SPEED CONTROL OF PERMANENT MAGNET SYNCHRONOUS MOTOR USING FIELD ORIENTED CONTROL
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https://doi.org/10.26782/jmcms.2019.12.00068

Abstract

In modern day technological developments, Engineering has played an important role. What drives Engineering is nothing but Efficiency, which in other terms can also be called as Accuracy. The accuracy of the system should be very high when it comes to certain applications. Similar is the topic that has been presented in the paper below regarding the speed control of Permanent magnet Synchronous motor by field oriented control. There are several ways to do it, but this type of control makes the PMSM system to be efficient and accurate. The entire Permanent Magnet Synchronous Motor control system is categorized into several independent units such as PMSM coordinate transformation unit, inverter unit, body unit, SVPWM production unit and so on. The mathematical model of the PMSM system can be attained by joining these units. The main benefit of SIMULINK when compared to other softwares is that, instead of compiling program code, the model is built sequentially by the blocks present in software. With the mathematical modelling, we can examine different models and waveforms to provide an effective means for the analysis and design of the PMSM system. It is familiar that the control properties of P-I-D controller are better when compared with that PI controller. In the following paper, the Field Oriented Control system is enabled using P-I-D instead of standard PI model.

Key words: PMSM, FOC-Field oriented control, Inverse park transformation, PID Controller
I. Introduction

Permanent magnet synchronous motor (PMSM) is a type of brushless motor which can be thought as a hybrid of brushless DC motor and an AC induction motor from the reference of rotor and stator respectively[III]. It basically offers high efficiency, high power factor, faster response times, rugged construction. The main objective here would be the speed control of the motor using Field produced by the stator[VI]. As it takes the three phase supply, we will be having three phase currents, these three phase currents will be further processed to achieve the desired speed. This process also involves tuning of PID controllers in the system.

II. Problem Statement

As mentioned above the main problem or the task to be accomplished is to tune the PID Controllers of the system to get the expected result. The methods of tuning the controllers are high in number but we follow most common and easiest way which is called as “Trail and Error method”. There will be mainly three gain constants (i.e.) proportional, integral and derivative[I,II,V]. They are represented as \( K_P, K_I, K_D \) respectively[IV]. In this the proportionality gain (i.e. \( K_P \)) is mostly used to strengthen the input signal. The integral gain is used to reduce the error and \( K_D \) is used to reduce the overshoot in the yielded output.

III. Field Oriented Control

Generally these AC Induction motors provide desirable characteristics such as sturdiness and easy to control mechanism[VII]. They are widely used in numerous applications varying from home appliances, industries and automobiles. However operating them under very high efficiency is a difficult act due to their non-linear characteristics at the saturation. This problem will bring into picture a very high performance control algorithm such as Field oriented control.

Field Oriented Control method

Defines the way in which the controlling of speed and torque are proportionally based on the electromagnetic position of the motor, like that of DC Motor[VIII]. Field Oriented Control technique is the primary technique to regulate the motor controlling variables of flux and torque. With the decoupling among the components of stator...
current the components that produce torque of the stator flux shall be controlled individually. This can be done only on a salient pole machine.

The working principle of this type of control involves manipulating the stator currents represented by a vector. This is based on projections that transform a three phase system which is time dependent into a two phase system that is time independent. This is achieved by Clarke and Park transformations.

a) **Clarke transformation**: Transforms a 3 phase system to 2 phase system in the existing stationary reference frame with orthogonal axes. New phase variables will be denoted as θ and β.

![Fig.2.Clarke Transformation](image)

b) **Park transformation**: Transforms a 3 phase system to 2 phase system with orthogonal axes in a different rotating reference frame but in one stationary reference frame. New phase variables will be denoted as d and q (i.e. direct and quadrature axis of the motor).

![Fig.3.Park Transformation](image)

**Mathematical model of PMSM**

The electrical equations of the PMSM in the rotor (dq) reference frame as follows:

\[ V_d = (R_S * i_d) + L_d * (d i_d / dt) - (L_q * I_q * w_e) \]

\[ V_q = (R_S * i_q) + L_q * (d i_q / dt) + (L_q * I_d * w_e) + (w_e * \lambda_A) \]
The mechanical equations of PMSM can be written as

\[ T_e = (1.5) (P) \left( \lambda_{AF} I_q + (L_d - L_q) I_d I_q \right) \]

\[ W_e = \left( \frac{P}{2J} \right) \int (T_e - T_l - \frac{2Bw_e}{P}) \, dt \]

- \( I_d \) - Stator Current (Direct Axis)
- \( I_q \) - Stator Current (Quadrature Axis)
- \( R_s \) - Resistance of stator
- \( L_d \) - Inductance (Direct axis)
- \( L_q \) - Inductance (Quadrature axis)
- \( J \) - Moment of Inertia (Kgm\(^2\))
- \( B \) - Viscous Friction Gain (Nm/rad/sec)
- \( P \) - Number of poles
- \( \lambda_{AF} \) - Rotor Flux Constant (V/rad/sec)
- \( w_e \) - Electrical speed of rotor (rad/sec)
- \( T_L \) - Load torque (N-m)
- \( T_E \) - Electromagnetic Torque (N-m)

**SIMULINK MODEL OF PMSM SYSTEM**

![Simulink Model](image.png)
2.4 DATA OF MODEL PARAMETERS

|   |   |   |   |   |
|---|---|---|---|---|
| 1. | $R_s$ | Stator Resistance | 18.7 ohms, 19.2 ohms, 16.5 ohms |
| 2. | $L_d$ | D-Axis inductance | 0.02682 mH |
| 3. | $L_q$ | Q-Axis inductance | 0.02682 mH |
| 4. | $J$ | Inertia | 0.0008 kg.m$^2$ |
| 5. | $N_p$ | No. of poles | 4 |
| 6. | $V$ | Voltage | 400 Volts |
OBSERVATIONS AND WAVEFORMS

| Controller | $K_p$ | $K_i$ | $K_d$ |
|------------|-------|-------|-------|
| Controller 1 | 400   | 30    | 1     |
| Controller 2 | 400   | 1     | 0.01  |
| Controller 3 | 400   | 2     | 0.03  |

Case – I:

For 1000 RPM

![Fig.7. With P-I-D Controller](image)

Case – II:

![Fig.8. With P-I and P-D Controller](image)
Fig. 9. Variation of ID, IQ, Torque

For 900 RPM

| Controller | $K_p$ | $K_i$ | $K_d$ |
|------------|------|------|------|
| Controller 1 | 600  | 0.01 | 5    |
| Controller 2 | 600  | 0.01 | 5    |
| Controller 3 | 600  | 0.01 | 5    |

Fig. 10. With P-I-D Controller
Fig. 11. With P-I and P-D Controller

Fig. 12. Variation of ID, IQ, Torque

| Controller | $K_p = 600$ | $K_i = 0.01$ | $K_d = 5$ |
|------------|-------------|--------------|-----------|
| Controller 1 |             |              |           |
| Controller 2 |             |              |           |
| Controller 3 |             |              |           |
Case-III:

For 800 RPM

**Fig.13. With P-I-D Controller**

**Fig.14. With P-I and P-D Controller**
Fig. 15. Variation of ID, IQ, Torque

IV. Conclusion

Field Oriented control is the best possible way to regulate the permanent magnet synchronous motor. The more accurate answer is that with the help of PID controller we are able to achieve the desired steady state of 1000 rpm with the error of 0.49%. The key components of this system are SVPWM and PID Controller which are errorless and defined over a set of parameters. With the above mentioned attributes the experiment was performed on MATLABR-2013A.

V. Future - Scope

In future, to improve the FOC of PMSM drive in both performance and economy, few of the following can be researched. Hybrid (FLC - ILC) for minimizing the torque pulsations in FOC of PMSM. Here, the FLC works at transient state and ILC is activated during steady state to suppress the torque ripples in PMSM. Hybrid (PI-ANN) for minimizing the torque pulsations in FOC of PMSM. Here, the PI controller works at transient state and ANN is activated during steady state to suppress the torque ripples in PMSM.
References

I. Chen ming, Gao Ranying, Song Rongming, "Simulation Study on a DTC System of PMSM" 2011 The 6th International Forum on Strategic Technology 978-1-4577-0399-7/11/$26.00 ©2011IEEE.

II. Hoang Le-Huy, "Modeling and Simulation of Electrical Drives using MATLAB/Simulink and Power System Block set", The 27th Annual Conference of the IEEE on Industrial Electronics Society, IECON '01. Vol. 3 (2001): Page(s): 1603-1611.

III. Jahns Thomas M., Kliman Gerald B. and Neumann Thomas W., "Interior Permanent-Magnet Synchronous Motors for Adjustable-Speed Drives," IEEE Transactions on Industry Applications, vol.IA22, no.4 (1986): pp.738-747.

IV. Mitra, Indranil, Gopa Roy Biswas, and Sutapa Biswas Majee. "Effect of Filler Hydrophilicity on Superdisintegrant Performance and Release Kinetics From Solid Dispersion Tablets of A Model BCS Class II Drug." International Journal 4.1 (2014): 87-92.

V. Pillay P. and Krishnan R., "Modelling of Permanent Magnet Motor Drives," IEEE Transactions on Industrial Electronics, vol.35, no.4 (1988): pp.537-541.

VI. Sebastian T. Slemon G. and Rahman M., "Modelling of Permanent Magnet Synchronous Motors," IEEE Transactions on Magnetics, vol. 22 (1986): pp. 1069-1071.

VII. Sukumar, Durga, Jayachandranath Jithendranath, and Suman Saranu. "Three-level inverter-fed induction motor drive performance improvement with neuro-fuzzy space vector modulation." Electric Power Components and Systems 42.15 (2014): 1633-1646.

VIII. Yadlapalli, Ravindranath Tagore, and Anuradha Kotapati. "A fast-response sliding-mode controller for quadratic buck converter." International Journal of Power Electronics 6.2 (2014): 103-130.