asynchronous machine the rotor speed is not equal to the rotor flux speed (there is a slip speed), then it needs a particular method to calculate θ. The basic method is the use of the current model which needs two equations (8) of the motor model .The block which is designed to generate the rotor field angle shown in Figure 6 as “teta” block.

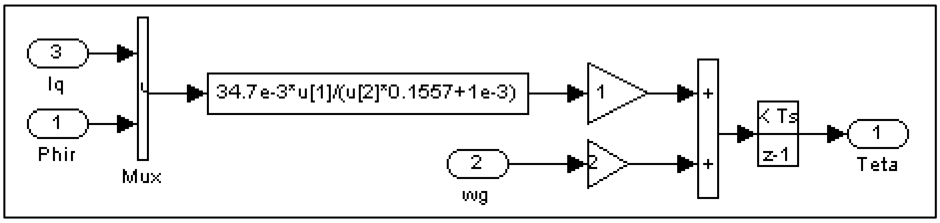

Figure 6.The Rotor field angle generation block

D. Transformation block from the d, q reference frame to the a, b, c reference frame

The transform block from the d, q reference frame to the a, b, c stator reference frame, denoted by (d,q to a,b,c conversion) is shown in Figure 3 as the “dq-abc transformation ” sub-block. The sub-blocks required to complete the transformation are shown in Figure 7.

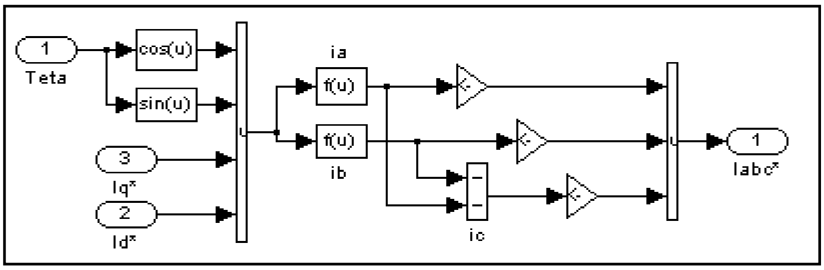

Figure7. d,q to a,b,c conversion

IV. RESULTS AND DISCUSSIONS

In the simulation, online analysis has been performed using MATLAB /SIMULINK. The "Constant speed» and "Constant torque" blocks are used. The Reference speed wref changed from 120 to 160 rad/s at t = 0.2 s and load torque changed from 0 to 200 Nm at t= 1.8s. The simulation shows the drive response to successive changes in speed reference and load torque. The main objective is to choose the best answer that gives us a better quality of establishment of the couple in this system control. The motor phase voltage has rectangular shapes in figure 8, stator current; rotor speed and torque are measured.

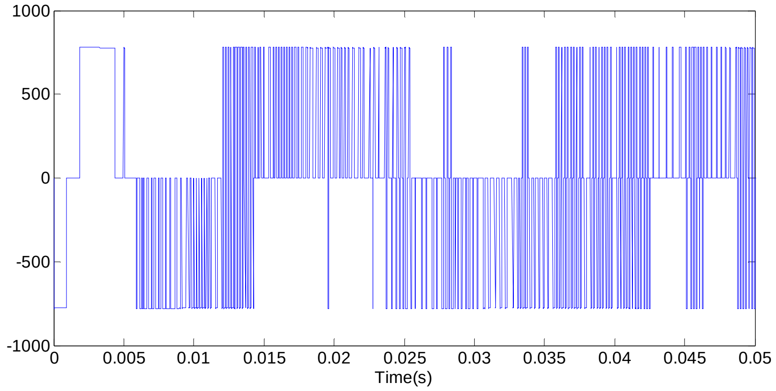

Figure 8. The motor phase voltage (a, b)

The two components (d,q) of the stator current are calculated and they are the inputs of the Park inverse transformation that gives the current (a,b,c) reference frame. The Isd and Isq components are compared respectively to the references flux and reference torque at figure 9. At this point, this control structure shows an interesting advantage: it can be used to control either synchronous or induction machines by simply changing the flux reference and obtaining rotor flux position [11].

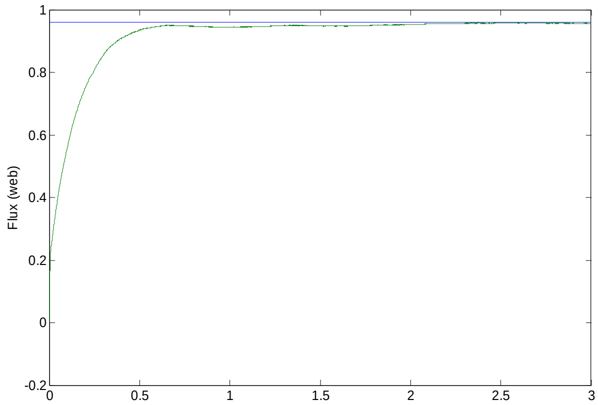

Figure 9. Comparison of measured flux and flux reference

The simulation result of dynamic performance of the asynchronous machine at load torque are presented in figures 10 and 11, we note that for a time t = 2s at Cr = 200N, and for various speed values (ω = 100, 80, 20 (rad / sec), the time of establishment of the torque in the case of indirect field control, is much faster. The choice of the indirect field oriented control method provides the best answer.

At time t = 0 s, the speed set point is 175 rad/s. Observe that the speed follows precisely the acceleration. At t = 2 s, the full load torque is applied to the motor shaft while the motor speed is still ramping to its final value. This forces the electromagnetic torque to increase to the user-defined maximum value (340N.m) and then to stabilize at 200 Nm once the speed is completed and the motor has reached 160 rad/s.

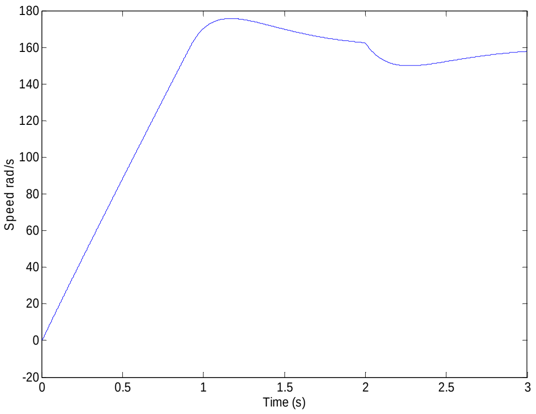

Figure 10. Speed characteristic (IFOC)

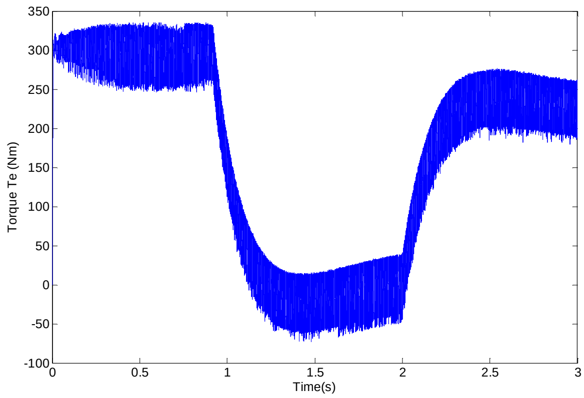

Figure 11. Torque characteristic (IFOC)

During starting motor draws high stator current in figure 12 with low frequency to develop the necessary starting torque and once the motor picks up speed the frequency increases and the magnitude of current reduces.

When the load is increased of rated torque at t = 2 sec, the speed controller maintains the motor at rated speed. The electromagnetic torque developed by the motor increases to the rated value 200 Nm to satisfy the load torque requirement with a proportional increase in the stator current. The direct axis current is a constant value depending up on the rated flux value and the quadrature axis current is proportional to the load torque. But when the drive is operated at light load condition, the efficiency is poor as the iron losses is maximum corresponding to the rated flux.

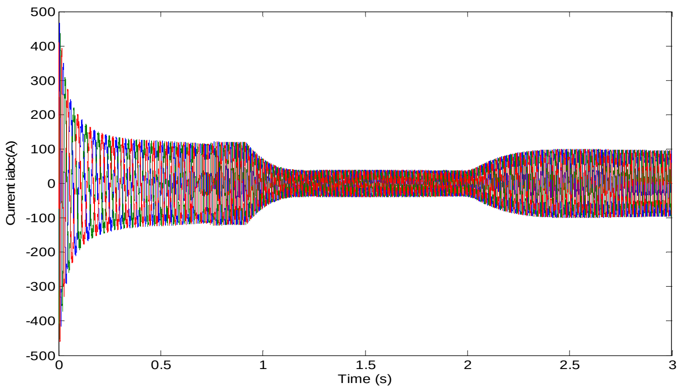

Figure12. Stator current characteristic of an indirect field oriented control

There are small ripples in the stator current and hence in the developed electromagnetic torque due to switching in hysteresis PWM current controller. The figure 13 shows the pulsations of the outputs of the current regulators witch applied from the inverse Park transformation. These are the inputs of the Space Vector PWM. It can be seen that the number of switching torque has been decreased when the hysteresis band was increased. However the torque and current ripple increases as seen from figure10 and figure 11 [7].

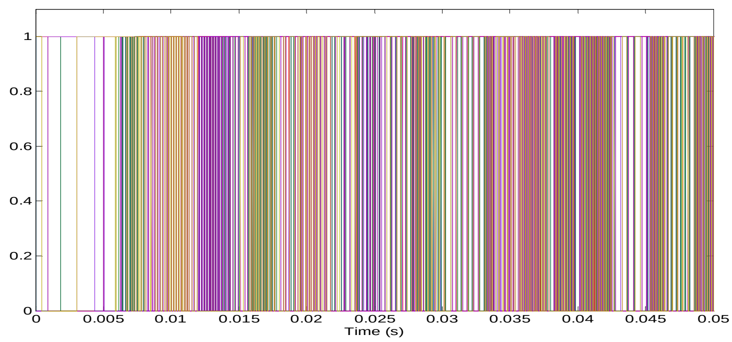

Figure 13: Variation in the gate signal generation pattern for change in hysteresis

V. CONCLUSION

The model system of indirect field oriented control is performer the two regulators speed and current regulators are used. After the completion of the design stage of the controller, the whole system including the motor, the power converter and the controller is modelled using Matlab/Simulink environment, its obtained results by using regulators hysteresis of point of view insensitivity towards the variations of the external and internal disturbances (that is parametric variations) are very satisfactory. This confirmed our approach. This model is simulated to see the effect of the controller in the control of the system. The Simulink measurement tools are used to observe and follow-up the output signals of each sub-block of the design and these signals are analysed and evaluated until obtaining the proper operation. It has been shown that the designed controller can achieve the desired torque control with appropriate speed regulation in both transient and steady state. The simulation model of indirect for induction motor shows excellent performance in both steady and transient state conditions. The indirect field oriented control is a good approach for controlling the induction machine. As a result, the induction machine responses to torque changes very quickly and precisely.

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