

Design And Implementation Of Speed Regulator For A PMSM Using Genetic Algorithm

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Abstract-- Power electronics plays an important role in controlling the drives. Digital control technology has been rapidly developed for power electronics and electrical drives, and it has been the impetus to the widespread use of a permanent magnet synchronous motor in many industrial applications such as chip mount machines, semiconductor production machines, high-resolution computerized numerically controlled machine tools, robotics, and hard disk drives. A PMSM has low noise, low inertia, high torque-to-current ratio, high efficiency, robustness, and low maintenance cost. We propose a genetic algorithm (GA) based speed regulator system for a permanent-magnet synchronous motor. By using the GA the motor acceleration observer as well as a speed regulator is designed. In terms of linear matrix inequalities, sufficient conditions for the existence of the regulator and observer are derived. Simulation and experimental results are given to verify that the proposed digital control method can be successfully used for a PMSM under model parameter and load torque variations.

Keywords—Genetic algorithm, speed regulation, Permanent magnet synchronous motor, driver, space vector modulation.

I.INTRODUCTION

The development and availability of very high-energy density Permanent Magnet materials has contributed to an increased use of the permanent magnet synchronous motor (PMSM) in high performance applications. High-speed electric machines are of interest as direct drives for high-speed milling machines, compressors and pumps, yielding a high output power at rather small machine dimensions. The high-speed permanent magnet Synchronous motor with sinusoidal

currents is the best choice for high-speed operation because of the high efficiency, low torque ripple, low noise and excellent control performance. The PMSM eliminates rotational cogging torque due to permanent magnet preferred positions, decreases core loss and thus increases efficiency, provides excellent torque to volume and power-to volume ratios and has a linear current versus torque relation. In the PMSM, in order to generate smooth torque and thus reduce noise and vibration, the current waveform should match the shape of the motor electromotive force (emf). The GA has found many applications in the area of the automatic tuning process for conventional and intelligent controllers. Some research has been conducted using genetic algorithms to help online or off line control systems. It has primarily been utilized as an off-line technique for performing a directed search for the optimal solution to a problem. In this paper, the GA is used on-line in real-time controller implementation to adaptively search through a population of controllers and determine the member most fit to be implemented over a given sampling period.

II.PERMANENT MAGNET SYNCHRONOUS MOTOR

The development of high-quality permanent magnet materials into commercial production has encouraged several manufacturers to launch various Permanent Magnet Synchronous Machines (PMSM) into the market. Permanent Magnet Synchronous Machines have been applied to servo drives for a long time already and nowadays, there are quite large permanent magnet synchronous machines also in industrial use. In wind mill generators

A. Equivalent circuit of PMSM

Similarly as separately excited synchronous machines, the PM Synchronous Machines are usually

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treated in a dq reference frame fixed to the rotor, Figure 2.7. The equivalent circuit of the machine is almost the same as for a separately excited synchronous machine.

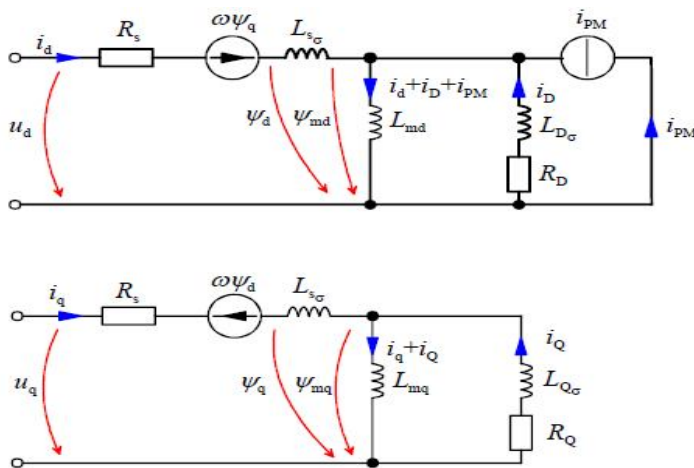


Fig 2.1 Equivalent circuits of a PMSM in d- and q- directions.

The permanent magnet can be depicted by a current source i_{PM} in the rotor circuit; in the magnetizing inductance, this current source produces the permanent magnet's share of the air gap flux linkage $\psi_{PM} = i_{PM} L_{md}$. If also the damper windings are included in the model, the voltage equations of a PM machine differ from a separately excited synchronous machine only by the fact that the equation for the field winding is lacking. Current vector control is quite widely adopted to the control of permanent magnet synchronous machines. A good performance can be achieved by this control method particularly because the parameters of PM machines do not vary as much depending on the operating situation as the parameters of other machine types do. Particularly in the motors applying surface mounted magnet rotor structures, the inductances remain constant quite well, and therefore the effect of armature reaction is small. Thus, the voltage equations of the PM machine are given in the rotor reference frame in the familiar form The flux linkage components in the equations are determined by the equations

$$\psi_{sd} = L_{sd}i_{sd} + L_{md}i_D + \psi_{PM},$$

$$\psi_{sq} = L_{sq}i_{sq} + L_{mq}i_Q,$$

$$\psi_D = L_{md}i_{sd} + L_Di_D + \psi_{PM},$$

$$\psi_Q = L_{mq}i_{sq} + L_Qi_Q.$$

$$i_{PM} = \frac{\psi_{PM}}{L_{md}},$$

Now the definitions for the flux linkages do not deviate from the definitions of a separately excited synchronous machine. However, it is worth noticing that due to the saturation of the magnetizing inductance L_{md} , i_{PM} is not constant.

III.DRIVER

In electronics, a driver is an electrical circuit or other electronic component used to control another circuit or other component, such as a high-power transistor. They are usually used to regulate current flowing through a circuit or used to control the other factors such as other components, some devices in the circuit. The term is often used, for example, for a specialized integrated circuit that controls high-power switches in switched-mode power converters. An amplifier can also be considered a driver for loudspeakers, or a constant voltage circuit that keeps an attached component operating within a broad range of input voltages. Typically the driver stage(s) of a circuit requires different characteristics to other circuit stages. For example in a transistor power amplifier, typically the driver circuit requires current gain, often the ability to discharge the following transistor bases rapidly, and low output impedance to avoid or minimize distortion. Every device, whether it is a printer, disk drive, or keyboard, must have a driver program.

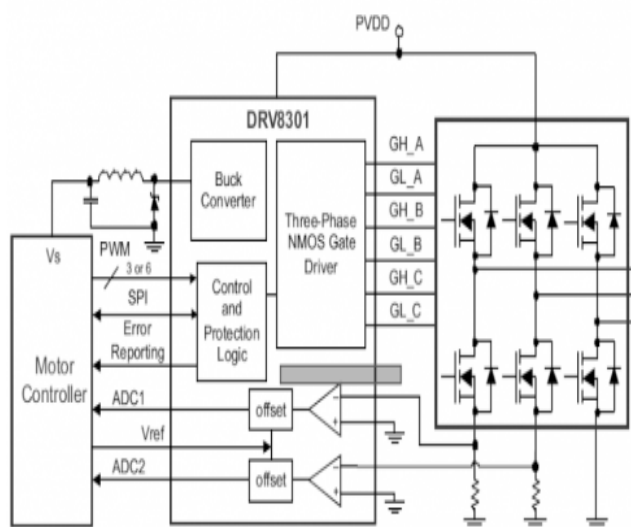


Fig 3.1 Motor Driver Component

The Motor Driver is the Integrated Part with Motor Power and Control Components. The Driver Controls the Motor Drive according to the input command from Motor Controller and power Circuit. In figure 4.5 DRV8301 is an example of motor Drive Components.

IV.SPACE VECTOR PWM (SVPWM)

Space Vector Modulation (SVM) can directly transform the stator voltage vectors from an α , β -coordinate system to Pulse Width Modulation (PWM) signals (duty cycle values). The standard technique for output voltage generation uses an inverse Clarke transformation to obtain 3-phase values. Using the phase voltage values, the duty cycles needed to control the power stage switches are then calculated. Although this technique gives good results, space vector modulation is more straightforward and realized more easily by a digital signal controller. SVPWM is actually just a modulation algorithm which translates phase voltage (phase to neutral) references, coming from the controller, into modulation times/duty-cycles to be applied to the PWM peripheral. SVPWM can directly transform the stator voltage vectors from the two-phase α , β -coordinate system into pulse-width modulation (PWM) signals (duty cycle values). Proverbial motor formulae are:

$$U_1 = \frac{d\psi_1}{dt} + R_1 i_1$$

U_1 is stator voltage vector, ψ_1 is flux vector, and i_1 is stator current vector.

When U_1 is a standard sine wave, that is the same size and direction continuous change, the trajectory is an ideal circle. So,

$$U_1 = \frac{d\psi_1}{dt} + R_1 i_1$$

When $R_1 \cdot i_1 \ll U_1$:

$$\psi_1 = \int U_1 dt$$

Flux trajectory depends on voltage vector.

So we can design the circuit of DC to 3-phase AC

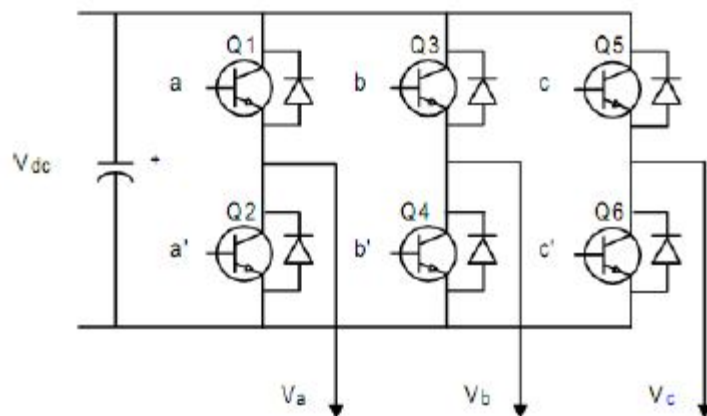


Fig 4.1 SVPWM inverter

As shown in figure 4.1, in the circuit diagram, have 6 power switch a, b, c, a', b', c' plot out they into 2 groups, S [a, b, c], S' [a', b', c'], they control the switch ON/OFF, and they mutex,

$$S_x = \begin{cases} S = 1 \\ S' = 0 \end{cases}$$

Its means each voltage vector is coded by the three-digit number and have eight possible switching states (vectors) are feasible.

For example: $S_x = [1, 0, 0]$

The point [a], [b'], [c'] switch ON, an [a'], [b], [c] switch OFF.

$$U_{aN} = U_{dc},$$

$$U_{bN} = U_{cN} = 0$$

In motor theory,

$$\begin{cases} U_a - U_b = U_{aN} - U_{bN} = U_{dc} \\ U_a - U_c = U_{dc} \\ U_a + U_b + U_c = 0 \end{cases}$$

Take $U_{aN} = U_{dc}$, $U_{bN} = U_{cN} = 0$ into the formula,

$$U_a = \frac{2U_{dc}}{3}, \quad U_b = -\frac{U_{dc}}{3}, \quad U_c = -\frac{U_{dc}}{3}$$

Similarly, can calculate other switching states, below in Table 4.1

Sa	Sa	Sa	Vector	U_{aN}	U_{bN}	U_{cN}	U_a	U_b	U_c
0	0	0	U_0	0	0	0	0	0	0
1	0	0	U_4	U_{dc}	0	0	$2U_{dc}/3$	$-U_{dc}/3$	$-U_{dc}/3$
1	1	0	U_6	U_{dc}	U_{dc}	0	$U_{dc}/3$	$U_{dc}/3$	$-2U_{dc}/3$
0	1	0	U_2	0	U_{dc}	0	$-U_{dc}/3$	$2U_{dc}/3$	$-U_{dc}/3$
0	1	1	U_3	0	U_{dc}	U_{dc}	$-2U_{dc}/3$	$U_{dc}/3$	$U_{dc}/3$
0	0	1	U_1	0	0	U_{dc}	$-U_{dc}/3$	$-U_{dc}/3$	$2U_{dc}/3$
1	0	1	U_5	U_{dc}	0	U_{dc}	$U_{dc}/3$	$-2U_{dc}/3$	$U_{dc}/3$
1	1	1	U_7	0	0	0	0	0	0

Table 4.1 Switching sequence of SVPWM

Form formula (4.3) and (4.4), the voltage space vector formula:

$$u_s = \left(\frac{2}{3}\right)(u_a + au_b + a^2u_c)$$

$$a = \exp\left(j\frac{2\pi}{3}\right) \quad a^2 = \exp\left(j\frac{4\pi}{3}\right)$$

Take table 4.1 vectors:

$$U_4 = \frac{2}{3}U_{dc} \quad U_6 = \frac{2}{3}U_{dc} \exp\left(j\frac{\pi}{3}\right) \quad (4.4)$$

$$U_2 = \frac{2}{3}U_{dc} \exp\left(j\frac{2\pi}{3}\right) \quad U_3 = \frac{2}{3}U_{dc} \exp(j\pi)$$

$$U_1 = \frac{2}{3}U_{dc} \exp\left(j\frac{4\pi}{3}\right) \quad U_5 = \frac{2}{3}U_{dc} \exp\left(j\frac{5\pi}{3}\right)$$

All of non-zero vectors have the same amplitude $2 U_{dc} / 3$, and between border two vectors angle is $\pi/3=60^\circ$ for example, $f=50\text{Hz}$, the vector change

$$t = \frac{60}{360} * \frac{1}{50} = 3.33\text{ms}$$

Graphical representation of all combinations of the hexagon shown in figure 4.3. There are six non-zero vectors, $U_0, U_6, U_{120}, U_{180}, U_{240}, U_{300}$, and two zero vectors, O_{000} and O_{111} , defined in α, β coordinates.

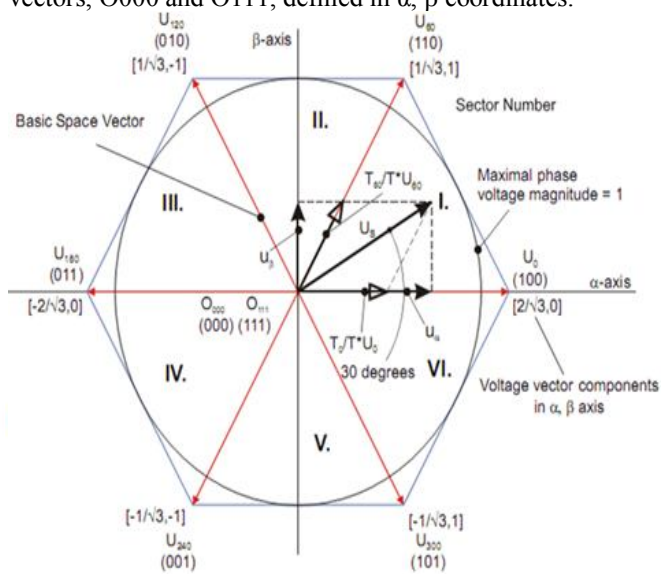


Fig 4.2 Vector diagram of SVPWM

In figure 4.3, the red line plot out the hexagon into six sectors, every between border two vectors angle is 60° , the border two vectors and zero vector could compose random voltage vector.

$$\int_0^T U_{ref} dt = \int_0^{T_x} U_x dt + \int_{T_x}^{T_x+T_y} U_y dt + \int_{T_x+T_y}^T U_0 dt$$

Or

$$U_{ref} T = U_x T_x + U_y T_y + U_0 T_0$$

This formula means, in sector the voltage vector rotating course could plot out many small part, it's have the same effect. So, in the interest of bring 3-phase sine AC voltage, use the voltage vector compose, begin from U4(100), every time increase a little increment, every increment could compose from between border two vectors and zero vector. Then the enactment voltage vector equivalent with the rotating voltage vector, and that all is SVPWM.

V. GENETIC ALGORITHM

A. Introduction

Genetic Algorithms (GAs) are the main paradigm of evolutionary computing. GAs is inspired by Darwin's theory about evolution—the "survival of the fittest". In nature, competition among individuals for scanty resources results in the fittest individuals dominating over the weaker ones.

- GAs are the ways of solving problems by mimicking processes nature uses; ie., Selection, Crossover, Mutation and Accepting, to evolve a solution to a problem.
- GAs is adaptive heuristic search based on the evolutionary ideas of natural selection and genetics.
- GAs is intelligent exploitation of random search used in optimization problems.
- GAs, although randomized, exploit historical information to direct the search into the region of better performance within the search space.
- The biological background (basic genetics), the scheme of evolutionary processes

B. The Genetic Algorithm for the PMSM

During time step, each member of the population is evaluated on how well it minimizes the ITAE. For each member of the population, the GA computes the speed

error (ω_e) and change in the speed error (ω_{ce}). The output variable of controller is change in the reference current ($(k) i\Delta$).

The ω_e and ω_{ce} are defined as:

$$e_{\omega}(k) = \omega^* - \omega(k)$$

$$c_e(k) = e(k) - e(k+1) \quad (4.6)$$

Where, ω^* is the reference speed.

(k) and $(k+1)$ denote actual and previous values.

In this application, feedback signals are the position θ and the phase currents a, b, c, d and the position signal is used to calculate the speed. The switching signal generator is used to control turn-on angle θ on, turn-off angle θ off, and pulse width modulation duty cycle.

The steps for speed regulation are summarized as follows:

- Sample the speed signal of the PMSM.
- Calculate the speed error and change in speed error.
- Choose the number of digits to represent each controller parameter K_p and K_i . Choose crossover probability (pc) and mutation probability (pm).
- Generate an initial population of K_p and K_i gains (we make a random selection) Initialize sample time T and set time t.
- Generate $\Delta i(k)$, for each population member C_i , $i=1,2,\dots,n$ using the conventional PI control laws. ($i(k) K_p e(k) + K_i \int e(k) \cdot T_p \omega_i \Delta t$)
- Assign fitness to each element of the population C_i , $i=1, 2, 3, n$, $P E(k) 1 \omega = 8$

$$p_1 = e_{\omega}(k)$$

$$p_2 = \Delta i(k)$$

$$F = \frac{1}{(\alpha_1 \cdot p_1^2 + \alpha_2 \cdot p_2^2)}$$

- Produce the next generation using GA operators and let $t := t+T$ go to step (d)
- The maximally fit C_i becomes C^* and send the change of control action ($i^*(k)$) to control the drive. Where $i^*(k)$ is the inferred change of reference current by the controller. At the k^{th} sampling time and defined as $i^*(k) = i^*(k+1) + \Delta_i(k)$ (11)

Where, $i^*(k + 1)$ is the previous reference current.

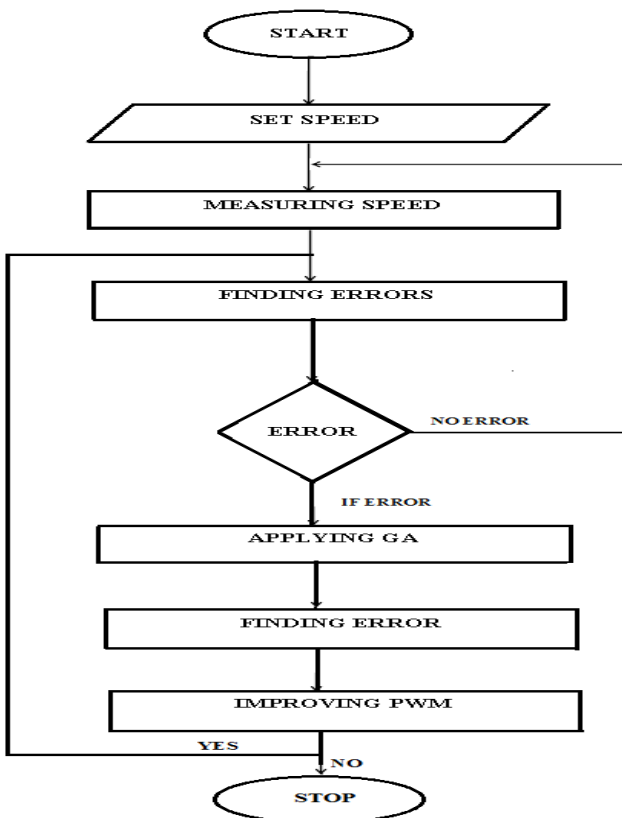


Fig 5.1 Flow chart for PMSM Drive

VI.SIMULATION OVERVIEW

A. Simulation of proposed system

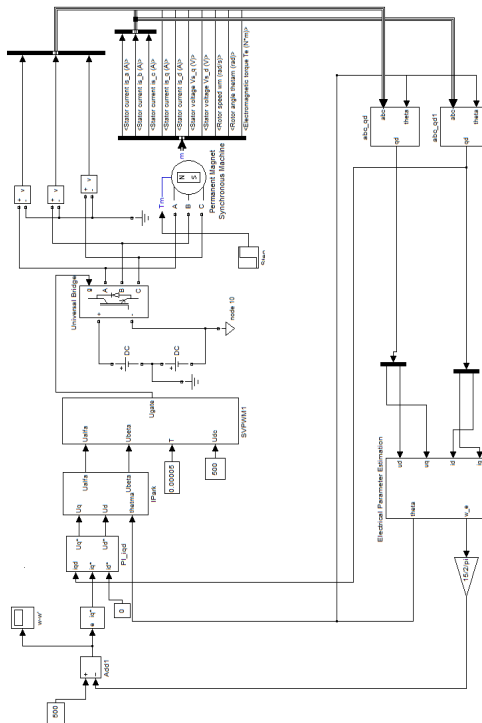


Fig 6.1 simulation Diagram

B. Results

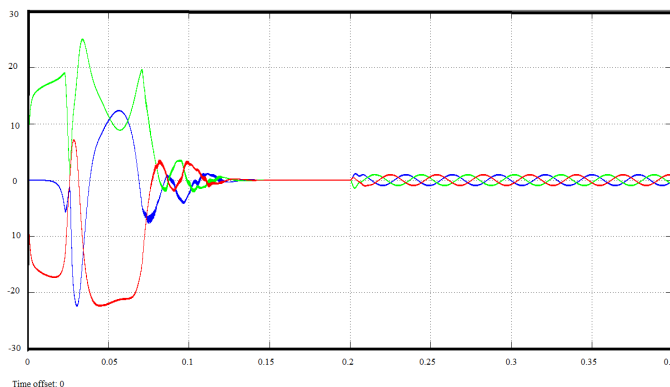


Fig 6.2 Stator Current waveform in abc axis

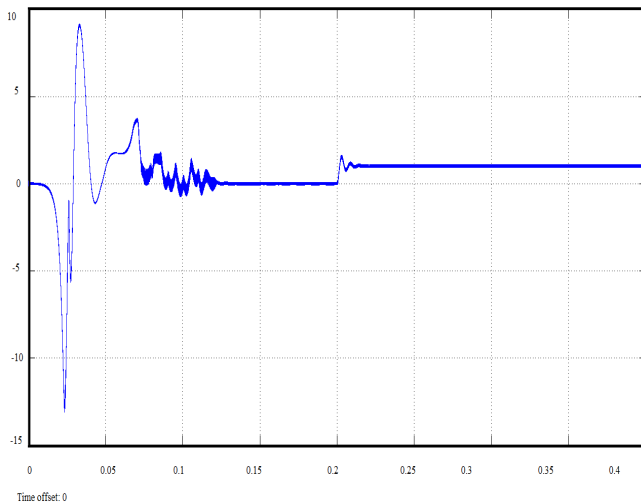


Fig 6.3 Torque waveform

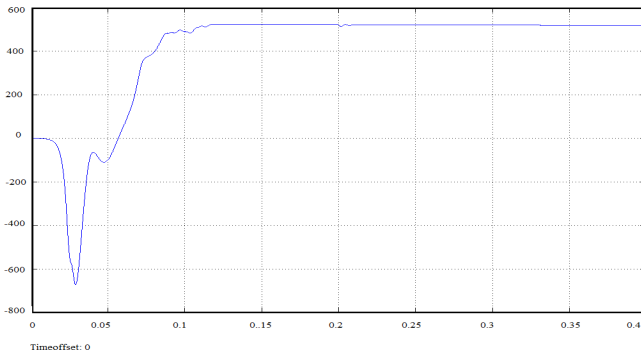


Fig 6.4 Speed waveform

VII. CONCLUSION AND FUTURE WORK

In this paper, a Genetic algorithm based PI speed controller for PMSM drive system is presented. Mathematical model of a PMSM fed by three phase inverter is realized, Genetic PI speed controller for speed regulation of PMSM are designed. The Genetic PI and conventional PI controller are designed and simulated individually and results are given. From the simulation results, it is clear that the designed the Genetic PI controller has better speed response than conventional PI controller. In Future, I will implement this in hardware.

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