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Permanent Magnet Synchronous Motor Control with Speed Feedback Using a Resolver

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Abstract

Synchronous Motor drives are close competitors to induction motor drives in many industrial applications. They are generally more expensive than induction motor drives, but the advantage is that efficiency is higher, which tends to lower cost. Permanent Magnet Synchronous Machines are used in low to medium power applications. Nowadays, Permanent Magnet Synchronous Motors evolved as preferred solution for speed and position control drives. One of the best control strategies is Vector Control or Field oriented control. In this paper, a resolver is used to detect rotor position of PMSM. Due to its robust structure and noise insensitivity, this is implemented here. Presented method is simulated using Power SIM.

Keywords

PMSM, Position Sensor, Vector Control, Resolver, PSIM

I. Introduction

Permanent magnet (PM) synchronous motors are widely used in low and mid power applications such as computer peripheral equipment, robotics, adjustable speed drives and electric vehicles [1]-[3]. The growth in the market of PM motor drives has demanded the need of simulation tools capable of handling motor drive simulations. Simulations have helped the process of developing new systems including motor drives, by reducing cost and time. Simulation tools have the capabilities of performing dynamic simulations of motor drives in a visual environment so as to facilitate the development of new systems. Due to its high power density and smaller size, PMSM has in recent years evolved as the preferred solution for speed and position control drives on machine tools and robots [4]-[7]. In vector control drive, the highly accurate position sensor is required to transform the 3-phase variables to the 2-phase variable in the synchronously rotating reference frame aligned with the rotor flux linkage vector [8]. Resolver is the one of position sensors that can measure the initial rotor position at standstill [9]-[11]. This feature is important to gain the maximum starting torque in such drive system. In this work, the simulation of a field oriented controlled PM motor drive system with Resolver is developed using PSIM.

II. Permanent Magnet Synchronous Motors

A permanent magnet synchronous motor (PMSM) is a motor that uses PMs to produce the air gap magnetic field rather than using electromagnets. These motors have significant advantages, attracting the interest of researchers and industry for use in many applications [1], [2].

A. Permanent Magnet Materials

The properties of the PM material will affect directly the performance of the motor and proper knowledge is required for the selection of the materials and for understanding PM motors. The earliest manufactured magnet materials were hardened steel. Magnets made from steel were easily magnetized. However, they could hold very low energy and it was easy to demagnetize. In recent years' other magnet materials such as aluminum nickel and cobalt alloys (ALNICO), strontium ferrite or barium ferrite (Ferrite), samarium cobalt (first generation rare earth magnet) (SmCo) and neodymium iron-boron (second generation rare earth magnet) (NdFeB) have been developed and used for making PMs. The rare earth magnets are categorized into two classes: samarium cobalt (SmCo) magnets and neodymium iron boride (NdFeB) magnets. SmCo magnets have higher flux density levels but they are very expensive. NdFeB magnets are the most common rare earth magnets used in motors these days. [2]

B. Classification of PM Motors depending upon direction of Field flux

PM motors are broadly classified by the direction of the field flux. The first field flux classification is radial field motor meaning that the flux is along the radius of the motor. The second is axial field motor meaning that the flux is perpendicular to the radius of the motor. Radial field flux is most commonly used in motors and axial field flux have become a topic of interest for study and used in a few applications [3].

C. Classification of PM Motors depending upon Flux Density Distribution

PM motors are classified on the basis of the flux density distribution and the shape of current excitation. They are PMSM and PMPM brushless motors. The PMSM has a sinusoidal-shaped back EMF and is designed to develop sinusoidal back EMF waveforms as listed below. [4]-[6]

1. Sinusoidal distribution of magnet flux in the air gap
2. Sinusoidal current waveforms
3. Sinusoidal distribution of stator conductors.

BLDC has a trapezoidal-shaped back EMF and is designed to develop the following trapezoidal back EMF waveforms.

1. Rectangular distribution of magnet flux in the air gap
2. Rectangular current waveform
3. Concentrated stator windings.

D. PM Radial Field Motors

In PM motors, the magnets can be placed in two different ways on the rotor. Depending on the placement they are called either surface PM motor or interior PM motor. Surface mounted PM motors have a surface mounted PM rotor. Each of the PM is mounted on the surface of the rotor, making it easy to build, and specially skewed poles are easily magnetized on this surface mounted type to minimize cogging torque. This configuration is used for low speed applications because of the limitation that magnets will fly apart during high-speed operations. These motors are considered to have small saliency, thus having practically equal inductances in both axes. The permeability of the PM is almost that of the air, thus the magnetic material becoming an extension of the air gap.[4]

The rotor has an iron core that may be solid or made of punched laminations for simplicity in manufacturing. Thin PMs are mounted on the surface of this core using adhesives. Alternating magnets of the opposite magnetization direction produce radially directed flux density across the air gap. This flux density then reacts with currents in windings placed in slots on the inner surface of the stator to produce torque.[5]

Interior PM motors have interior mounted PM rotor. Each PM is mounted inside the rotor. It is not as common as the surface mounted type but it is a good prospect for high-speed operation. There is inductance variation for this type of rotor because the PM part is equivalent to air in the magnetic circuit calculation. These motors are considered to have saliency with q axis inductance greater than the d axis inductance.[6]

III. Position Sensor

Operation of PM synchronous motors requires position sensors in the rotor shaft when operated without damper winding. The need of knowing the rotor position requires the development of devices for position measurement. There are four main devices for the measurement of position, the potentiometer, linear variable differential transformer, optical encoder and resolvers. The ones most commonly used for motors are encoders and revolvers. Depending on the application and performance desired by the motor a position sensor with the required accuracy can be selected. [6]-[8]

A. Optical Encoders

The most popular type of encoder is the optical encoder, which consists of a rotating disk, a light source, and a photo detector (light sensor). The disk, mounted on the rotating shaft, coded patterns of opaque and transparent sectors. As the disk rotates, these patterns interrupt the light emitted onto the photo detector, generating a digital pulse or output signal. Optical encoders offer the advantages of digital interface. There are two types of optical encoders, incremental encoder and absolute encoder. [6]-[7]

B. Incremental Encoders

Incremental encoders have good precision and are simple to implement but they lack information when the motor is at rest position and in order for precise position the motor must be at the starting point. The most common type of incremental encoder uses two output channels (A and B) to sense position. Using two code tracks with sectors positioned 90° degrees out of phase, the two output channels of the quadrature encoder indicate both position and direction of rotation. If A leads B, for example, the disk is rotating in a clockwise direction. If B leads A, then the disk is rotating in a counter-clockwise direction. By monitoring both, the number of pulses and the relative phase of signals A and B, it's possible to track position and direction of rotation. Some quadrature encoders also include a third output channel, called a zero or index or reference signal, which supplies a single pulse per revolution. This single pulse is used for precise determination of a reference position. The precision of the encoder is fix by its code disk but it can be increased by detecting the Up and Down transitions on both the A and B channels. [6]-[7]

C. Absolute Encoders

The absolute encoder captures the exact position of the rotor with a precision directly related to the number of bits of the encoder. It can rotate indefinitely and even if the motor stops, the position can be measured or obtained. It provides a "whole word" output with a unique code pattern representing each position. This code is derived from independent tracks on the encoder disc (one for each "bit" of resolution) corresponding to individual photo detectors. The output from these detectors is HI (light) or LO (dark) depending on the code disc pattern for that particular position. Absolute encoders are used in applications where a device is inactive for long periods of time or moves at a slow rate, such as flood gate control, telescopes, cranes, valves, etc. They are also recommended in systems that must retain position information through a power outage. [6]-[7]

D. Position Resolver

Position resolver as shown in Fig. 1, also called rotary transformers, works on the transformer principle. The primary winding is placed on the rotor and depending upon the rotor shaft angle the induced voltage at the two secondary windings of the transformer shifted by 90° would be different. The position can be calculated using the two voltages.

The resolver is basically a rotary transformer with one rotating reference winding (V_{ref}) and two stator windings. The reference winding is fixed on the rotor, and therefore, it rotates jointly with the shaft passing the output windings, as is depicted in Fig. 2. Two stator windings are placed in quadrature (shifted by 90°) with one another and generate the sine and cosine voltages (V_{sin} , V_{cos}) respectively. Both windings will be further referred to as output windings. In consequence of the excitement applied on the reference winding V_{ref} and along with the angular movement of the motor shaft θ, the respective voltages are generated by resolver output windings V_{sin} , V_{cos}. The frequency of the generated voltages is identical to the reference voltage and their amplitudes vary according to the sine and cosine of the shaft angle θ. Considering that one of the output windings is aligned with the reference winding, it has generated full voltage on that output winding and zero voltage on the other output winding and vice versa. [7]-[8]

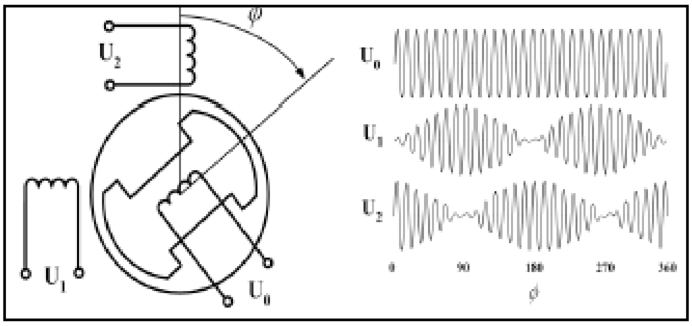

Fig. 1: Position Resolver

IV. Vector Controlled PMSM with Resolver

Fig. 2 below shows the block diagram of vector controlled drive system of PMSM using resolver sensor [9]-[11].

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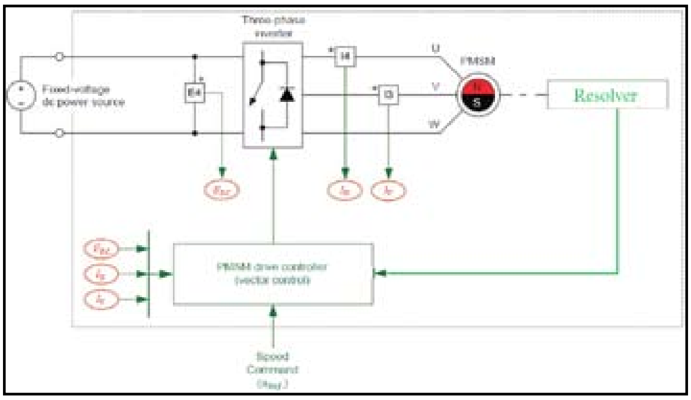

Fig. 2: Vector controlled drive system of PMSM using resolver

The schematic of resolver is shown in Figure 2. Three signals (i.e., excitation, sine and cosine signals) are obtained from the resolver. The sinusoidal excitation signal (U0) is applied to the rotor winding. The resolver outputs (stator windings) consist of two sinusoidal signals whose amplitudes are modulated according to the sine and cosine (U1 and U2) of the rotor position (θ).
The relevant equations of rotor winding (*U*0) and stator windings (*U*1 and *U*2) are summarized as follows.

$Uo(t) = Uo^* \sin(\omega t)$

$U1(\theta,t) = Uo^* \, k \sin\theta \sin(\omega t)$

$U2(\theta,t) = Uo^* \, k \cos\theta \sin(\omega t)$

Where k is turn ratio of resolver
Uo^* is peak value
ω is frequency of excitation signal
θ is rotor position

Fig. 3 shows the block diagram of resolver algorithm, including the demodulation and Speed/position calculation. The algorithm attempts to minimize the error between the actual rotor angle θ and the computed angle θ1, using a feedback loop. This error is controlled to zero by PI controller. The integrator is used to increase the resolution of computed angle. Once this control loop is accomplished (i.e., err = 0), then the computed angle θ1, which is limited within 0-2π rad, is equal to the actual rotor angle θ.

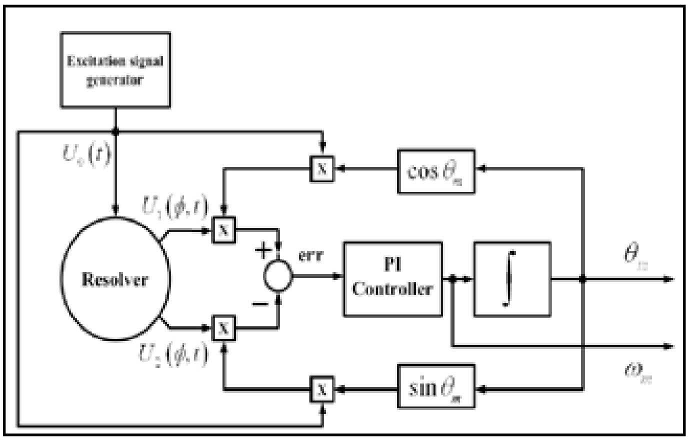

Fig. 3 : Resolver Algorithm

V. Simulink Circuits

Vector Controlled PMSM with Resolver circuit consists of four main blocks which are Speed and Current Loop Control, PWM Generator, PWM Inverter fed PMSM drive and Resolver are simulated using PSIM which are shown below.

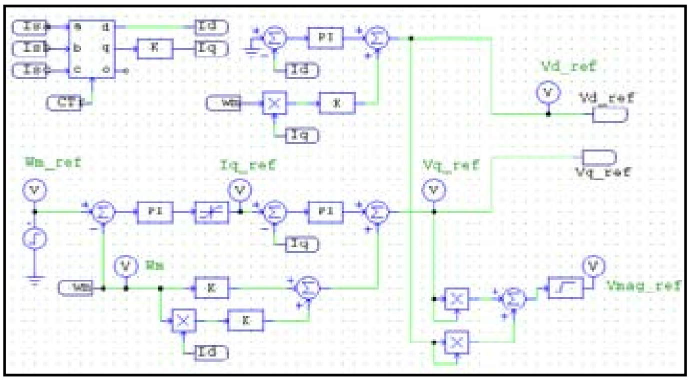

Fig 4. PSIM model of Speed and Current Loop Control

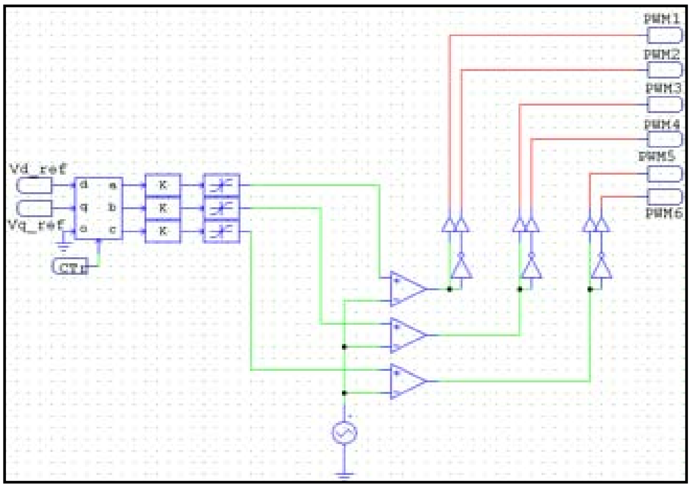

Fig. 5 : PSIM model of PWM Generation

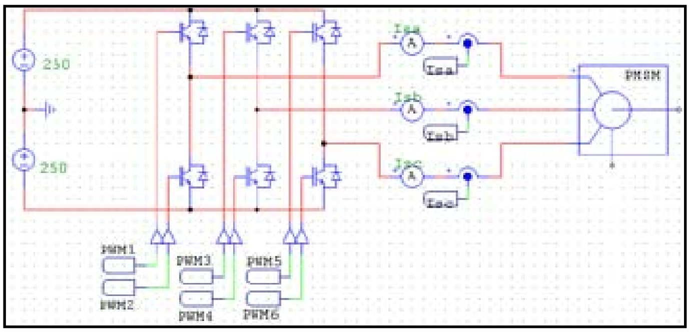

Fig. 6 : PSIM model of PWM Inverter fed PMSM drive

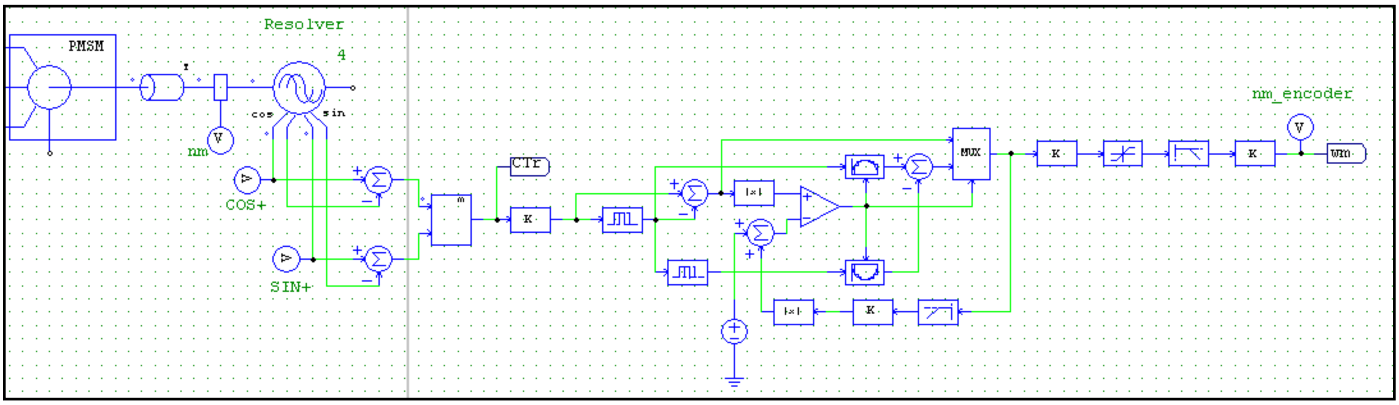

Fig. 7: PMSM Model of Resolver

VI. Simulink Results

The above-mentioned Simulink circuits are simulated and the obtained results are shown below.

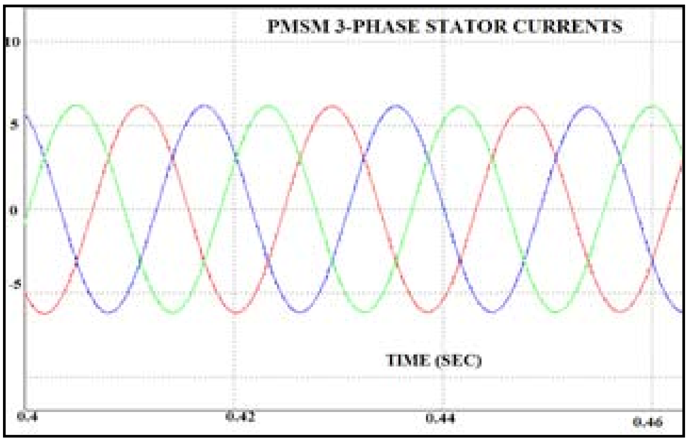

Fig. 9: Waveforms of 3-phase PMSM Stator Currents

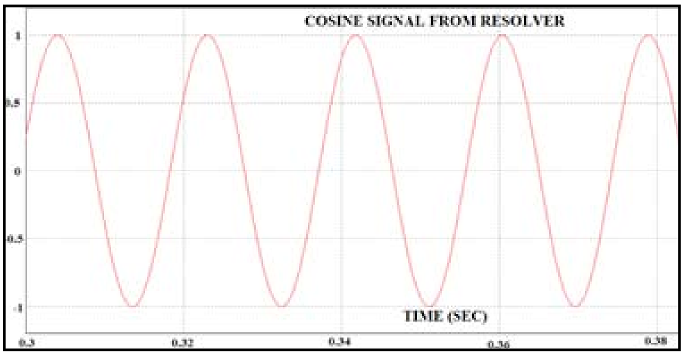

Fig. 10: Waveforms of Cosine signal from Resolver

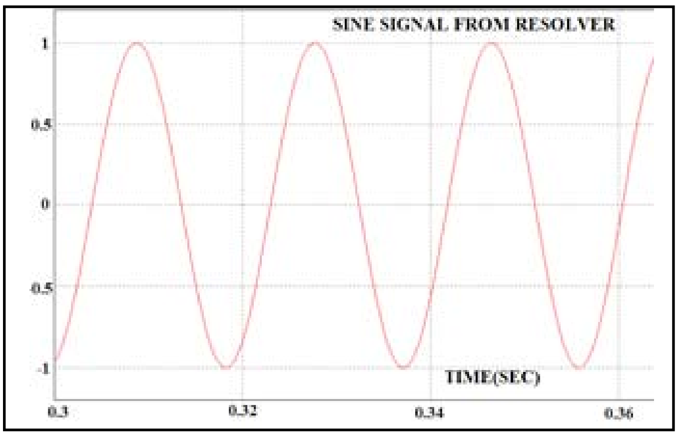

Fig. 11: Waveforms of Sine signal from Resolver

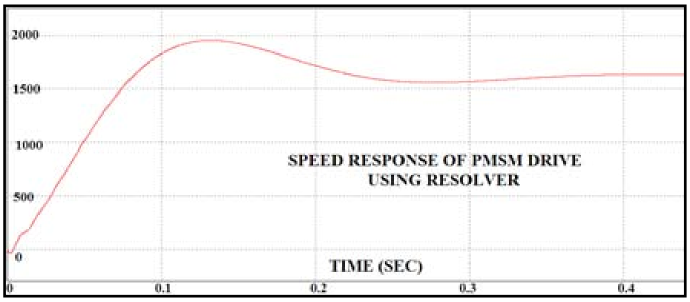

Fig. 12: Waveform of Speed Response of PMSM drive with Resolver

VII. Conclusions

In this paper, vector control is implemented on PMSM drive using resolver. PMSM is controlled using Speed feedback using Resolver. It is simulated in PSIM and obtained waveforms are shown. According to this resolver algorithm, computed angle can eventually match with actual rotor angle.

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