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Modeling and Control of a PMSM Motor

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Abstract: This study is made upon the modeling of a Permanent-Magnet Synchronous Motor PMSM with torque conditions and variable speed in a matrix and simplified way using mathematical transformation techniques applied to electric machines such as Park transformation. Furthermore, it analyses the model's behavior by making a simulation with the Matlab's simulink tool, it also designs a Pulse-Width Modulation PWM controller which supplies the D-Q Model of the three-phase electric machine under normal conditions. Later on, different PID control models will be implemented under different reference values in order to bring it's behavior to reality. The main outcome is the identification of the best control method by comparing the stabilization time of the obtained signals. Finally, as a conclusion, it reviews the importance of the mathematical modeling for designing control techniques for PMSM.

Key words: Control, D-Q Model, park transformation, PMSM motor, PWM, synchronous

INTRODUCTION

Based on the needs shown in the electric industry on aerospace applications, robotic and specially the automotive industry for creating prototypes that work with electric motors, the control area of those motors has lately created a research field and therefore, the implementation of these control types is made upon the different applications on which they will be used such as drones or hybrid vehicles.

Brushless motors (BLDC) that are part of the Permanent-Magnet Synchronous Motors family (PMSM), are part of the electric motors family that work under a Direct Current power supply (DC) this DC signal works switched by exciting the coils according to the rotor's position in order to produce the machine's best torque. The machine's controller and the operating sequence is worked based on pulses which is part of one of the control techniques in this type of motors (Arroyo, 2006). The Pulse-Width Modulation signal (PWM) which consists on the variation a periodic signal's working cycle allows to excite the stator to obtain a torque in the motor.

For a better analysis, there's a mathematical model of the equations in a dynamic state of a PMSM motor (Ohm, 2000), aiming to understand the different variables acting against the asynchronous machine then Park transformation is made out of this mathematical model under a switched three-phase supply (Kishore *et al*., 2006) this in order to visualize in a more simple way a three-phase system in a d-q coordinates system which can be applied to electric machines. That is an added value to the d-q model simulation.

The purpose of this investigative work is to determine what the best way is to obtain a shorter stabilization time of the system's output signals under the different control techniques, it was decided to study a PID controller in torque and speed variables with desired reference values which are according to the PMSM motor modeling (Sehgal *et al*., 2013). Concluding this study, the best technique is identified according to the stabilization time of the system to a feedback reference signal.

Literature review: The mathematical model simplification obtained in this study, comes up from the synchronic model described by Arroyo (2006) where it shows all the mathematical complexity of the model which includes the full the three-phase system and the mechanical and hysteresis losses, adding a feedback by the hall effect sensor. This is generated as a result of a deep analysis of the model's behavior and the hall effect importance. The significant differences by developing this work starts with the knowledge of the rotor's position based on the magnetic field and not as an additional device as well as the mathematical model's simplification.

The different types of control presented mainly focus on managing the two generated currents (I_q y I_d) by Patel and Pandey (2013) there is a more simplified mathematical model but it has more complex control

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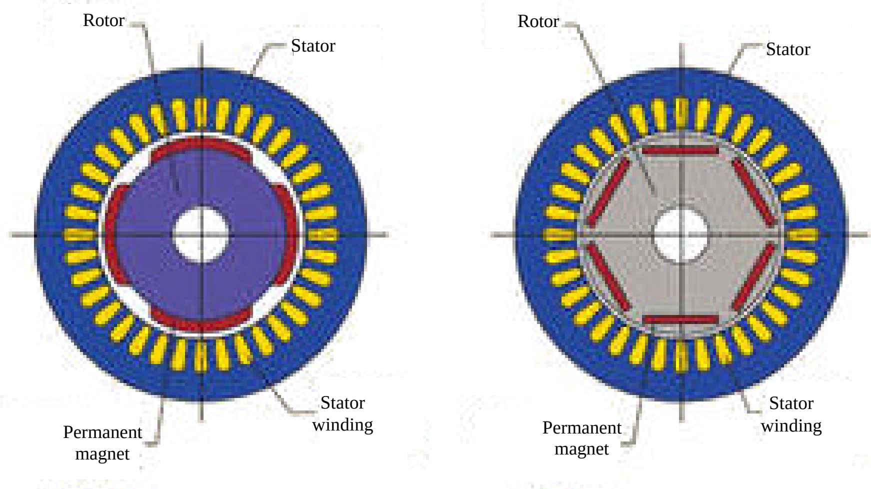

Fig. 1: Basic configurations of the PMSM motor; a) Superficial permanent magnets motor and b) Previous permanent magnets motor

techniques due to the variables that intervene. This causes as a result the complexity of the control process and the need to simplify it. Within this article's development, the mathematical model simplification is important therefore, a standard model of the variables that intervene is kept and it reduces the variables to intervene (I_q y I_d) in order to have the maximum field generated, however, doing $I_q = 0$, it leaves only one variable (I_d) that simplifies even more the model to control. The PWM controller presented (Real *et al*., 2010) shows different ways to control its operating frequency which outcome is the variation on the operating frequency with the purpose of determining the best response of the mathematical model presented in this case, the PWM controller cannot be modified and it maintains a 0.5 sec per cycle.

The complexity of the control tools for a PMSM motor due to the mathematical models presented in study (Haute *et al*., 1998; Janpan *et al*., 2012; Hernandez *et al*., 2013) is based on the different variables to be controlled, depending on the expected response signal. In the development of the current work compared to the previous ones, the control model is unique and it is capable of controlling the RPM and generated torque variables, looking for the shortest system stabilization time. Now a days, there are many studies raised upon the control techniques by separate but this investigation applies a unique control system, managing two independent variables that are related due to the way the mathematical model is proposed and the d-q Model's simulation (Ohm, 2000).

Characteristics of the PMSM motor: There are two basic configurations of the PMSM motor in function of the permanent magnets within the rotor, superficial assembly and inner magnets. Having this peculiarity within the rotor's structure, provides it with the advantages of having a higher reliability, lower maintenance cost and a greater efficiency but as a consequence in order to do the pulse switch to energize the stator's group of coils, it is necessary to implement sensors that allow to know the rotor's locations in order to energize the stator (Fig. 1).

The complexity of a PMSM motor switching system is one of the dilemmas for the different applications where this type of motors can be used. Because of that this study aims to determine the best way to control the torque and speed under a constant reference.

MATERIALS AND METHODS

The methodology for achieving the objective of determining which the best control technique for a PMSM motor is that allows to decrease the stabilization time with a unique controller based on the PMSM motor's mathematical model is presented as follows:

- Obtaining a monophasic mathematical model of a PMSM motor. Obtaining this model comes out from the Kirchhoff equations of a synchronous machine's circuit
- Deduction of the three-phase model of a PMSM motor based on the monophasic model, obtaining the matrix model
- Generation of the d-q model based on the matrix model, through Park transformation
- Design of a controller based on a PWM signal which will supply the synchronous machine's model
- Simulation of the d-q model of the PMSM motor using Matlab's simulink tool
- D-q model simulation of the PMSM motor under PID control using Matlab's simulink tool

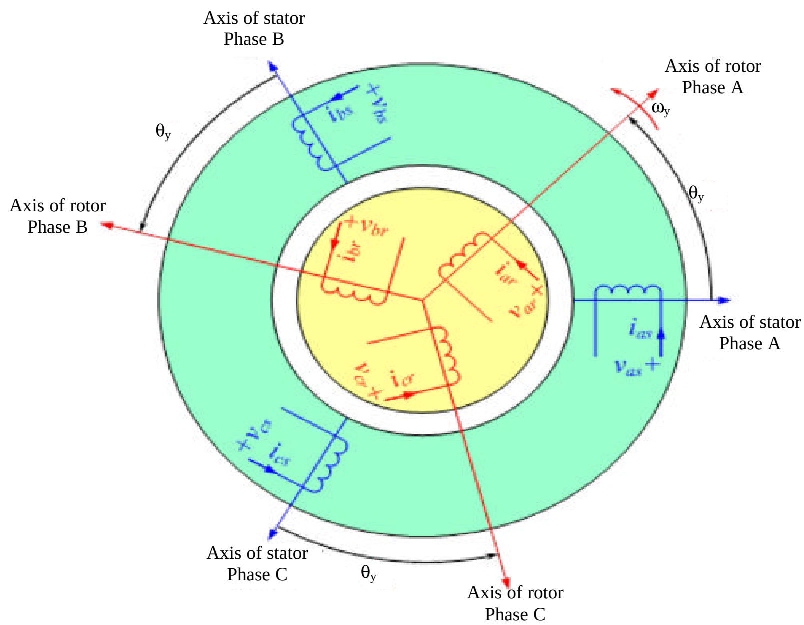

Fig. 2: PMSM motor representation regarding rotor and stator axes (Kishore *et al*., 2006)

PMSM motor dynamic model: The mathematical model was developed under the conditions of an "ideal" and precise synchronous machine that involves the electrical and physical variables that describe the machine's electromagnetic phenomena. The devolped model's ideal conditions of the PMSM motor are these:

- Losses caused by currents within the air gap and Foucault currents are despised
- The air gap magnetic permeability is ideal $\mu_{Fe} \rightarrow \infty$
- The physical conditions of the machine are despised such as: rotor's and stator's diameters and windings slotted

The mathematical model starts from Kirchoff equations of the PMSM motor electric ciurcuit (Fig. 2 and Eq. 1-3:

$$V_a = I_a R_s + \frac{d\psi_a}{dt} \quad (1)$$

$$V_b = I_b R_s + \frac{d\psi_b}{dt} \quad (2)$$

$$V_c = I_c R_s + \frac{d\psi_c}{dt} \quad (3)$$

Where:

V_c = Potential difference through the stator's coils
I_a = Current through the stator's coils
R_s = Stato's equivalent resistance
ψ_a = Magnetic flow produced by the coils within the stator
d/dt = Differential factor

The contribution of the magnets installed in the machine and the coils, contribute to the total magnetic flow. The total magnetic flow is defined by Eq. 4-6:

$$\psi_a = [(L_{aa} \times i_a)+(L_{ab} \times i_b)+(L_{ac} \times i_c)]+\psi_{am} \quad (4)$$

$$\psi_b = [(L_{ba} \times i_a)+(L_{bb} \times i_b)+(L_{bc} \times i_c)]+\psi_{bm} \quad (5)$$

$$\psi_c = [(L_{c\alpha} \times i_{\alpha})+ (L_{cb} \times i_b)+(L_{cc} \times i_c)]+\psi_{cm} \quad (6)$$

Where:

$L_{\alpha\alpha} = L_{bb} = L_{cc}$ = Stator's inductance
$L_{b\alpha} = L_{bc} = L_{c\alpha}$ = Mutual inductance among stator's phases
$\psi_{\alpha m}$ = Installed magnets in phase flow input

Regarding the stator's inductances, these are in function of the rotor's angle and its own fluctuating inductances of the motor's magnetization as described in Eq. 7-12:

$$L_{aa} = L_s \times L_m \cos(2\theta_r) \quad (7)$$

$$L_{bb} = L_s \times L_m \cos(2(\theta_r - 2\pi/3)) \quad (8)$$

$$L_{cc} = L_s \times L_m \cos(2(\theta_r + 2\pi/3)) \quad (9)$$

$$L_{ab} = L_{ba} = -M_s - L_m \cos(2(\theta_r + \pi/6)) \quad (10)$$

$$L_{bc} = L_{cb} = -M_s - L_m \cos(2(\theta_r + \pi/6 - 2\pi/3)) \quad (11)$$

$$L_{ca} = L_{ac} = -M_s - L_m \cos(2(\theta_r + \pi/6 - 2\pi/3)) \quad (12)$$

Where:

L_s = Inductance by stator's phase
L_m = Stator's fluctuant inductance
M_s = Stator's mutual inductance

One of the synchronous motors characteristics is the constan variation of the rotor's angle. For the desing's convenience, the best flow scenario of input from the machine's own permanent magents is disposed (Arroyo, 2006) where the flow is given by Eq. 13-15:

$$\psi_{am} = \psi_m \cos\theta_r \quad (13)$$

$$\psi_{bm} = \psi_m \cos(\theta_r - 2\pi/3) \quad (14)$$

$$\psi_{cm} = \psi_m \cos(\theta_r + 2\pi/3) \quad (15)$$

PMSM Matrix model: Equation 16-18 express in a matrix way Eq. 13-15:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \times \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} \frac{d\psi_a}{dt} \\ \frac{d\psi_b}{dt} \\ \frac{d\psi_c}{dt} \end{bmatrix} \quad (16)$$

$$\begin{bmatrix} \psi_a \\ \psi_b \\ \psi_c \end{bmatrix} = \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \times \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} \psi_{\alpha m} \\ \psi_{bm} \\ \psi_{cm} \end{bmatrix} \quad (17)$$

$$\begin{bmatrix} \psi_{am} \\ \psi_{bm} \\ \psi_{cm} \end{bmatrix} = \begin{bmatrix} \psi_m \cos\theta_r \\ \psi_m \cos(\theta_r - 2\pi/3) \\ \psi_m \cos(\theta_r + 2\pi/3) \end{bmatrix} \quad (18)$$

Equation 16-18 represent the mathematical relation of the mechanical and electric variables in the model of a PMSM motor which responds to an electric circuit consisting of inductances with inducted tensions due to the flow variation in each phase both auto-inducted and inducted by other coils and the input by the motor's permanent magnets. This model involves the different electric and electromagnetic factors within an ideal machine but it also is a highly non-linear model with a great amount of variable coeficients a clear example of this are the mutual inductances among the windings lodged in the stator and the rotor that depend on the rotor's position and therefore, the time.

In order to create the PMSM motor model, some mathematical transformations are involved which are applicable to our three-phase model which correspond to Park transformations (Haute *et al*., 1998).

D-Q model and park transformation: Park transformation corresponds to a model of two supplies and one reference axis (D-Q) which comes from a three-phase model. The variables that represent the machine's state around an operating point, correspond to the tensions and currents associated to the stator's and rotor's winding, the instant tension and current values are related to each other by the magnetic flow equations, represented by mutual and own inductances from the machine's winding. This variables are normally referenced to axes which directions match the tension vector's angle submitted on each phase which by convenience was set to 120° to achieve the similarity to an AC machine. Likewise, the inductances values vary according to the rotor's angle. The previously mentioned model is overlapping a new coordinates framework named d-q which turn into constant the values of the inductances during the rotor's rotation (Kishore *et al*., 2006) simplifying, the mathematical model. These three new axes have these characteristics:

- The extension of the direct axis "d" will be all the way throughout the rotor's direct axis
- The extension of the axis quadrature "q" will be all the way throughout the winding's neutral axis (Neutral point)
- The extension of axis 0 will be upon a stationary axis

In Park transformation, the axis "d" matches the "a" pahse axis and the phase currents of the stator are described as I_{as}, I_{bs}, I_{cs}. These currents are screened throughout axes "d" and "q" of the rotor (Fig. 3) obtaining Fig. 4 and Eq. 19 and 20.

$$I_q = \sqrt{2/3}\,[I_a \sin\theta + I_b \sin(\theta - 2\pi/3) + I_c \sin(\theta + 2\pi/3)] \quad (19)$$

$$I_d = \sqrt{2/3}\,[I_a \cos\theta + I_b \sin(\theta - 2\pi/3) + I_c \cos(\theta + 2\pi/3)] \quad (20)$$

Park transformations consist on turning all strator's variables from phases a, b and c into new variables

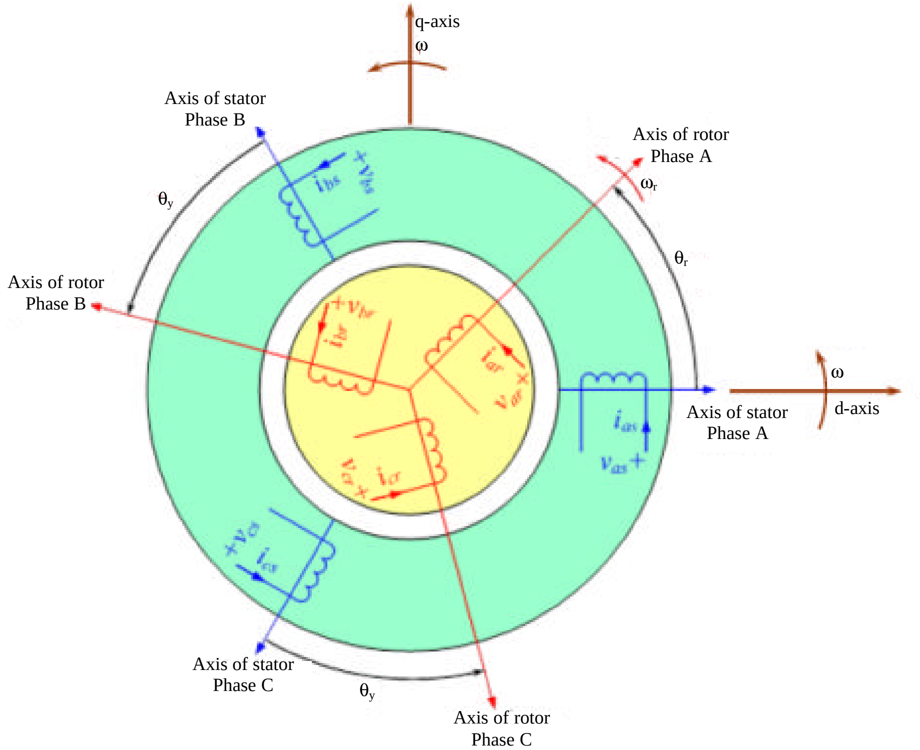

Fig. 3: Representation PMSM motor with “D-Q” axis (Kishore *et al*., 2006)

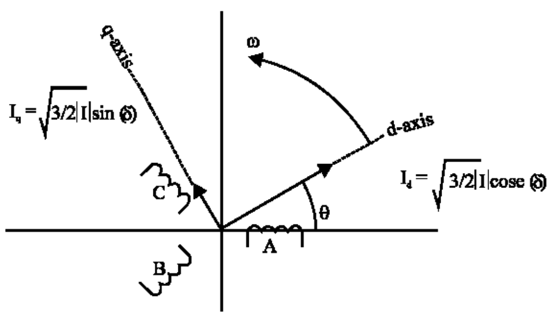

Fig. 4: Projection of currents I_{as}, I_{bs} y I_{cs} in axes d and q representation

that spin at the same speed as the rotor. This way, it is possible to represent in axes 0-d-q each one of the three variables obtained and the three projection variables. The projections in axes d and q are taken as variables and the projection upon axis 0 as a stationary current with sequence 0. In order to represeawnt in a more simple way the conversion of variables based on Park transformation in coordinates 0-d-q (Eq. 21) a multiplier P is used, described by Eq. 22:

$$I_{0dq} = P \times I_{abc} \tag{21}$$

And the multiplier P defined as:

$$P = \sqrt{2/3}\begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ \cos\theta & \cos(\theta\text{-}2\pi/3) & \cos(\theta+2\pi/3) \\ \sin\theta & \sin(\theta\text{-}2\pi/3) & \sin(\theta+2\pi/3) \end{bmatrix} \tag{22}$$

The magnetic flow produced by the field’s winding is upon axis “d” of the rotor, this effect’s consequence is that the electromotive force has a 90° delay, therefore, the electromotive force (fem) is under the axis q of the rotor. Converting the stator’s variables in terms of factor P, obtained Eq. 23-26:

$$\begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} = P \times \begin{bmatrix} I_\alpha \\ I_b \\ I_c \end{bmatrix} \tag{23}$$

$$\begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ \cos\theta & \cos(\theta\text{-}2\pi/3) & \cos(\theta+2\pi/3) \\ \sin\theta & \sin(\theta\text{-}2\pi/3) & \sin(\theta+2\pi/3) \end{bmatrix} \times \begin{bmatrix} I_\alpha \\ I_b \\ I_c \end{bmatrix} \tag{24}$$

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = P \times \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{25}$$

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ \cos\theta & \cos(\theta\text{-}2\pi/3) & \cos(\theta+2\pi/3) \\ \sin\theta & \sin(\theta\text{-}2\pi/3) & \sin(\theta+2\pi/3) \end{bmatrix} \times \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (26)$$

Replacing Eq. 16 in Eq. 26, Eq. 27 is obtained:

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ \cos\theta & \cos(\theta\text{-}2\pi/3) & \cos(\theta+2\pi/3) \\ \sin\theta & \sin(\theta\text{-}2\pi/3) & \sin(\theta+2\pi/3) \end{bmatrix} \times \left\{ \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \times \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} \frac{d\psi_a}{dt} \\ \frac{d\psi_b}{dt} \\ \frac{d\psi_c}{dt} \end{bmatrix} \right\} \quad (27)$$

Resolving Eq. 24 and replacing the result in Eq. 26 and then resolving for variables V_d and V_q, Eq. 28 and 29 are obtained:

$$V_d = R_s I_q + \frac{d\psi_q}{dt} + w_r \psi_d \quad (28)$$

$$V_q = R_s I_d + \frac{d\psi_d}{dt} + w_r \psi_q \quad (29)$$

The electric torque is developed in Eq. 30 and 31:

$$T_e = \frac{3}{2}\frac{P}{2}(I_d \times \psi_q \text{-} I_q \times \psi_d) \quad (30)$$

$$T_e = [T_l + T_f + (\beta \times W_{rm}) + (J\frac{dW_m}{dt})] \quad (31)$$

Resolving for term W_{rm} from Eq. 31 and 32 is obtained:

$$W_m = \int \frac{T_e \text{-} T_l \text{-} (\beta \times W_{rm})}{J} \times dt = W_r \times \frac{2}{P} \quad (32)$$

The flows relation in axis d and q are given by Eq. 33 and 34. The different variables of Eq. 28 through 34 are described as follows:

$$\psi_q = I_q \times L_q \quad (33)$$

$$\psi_d = I_d \times L_d + \psi_{ip} \quad (34)$$

Where:

T_e = Electric torque
T_l = Mechanical load
W_m = Mechanical speed
W_r = Electric speed in the rotor
J = Mechanical inertia
β = Friction factor

The previous d-q model of PMSM motor can be compared to the model presented in reference (Krykowski and Hetmanczyk, 2013). The main differences among the two models are presented as follows:

- The values of mutual inductances (Lm) among stator and rotor will not be considered since they're not comparable to the own inductances between phases and each phase
- The number of poles will be taken into account in order to provide constructive considerations along this document for special applications where a special torque is needed
- The constant torque strategy starts where the current I_d reaches its maximum value and value I_q takes the value of 0

Based on the previous conditions, Eq. 35-37 are obtained:

$$T_e = \frac{3}{2}\frac{P}{2}(I_d \times \psi_q) \quad (35)$$

Assuming that:

$$K_e = \frac{3}{2}\frac{P}{2} \times \psi_q \quad (36)$$

$$T_e = K_e + I_d \quad (37)$$

Where, K_e = Motor's electromotive constant. The torque strategy was not taken into account for analyzing the torque's control of the PMSM motor.

Controller PWM for PMSM motor: The controller is designed based on the modulation frequency (pulse) according to the model previously presented. The model is developed on Matlab's simulink tool with a feedback closed to the position (angle) of the rotor in this case, it has a square one-signal modulation as shown in Fig. 5.

The PWM signal consists on modifying the working cycle of a periodic signal (a sinusoidal signal or a square signal like in this case) for either transmitting information through a communication channel or controlling the

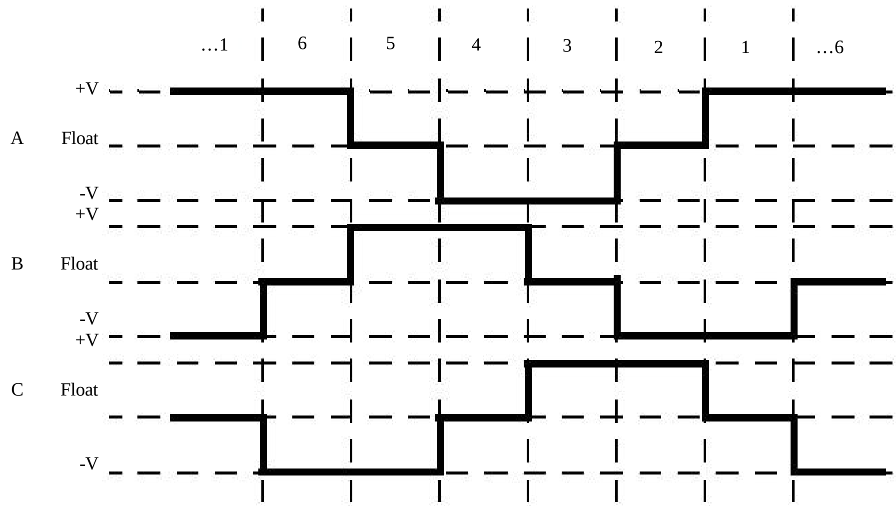

Fig. 5: Electronic switching in PMSM motor input (Janpan *et al*., 2012)

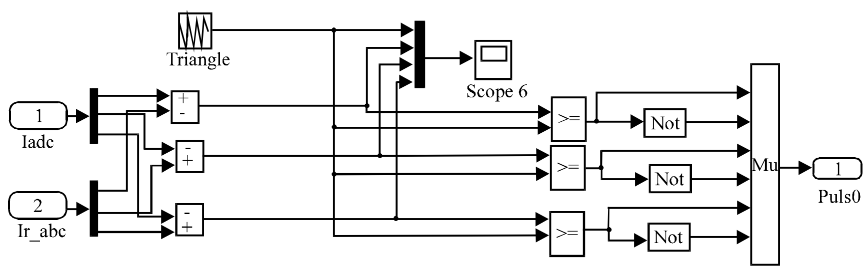

Fig. 6: Simulink model electronic switching in PMSM motor input source

amount of energy being sent to a load (DC motor like in this case). A periodic signal's working cycle is the relative width of its positive part in relation to the period, described by Eq. 38:

$$D = \frac{\tau}{T} \tag{38}$$

Where:

D = Working cycle
τ = Positive function time
T = Function period

This controller's supply will be the currents of the PMSM machine's rotor and stator and it will obtain as an output a pulse signal based on a previously parameterized triangular signal as reference (Fig. 5). The controller's outcome is shown in Fig. 6.

RESULTS AND DISCUSSION

The attained results along this investigative work are presented as follows.

D-Q Model of PMSM motor simulation: The introduction of the developed equations in regards to the D-Q Model of the PMSM motor on simulink are shown in Fig. 7 and 8. It describes the D-Q Model using Park transformation and Fig. 9 and 10 descibe the resulting signal without applying the PWM electronic switch to take them as a reference of the behavior of the simulated D-Q motor model (Kishore *et al*., 2006). The data and the resulting signals correspond to signals under a pure sinusoidal supply. In order to generate a pair in a synchronous motor of permanent magnets there must be a current circulation through the stator's phases following an established switching sequence. The current to circulate through the motor's phases can be synthetized as a vector of a certain intensity and direction. The pair is produced due to the interaction among the magnetic field generated by the stator's coils and the permanent magnets. Ideally, the maximum pair is produced when these two fields are 90° between them and null if they move together in the fields. Aiming to maintain the motor running, the magnetic field produced by the coils must change position because the rotor moves in order to follow the stator's field (De, 2011).

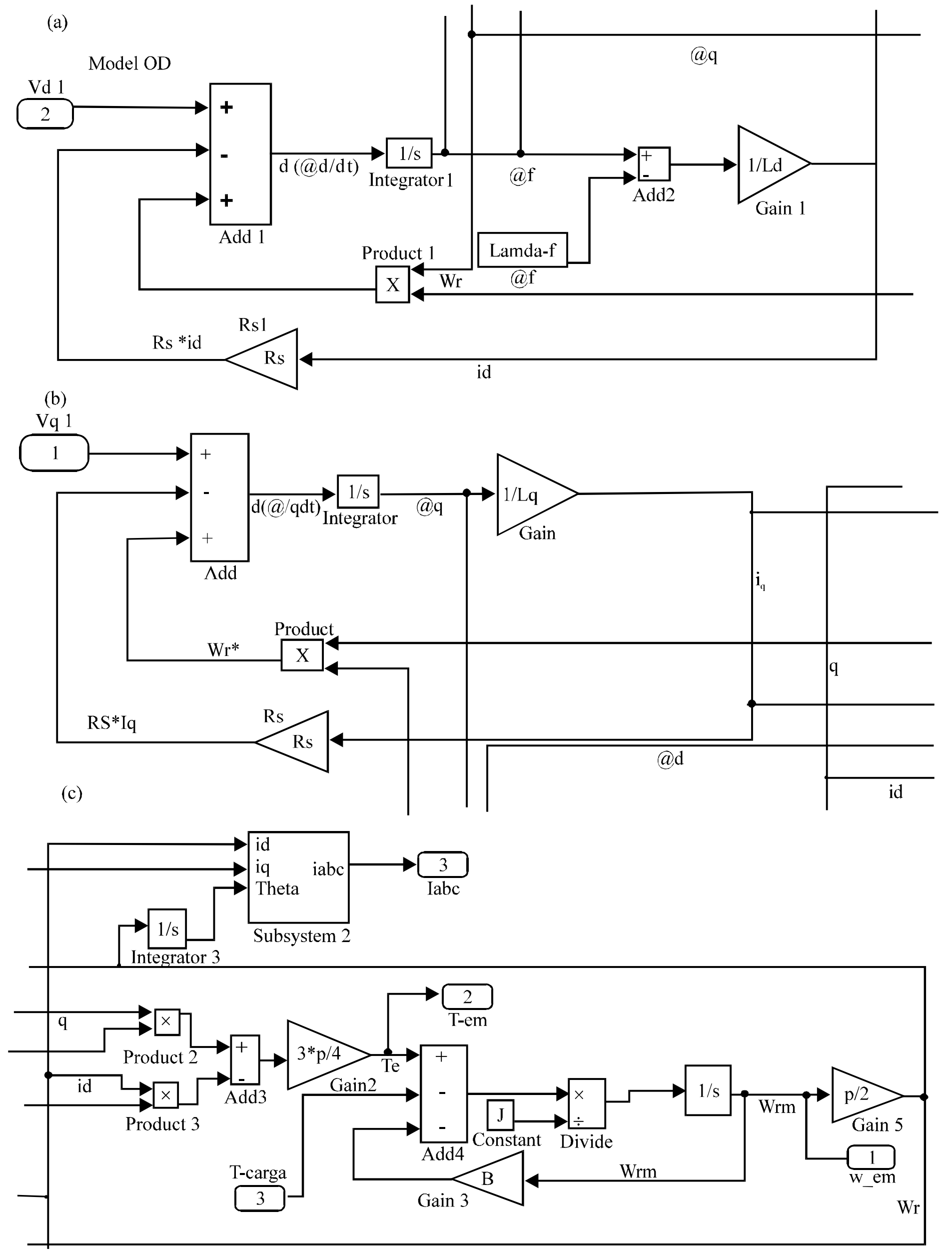

Fig. 7: Model developed on simulink; a) model d; b) model q and c) model electric torque and mechanical speed

D-Q Model of PMSM motor under pid control simulation: Figure 11 shows the full simulation of the model developed, integrating the D-Q Model, Park transformation, the PWM generator and the PI controller closely. The results obtained from RPM and torque are shown in Fig. 12 and 13, respectively. The gaining of each of the control types was made manually with the purpose of obtaining the best response according to the selected references from both RPM and torque. A PID controller is a mechanism of control by feedback widely used in industrial control systems. It calculates the deviation or error between a measured value and a desired value. The PID control's algorithm consists of three different parameters; the proportional, the integral and the derivative. The proportional value depends on the current error. The Integral depends on past errors and the derivative is a prediction of future errors. The sum of these three actions is used to adjust the process through

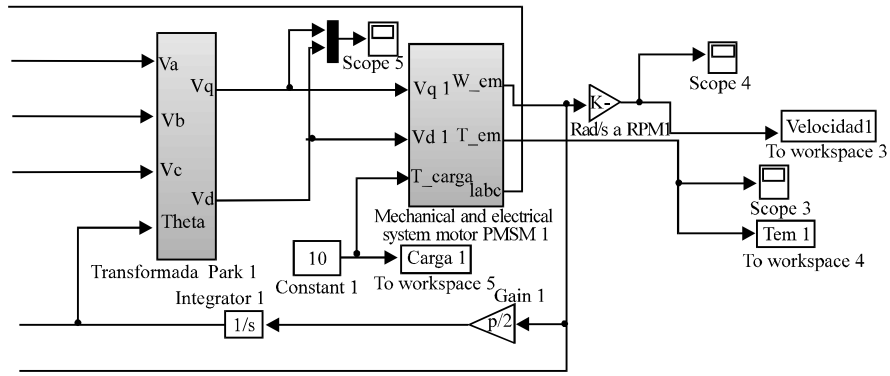

Fig. 8: PMSM motor model and Park's transference block

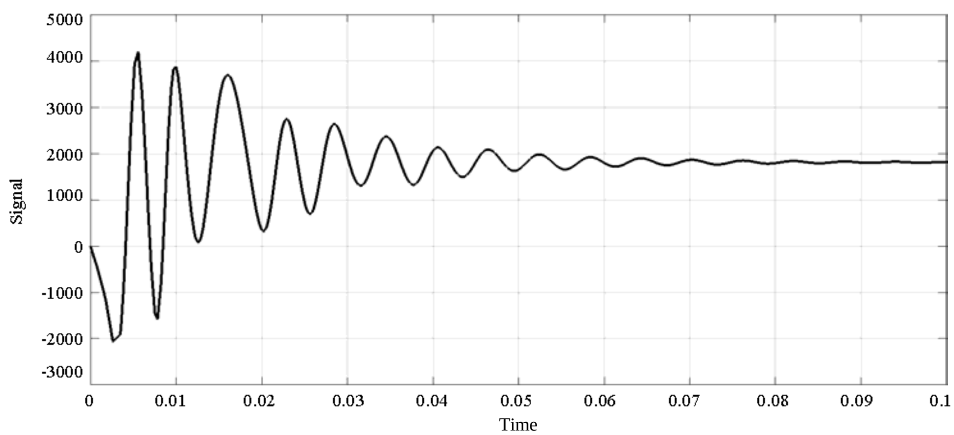

Fig. 9: RPM resulting signal vs. time

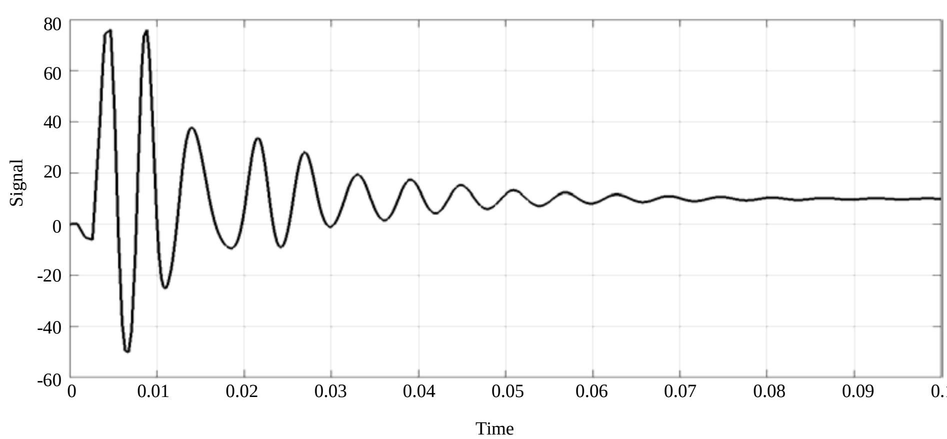

Fig. 10: Resulting torque signal vs. time

a control element such as the position of a control valve or the potency given to a heater. In our case, the signal to feedback is both the torque signals and RPM which will be adjusted to an established reference signal.

The method for controlling the torque consists on modifying the α angle between the inducted fem and the d axis as well as the properties of this angle α properly depend on the currents I_d y I_q. Calculating this angle is given by Eq. 39:

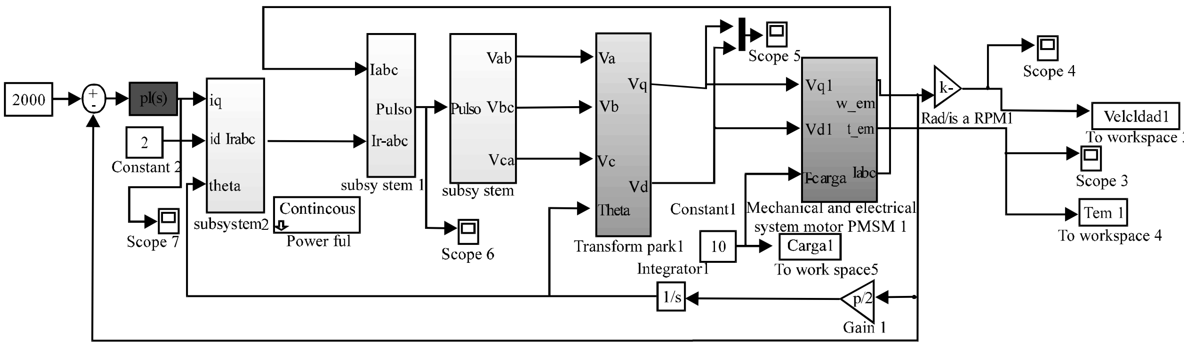

Fig. 11: D-Q Model under PID control

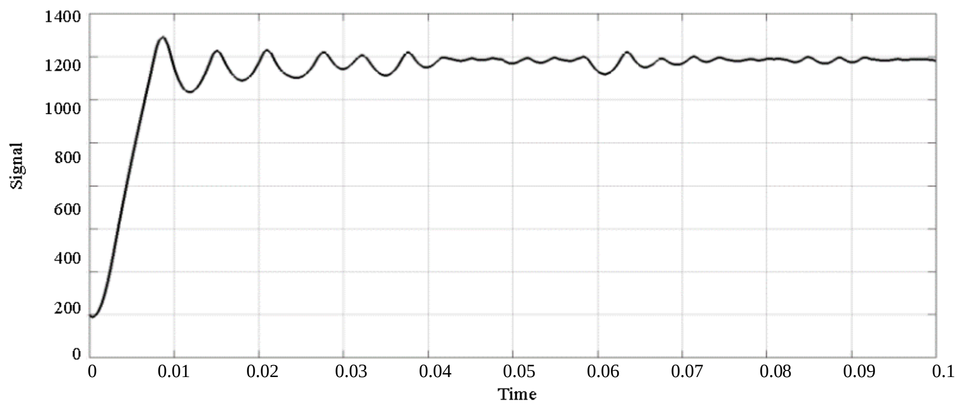

Fig. 12: Resulting RPM signal vs. time under PI control, 1200 RPM

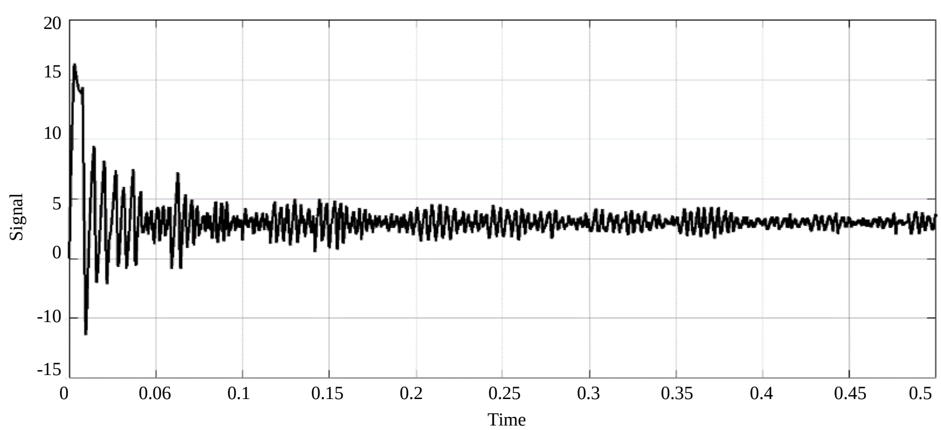

Fig. 13: Resulting torque signal vs. time under PI control, 10 N/m

$$\alpha = \mathrm{Tan}^{-1}\left[\frac{I_q}{I_d}\right] \quad (39)$$

The previous simulations were made under a 0.5 sec. Time which represents the maximum stabilit point of each one of the obtained signals. Figure 14 describes Parks transformation block used to obtain the resulting signal shown in Fig. 15.

Results analysis: The outcomes attained with the PI controller and even PID, show that torque and RPM

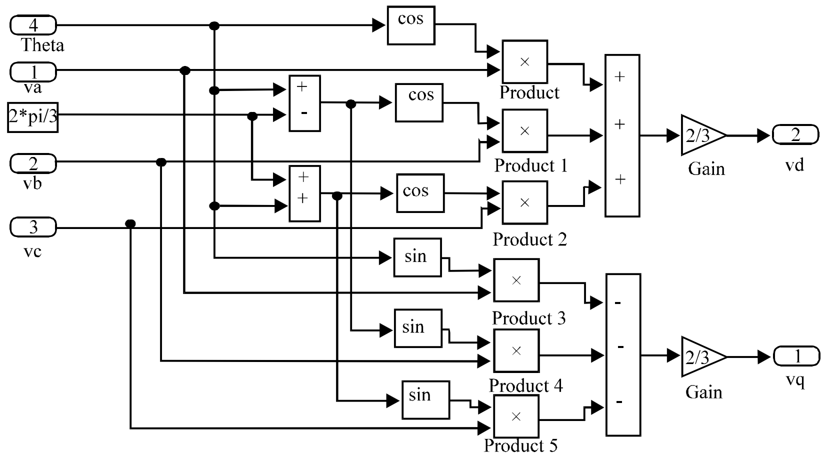

Fig. 14: Park's transformation model, factor P

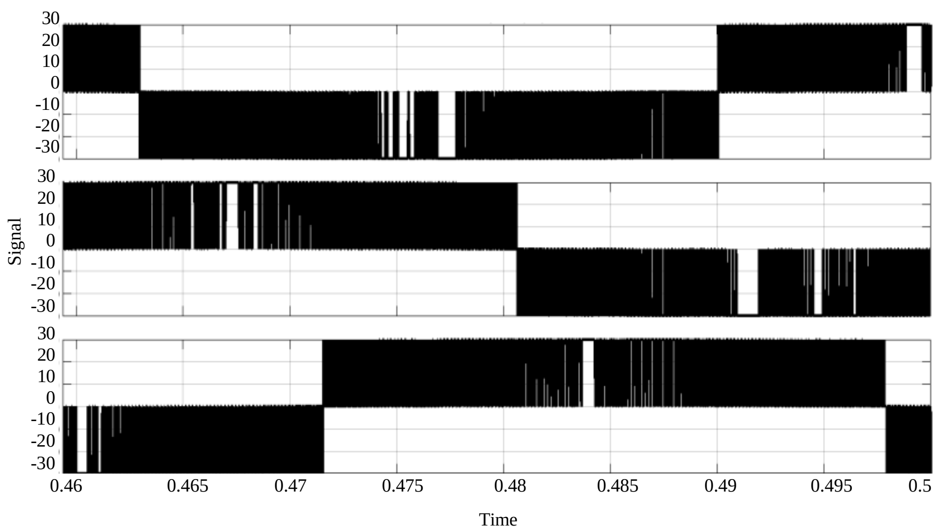

Fig. 15: Resulting signal from the PWM controller for supplying PMSM motor; inverter output vabc (volts)

signals are not fully stable in the established references values in the case of RPM a reference value was raised of 1200 RPM and obtained a value of 1165 RPM having a 97% approximation. In the case of the torque in order to know the exact value it is recommendable to use formulas such as medium value. The importance of switching and a great management of period and/or pulses modulation of supply signal must be as precise as possible this avoids the frizzle produced the resulting signals of both torque and RPM. The application of the motors magnetization constant simplifies the d-q model of the simulation and also the response in torque of the PMSM machine, causing the current I_q to be deleted from the model.

CONCLUSION

The relation between the electric machines of a three-phase model and a D-Q Model can possibly be extended to the equivalences in the behavior of the electric machines in currents generated in its armature and rotor. The mathematical model is a useful tool for analysis and an input for designing the controller of a PMSM motor as shown in the obtained ideal electronic switching graphics. The results obtained allow the functioning of the mathematical model, however, his can be enhanced with more effective electronic switching techniques. The selection of an IP control method (Integral Proportional) is the best if compared through the stabilization time attained with the other control types.

The IPD control does not make a difference, if the stabilization time is obstructed with frizzle due to its derivative component.

The model's simplicity is favorable point to understand the way the response signals can be managed and thus, attain a better stability of the system. If there's a need to implement a feedback based on a sensor of hall effect position, the mathematical model and the type of control suggested are not applicable.

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