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A COMPARITVE STUDY OFFIELD ORIENTATION CONTROL AND DIRECT TORQUE CONTROL OF INDUCTION MOTOR BY USING MATLAB SIMULINK

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ABSTRACT: In this thesis, we are doing study and compare two most commonly used control methods of induction motors (IM). These methods, which have been used for three decades are Field Orientation Control (FOC) and Direct Torque Control (DTC). Theoretical background for both methods is explained. In this thesis we are going to check the performance of DTC and FOC model and that are developed by MATLAB/ SIMULINK tool due to its simplicity of use. And compare the important parameters of induction motors by applying both techniques. The comparative study of speed and torque are performed by using the FOC and DTC.

I. INTRODUCTION

Mechanical energy is needed in the daily life use as well as in the industry. Induction motors play a very important role in both worlds, because of low cost, reliable operation, robust operation and low maintenance. There are two main types of induction motors which are the wounded rotor and squirrel-cage design and both of them are in widespread use. Squirrel-cage rotor winding design is considered of the two more reliable and cheaper to make. When induction motors are operated without a proper control (drive), the motors are consuming large energies and the operating costs are high. In last few decades, power electronics has emerged, Digital signal Processing (DSP) and microcontrollers are now well established, motion and I-V sensors are ubiquitous allowing improved the performance. The contribution of power electronics in driving the AC motors which is so called “adjustable speed drives”, is characterized by the three phase mains voltages being converted to DC through conventional rectifier circuits to a DC rail. Next to the DC rail is inverted to AC but with both a different voltage and different frequency, VOUT (fOUT). Because the motor speed depends on the applied frequency, speed control is facilitated. The DC to AC inverter is usually built using Pulse Width Modulation (PWM) methodology to piecewise simulate the desired V (f). DSP is considered a very important component in recording and analyzing the PWM I-V data from motion and I-V sensors and to compare it with the desired conditions in the motor controller. Dynamic models (mathematical models) are employed in to better understand the behavior of induction motor in both transient and steady state. The dynamic modeling sets all the mechanical equations for the inertia, torque and speed versus time. It also models all the differential voltage, currents and flux linkages between the stationary stator as well as the moving rotor. My mathematical model will be done using MATLAB/Simulink which will represent the three phase induction motor including a three phase to d-q axis transformations. The main benefit with MATLAB Simulink is that in the electromechanical dynamic model can be accomplished in a simple way and it can be simulated faster using function blocks. Hasse in 1969 and Blaschke in 1972 proposed the concept of the vector control method or so called Field Orientation method of AC motors, based on making the well-established separately excited dc machine. Here the torque is defined as the cross vector product of the magnetic field from the stator poles and the armature current. To a good approximation the two are perpendicular, thus the maximum torque can be achieved and independent control of the motor facilitated. This is why vector control is often called “decoupling control”. Direct Torque Control concepts were proposed by Takashi and Noguchi in 1986. The idea of this method is based on comparing the measured stator flux and torque with the theoretically desired bands. The vector differences will control the subsequent switching sequence of the SVPWM inverter voltage based on the switching logic table. That however restricts the means the stator flux and torque to fall in the pre-established bands.

II. VECTOR CONTROL

The way of determining the angle (position) of the rotor flux vector, rotating at the synchronous speed, depends on the type of the field orientation: either direct field orientation or indirect field orientation

A. Direct Field Orientation Method (DFO)

When the identification of the flux vector is done by direct Hall sensor measurement or even indirectly by estimation of other motor electrical variables, it is called direct field orientation. This method depends on measuring the air gap flux using special sensor is called Hall-Effect-Device. The magnetic flux measured is the mutual flux not the rotor flux, which has angle ρ, which is important to be properly oriented. The connection with the known stator current provides the solution of determining this angle. Proportional Integral (PI) controller methodology is used in both the flux and the torque loops to get the desired direct and quadrature components of the stator current in the synchronous reference frame. Those are then transformed to the same component in the stationary frame. Finally the equations of control are referenced to the three phase motor drive currents to control the inverter operating conditions [1].

The complex multi-step mathematical procedure is explained as follows:
First, the three phases are transformed to d-q stationary components as the equations 1 and 12.

$$i_{qs}^{s} = \frac{2}{3}\, i_{as} - \frac{1}{3}\, i_{bs} - \frac{1}{3}\, i_{cs} \;\; A \tag{1}$$

$$i_{ds}^{s} = \frac{1}{\sqrt{3}}(i_{cs} - i_{bs})\, A \tag{2}$$

Because $\lambda smq = Lm$ $(isqs + i'sqr)$, the flux linkage components $\lambda'sqr$ and $\lambda'sdr$ can be written as:

$$\lambda_{qr}^{\prime s} = \frac{L_r'}{L_m}\, \lambda_{mq}^{s} - L_{lr}'\, i_{qs}^{s} \tag{3}$$

$$\lambda_{dr}^{\prime s} = \frac{L_r'}{L_m}\, \lambda_{md}^{s} - L_{lr}'\, i_{ds}^{s} \tag{4}$$

The calculated $\lambda'sdr$and $\lambda'sqr$ give the ability to obtain the cosine and the sin of the angle ρ using the following equations:

$$\sin\left(\frac{\pi}{2} - \rho\right) = \cos\rho = \frac{\lambda_{dr}^{\prime s}}{\lambda_r^{\prime s}} \tag{5}$$

$$\cos\left(\frac{\pi}{2} - \rho\right) = \sin\rho = \frac{\lambda_{qr}^{\prime s}}{\lambda_r^{\prime s}} \tag{6}$$

After determining the angle ρ which is used to the following step, d-q synchronous frame to d-q stationary frame, the transformation will be as follows:

$$i_{qs}^{s*} = i_{qs}^{e*} \cos\rho + i_{ds}^{e*} \sin\rho \quad A \tag{7}$$

$$i_{ds}^{s*} = -\, i_{qs}^{e*} \sin\rho + i_{ds}^{e*} \cos\rho \quad A \tag{8}$$

Finally, the stationary reference frame components of stator current are transformed to three phases to control the inverter operating conditions, which set three phase currents and phases to complete the control loop.

$$i_{as}^{*} = i_{qs}^{s*} \quad A \tag{9}$$

$$i_{bs}^{*} = -\frac{1}{2}\, i_{qs}^{s*} - \frac{\sqrt{3}}{2}\, i_{ds}^{s*} \quad A \tag{10}$$

$$i_{cs}^{*} = -\frac{1}{2}\, i_{qs}^{s*} + \frac{\sqrt{3}}{2}\, i_{ds}^{s*} \quad A \tag{11}$$

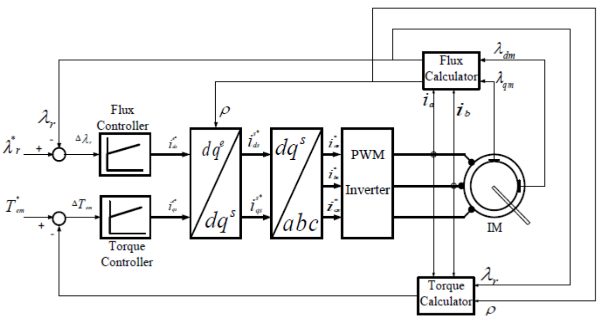


Figure 1 The Block diagram of direct vector control of Induction motor

This multi-step procedure is shown simplified in the block diagram of the direct field orientation methodology illustrated in Fig 1. Practically, this kind of sensor and its position can decrease the degree of ruggedness of the induction motor. In our comparison, this method is going to be used in the comparison with DTC because of the modeling simplicity.

B. Indirect Field Orientation Method (IFO)

The other way of applying vector control methodology to induction motor operation, which is the indirect field orientation (IFO) pathway. This method does not depend on the measurement of air-gap magnetic flux but rather employs equation 5 as follows. Torque can be controlled by either changing $ieqs$ or the slip speed $(\omega e - \omega r)$ .The rotor flux can also be controlled by varying $ieds$, because if the desired rotor flux is measured or given, then the $ie*ds$is determined by using equation 10. Then, the desired torque can be found as equation 12.

$$T_{em}^{*} = \frac{3}{2}\frac{P}{2}\,\frac{L_m}{L_r'}\, \lambda_{dr}^{\prime e*}\, i_{qs}^{e*} \tag{12}$$

Equation 9 has shown that the optimum orientation of $i'edr$ is to be zero, so the desired slip speed is as summarized equation (3.23).

$$\omega_2^{*} = (\omega_e - \omega_r) = \frac{r_r'\, i_{qr}^{\prime e*}}{L_m i_{ds}^{e*}} \tag{13}$$

Fig 3.4 shows the block diagram of the indirect torque control of an induction motor. Notice that that the angle of orientation (ρ) is the summation of the rotor angle (θr) and the slip speed angle $(\theta 2)$.

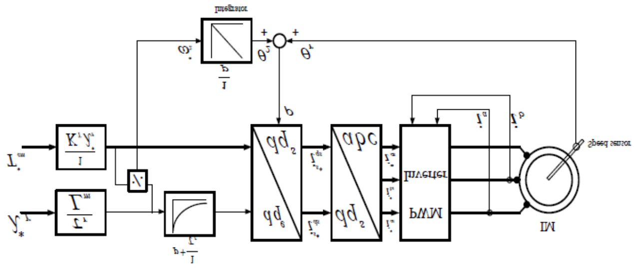


Figure 2 Block diagram of indirect vector control of Induction motor

III. DIRECT TORQUE CONTROL

With vector control method for induction motor operation, the magnitude and the phase of stator voltage can be controlled. Direct torque control has a very fast response and simple structure which makes it to be more popular used in industrial world. This method of control implies a comparative control of the torque and the stator fluxes which must fall into two separate certain bands (limits) to be applicable [3], [16]. The Basic Principles of Direct Torque Control of Induction Motor The basic concept of the Direct Torque Control (DTC) method was proposed by Takahashi and Noguchi in 1986. This method is more used in controlling the induction motor because it is considered a simple and robust method. The power inverter operational control is an important key in this method and modern power electronics has made this cost effective as well. The simple objective is to control two quantities which are the stator flux vector and the electromagnetic torque. Those quantities are directly controlled by selecting the proper inverter state with a combination of sense, command and control feedback loops and by power electronics drive control in the inverter stage. High dynamic performance can be achieved by the stator flux because the latter is close to being sinusoidal. The stator EMF depends on the stator flux, so the magnitude of the EMF depends on the stator voltage. Hence, $\lambda s = \int (Vs - rsis)dt$, and the torque, as the general definition, is the cross product of the stator flux and the rotorflux. As a result, the magnitude of the stator flux and the developed electromagnetic torque can be adjusted by selecting the state of the inverter of space vectors of the stator voltage [1], [20].

IV. MATLAB/ SIMULINK MODEL OF DTC and FOC

MATLAB/ SIMULINK has been a very powerful tool to model the electrical and the mechanical systems because of its simplicity. The dynamic simulation of induction motor is first performed employing the MATLAB/ SIMULINK. Vector control methods and Direct Torque Control method on induction motors follows. A comparison between those two methods is accomplished based upon many aspects but with emphasis on the speed response, torque response, and others detailed has been discussed. The DTC and FOC models are show in fig.3 and fig.4 respectively.

A. MATLAB/ SIMULINK Model of DTC

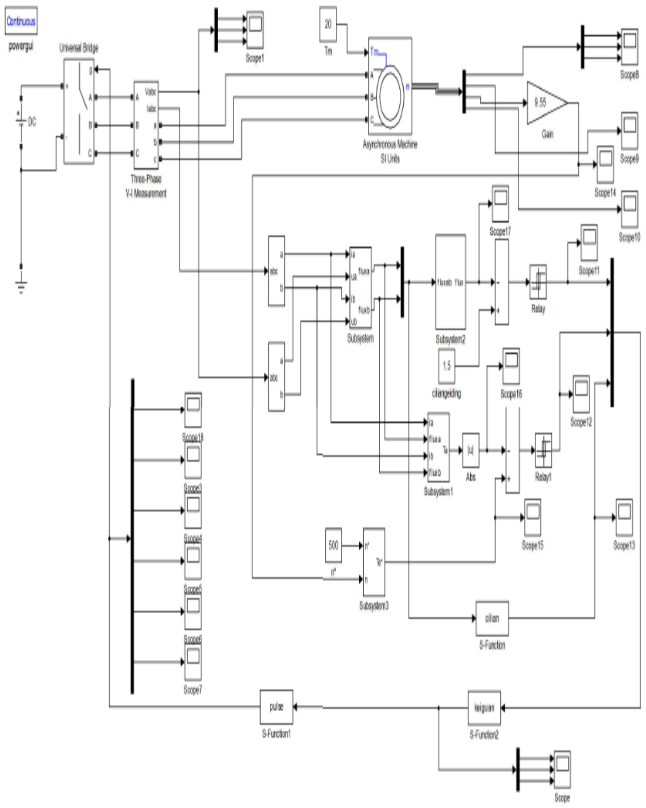


Fig 3 Simulated Model of DTC

B. MATLAB/ SIMULINK Model of FOC

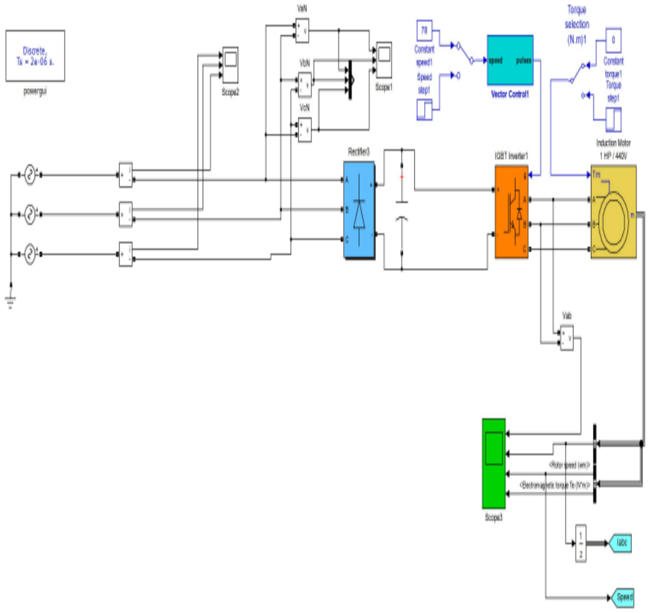


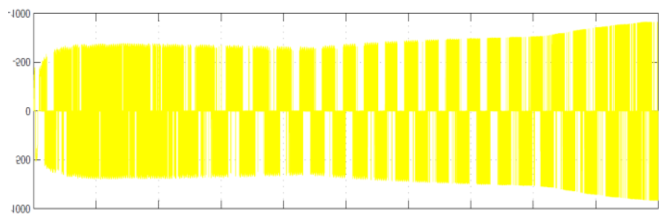
Fig 4 Simulated Model of FOC

V. SIMULATION RESULTS

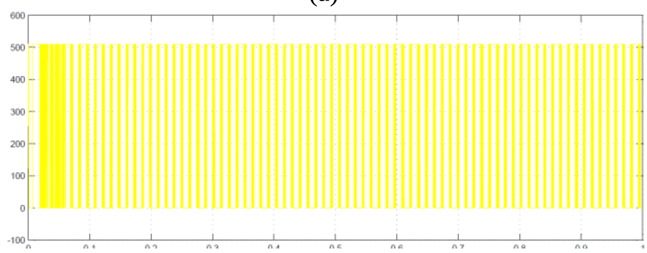
The results which are presented and compared are the torque, speed, and the three phase current of the stator.In this section, speed, electromagnetic torque, and the three phase current are going to be compared. After the simulation is done, the following results are extracted.

A. Speed Comparison

From Fig 5, we can notice that the deviation of the speed due to the load is so small in Field Orientation Control (FOC) and the speed returns to the desired speed in 0.15 second and the deviation of the speed as shown in fig 5 (a). From below fig 5 (b), the speed decreases and returns to the desired speed after 1 sec. That shows the advantage of FOC over DTC in speed response.



(a)

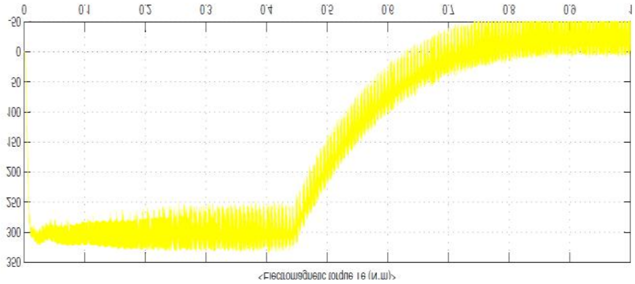


(b)

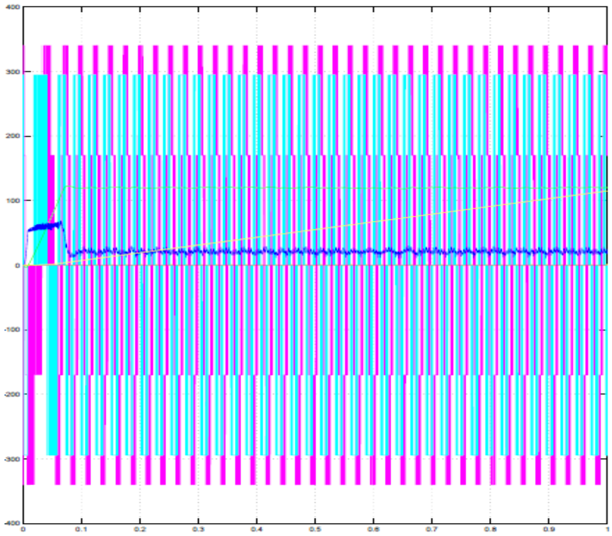
Figure 5 Motor speed response (a) FOC (b) DTC

B. Torque Comparison

We can say that the torque in below fig 6 (a), which is FOC model has less transient ripples and shown by yellow color. The torque in fig 6 (b), which is the DTC model, is smoothly following the load torque and it reaches the desired torque slower. But we have seen that the FOC, the spike in the torque when the motor is suddenly loaded. Due to this spiky torque, motor is forced to draw a higher current especially.



(a)

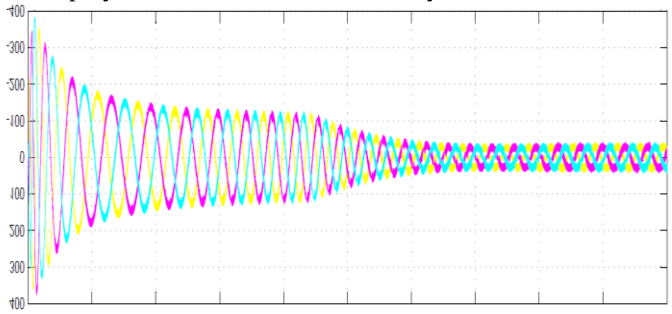


(b)

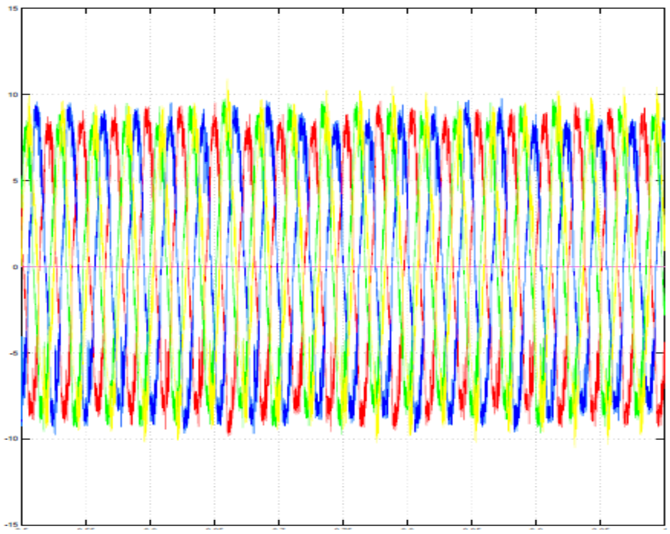
Figure 6 Electromagnetic Torque (a) FOC (b) DTC

C. Three phase current Comparison

The three phase current analysis in FOC and DTC models are shown in Fig 7 (a) and (b) respectively. We have seen thatFig 7 (b) has a higher transient current, but when the motor is loaded, the current is reaching the nominal current smoothly. In case of FOC, when the motor is loaded, the current is reaching the normal current immediately, and sometimes little spiky current if the motor is heavily loaded.



(a)



(b)

Figure 7 Three phase motor current (a) FOC (b) DTC

VI. CONCLUSION

In this paper, two induction motor drive techniques (FOC and DTC) are first studied theoretically by using MATLAB/SIMULINK. We also explain the basic principles of those two differing methods and the mathematical representations and the needed operation to achieve the high performance control. Those methods are compared by using MATLAB/SIMULINK models of FOC and DTC. In the comparative study of DTC and FOC, the speed response resultant from the FOC is faster and more robust than the DTC. The DTC technique has a better torque response, which is following the load torque smoothly instead of having the torque overshoot to a higher value than the required. That is a distinct disadvantage, because of the higher current that the motor must draw. DTC is easier to implement but FOC is more complicated because of the coordinate transformation which helps in the decoupling control. Thus, it is hard to say that DTC is better than FOC each of the techniques has the excellence in some of the comparison aspects on the other. In generally, each technique has over advantages and disadvantages. So finally, we cannot say that one of them is best than the other because it is based on particular application.

REFFERENCES

[1] A. M. Trzynadlowski, Control of induction motors: Academic Pr, 2001.
[2] C. M. Ong, Dynamic simulation of electric machinery: using MATLAB/SIMULINK vol. 5: Prentice Hall PTR Upper Saddle River, NJ, 1998.
[3] W. Theodore, Electrical Machines, Drives and Power Systems, 6/E: Pearson Education India, 2007.
[4] P. Vas, Vector control of AC machines: Clarendon press Oxford, 1990.
[5] N. Mohan and T. M. Undeland, Power electronics: converters, applications, and design: Wiley-India, 2007.

[6] T. Gonen, Electrical Machines withMatlab: CRC Press, 2011.
[7] K. S. Gaeid, H. W. Ping, and H. A. F. Mohamed, "Simulink representation of induction motor reference frames," 2009, pp. 1-4.
[8] J. A. Santisteban and R. M. Stephan, "Vector control methods for induction machines: an overview," Education, IEEE Transactions on, vol. 44, pp. 170-175, 2001.
[9] X. Wang, Y. Yang, and W. Liu, "Simulation of vector controlled adjustable speed System of induction motor based on Simulink," 2011, pp. 2563-2566.
[10] R. Lee, P. Pillay, and R. Harley, "D, Q reference frames for the simulation of induction motors," Electric power systems research, vol. 8, pp. 15-26, 1984.
[11] S. Masoudi, M. R. Feyzi, and M. Sharifian, "Speed control in vector controlled induction motors," 2009, pp. 1-5.
[12] K. Shi, T. Chan, and Y. Wong, "Modelling of the three-phase induction motor using SIMULINK," 1997, pp. WB3/6.1-WB3/6.3.
[13] A. Diaz, R. Saltares, C. Rodriguez, R. Nunez, E. Ortiz-Rivera, and J. Gonzalez-Llorente, "Induction motor equivalent circuit for dynamic simulation," 2009, pp. 858-863.
[14] A. Iqbal, A. Lamine, and I. Ashra, "Matlab/Simulink Model of Space Vector PWM for Three-Phase Voltage Source Inverter," 2006, pp. 1096-1100.
[15] F. M. Abdel-kader, A. El-Saadawi, A. Kalas, and O. M. EL-baksawi, "Study in direct torque control of induction motor by using space vector modulation," 2008, pp. 224-229.
[16] S. Allirani and V. Jagannathan, "High Performance Direct Torque Control of Induction Motor Drives Using Space Vector Modulation," International Journal of Computer Science, vol. 7.
[17] Y. Tang and G. Lin, "Direct torque control of induction motor based on self-adaptive PI controller," 2010, pp. 1230-1234.
[18] J. N. Nash, "Direct torque control, induction motor vector control without an encoder," Industry Applications, IEEE Transactions on, vol. 33, pp. 333-341, 1997.
[19] H. Le-Huy, "Comparison of field-oriented control and direct torque control for induction motor drives," 1999, pp. 1245-1252 vol. 2.
[20] S. Vaez-Zadeh and E. Jalali, "Combined vector control and direct torque control method" Energy conversion and management, vol. 48, pp. 3095-3101, 2007.

