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Speed Control of IPM Motor Using Vector Control in Self-Synchronous Mode

Aakanksha Sharma[1] & B. N. Phadke[2]

[1]Student, M.Tech (Power Electronics) Department of Electrical and Electronics Engineering, Electronics Engineering, I.E.S, IPS Academy, Indore,I.E.S, IPS Academy, Indore, India.

[2]Head of Department, Department of Electrical and Department of Electrical and Electronics Engineering, Electronics Engineering, I.E.S, IPS Academy, Indore,I.E.S, IPS Academy, Indore, India. India.

sharmaaakanksha21@gmail.com; bnphadke@gmail.com

ABSTRACT

This paper presents a comparative study of different controlling techniques used for an IPM motor in electric vehicles and benefits of self-synchronous control using vector control of IPM motor. In self synchronous mode, the rotor speed is sensed using an encoder, the rotor speed and stator speed are then compared to generate an error signal. The speed of the stator field is changed according to the error signal using vector control, and the rotor track this synchronous speed. In this project, indirect vector control is done by generating command torque signals with the help of speed signals. The system is developed by using simulation model in SIMULINK.

KEYWORDS: PMSM motor; IPM motor; self-synchronous control; Electric vehicles; Vector control

A) INTRODCTION

1. <u>IPM MOTOR : INTERIOR PERMANENT MAGNET MOTOR</u>
   IPM motor is a type of permanent magnet synchronous motor (PMSM). In this kind of motor, the permanent magnets are buried inside the rotor. The arrangement of magnets makes the d-axis inductance, Ld larger than the q-axis inductance, Lq. This arrangement gives the rotor an inherent saliency. This saliency is responsible for armature reaction the motor offers. The speed of the motor can be increased beyond the base speed because of this armature reaction. These motor are now gaining popularity in terms of better efficiency and high torque than induction motor and no external excitation requirement(unlike synchronous motor). The main applications of this motor are: EVs (Electric Vehicles)& HEVs (Hybrid ElectricVehicles). The torque (Te) of this motor has two components: the first term due to torque generated by magnets and the second term due to reluctance torque:

   Te=(3P/4ωb)[(Fds+vf)iqs - (Fqs.ids)] ……………………(1) [9] where, Fds & Fqs are flux linkages in d & q axis respectively, vf is induced emf and id &iq are d-&q- axis currents respectively, P is number of poles & ωb is the base frequency.

2. <u>VARIOUS TYPES OF CONTROL USED FOR IPM MOTOR</u>
   There are mainly two modes of controlling speed of IPM motor: a) true synchronous mode and b) self-synchronous mode. In true synchronous mode the rotor speed is changed by changing stator supply frequency. This change in stator supply frequency is done independently, and difference between the rotor speed and stator speed is kept generally small so as to make rotor to track the changes in synchronous speed. Therefore, in this case damper winding is necessary to use to avoid hunting while chasing the stator frequency.

In self-synchronous mode (self-controlled mode) of control, encoders are usually mounted on the shaft of machine so as to track the speed of rotor. These encoders generate signals which are in proportion to the rotor speed. This signal is utilised to change the stator supply frequency, so that the rotor speed remains same as the synchronous speed.This control hence, does not require any damper winding, as the machine remains in synchronism at all frequencies, hence, called self-synchronous mode.

After 80s, many sensorless techniques were developed for speed control of IPM motor. The input given to the speed regulator is a signal, proportionalto the rotor speed [1]. But, as the encoder was not used in this method; a software was developed by using state observer to determine the speed. This method gave results which were good enough. Advantages of sensorless control are reduced hardware, complexity and lower cost, reduced size of the drives, elimination of the sensors [2]. Sensorless control are of either open loop scheme or closed loop scheme. Various observers in closed loop schemes are being used. These observers are Sliding mode observer, Extended Kalman Filter & model reference adaptive system etc. But, major problem associated with the sensorless control technique is ineffectiveness of speed control at low speeds because of its inability to identify rotor position at such low speeds. Therefore, for improvement in controlling at low speeds, injected signals with frequencies different from the fundamental frequency are used to determine the rotor position (also at standstill). Likewise, many other methods of sensorless control generally use high frequency injection technique to determine rotor position at low speed or during standstill. But these methods introduces ripple and noise in the system, apart from parameters variations [3]. Also, the method of using magnetic saliency to determine the rotor position is different as the method is based on the difference in the north and south pole position. This position is estimated by the offset currents. At low speeds, the flux gets saturated and impedence of the north pole decreases andsouth poleincreases. The direction of flow of offset current determines the north pole position; but the response is usually weak due to the use of low pass filter to determine offset currents. Hence, they also used high frequency injection technique under various loads and to obtain accurate pole position, hysteresisphenomena was used.The rotor position estimation in sensorless method is done by using the motor voltages, currents and motor parameters [4]. These methods employ difficult and complex calculations. Also, the efficiency and accuracy is affected by wrong estimations and generate errors. But, in V/f control or open loop control, there is no use of pole position and current regulators. Thus, there is no use of motor parameters and this method is thus simpler in terms of control. Due to large armature inductance of IPM motor,it shows good flux-weakening property (because of armature reaction)[5].This property makes the motor suitable to operate in constant power region. But, at high speeds the demand of voltage increases due to increase in command voltage, thereby, saturating the current regulators. This leads to poor response of the motor. So, a voltage command compensator was used. A similar problem was highlighted in [6]. In this, the motor performance was improved by using PWM inverters in constant torque region and to avoid the saturation problem of PI controller at higher speeds; square wave mode inverter was used above base speed. So that a smooth transition from one region (constant torque)to another region (constant power)can happen. Performance of any drive depends on the methods of implementation. It also depends on the system parameters considered while controlling speed [7]. The main application of IPM motor is in propulsion system in EVs.This paper states the method to improve the performance of motor by Maximum Torque per Ampere control

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method. This method is useful in constant torque region when the speed of motor is below base speed. Many previous papers took id value as zero but actually the complexity in calculations arises due to nonlinearity, because of taking id merely zero. Thus, by calculating id from iq, power capability can be improved. In many methods employing flux weakening control, inductances were assumed to be constant, but actually these are a function of d- and q-axis stator currents [8]. Hence, cannot be considered as constant if optimization is main aim of speed control. Also, the paper mentioned that both stator resistance and magnetic saturation affect the optimization in controlling. In this paper unlike the previous papers, value of id is not considered as zero for better controlling. Though above methods aim to control speed successfully but, they have many limitations as follows:

1.In V/f control, the method is feasible only till the rotor is able to track the changes in stator frequency. This is possible only when changes in frequency are slow enough that rotor can trace it. Also, damper winding is necessary.

2.In sensorless control method, the main challenge is to construct such an estimator that can withstand changes in temperature, noise etc.

3.Also, the challenge is to implement such an estimator that is very close to the mathematical model of the motor. This is something very hard to achieve and thus leads to instability and inaccuracy problems.

4.Though, it is very much possible to estimate speed of rotor with the help of digital Signal Processor but the calculation and estimation are complex. Many other factors such as, offset currents, drifts, non-linearities and disturbances add to the problem of complexity.

5.Sensorless control are very difficult to implement at low speed region. The phase inductances vary at different rotor positions due to rotor saliency. The determination of rotor position from the knowledge of inductances is generally implemented using high frequency signals. These high frequencieshave adverse effects on motor dynamics and also,apart from all the above methods, several other methods such as variable structure method,hardware is required for signal injection.

6.Apart from all the above methods, several other methods such as variable structure based technique, artificial intelligence and fuzzy logic for speed estimation require large memory and computational complexity.

7. Hence, self-controlled (closed loop) vector control proves to be more promising in terms of accuracy and performance. Though this method requires speed encoder which increases the weight and size. In this paper, self-synchronous mode is used and speed controlling is done using vector control in SIMULINK. The model is shown below with description.

B) SELF-SYNCHRONOUS MODE: VECTOR CONTROL OF IPM MOTOR

The rotor actual speed (Wr) is compared with a reference speed (as shown in fig-1). The reference speed is taken as 2000 rpm. The resultant signal called an error signal thus, generated is sentto a PI controller. The output of PI controller is a command torque (Te*), also, command flux is generated using a function generator, FG1 from the rotor actual speed. These command signals are utilised to generate d-& q- axis currents id* and iq*. These command currents are then utilised to generate command stator current (is*), by using function generator, FG2.

$$Is^* = \sqrt{(id^{*2} + iq^{*2})} \quad \text{……………(2) [9]}$$

This stator current is then converted into three phase command currents,Iabc*. This three phase currents are then compared with actual three phase currents of the motor to generate pulses, which are given to a PWM inverter. The PWM converter gives variable three phase voltages, va, vb, vc. These voltages are then converted into two phase

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rotating frame (to control torque and flux)vd and vq.

Conversion from three phase to two stationry phase:

$vqs^s = vas$

$vds^s = -(1/\sqrt{3})vbs + (1/\sqrt{3})\,vcs$ …………(3) [9]

Conversion from two stationary phase to two synchronously rotating frame:

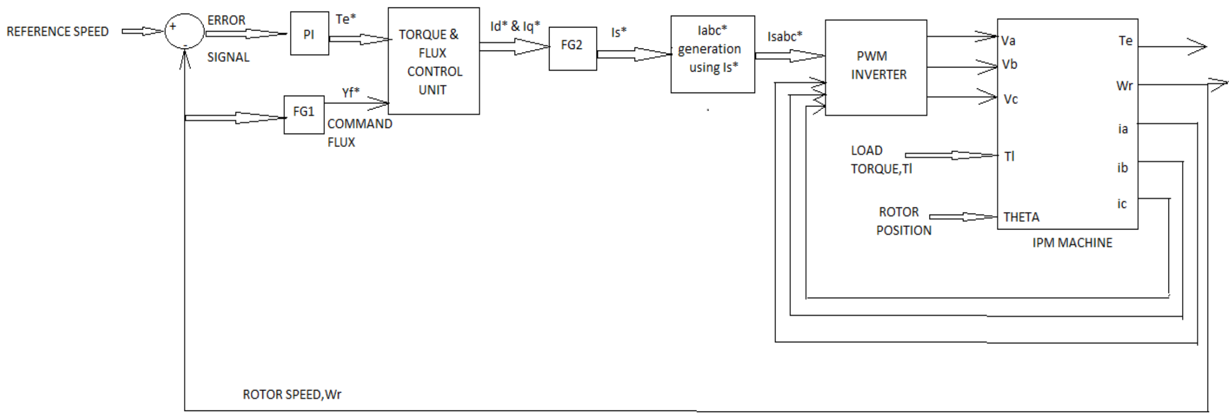
$vqs^e = vqs^s \cos\Theta e - vds^s \sin\Theta e$

$vds^e = vqs^s \sin\Theta e + vds^s \cos\Theta e$ …………(4)[9]

where, ϴe is the angle between q^s axis and q^eaxis.These synchronously rotating frame voltages are used to generate current commands ids and iqsby using function generator. These currents are ultimately used to generate desired torque and speed by using (1) and (5).

$Te = T_L + (\,^{2}/_{P}\,)J\,(^{d\omega e}/_{dt})$ …………..(5)[9]

Also these two phase currents are converted back to three phase currents iabc. The block diagram of the model used in this project is also shown below.



SIMULATION MODEL SHOWING SPEED CONTROL OF IPM MOTOR

Fig-1: BLOCK DIAGRAM OF SIMULATION MODEL

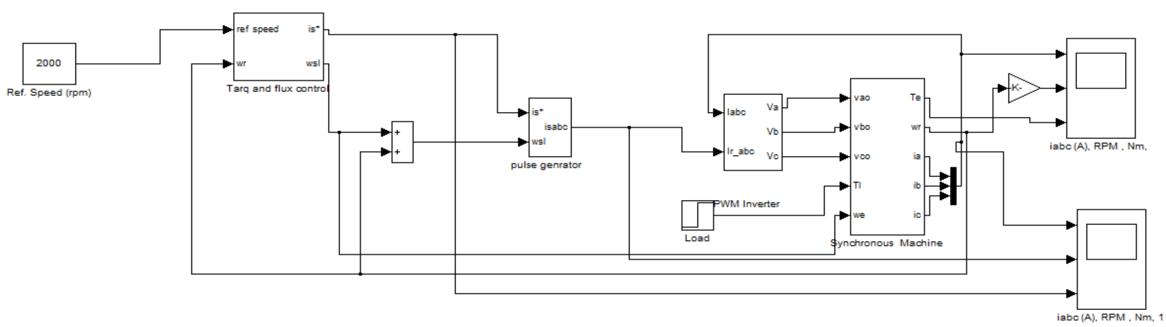


Fig- 2: Simulation model of vector control

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C) RESULTS OBTAINED

In this project, the reference speed is taken as 2000rpm, and the results obtained are close to the desired speed. The graphs are shown below for various values of parameters considered for simulation. The first graph shows three phase currents (iabc), second graph shows speed vs time curve and the third graph is showing torque vs time curve.

Base frequency, fb	113.076 Hz
Induced emf, vf	40.2 V
Stator resistance, Rs	0.00443 ohm
Rotor leakage reactance, Xlr	0.0189 ohm
Magnetising reactance, Xm	0.2532 ohm
Rotor inertia, J	0.226 Nm
Poles, P	4
Rotor resistance, Rr	0.0051 ohm

Table-1: Motor Parameters used in simulation

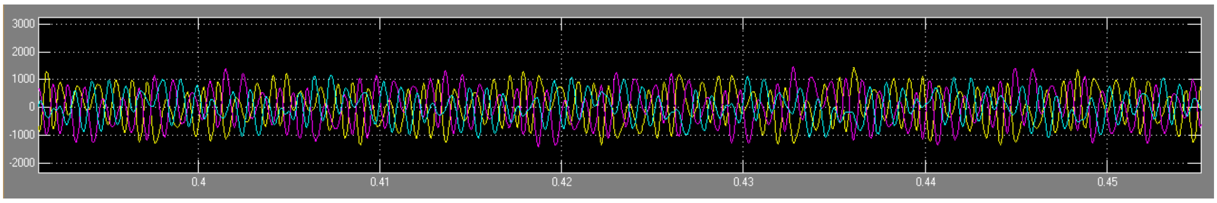

Fig-3

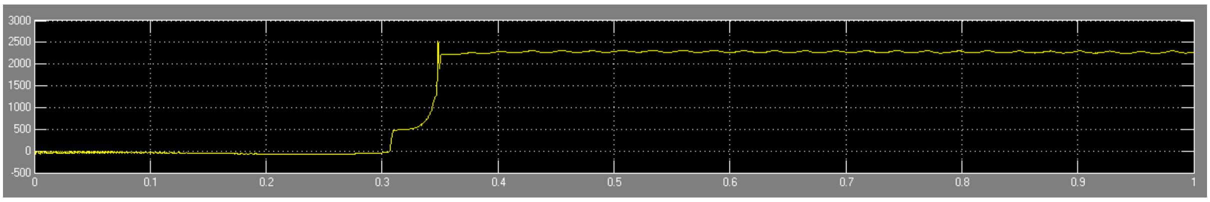

Fig-4

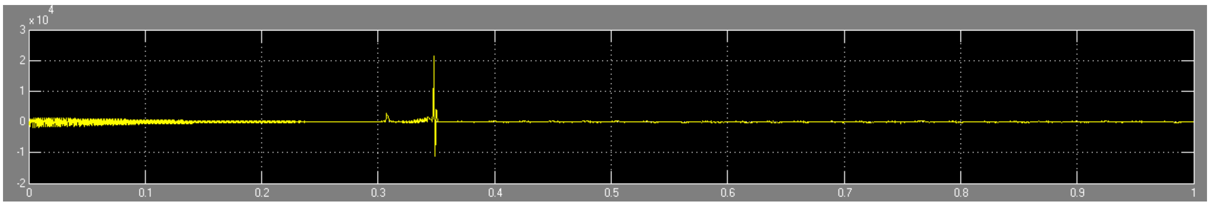

Fig-5

The torque of this motor is coming as 300Nm. This result show that the model used for the self-synchronous control is quite good in terms of controlling speed. Hence, this method can be employedin various applications for better efficiency.

D) CONCLUSION

The self-synchronous mode of control of IPM motor has many advantages: the machine doesn't have any stability or hunting problem, with magnets placed inside the rotor- so rotor inertia can be greatly reduced, by changing the delay angle- the phase angle between stator current and flux can be changed to achieve required torque. Also the method is simple to implement. The saturation problem of PI regulator can be solved by using voltage boosters. Though it is not used here.The simulation is done for IPM motor as per the selected parameters and output thus generated is quite satisfactory.

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