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Universal Algorithm for Permanent Magnet Motor

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***Abstract*—This paper presents sensored and sensorless field oriented control algorithm in which initially motor startup takes place by using resolver, when motor achieves 10% of the rated speed algorithm will automatically shifts on sensorless algorithm as both methods has its own advantages and disadvantages. At low speed sensorless control does not gives correct rotor position and at high speed sensored control current and hence torque contains more ripple, to eliminate this issue sensored and sensorless control is combined. For motor control, C2000 series Piccolo LaunchPad TMS320F28069M of 90MHz is used.C2000 has in built Instaspin MOTION which gives Flux, Rotor angle, Speed and Torque of motor. Model based design approach is used in Altair Embed. At low speed sensorless control does not gives correct rotor position and at high speed sensored control current and hence torque contains more ripple, to eliminate this issue sensored and sensorless control is combined.**

***Index Terms*—C2000,TMS320F28069M, Resolver, Sensorless, Field Oriented Control**

I. INTRODUCTION

The Permanent Magnet motors are widely used in applications such as robotics, aeronautics, automotive, machine tools, etc. These motors have high power density, high reliability, maintenance free, silent operation which makes them ideal for high torque to weight ratio applications

For three-phase BLDC/PMSM motors, six-step commutation with 120 degree conduction time allows the current to flow in only two phases at any one time. This leaves the third phase available for sensing back EMF, which indicates the rotor position. Since the back EMF is directly related to the rotor position, sensing the back EMF will enable the controller to drive the motor without Hall or other type position sensors. Lizuka and Uzuhashi [1] originally proposed the method of sensing back EMF. However, since this direct back-EMF- sensing scheme requires a minimum PWM “off” time, the duty cycle is limited to something less than 100%.

In many automotive applications, the desire is to run the motor at 100% duty cycle to fully utilize the low bus voltage, this improvement is done in [2]-[5].[6] shows a simple structure PMSM rotor position sensor, which is composed of 4 linear Hall sensors displaced (90+k360)0 ,electrically, a stator frame, a permanent magnetic ring with 10 SmCo magnets which can produce an essentially sinusoidal air-gap magnetic field and a hollow shaft. The proposed rotor position sensor in [6] can reduce the size of motor drivers because of its simple signal processing circuits.

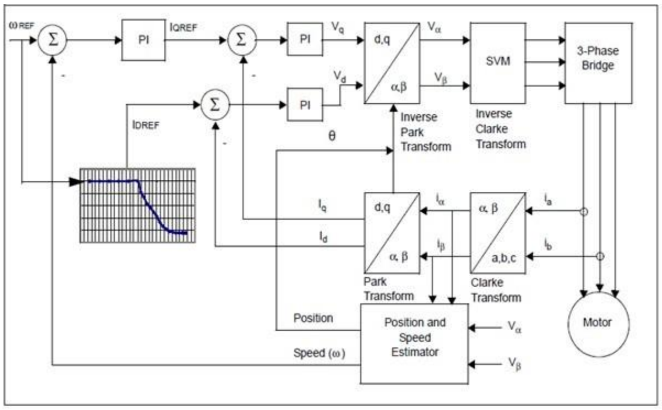


Fig. 1. Field oriented Control Block Diagram

[7] gives understanding of electrical drives starting at a basic level with minimum theoretical content and/or develop their own AC drive application using sensored or sensor less technology. Modules (3-5) in [7] provides hands on experiments based on Altair Solid Thinking EMBED software.

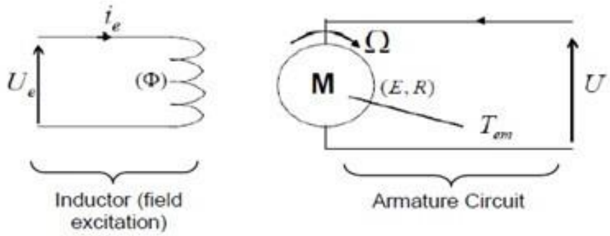
In this project title, Sensored and sensorless field oriented control algorithm is developed where sensored algorithm can switched into sensorless algorithm when 10 % of maximum speed is achieved as there are specific advantages of sensored and sensorless depending on the performance and application. To do this, C2000 series TMS320F28069M is used which is having in built Instaspin MOTION that gives Flux, Rotor angle, Speed and Torque of motor.

II. FIELD ORIENTED CONTROL

A. The main philosophy behind the FOC

In order to understand the spirit of the Field Oriented Control technique, let us start with an overview of the separately excited direct current (DC) Motor. In this type of motor, the excitation for the stator and rotor is independently controlled. Electrical study of the DC motor shows that the produced torque and the flux can be independently tuned.

The strength of the field excitation (i.e. the magnitude of the field excitation current) sets the value of the flux. The current through the rotor windings determines how much torque is produced. The commutator on the rotor plays an interesting part in the torque production. The commutator is in contact with the brushes, and the mechanical construction is designed to switch into the circuit the windings that are mechanically aligned to produce the maximum torque. This arrangement then means that the torque production of the machine is fairly near optimal all the time. The key point here is that the windings are managed to keep the flux produced by the rotor windings orthogonal to the stator field.



$$\boxed{\begin{aligned} T_{em} &= K.\Phi.I \\ E &= K.\Phi.\Omega \\ \Phi &= f(I_e) \end{aligned}}$$

Fig. 2. Seperately Excited DC Motor Model

AC machines do not have the same key features as the DC motor. In both cases we have only one source that can be controlled which is the stator currents. On the synchronous machine, the rotor excitation is given by the permanent magnets mounted onto the shaft. On the synchronous motor, the only source of power and magnetic field is the stator phase voltage.The goal of the FOC (also called vector control) on synchronous and asynchronous machine is to be able to separately control the torque producing and magnetizing flux components. The control technique goal is to (in a sense), imitate the DC motor's operation. FOC control will allow us to decouple the torque and the magnetizing flux components of stator current. With decoupled control of the magnetization, the torque producing component of the stator flux can now be thought of as independent torque control. To decouple the torque and flux, it is necessary to engage several mathematical transforms, and this is where the microcontrollers add the most value. The processing capability provided by the microcontrollers enables these mathematical transformations to be carried out very quickly. This in turn implies that the entire algorithm controlling the motor can be executed at a fast rate, enabling higher dynamic performance. In addition to the decoupling, a dynamic model of the motor is now used for the computation of many quantities such as rotor flux angle and rotor speed. This means that their effect is accounted for, and the overall quality of control is better. According to the electromagnetic laws, the torque produced in the synchronous machine is equal to vector cross product of the two existing magnetic fields:

$$T_{em} = \bar{B}_{stator} \times \bar{B}_{rotor}$$

This expression shows that the torque is maximum if stator and rotor magnetic fields are orthogonal meaning if we are to maintain the load at 90 degrees. If we are able to ensure this condition all the time, if we are able to orient the flux correctly, we reduce the torque ripple and we ensure a better dynamic response. However, the constraint is to know the rotor position: this can be achieved with a position sensor such as incremental encoder. For low-cost application where the rotor is not accessible, different rotor position observer strategies are applied to get rid of position sensor.

In brief, the goal is to maintain the rotor and stator flux in quadrature: the goal is to align the stator flux with the q axis of the rotor flux, i.e. orthogonal to the rotor flux. To do this the stator current component in quadrature with the rotor flux is controlled to generate the commanded torque, and the direct component is set to zero. The direct component of the stator current can be used in some cases for field weakening, which has the effect of opposing the rotor flux, and reducing the back-emf, which allows for operation at higher speeds.

B. *Mathematical model of PMSM*

PMSM are of a modern rare-earth variety with high resistivity, so induced currents in the rotor are negligible. In addition, there is no difference between the back EMF produced by a permanent The stator of the PMSM and the wound rotor SM are similar. The permanent magnets used in the magnet and that produced by an excited coil. Hence the mathematical model of a PMSM is similar to that of the wound rotor SM. The following assumptions are made in the derivation:

1) Saturation is neglected although it can be taken into account by parameter changes.
2) The induced EMF is sinusoidal..
3) Eddy currents and hysteresis losses are negligible.
4) There are no field current dynamics.
5) There is no cage on the rotor.

With these assumptions, the stator d, q equations of the PMSM in the rotor reference frame are[8]-[10]:

III. ENCODER

In this work,Absolute encoder is used which gives analog outputs. It provides analog sine and cosine output voltages that describe the magnet angle in a range of 0 to 360°.Placement of

$$\begin{bmatrix} V_{ds}^{r} \\ V_{qs}^{r} \end{bmatrix} = \begin{bmatrix} R_d + L_{ds} * P & -\omega_r + L_{qs} \\ \omega_r + L_{ds} & R_q + L_{qs} * P \end{bmatrix} \begin{bmatrix} i_{ds}^{r} \\ i_{qs}^{r} \end{bmatrix} + \begin{bmatrix} 0 \\ \omega_r * \psi_{fr} \end{bmatrix}$$

Where,

$$V_{ds}^{r} = L_{ds} * i_{ds}^{r} + \psi_{fr}$$

$$\psi_{qs}^{r} = L_{qs} * i_{qs}^{r}$$

Torque Equation in rotor reference frame,

$$T_e = \frac{3}{2} * \frac{P}{2} \left[\psi_{ds}^{r} * i_{qs}^{r} - \psi_{qs}^{r} * i_{ds}^{r} \right]$$

By substituting and rewriting,

$$T_e = \frac{3}{2} * \frac{P}{2} \left[\underbrace{(L_{ds} - L_{qs}) i_{qs}^{r} * i_{ds}^{r}}_{\text{Reluctance Torque Component}} + \underbrace{L_{md} * i_{fr}^{r} i_{qs}^{r}}_{\text{Field or Excitation Torque Component}} \right]$$

$$T_e = \frac{3}{2}\frac{P}{2}\left[L_{md} * i_{fr} * i_s \right]$$

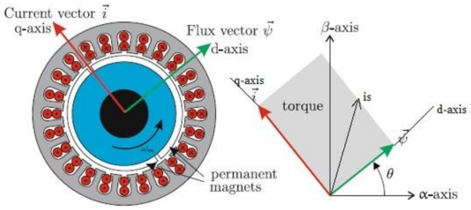


Fig. 3. Cross Section and Vector diagram

angle sensor is shown in fig.4 Some features of angle sensors are

1) 360° contactless angle measurement.
2) Output amplitude optimized for circuits with 3.3 V or 5 V supply voltage.
3) Operating temperature: -40°C to 125°C.

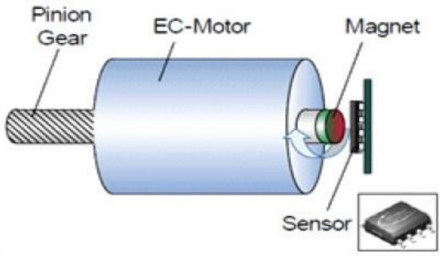


Fig. 4. Typical placement of anglr sensor

A. Implementation of angle calculation

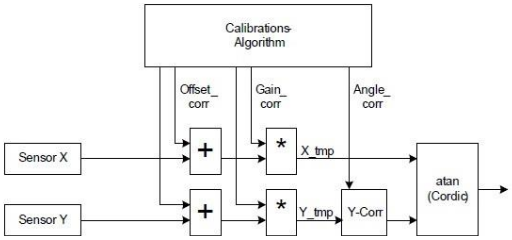


Fig. 5. Implementation of angle sensor

To get highly accurate angle values, the following angle calculation must be performed. Fig.5 shows the implementation within a microcontroller[11]. All the equations are implemented in Altair Embed by using [11] as shown in fig.6

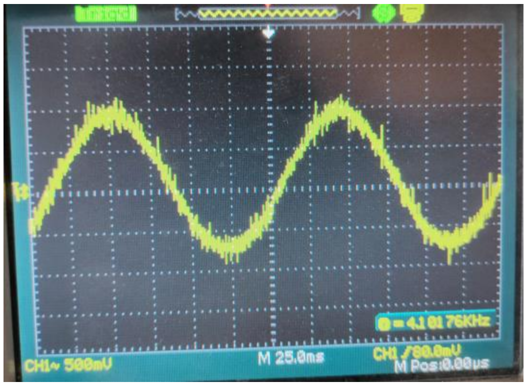


Fig. 6. External signal without filter

Fig. 7. External signal with filter

Analog output containing some noise and this noise is eliminated by using External RC filer which reduces ripples in the original signal as shown in fig.6 and fig.7 RC low pass Filter R=3.2KOhm and C=3.3nF.

Filtered signal from encoder and Commanded or reference Q-axis current is used for motor startup and when motor acheives 10% of rated speed algorithm will shift on sensorless control due to specific advantages and disadvantages of both the methods.

FOC algorithm and all equations in [8]-[10] are implemented in fig.8

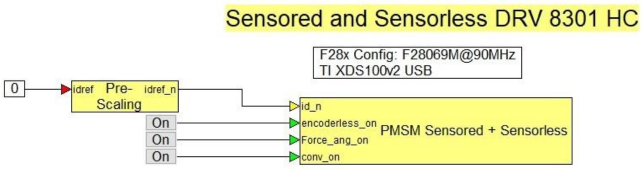


Fig. 8. FOC sensored and sensorless

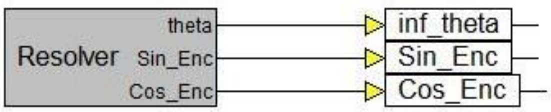


Fig. 9. Implementation of angle sensor in Altair Embed

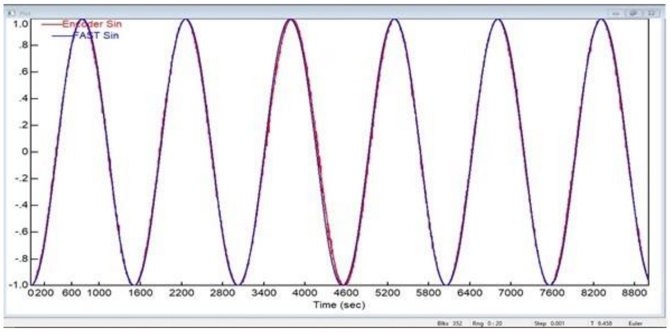


Fig. 10. Results of Resolver sin and Fast Sin

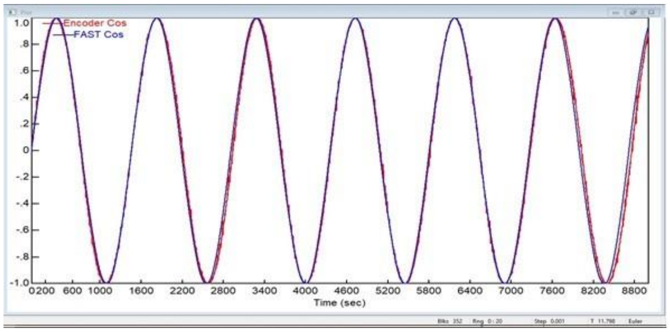


Fig. 11. Results of Resolver Cos and Fast cos

TABLE I

Model Parameters	Values
Stator Resistance (Rs)	0.03026 Ohm
D-axis inductance (Ld)	26.356 uH
Q-axis inductance (Lq)	26.356 uH
PM flux	20.613 mWb
Poles	8

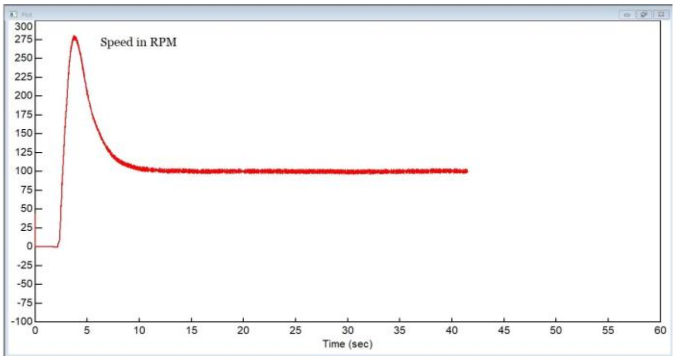


Fig. 12. Speed Vs Time

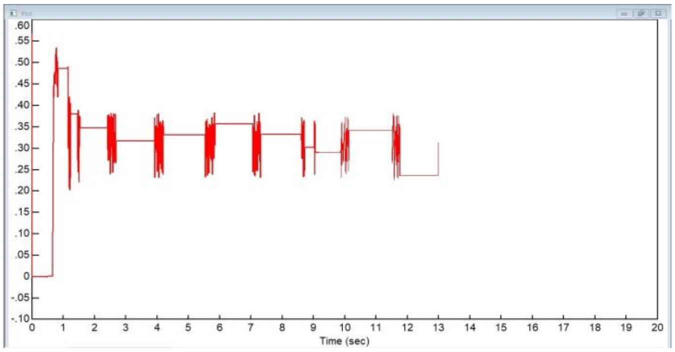


Fig. 13. Torque Vs Time

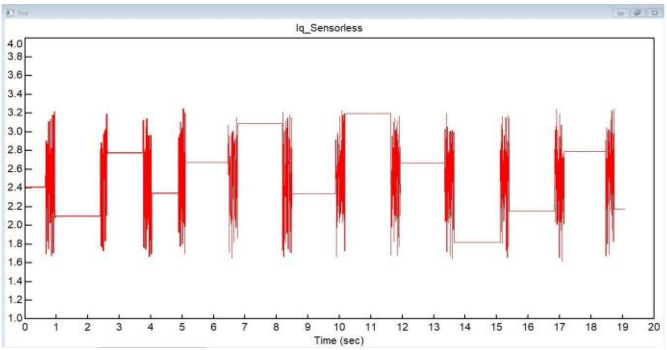


Fig. 14. Iq semsorles Vs Time

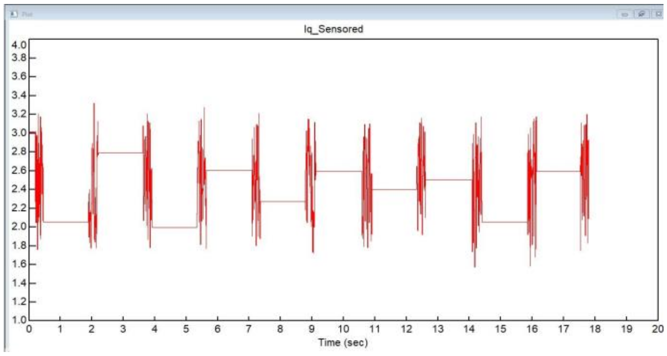


Fig. 15. Iq sensored Vs Time

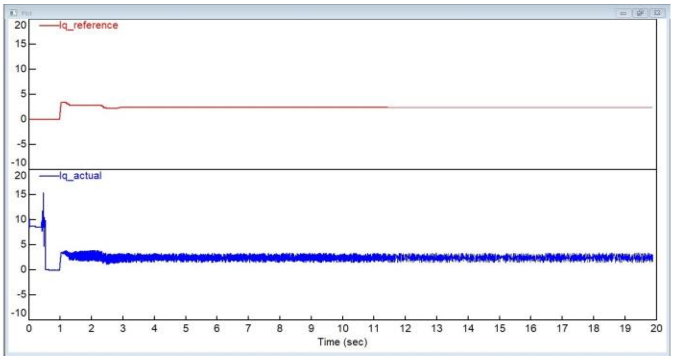


Fig. 16. Iq Vs Time

REFERENCES

[1] Iizuka, Kenichi, Hideo Uzuhashi, Minoru Kano, Tsunehiro Endo, and Katsuo Mohri. ”Microcomputer control for sensorless brushless motor.” IEEE Transactions on Industry Applications 3 (1985): 595-601.
[2] Shao, Jianwen. ”An improved microcontroller-based sensorless brushless DC (BLDC) motor drive for automotive applications.” IEEE Transactions on industry applications 42, no. 5 (2006): 1216-1221.
[3] Ogasawara, Satoshi, and Hirofumi Akagi. ”An approach to position sensorless drive for brushless DC motors.” IEEE Transactions on Industry Applications 27, no. 5 (1991): 928-933.
[4] Lin, Cheng-Tsung, Chung-Wen Hung, and Chih-Wen Liu. ”Position sensorless control for four-switch three-phase brushless DC motor drives.” IEEE transactions on power electronics 23, no. 1 (2008): 438-444.
[5] Davoine, Jacques, Robert Perret, and Hoang Le-Huy. ”Operation of a self-controlled synchronous motor without a shaft position sensor.” IEEE Transactions on Industry Applications 2 (1983): 217-222.
[6] Hu, Jianhui, Jibin Zou, Fei Xu, Yong Li, and Yanchao Fu. ”An improved PMSM rotor position sensor based on linear Hall sensors.” IEEE Transactions on Magnetics 48, no. 11 (2012): 3591-3594.
[7] Pulle, Duco WJ, Pete Darnell, and Andre´ Veltman. ”Applied control of electrical drives.” (2015).
[8] Pillay, Pragasen, and Ramu Krishnan. ”Modeling, simulation, and analysis of permanent-magnet motor drives. I. The permanent-magnet synchronous motor drive.” IEEE Transactions on industry applications 25, no. 2 (1989): 265-273.
[9] Chen, Jiexin, Jinhui Zhang, and Ran Huang. ”Disturbance observer based fuzzy speed regulator for permanent magnet synchronous motor.” In 2016 35th Chinese Control Conference (CCC), pp. 148-153. IEEE, 2016.
[10] Pillay, Pragasen, and Ramu Krishnan. ”Control characteristics and speed controller design for a high performance permanent magnet synchronous motor drive.” In 1987 IEEE Power Electronics Specialists Conference, pp. 598-606. IEEE, 1987.
[11] Infineon Technologies, Munich, Germany.”TLE5309D” Edition 2017-10.
[12] Ramamoorthy, Ramesh T., Brett Larimore, and Manish Bhardwaj. ”Sensored Field Oriented Control of 3-Phase Permanent Magnet Synchronous Motors Using TMS320F2837x.” (2016).