

PMSM Position Control with a SUI PID Controller

Mohamed I. Abu El-Sebah[†]

[†] Electronics Research Institute, Cairo, Egypt

Abstract

This paper introduces the application of a SUI PID controller for permanent magnet (PM) drive systems. The drive system model is developed via FO control. Simulation of the system is carried out to predict the performance at no load and under load. The results and comparisons indicate that application of a SUI PID controller is effective for sensorless PM drive systems.

Key Words: FO controller, Permanent magnet synchronous motor, PM drives system, SUI PID

I. INTRODUCTION

Drive system position control requires three controllers for speed, position and current loops. Rotor speed and position are an essential component of any FOC system; therefore a good tracking controller must be used. An intelligent controller in the position and speed loops tends to eliminate the need for accurate sensors. This allows determination of speed and position via either estimation or low accuracy measuring devices, which result in a low cost drive system [1]–[3].

In PMSM position control systems, many researches tend to improve the performance of the position controller and speed controller by using intelligent controllers or adaptive PID controllers, which adapt using intelligent systems. Improving controller performance tends to complicate the design process and it leads to a complicated control program [4]–[8]. Other researchers have proposed MDOF controllers in simple manner [9], [10].

This paper presents an advanced controller SUI PID (Simplified Universal Intelligent PID) for PM machines using the FO approach.

A mathematical model of the machine, a CRPWM inverter, and a control technique based on FO will be derived for utilization in the drive system simulation. A simulation of the drive system will be carried out to predict and compare the responses with other intelligent controllers for high performance PM drive systems.

II. PMSM MOTOR MODEL

The motor model used in the drive system simulation is deduced by referring to the stator voltage equation:

$$\bar{v}_s = R_s \bar{i}_s + \frac{d}{dt} \bar{\lambda}_s. \quad (1)$$

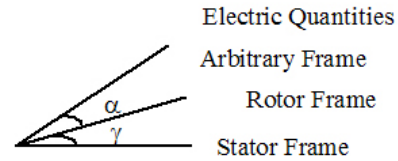


Fig. 1. Stator and rotor frame.

Referring to Fig. 1:

$$\frac{d}{dt}(\gamma + \alpha) = \omega_a, \quad \frac{d}{dt}\alpha = \omega_a - \omega_r, \quad \frac{d}{dt}\gamma = \omega_r. \quad (2)$$

This is then referred to an arbitrary reference frame:

$$v_s^s e^{j(\gamma + \alpha)} = R_s i_s^s e^{j(\gamma + \alpha)} + \frac{d}{dt} [\lambda_{af} e^{j(\gamma + \alpha)} + L_s i_s^s e^{j(\gamma + \alpha)}]. \quad (3)$$

$$v_s = R_s i_s + j\omega_a [\lambda_{af} + L_s i_s] + \left[\frac{d}{dt} \lambda_{af} + \frac{d}{dt} L_s i_s \right]. \quad (4)$$

The PMSM model is developed to operate in the rotating reference frame ($\omega_a = P\omega_r$) [9].

$$P \cdot \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = \begin{bmatrix} \frac{R_s}{L_d} & -P\omega_r \\ P\omega_r & \frac{R_s}{L_q} \end{bmatrix} \cdot \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_d} & 0 \\ 0 & \frac{1}{L_q} \end{bmatrix} \begin{bmatrix} \frac{1}{L_d} & 0 \\ 0 & \frac{1}{L_q} \end{bmatrix} \cdot \begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_d} & 0 \\ 0 & \frac{1}{L_q} \end{bmatrix} \begin{bmatrix} 0 \\ P\omega_r r \lambda_{af} \end{bmatrix}. \quad (5)$$

The mechanical equations for a PMSM are expressed as follows:

$$T = \frac{3P}{2} (i_{sq} \cdot i_{sd} (L_d - L_q) + \lambda_{df} i_{sq}) \quad (6)$$

$$T = J \frac{d}{dt} \frac{\omega_e}{p} + B \cdot \frac{\omega_e}{p} + T_l. \quad (7)$$

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[†] Corresponding Author: Mohamedibrah32@hotmail.com

Tel: +202-33310552, Electronics Research Institute

Electronics Research Institute, Egypt

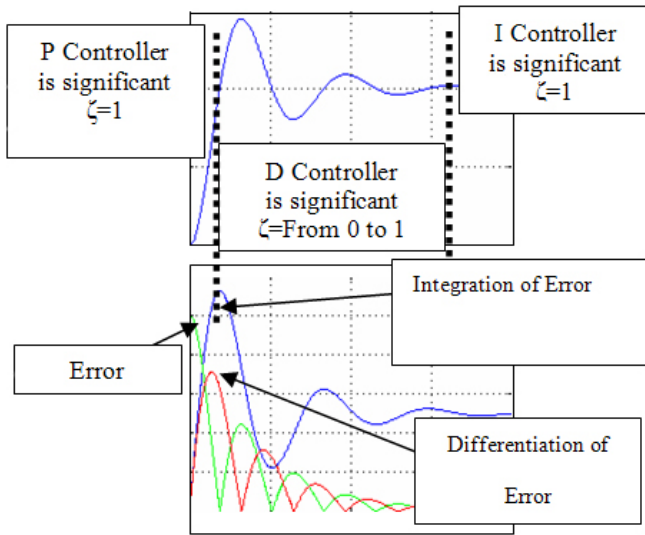


Fig. 2. The system response Intelligent PID Controller.

III. PROPOSED SUI PID CONTROLLER

Fig. 2 illustrates the second order system step response divided into three different regions to show the significant required action in each region. It is easy to adapt the PID constants to improve the PID response by increasing the controller term constant in its corresponding region.

The PID controller consists of three terms:

The first term controller $P = K_p * \text{error}$.

The second term controller $I = K_i * \int \text{error} \cdot Dt$

The third term controller $D = K_d * d(\text{error})/dt$

The following values can then be substituted into the PID controller equation:

$K_p = \text{ABS}(\text{error})$

$K_i = \text{ABS}(\int \text{error})$,

$K_d = \text{ABS}(d(\text{error})/dt)$

Selecting the controller constants from the above explanation leads to a simple design algorithm and simplified adaptive weighting for the three terms.

The proposed intelligent PID controller is constructed by using the multi degree of freedom controller (MDOF) concept [9], [10]. Applying the intelligent PID controller eliminates the need to know the system steady state gain.

$$Cm = C * K * \text{error} + C * \frac{1}{K} * (1 - \text{error})$$

$$Cm = C * \text{error} * \left(K - \frac{1}{K}\right) + \frac{C}{K}$$

$$\text{For } K \gg 1 \quad C = C * \text{error} * K$$

where:

K : the modified controller gain

C : the controller output

Cm : the modified controller output

The proposed SUI PI controller is a classical PI with a universal PID constant, so no specific design is needed and therefore there is no need for a system model. The SUI PID controller constants K_p and K_i are the absolute values of errors and integration of errors as shown in Fig.3.

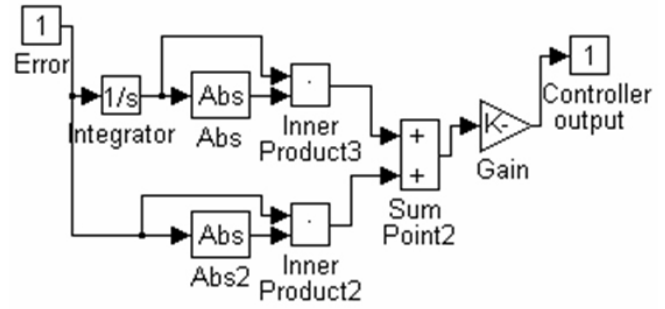


Fig. 3. Block diagram of the MDOFF Controller.

IV. THE PMSM POSITION CONTROL SYSTEM

The PMSM position control system uses three loop controllers. The inner loop is a current control loop, while the second loop for speed receives the speed command from the outer position loop. Three controllers are needed to carry out the control algorithm. The inner loop uses the motor equations as a current controller. The two outer loops use a PI controller or like a PI controller. The proposed controller has been used to improve system performance. The controller can also reduce system cost by using low cost sensors or estimation while improving the drive system response.

V. SIMULATION RESULTS

The PM drive system block diagram shown in Fig. 4 is simulated using Matlab to predict the drive system performance with different loading conditions.

The PM drive system is simulated with a fuzzy controller as shown in Fig. 4(a), while the proposed controller is used in the drive system as illustrated in fig.4(b). The simulation is carried out for two different cases and the simulation results are presented as follows.

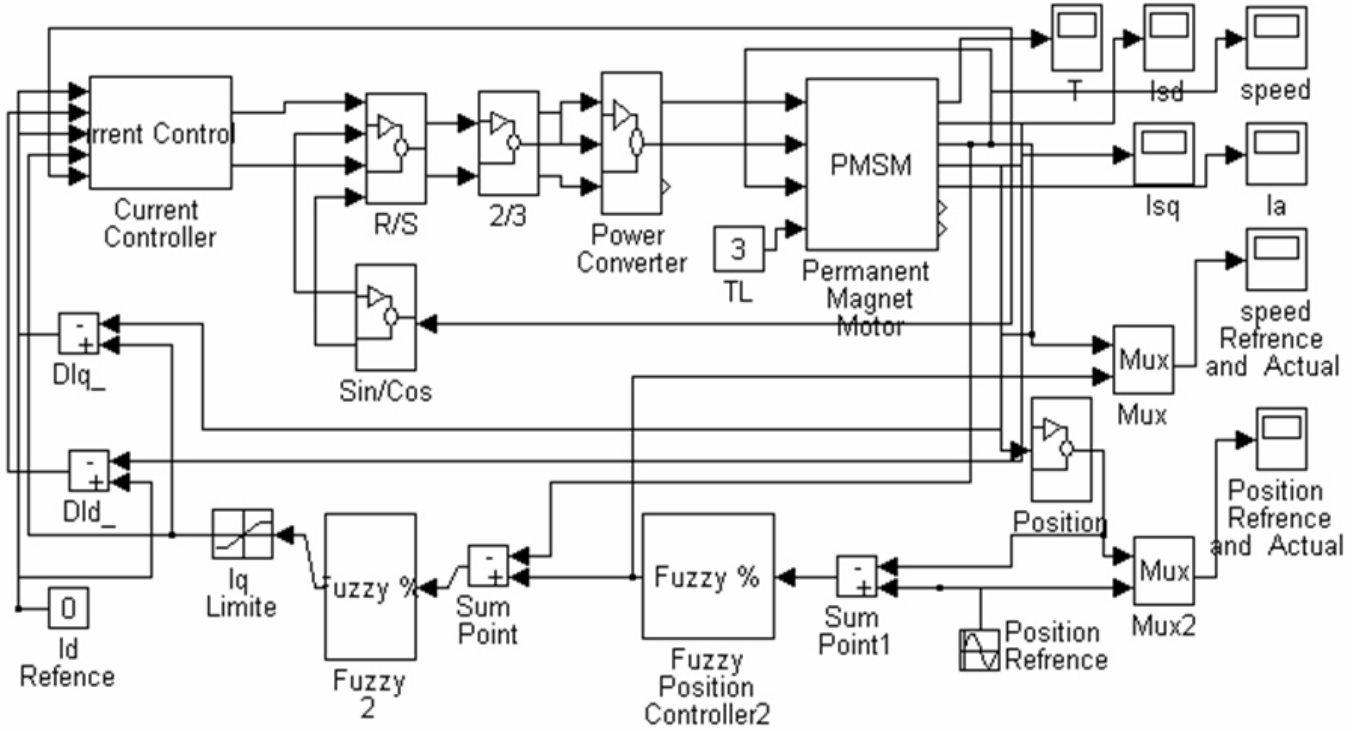
Fig. 5 shows the position and speed response with reference values using a fuzzy controller under the no load condition, while Fig. 6 illustrates the same case when the fuzzy controller is replaced with a SUI PI controller.

The position and speed response with reference values using a fuzzy controller under the loading condition is shown in Fig. 7, while the same case is repeated with a SUI PI controller in Fig. 8.

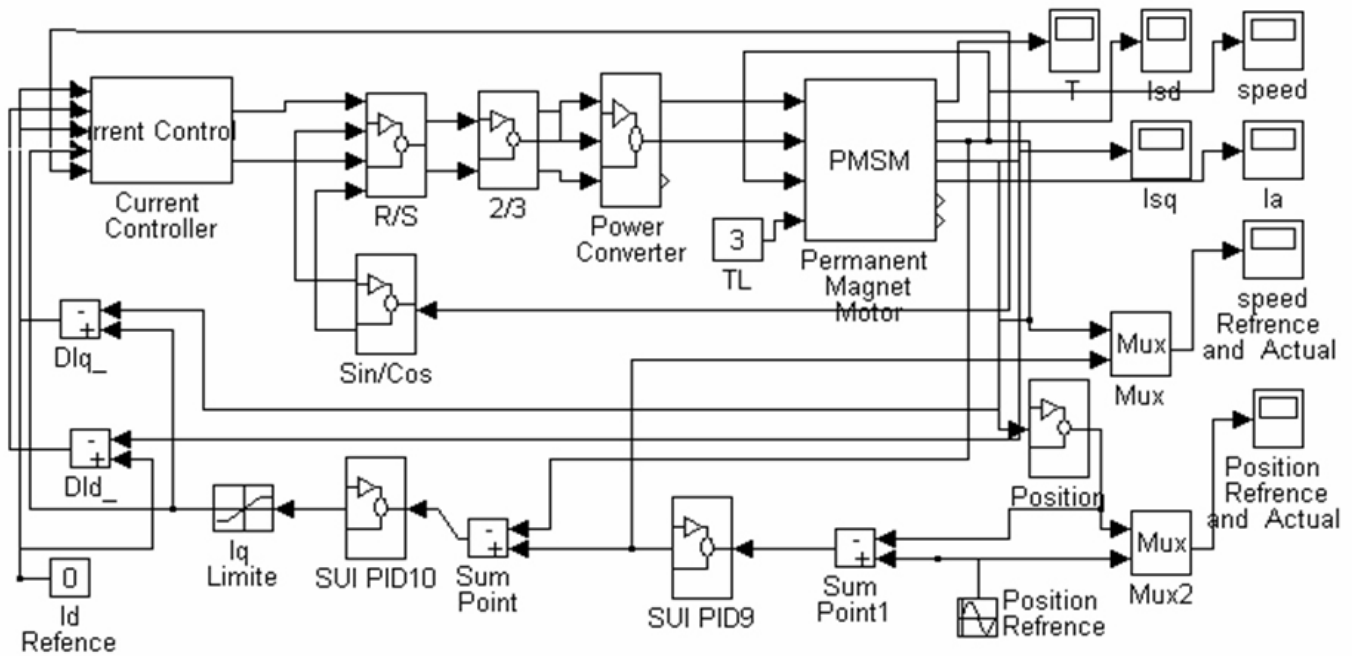
The results verify the power of the proposed SUI PI performance compared with the fuzzy response in PMSM position control.

VI. CONCLUSIONS

This work presents the application of a new SUI PID controller with a PM motor drive system. The proposed controller algorithm has been deduced to be suitable for application to any process regardless of the process model or parameters. The drive system model has been developed and a simulation has been carried out for a performance prediction under different loading conditions with different command signals. The results of the simulation indicate that the SUI PID controller is effective and powerful for PM drive systems.

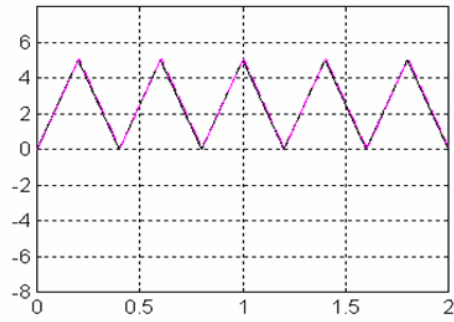


(a) Block Diagram for PMSM Position Control Using Fuzzy Controller

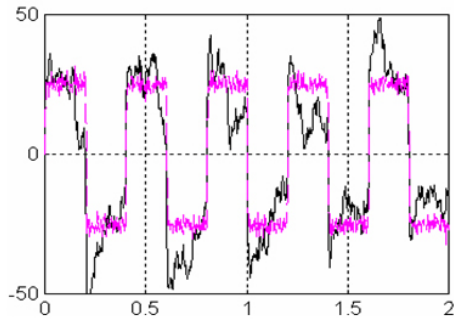


(b) Block Diagram for PMSM Position Control Using SUI PI Controller

Fig. 4. PMSM Drive system position control.

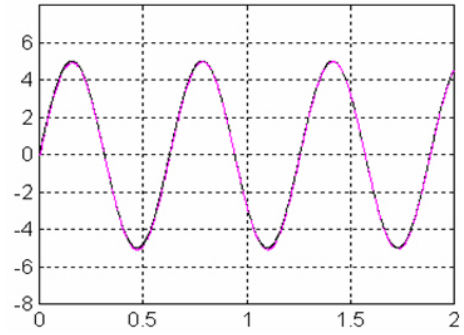


(a) Rotor Position

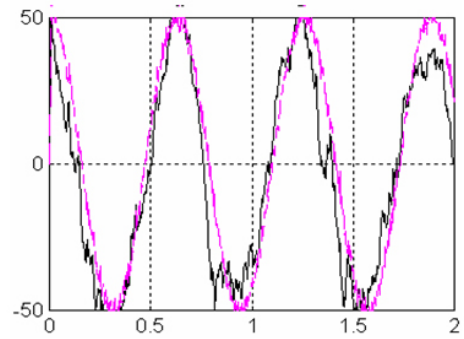


(b) Rotor Speed

Fig. 5. The drive system position control at no load with Fuzzy.

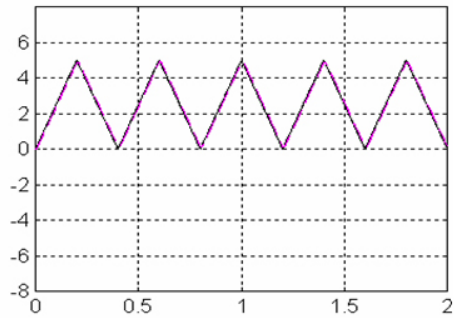


(a) Rotor Position

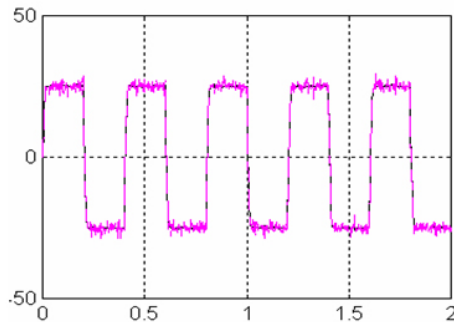


(b) Rotor Speed

Fig. 7. The drive system position control under loading with Fuzzy.

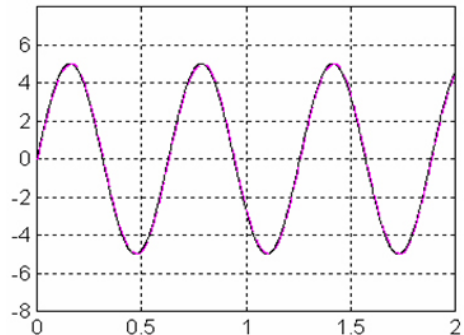


(a) Rotor Position

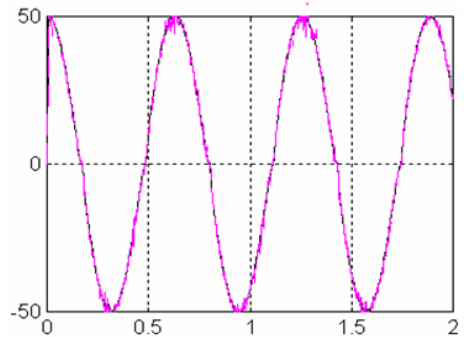


(b) Rotor Speed

Fig. 6. The drive system position control at no load with SUI PI.



(a) Rotor Position



(b) Rotor Speed

Fig. 8. The drive system position control under loading with SUI PI.

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Mohamed I. Abu El-Sebah received his B.S, M.S and Ph.D. in Electrical Engineering from Cairo University in 1990, 1996 and 2003 respectively. Since graduating, he has been with the Electronics Research Institute (ERI) in Cairo, Egypt. In 2003 he became an Assistant Professor at ERI. His research interests include electric drives, power electronics and digital control.