

## SPEED CONTROL OF INDUCTION MOTOR USING VECTOR OR FIELD ORIENTED CONTROL

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**ABSTRACT:** AC induction motors of different power ratings and sizes can be utilized in applications ranging from consumer to automotive goods. A few of these applications from the multitude of possible scenarios demand for high speeds while high torque at low speeds only. A common everyday example with these mechanical requirements is of the motor installed in a washing machine. This requirement can be addressed through Vector Field Oriented Control or the FOC of an Induction machine. The objective of this Application Note is developing and implementing an efficient Field Oriented Control (FOC) algorithm that could be implanted to control the speed and torque of three phase asynchronous motors more effectively and efficiently.

**KEYWORDS:** vector-control, speed control, torque control, induction motor, speed regulator, IGBT Inverter

### I. INTRODUCTION

Vector control principles applied to an asynchronous motor which are based on the decoupling between the components of current used to generate torque and magnetizing flux. The decoupling allows the induction motor to be controlled as a simple DC motor. The vector control implies the translation of coordinates from the fixed reference stator frame to the frame of rotating synchronous [4][6]. Due to this translation; it is possible the decoupling of the stator current divided into two components, which are responsible for the generation of torque and magnetizing flux. AC Induction motors have desirable characteristics such as robustness, reliability and ease of control[1]; are used in various applications ranging from industrial motion, control systems to home appliances. A few years ago the AC motor used plugged directly into the mains supply or controlled the well-known scalar V/f method. When power is supplied to an induction motor at the specifications, it runs at its rated speed with this method, even small change is impossible and its system is dependent on the motor design like starting torque vs. maximum torque and torque vs. inertia or number of pole pairs. However many applications need variable speed operation. The scalar Vector control method is used to provide speed variation but does not handle transient condition and control is valid only during steady state[6]. This method is most suitable for applications without position control requirements or the need for high accuracy of speed control and leads to over-currents and overheating, the last few years have seen rapid growth in the field of electrical drives[3]. This growth mainly to the advantages offered by semiconductors in both signal electronics and

power[7][9]; hence giving beneficial to powerful microcontrollers and DSPs. These technological for very effective AC drive controls, marked with lower power dissipation hardware and accurate control structures. Using three phase current and voltage the electrical drive controllers even more accurate. This application describes the efficient scheme of vector control - the Field Oriented Control (FOC). On the application of this control structure to an AC machine, with a speed position sensor coupled to the shaft, the AC machine acquires advantage of a DC machine control structure i.e. a very accurate steady state and transient control along with higher dynamic performance.

### II. THE FOC ALGORITHM

FOC (or vector-control) algorithm is summarized Below:

1. Measure the stator phase currents  $i_a$ ,  $i_b$  and  $i_c$ . If only the values of  $i_a$  and  $i_b$  are measured  $i_c$  can be calculated as for balanced current  $i_a + i_b + i_c = 0$ .
2. Transform the set of these three-phase currents onto a two-axis system. This conversion provides the variables  $i_\alpha$  and  $i_\beta$  from the measured  $i_a$ ,  $i_b$  and  $i_c$  values where  $i_\alpha$  and  $i_\beta$  are time-varying quadrature current values, This conversion is popularly known as Clarke Transformation.
3. Calculate the rotor flux and its orientation.
4. Rotate the two-axis coordinate system such that it is in alignment with the rotor flux.
5. Using the transformation angle calculated at the last iteration of the control loop.
6. This conversion provides the  $i_d$  and  $i_q$  variables from  $i_\alpha$  and  $i_\beta$ . This step is more commonly known as the Park Transformation.
7. Flux error signal is generate using reference flux and estimated flux value.
8. A PI controller is then used to calculate  $i^*d$  using this error signal.
9.  $i^*d$  and  $i^*q$  are converted to a set of three phase currents to produce  $i^*a$ ,  $i^*b$ ,  $i^*c$ .
10.  $i^*a$ ,  $i^*b$ ,  $i^*c$  and  $i_a$ ,  $i_b$ ,  $i_c$  are compared using hysteresis comparator to generate inverter gate signals.

### III. MATLAB SIMULATION OF FOC OR VECTOR CONTROL

To apply above the algorithm to developed it SIMULINK model and a powerful simulation software with very helpful in forming a complete model. System Overview: The motor to be controlled is in a close loop with the FOC block which generates inverter switching commands to achieve

the desired electromagnetic torque at the motor shaft.

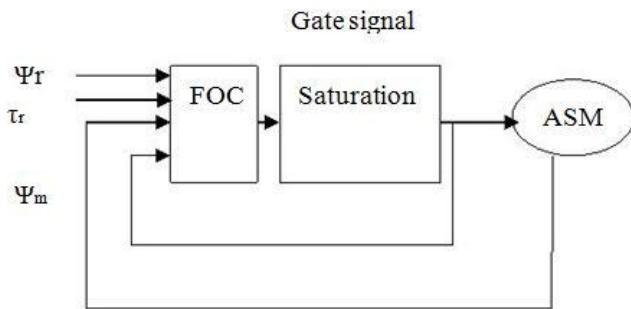


Figure 1: Complete Schematic Diagram

Flux Estimator: This block is used to estimate the motor's rotor flux. This calculation is based on motor equation synthesis[8].

$$\Psi_r = \frac{Lm}{1+Trs} (i_{ds})$$

θ<sub>r</sub> Calculation : This block is used to find the phase angle of the rotor flux rotating field using the following equations. θ<sub>r</sub> = θ<sub>r</sub> + θ<sub>m</sub> From which it can be established that,

$$\frac{d\theta_f}{dt} = \frac{d\theta_r}{dt} + \frac{d\theta_m}{dt}$$

Which can also be written as

$$\frac{d\theta_f}{dt} = \omega_r + \omega_m$$

Therefore,

$$\theta_f = \int (\omega_r + \omega_m) dt \text{ with } \omega_r = \frac{Lm i_{ds}}{Tr \Psi_r}$$

Park Transformation:

This translation of the a,b and c phase variables into dq components of the rotor flux rotating field reference frame[11].

Inverse Park Transformation:

This conversion of the dq component of the rotor flux rotating field reference frame into a, b and c phase variables.

i<sub>qs</sub> Calculation:

Shown in fig 3, The calculated rotor flux and the torque reference to compute the stator current quadrature component and required to produce the electromagnetic torque on the motor's shaft[5].

Flux PI:

The estimated rotor flux and the reference rotor flux as the input to a Proportional Integrator which calculates the flux. This flux is applied to the motor and which is used to compute the stator current or direct component required to produce the required rotor flux in the machine [7][8]. shown in fig 2

Current Regulator:

The current regulator is a current controller with

adjustable hysteresis band width[5]. Modulation Technique used in current regulator. The hysteresis modulation is a feedback current control method. Where the motor current tracks the reference current within a hysteresis band[2]. The operation principle of the hysteresis modulation to controller and generates sinusoidal reference current of desired magnitude frequency which then is compared to the actual motor line current. If current cross the upper limit of the hysteresis band, the upper switch of the inverter arm is turned off and the lower switch is turned on. As a result, the current starts to decrease. If the current cross the lower limit of the hysteresis band[6][5], the lower switch of the inverter arm is turned off and the upper switch is turned on. As a result, the current gets back into the hysteresis band. Hence, the actual current is forced to track the reference current within the hysteresis band.

SIMULINK model of FOC:

All the algorithms is applied on the working of vector control and to generate a proper output voltage from inverter ,This inverter control is done by given the signal to the gate terminal of inverter, inverter generate desired voltage of by compare with reference voltage to rotor voltage. Blocks discussed above which make up the complete FOC block. The switching control is used to limit the inverter commutation frequency to a maximum value specified by the user.

SIMULINK sub FOC Blocks:

Fig 5 shown a complete vector control simulink block diagram. Represent the SIMULINK version of various FOC blocks explained earlier i.e. blocks used for coordinate transformation namely the Park and Inverse Park transformations.

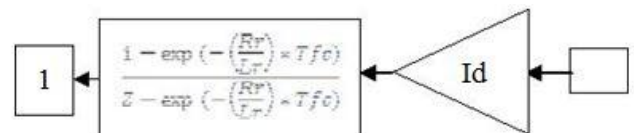


Figure 2: Flux Estimator

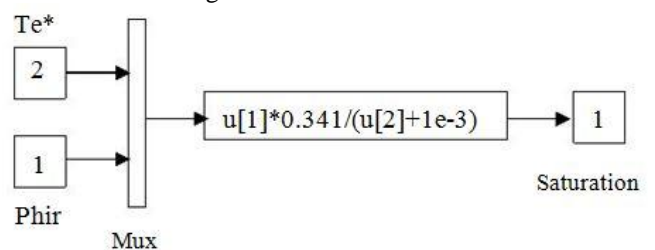


Figure 3: I\*qs calculation

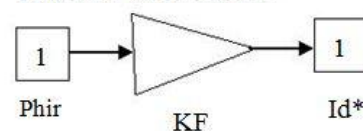


Figure 4: id\* calculation

Parameters equation:

Teta= Electrical angle= integ ( wr + wm)  
 wr = Rotor frequency (rad/s)=Lm \*Iq / ( Tr \* Phir)  
 wm= Rotor mechanical speed (rad/s)  
 Lm = 34.7 mH

$L_r = L_l'r + L_m = 0.8 + 34.7 = 35.5 \text{ mH}$   
 $R_r = 0.228 \text{ ohms}$   
 $T_r = L_r / R_r = 0.1557 \text{ s}$   
 $I_q = (2/3) * (2/p) * (L_r/L_m) * (T_e / \Phi_{hir})$   
 $I_q = 0.341 * (T_e / \Phi_{hir})$   
 $L_m = 34.7 \text{ mH}$   
 $L_r = L_l'r + L_m = 0.8 + 34.7 = 35.5 \text{ mH}$   
 $p = \text{nb of poles} = 4$   
 $\Phi_{hir} = L_m * I_d / (1 + T_r.s)$   
 $L_m = 34.7 \text{ mH}$   
 $T_r = L_r / R_r = 0.1557 \text{ s}$   
 $L_r = L_l'r + L_m = 0.8 + 34.7 = 35.5 \text{ mH}$   
 $R_r = 0.228 \text{ ohms}$

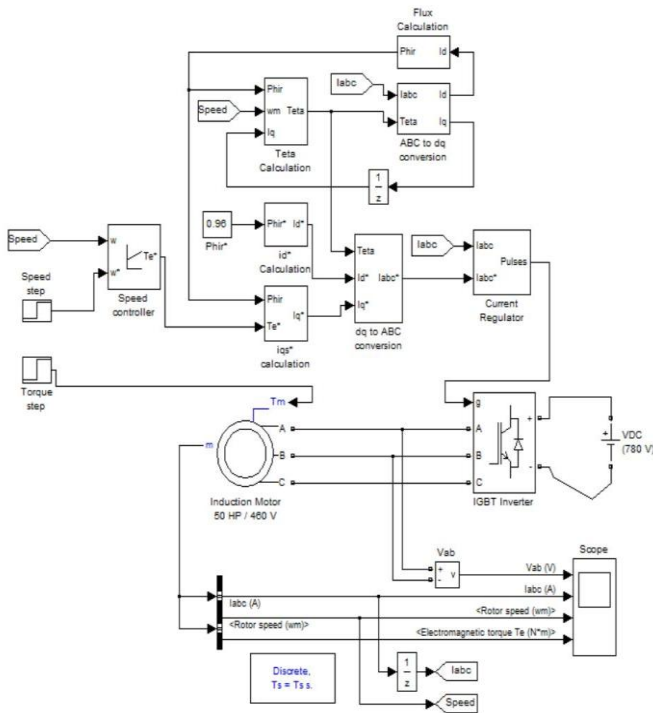


Figure 5: Simulink Block Diagram Of vector or Filed Oriented Control Method.

#### IV. SIMULATION RESULTS

##### FOC Simulation Results:

Motor Parameter: 50 HP/460v/60Hz/1780 rpm Graph shows voltage, phase current, rotor speed and electromagnetic torque wave form respectively.

##### Speed Parameters:

Step Time=0.2; Initial Value=120; Final Value=160;  
 Torque parameters: Step Time=1.8; Initial value=0; Final value=300; Sample time=-1; Result shows in fig. 6.

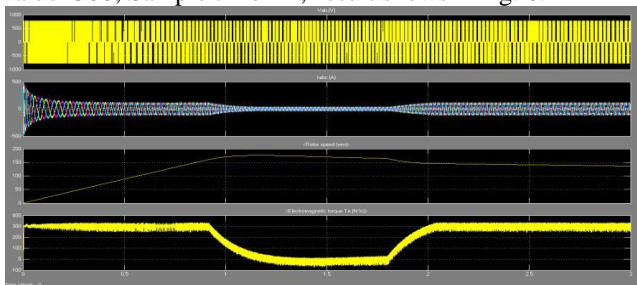


Figure 6: Result 1.

##### Speed Parameters:

Step Time=0.2; Initial Value=120; Final Value=160;  
 Torque parameters: Step Time=1.8; Initial value=300;  
 Final value=0; Sample time=-1; Result shows in fig. 7.

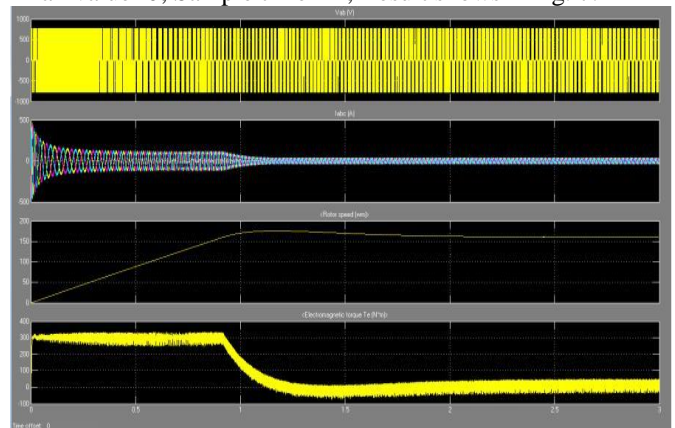


Figure 7: Result 2.

##### Speed Parameters:

Step Time=0.2; Initial Value=150; Final Value=160;  
 Torque parameters: Step Time=1.8; Initial value=0; Final value=300; Sample time=-1; Result shows in fig. 8.

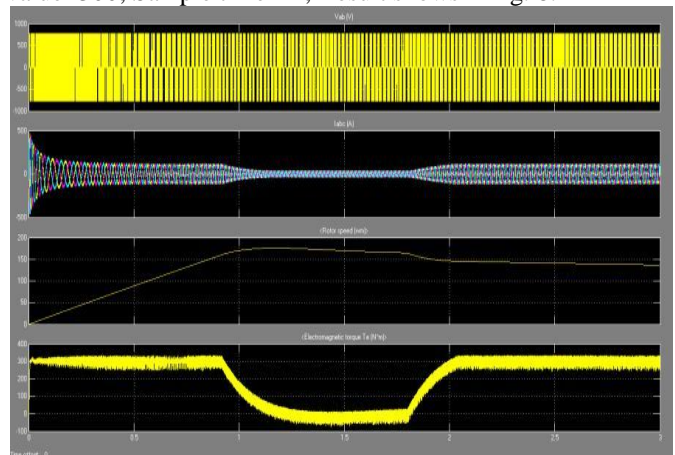


Figure 8: Result 3

##### Speed Parameters:

Step Time=0.2; Initial Value=120; Final Value=200;  
 Torque parameters: Step Time=1.8; Initial value=0; Final value=300; Sample time=-1; Result shows in fig. 9.

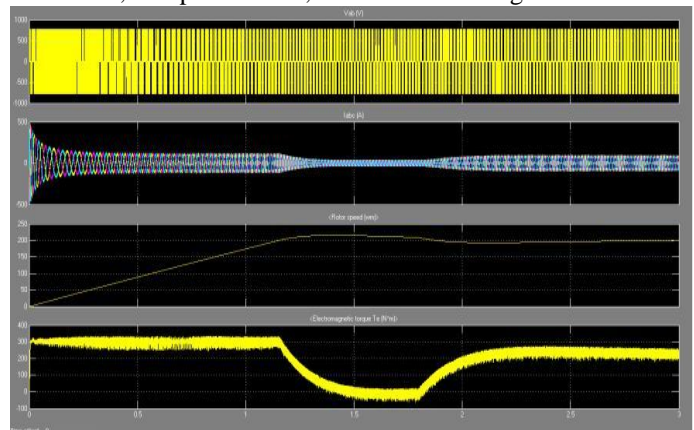


Figure 9: Result 4

## V. CONCLUSION

Fast response of vector control make it better than other method of speed control of induction motor, By using this method we attend maximum response in minimum time .By result analysis change in load torque speed attend reference speed in minimum time, by comprise with scalar control method this method is fast accurate and control variable speed of induction motor. We can control speed by varying parameters of motor, load torque, load limit value. Its sharp and accurate function of flux and speed control. By redefining the maximum torque and acceleration limit parameters the rise time could also be modified easily. The degraded performance for a sampling time Scalar control is simple to implement, but the inherent coupling effect (that is both the flux and the torque are functions of voltage or current and frequency) gives sluggish response and the system is prone to instability because of a high order system effect. If the torque is increased by incrementing the slip or frequency the flux tends to decrease and this flux variation is very slow. The flux decrease is then compensated by the flux control loop, which has a large time constant. Normal scalar control of induction machine aims at controlling the magnitude and frequency of the currents or voltages but not their phase angles. Separately excited dc motor drives are simple in control because they independently control flux, which, when maintained constant, contributes to an independent control of torque. This is made possible with separate control of field and armature currents, which control the field flux and the torque independently. The dc motor control requires only the control of the field or armature current magnitudes, This is not possible in scalar control method with an ac machine. In contrast, the induction motor drive requires a coordinated control of stator current magnitudes, frequencies and phase magnitude making it a complex control. As with the dc motor drives, independent control of flux and the torque is possible in ac drives.

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