



# Field Oriented Control of PMSM Using Improved Space Vector Modulation Technique

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**Abstract:** The Field Oriented Control is an external device that regulates and controls the performance of Permanent Magnet Synchronous Motor. With the fluctuations accessed in the motor, rotor magnets structured from ferrite core experience turbulent flow and hysteresis loss. The Space Vector Pulse Width Modulation is a standard model that provides pulse to the inverter. The orientation of pulse from FOC to PMSM is subjected to monitoring and control, made feasible by PI controllers. It is popularized that control properties of PID controller is far superior in consideration with PI controller. In this paper, the FOC system is enabled with PID replacing PI from standard model. The system was experimented on MATLAB/SIMULINK 2010a and the results with proposed structure outperformed the standard model. The evaluation parameters for the system were THD Stator Current Value, Torque, Speed and d-q axis current.

**Keywords:** SVPWM, FOC, PI, PID, PMSM.

## 1. INTRODUCTION

Permanent Magnet Synchronous Machine is the brushless motor designed for low voltage electronic equipment. In their initial stage the operations of PMSM were limited to simple DC motor circuits with low power input and high performance index. However, with later improvement in machines introduced the applications of PMSM in heavy industrial equipment considering the benefits over conventional motors. The panorama of PMSM has covered areas of automobiles, military, precision tools, Medical instruments etc. However PMSM motors perform poorly with open-loop scalar V/Hz control, since there is no rotor coil to provide mechanical damping in transient conditions.

Field Oriented Control is the most popular control technique used with PMSMs. FOC technique operates smoothly and provides maximum torque, full speed range and instantaneous acceleration and deceleration by controlling the  $i_q$  and  $d_q$  currents for three phase voltage supply in lower performance

applications. To convert the low voltage input in high voltage for motor coordination, the FOC is implemented with a voltage inverter. The capability of inverter to modulate the voltage signifies the operating range of PMSM. The inverters have accessibility of modulation range up to 127% for a particular input voltage. The difference in the input voltage pulse and the required modulation voltage are subject of PI controllers installed in FOC controllers. However, to generate maximum torque at zero speed and maximize the overall performance of PMSM the inverters are generally operated in over modulation range. This leads in parallel, the generation of harmonic components and voltage saturation of inverters [1]. The difference in actual flux and torque compared with estimated values are basis for switching of inverters. The gate (electric) pulses for control of inverter are derived from a standard unit known as Space Vector Pulse Width Modulation.

This paper supplements the PI controller with PID controllers. The fast response of PID controllers clips the time gap for calculation of required modulation voltage required to operate PMSM for different speeds and input current. The comparative study of PI based control and PID based control is explained in mathematical model. Further the SVPWM is discussed in vector model that compensate inverter to match reference value. The paper is concluded with comparative analysis of results for PI and PID controlled systems.

## 2. PROBLEM DEFINITION AND LITERATURE REVIEW

PI controllers are conventional tool to generate reference voltage required by inverter for modulation. The gain pulses from SVPWM are provided to inverter based on the difference in reference voltage and actual current value. PI controllers eliminate forced oscillations and steady state error and results in on-off controllers. However, the presence of

integral mode also introduces the slow response time and negative impact on overall stability of system.

Many authors focused on the SVPWM based PMSM with their research concentrated on pulse width modulation. From literature it is concluded that the problem of delay and stability response generated by PI controllers is generally overlooked. The literature present is two folded i.e. the comparative study of PI and PID controllers and second part is the development of PI based systems.

Farhad Aslam [2] gave the comparative study of controllers. Based on the study of chemical strengths of fluids, the concentration of fluids was controlled by different controllers. The authors figured that PID controller was ahead in terms of error control and response time and compared to PI controllers. On a SIMULINK model of verbal controlled robots [3], the response time, delay analysis and overall stability of PID controllers were far better compared to PI controllers. Prakash Verma [4] optimized the performance of DC motor by AB colony based PID controller.

S. K. Mondal [5] applied the neural network for both the under modulation ( $0 < m < 0.907$ ) and the Overmodulation range ( $0.907 < m < 1$ ). Performed on 300 V DC with sampling rate of 50 microseconds, 5 hp 320 V four pole and frequency range 0-60 Hz, the V/Hz controlled device performance comparison of all modes the neural network outperformed the conventional DSP-based SVM. The digital words were turned on by ANN and converted pulse width through single timer. The ANN based SVM provides much higher switching frequency in comparison with DSP based SVM.

The permanent magnet synchronous motor (PMSM) is the best selected servo drive for many industrial applications. The paper of **Madhu et al.** [6] demonstrates the MATLAB/SIMULINK model of Field Oriented Control controlling the PMSM. The control technique is the advanced architecture to control current and speed. The three phase inverter is the supply and the switching is done by the Space Vector Pulse Width Modulation (SVPWM) technique. The Sinusoidal pulse width modulation in comparison is outperformed due to better DC link utilization with less harmonic distortions generated in output of current. The PMSM model drive powered

by SVPWM is simulated for analysis of results. Mathematical model of PMSM motor is done in d-q rotor reference frame.

D. Paulus et al. in their paper [7] presented a saliency based sensorless control method that does not rely on a certain form of injection. B. Adhavan et al. [8] presented a simulation of speed control system on fuzzy logic approach for an indirect vector controlled permanent magnet synchronous drive by applying space vector modulation. A. Samar et al. in their paper [9] presented the implementation of the permanent magnet synchronous motor (PMSM) controller by employing the conventional Field Oriented Control (FOC) method for controlling the machine over overmodulation purpose. F. Genduso [10] proposed a low-time-consuming and low-cost sensorless-control algorithm for high-dynamic performance permanent-magnet synchronous motors.

### 3. PROPOSED MODEL

#### 3.1 PID Controller

Proportional Integral Derivative (PID) controller are the upgraded version of PI controllers with various modifications over limited constrained of previous scheme. Some of foreseen advantages lies in high response time, better stability and control error in oscillations. The additional Derivative mode enhance the system gain (K) and reduce integral time constant ( $T_i$ ) which is inversly proportional to speed of motor.

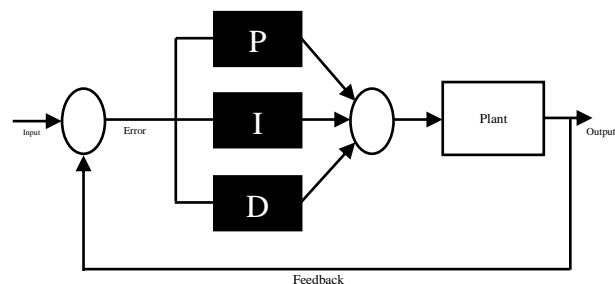


Figure 1: Schematic of the PID Controller- Non Interacting form

It is interesting to note that more than half of the industrial controllers in use today utilize PID or modified PID control schemes. A diagram illustrating the schematic of the PID controller is shown in figure

1. Such set up is known as non-interacting form or parallel form.

In proportional control,

$$P_{\text{term}} = K_P * \text{Error} \quad (1)$$

It uses proportion of the system error to control the system. In this action an offset is introduced in the system.

In Integral control,

$$I_{\text{term}} = K_I * \int \text{Error} dt \quad (2)$$

It is proportional to the amount of error in the system. In this action, the I-action will introduce a lag in the system. This will eliminate the offset that was introduced earlier on by the P-action.

In Derivative control,

$$D_{\text{term}} = K_D * \frac{d(\text{Error})}{dt} \quad (3)$$

It is proportional to the rate of change of the error. In this action, the D-action will introduce a lead in the system. This will eliminate the lag in the system that was introduced by the I-action earlier on.

The three controllers when combined together can be represented by the following transfer function.

$$G_C(s) = K (1 + 1/sT_i + sT_d) \quad (4)$$

This can be illustrated below in the following block diagram:

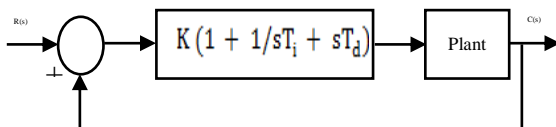


Figure 2: Block diagram of Continuous PID Controller

What the PID controller does is basically is to act on the variable to be manipulated through a proper combination of the three control actions that is the P control action, I- control action and D control action.

### Zielger-Nichols Method

Tuning of PID controller is mandatory to validate parameters in accordance with required control response. The process utilizes only proportional control action.

The tuning procedure is as follows:

1. Bring the process to (or as close to as possible) the specified operating point of the control system to ensure that the controller during the tuning is “feeling” representative process dynamic<sup>6</sup> and to minimize the chance that variables during the tuning reach limits. You can bring the process to the operating point by manually adjusting the control variable, with the controller in manual mode, until the process variable is approximately equal to the setpoint.

2. Turn the PID controller into a P controller by setting set  $T_i = \infty$  and  $T_d = 0$ . Initially set gain  $K_p = 0$ . Close the control loop by setting the controller in automatic mode.

3. Increase  $K_p$  until there are sustained oscillations in the signals in the control system, e.g. in the process measurement, after an excitation of the system. (The sustained oscillations corresponds to the system’s Ker value).

### 3.2 SVPWM

Space Vector Pulse Width Modulation is a standard unit to provide gain pulses. The mathematical model of SVPWM is standard and studied by enormous researchers. Space Vector PWM (SVPWM) is widely used in variable frequency drive applications, by its superior harmonic quality, less switching losses and extended linear range of operation. A three-phase 2-level inverter with dc link configuration can have eight possible switching states, which generates output voltage of the inverter. Each inverter switching state generates a voltage Space Vector ( $V_1$  to  $V_6$  active vectors,  $V_7$  and  $V_8$  zero voltage vectors) in the Space Vector plane (Figure 3). The magnitude of each active vector ( $V_1$  to  $V_6$ ) is  $2/3 V_{dc}$  (dc bus voltage).

The Space Vector PWM (SVPWM) module inputs modulation index commands ( $U_{\text{Alpha}}$  and  $U_{\text{Beta}}$ ) which are orthogonal signals (Alpha and Beta) as

shown in Figure 3 [11]. The gain characteristic of the SVPWM module is given in Figure 4. The vertical axis of Figure 4.4 [12] represents the normalized peak motor phase voltage (V/Vdc) and the horizontal axis represents the normalized modulation index (M)

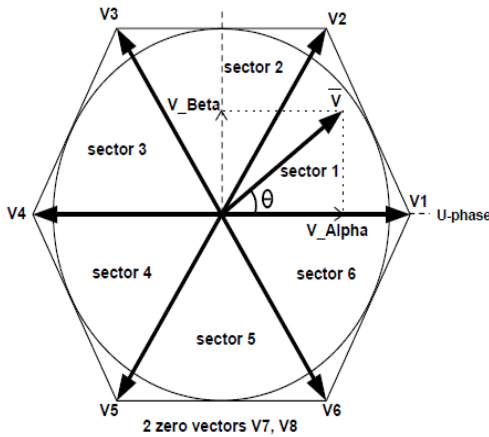


Figure 1: Space Vector Diagram

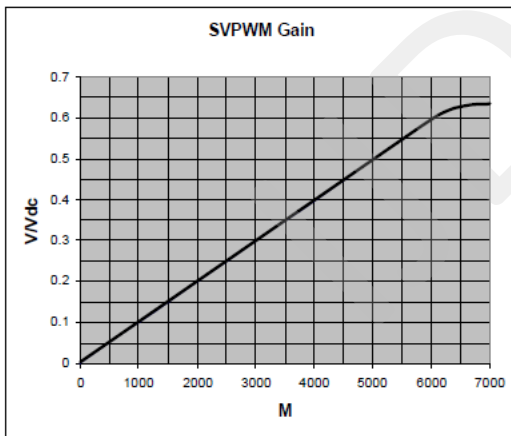


Figure 4: Transfer Characteristics

The MATLAB model of configured system (figure 5) depicts the placement of individual components in Field Oriented Control. The testing of model is carried out based on simulation parameters and calculation of speed, current and torque. Next section discuss the simulation parameters introduced in the system.

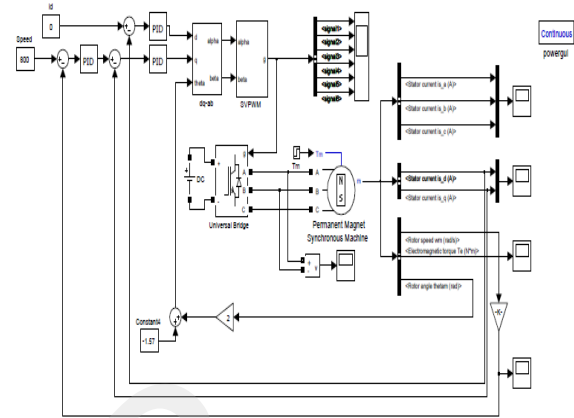


Figure 5: Field Oriented Control with PID controller

#### 4. SIMULATION PARAMETERS

Simulation Parameters:

- 4.1 For speed of motor-
  - Set Point- 800 RPM
  - No Load Condition- Before 0.2 sec
  - Full Load Condition- After 0.2 Sec
- 4.2 For Torque of motor, Stator Current and d-q axis current-
  - Set Point- 0 Nm
  - No Load Condition- Before 0.2 sec
  - Full Load Condition- After 0.2 Sec

#### 5. RESULTS

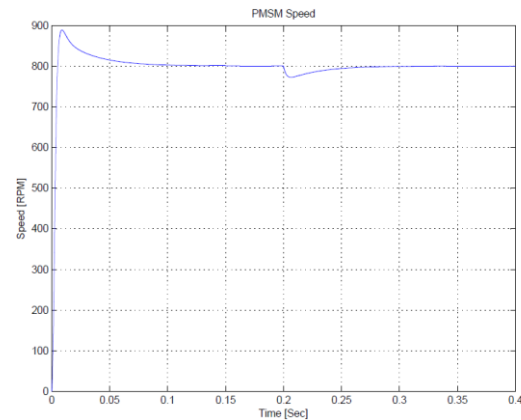


Figure 6: PMSM Speed with PI Controlled SVPWM

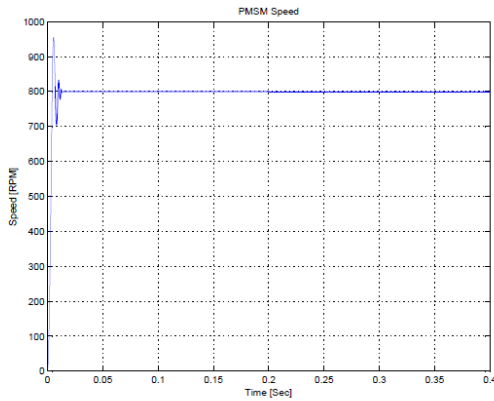


Figure 7: PMSM with PID controlled SVPWM

By comparing figure 6 and 7 it can be seen that PID controller has faster speed response than PI controller. Also the deviation is negligible in PID controller when there is change in speed reference at 0.2 seconds.

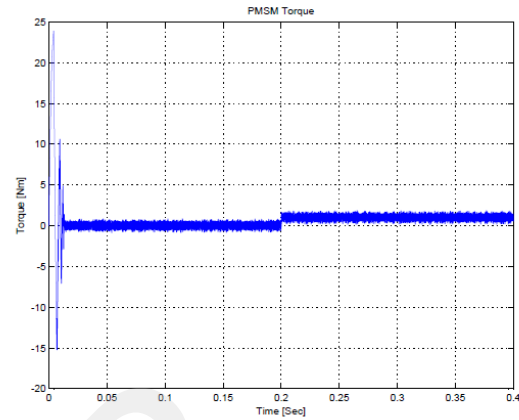


Figure 9: PMSM with PID controlled SVPWM

By comparing figure 8 and 9 it can be seen that PID controller has faster settling of reference torque than PI controller. Also the deviation is negligible in PID controller when there is change in load torque at 0.2 seconds.

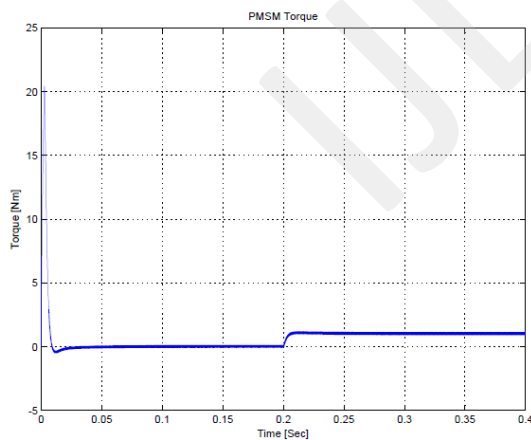


Figure 8: PMSM Torque with PI controlled SVPWM

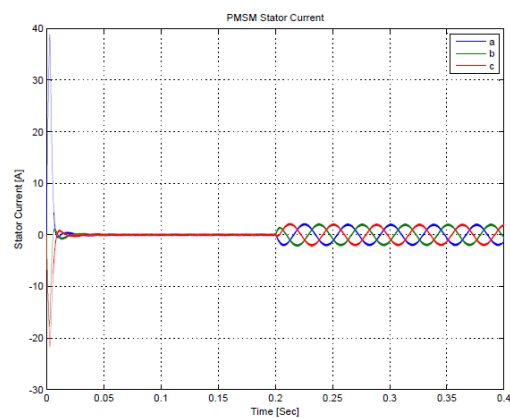


Figure 10: PMSM Stator Current with PI Controlled SVPWM

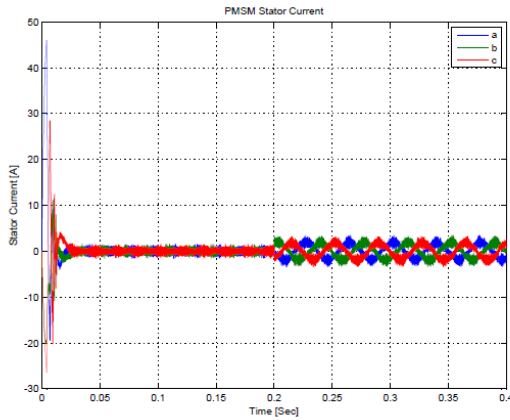


Figure 11: PMSM Stator Current with PID controlled SVPWM

By comparing figure 10 and 11 it can be seen that PID controller has better THD of stator current than PI controller when load is introduced at time = 0.2 seconds.

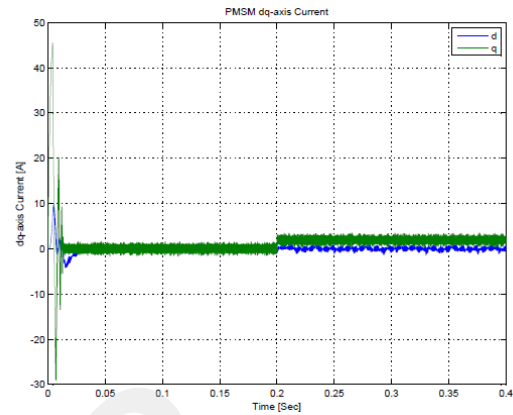


Figure 13: PMSM d-q axis Current with PID controlled SVPWM

By comparing figure 12 and 13 it can be seen that PID controller achieves reference Q and D axis current faster than PI controller at no load and on load condition at time = 0.2 seconds.

Table 1: THD Stator Current

	With PI	With PID
THD Stator Current Value	3.370	2.270

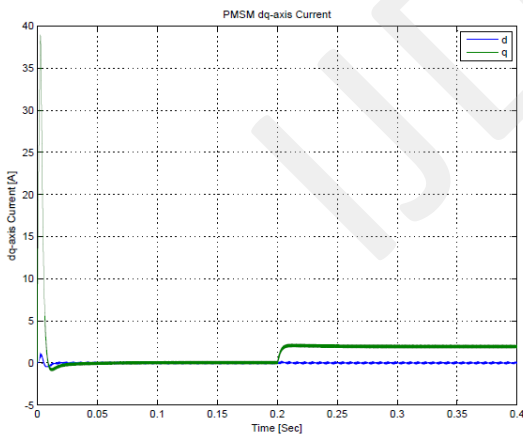


Figure 12: PMSM d-q axis current with PI controlled SVPWM

## 6. CONCLUSION

FOC is the standard regulator for Permanent Magnet Synchronous Motors. This algorithm has been used for years for its benefits and prolonged performance. The chief constituents of this algorithm for example SVPWM and PI controllers are error less models with constant performance defined over a set of parameters. However, this paper evaluated the PID in comparison with PI controller and found the superiority of PID in every single parameter under consideration. Next in functioning of FOC the PI controllers were replaced by PID controllers and again a set of evaluation was performed for new architecture. With desired simulation parameters and

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experiments performed on MATLAB 2010a model, the system proposed validated the better expectations from against the standard architecture. In future we tend to enhance the system performance by optimizing the SVPWM and updating the inverter pulse generated for PMSM.

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