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Real Time Power Factor Control in Permanent Magnet Synchronous Motor Using Genetic Algorithm

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Abstract

This research presents a dynamic simulation of permanent magnet synchronous motor (PMSM), which is designed to achieve the maximum Efficiency of the system. To this end, the motor efficiency is improved by using a Genetic optimization algorithm in order to maintain the maximum motor power Factor. First the maximum function of the formulation efficiency is optimized using the motor characteristic equation, and then a genetic algorithm is used to optimize the maximum power Factor. The simulations are conducted using genetic optimization and are compared before optimization. The results confirm the stability of the proposed method.

Keywords: *Genetic Algorithm, Loss Minimization, Output Optimization, Permanent Magnet Motor Drive, Vector Control.*

1. Introduction

Because of their high efficiency, high power density and simple control, permanent magnet motors are employed extensively in drive industries as well as applications with variable velocity. These motors used to be employed only in low powers, because magnetic material were expensive and low-power. The emergence of powerful magnetic material and a reduction in their cost, provided the opportunity for these motors to find their place in applications with higher power, such as electric vehicles[1-3]. Development and advancement in power electronic also helped the extension of these motors in modern industry. Higher thermal resistance, higher power density, and thus lower dimensions, are some of other advantages of these new motors. Considering the advancement of these motors, it seems necessary to develop control systems with high-speed dynamics[4-5]. Various optimum controlling methods, aiming at maximum power and efficiency, have been presented for these motors[1-10]. However, the power factor on drive control have been understudied in this field. Since a higher power Factor can lead to optimum use of the inverter and stator loss reduction, it is necessary to consider this parameter in motor design. This paper tries to design and investigate different parts of a vector controlling system for permanent magnet synchronous motors, in order to maximize the

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power Factor. Then, using MATLAB/SIMULINK Software, the controlling system is investigated comprehensively. Next, in section 2, a mathematical model of PMSM is summarized. Section 3 presents the efficiency optimization algorithm. Analysis of the results and conclusions are provided in sections 4 and 5, respectively.

2. The Mathematical Model of PMSM

PMSM relations are presented as the following[1]:

$$v_{qs} = r_s i_{qs} + p\lambda_{qs} + w_s\lambda_{ds} \quad (1)$$

$$v_{ds} = r_s i_{ds} + p\lambda_{ds} - w_s\lambda_{qs} \quad (2)$$

$$\lambda_{qs} = L_s i_{qs} \quad (3)$$

$$\lambda_{ds} = L_d i_{ds} + \lambda_f' \quad (4)$$

In this state, the generated electromagnetic torque is as follows:

$$T = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}) \quad (5)$$

Equation (5) can be rewritten in terms of two axial currents, which can be seen in (6):

$$T = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)(\lambda_f' i_{qs} + (L_d - L_q) i_{qs} i_{ds}) \quad (6)$$

This equation shows that the generated electromagnetic torque is consisted of a component proportionate to q-axis current, multiplied by flow amplitude produced by the permanent magnet; and the other component is the result of differential inductances of d- and q-axis, which is called reluctance torque.

As such, the motor dynamic equation provides a momentarily report of the relationship between the generated electromagnetic torque and the rotor velocity (w_r) according to the torque applied to the motor shaft.

$$T_e - T_l = J\left(\frac{2}{P}\right)P\omega_r + \left(\frac{2}{P}\right)\omega_l \quad (7)$$

Where *p* is the number of poles, T_L is the load torque (N.M), B_m shows the damping coefficient (N.M.S/Rad), and J denotes the motor inertia in terms of Kg.m^2. Figure 1 shows the dynamic model of the motor.

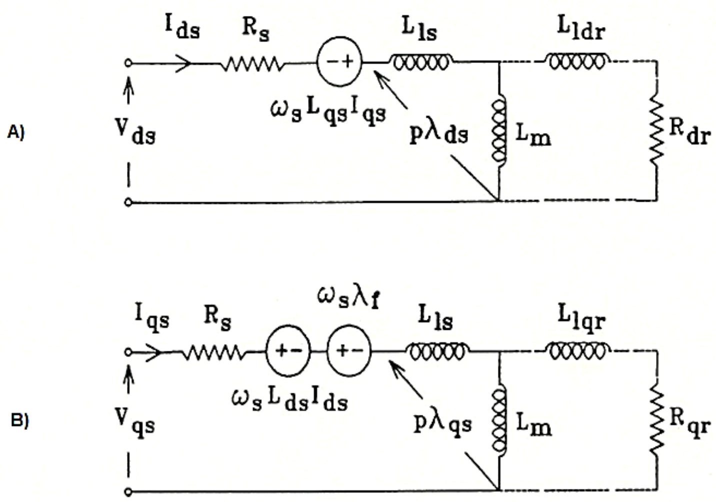

Figure 1. The dynamic model of the motor; **A**: d-axis loop, **B**: q-axis loop.

2.1. The Dynamic Model of Motor

In designing a high performance controller for a PMSM, the exact details of the model are required. In fact, some applications need the most capable power factor during the motor operation. It serves as an instruction for motor variables and revises voltage and current [8]. Figure 2 shows the PSMS drive control structure.

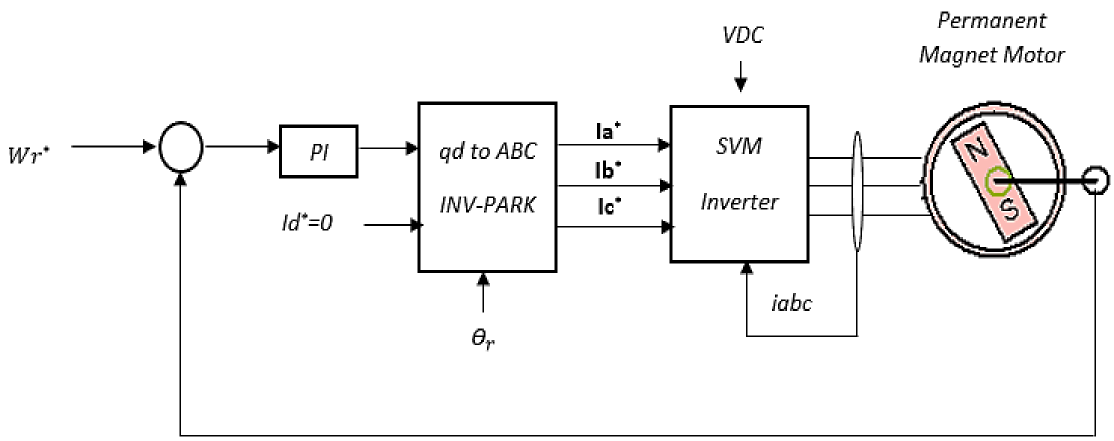

Figure 2: The drive structure of a PMSM (id=0)

As it can be seen in the block diagram in Figure 2, in PMSMs the flow obtained from permanent magnet is proportionate to d-axis stator. Therefore, the permanent magnet flow position can only be determined by obtaining the rotor position. If the starting point and the reference point are specified, the rotor position can be obtained by finding the rotor speed (given its fixed value). θ_r can be determined using a digital encoder shaft. It is a well-known fact that controlling these machines requires information about the exact position of the rotor. Nevertheless, it is also possible to calculate θ_r angle, even when one cannot use encoder. To do this, the exact measurements of machine terminal current and voltage should be used. According to this θ_r, the control feedback path can be established. These methods are called sensor-less methods, and have been studied in numerous papers [1,11]. The stator current should be controlled in a way that the spatial vector of the stator current on the rotor axis in stationary coordinates only includes q-axis component (I_{sq}). This works like a separately excited DC machine, where current is transferred through a commutator.

In order to increase velocity beyond the basic velocity, the flow should be weakened. However, because in these machines the rotor flow is constant, it cannot be weakened directly. So, in order to weaken the rotor flow an anti-magnetizing field is used, which increase i_{ds} in the opposite direction to d-axis. The spatial vectors of stator current and voltage, below and above the basic velocity, are shown in Figure 3.

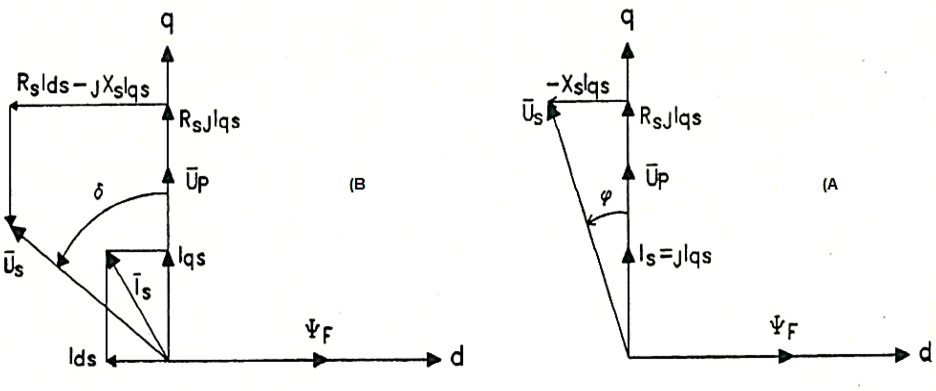

Figure 3: Phasor diagram of PMSM in permanent mode

A: below the basic velocity; **B:** above the basic velocity

Now the structural model from Figure 2 should be simulated in MATLAB Software environment. By implementing the model (id=0), the results presented in Figures 4 to 6 arte obtained.

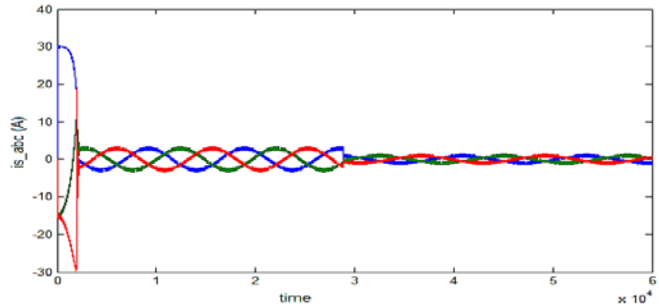

Figure 4: the current for three stator phases

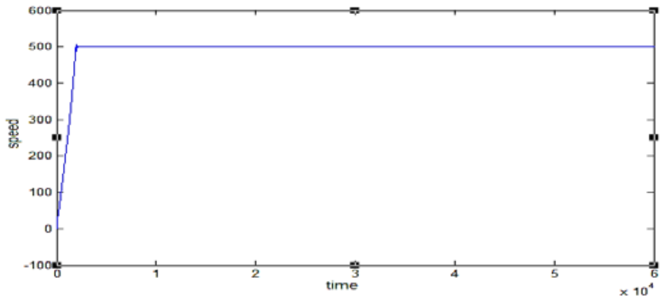

Figure 5: the motor velocity

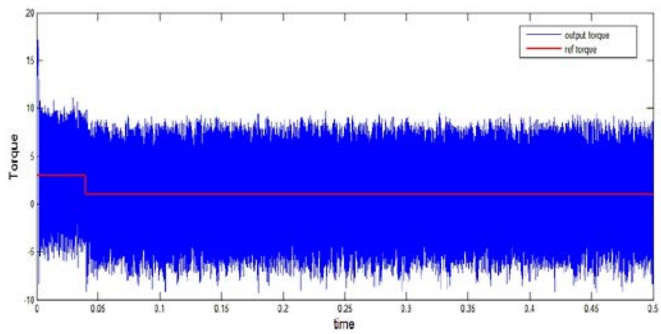

Figure 6: Torque to time

The figures obtained from the structural model of Figure 2 are summarized as follows:

In this system, the motor speed error is applied to a controlling system in order to obtain the necessary instructions for generating PWM pulses to be applied to the inverter. In this stage, the motor behavior under the normal method is simulated. The PWM inverter is designed according to the Simulink standards. The load torque is applied to the machine shaft, which is considered between 3 NM and 1 NM in T = 0.04S. Two control loops are used: the internal loop regulates the stator currents, while the external loop controls the motor speed. In T = 0.04S, by decreasing the load, the current amplitude also decreases. In the above figures, the results of implementing the motor model, with a reference speed of 500 Rad/s, are presented.

3. Maximum Power Factor to Increase Efficiency

In this section, the efficiency of the system is increased by controlling the power Factor. To this end, the relations of this theorem are rewritten according to Figure 7.

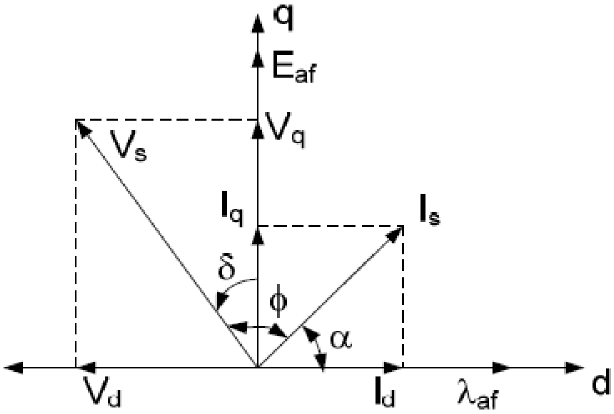

Figure 7: The motor components

The equation for the power Factor of a PMSM is [1]:

$$p.f = cos(\varphi) = \cos\left(\frac{\pi}{2} + \delta - \alpha\right) \quad (8)$$

Where δ is the torque angle, and α is the current angle.

Equation (8) states that in order to have p.f = 1, it is better to consider $\frac{\pi}{2} + \delta - \alpha = 0$. The next relations address the input power, the output power, and the motor efficiency, respectively.

$$p_{in} = 3\,Vs\,I_s\,p.f = \left(\frac{3}{2}\right)\left(v_d I_d + v_q I_q\right) \quad (9)$$

$$p_{out} = p_{in} - P_{cu} \quad (10)$$

$$\eta = \frac{p_{out}}{p_{in}} \quad (11)$$

4. The Proposed Structure

In recent years, genetic algorithm has been recognized as a potential method to address motor optimization problems. One of the most important advantages of GA is that it can find the global minimum [12-13]. Another advantage for GA is that it does not depend on derivative relations, since these relation cannot be obtained easily or sometimes they do not exist [7]. The loss minimization mechanism with real time power factor control are described here:

The momentary feedback from the electromagnetic torque and speed of the motor output are reported. For each torque and speed feedback from the GA, the initial population is generated. The initial population includes torque angle (δ), current angle (α), and stator voltage (Vs). These values are put in equation (8) to (11). In each iteration the power factor is checked as the problem constraint. Those populations are selected that have a power factor of 1 or at least bigger than 0.8 (P.F> 0.8 is considered as the problem constraint). The following block diagram shows the proposed model.

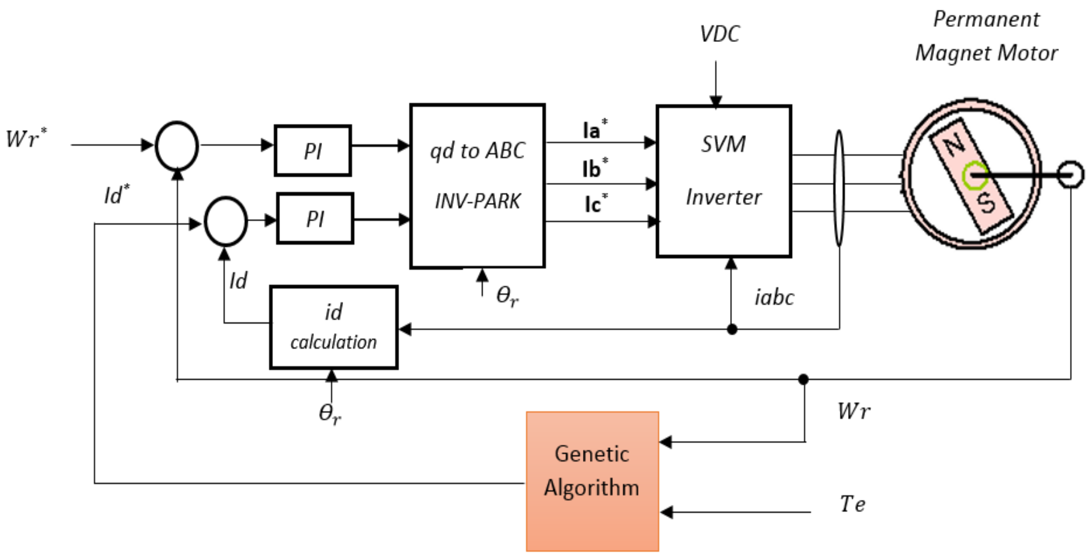

Figure 8: the proposed model (id≠0)

The Genetic Algorithm block diagram in Figure 8 includes equation (8) to (11). For every torque and speed received from the motor output, an initial population of torque angle (δ), current angle (α), and stator voltage (V_s) is selected randomly. Torque angle and current angle vary between zero and 90 degrees and the stator voltage can vary between 0 and 200 volts (Vs = 200v is related to the steady state characteristic of motors). The initial population has been considered 400 for each iteration. This population has been obtained through trial-and-error as well as according to the optimum answer.

Generally, it can be said that the following goal is pursued:

Max efficiency = Max (Pout/Pin)

P.F≥0.8

The problem constraint is power factor, which is controlled in real time. Figure 9 shows the flowchart of the proposed system:

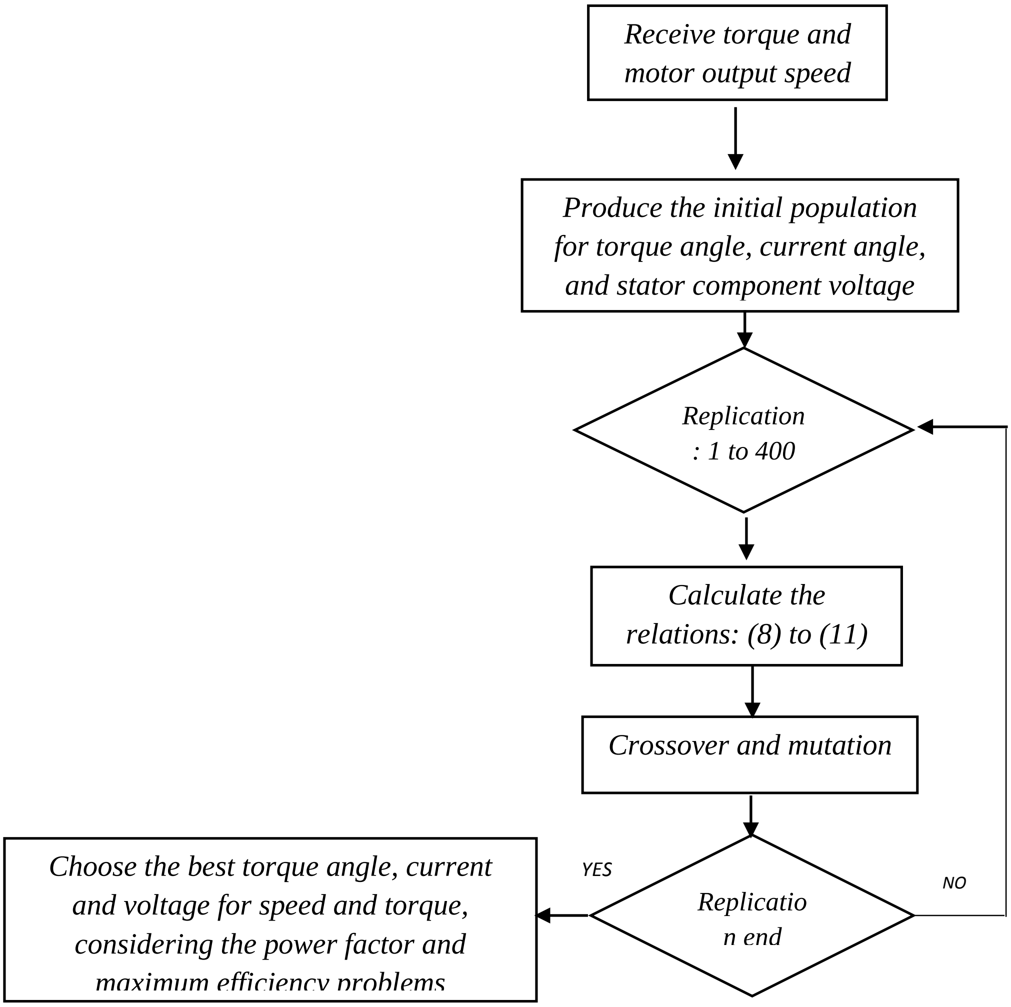

Figure 9: the proposed system flowchart

The results of the proposed system implementation are presented in Figure 10. The results of the optimization mode are compared to the results obtained of without optimization mode. As it can be seen, when GA is used, the efficiency provides a better performance and is able to approach to 1.

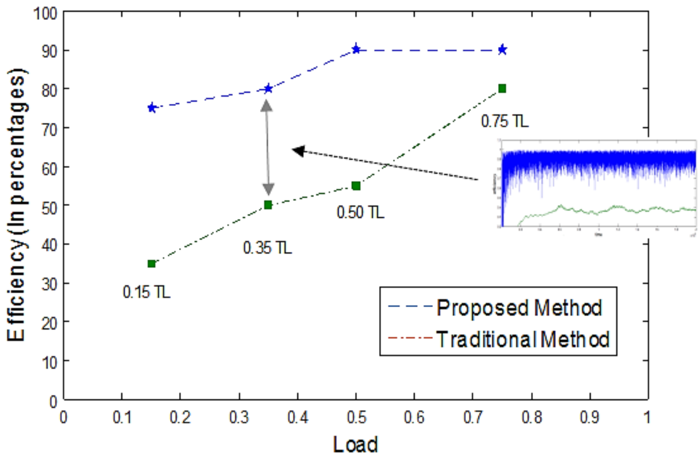

Figure 10: Efficiency in two modes

It can be obviously seen that using the proposed approach will provide a better performance for efficiency. The motor load has been set in 15%, 35%, 50% and 75% of the nominal load.

Conclusion

Considering the increasing demand for electric machines in different industries, the optimization of these machines to achieve a high efficiency is of utmost importance. Genetic Algorithm, as a potential method for optimization problems, has been used in this research to improve the efficiency. Optimization has been conducted based on PMSM power factor as a problem constraint. The relationships between losses and PMSM were obtained on the basis of power factor. By employing the proposed approach, the motor efficiency was increased between 40% and 50%. This means that by using a lower power, the required torque for the motor was provided. To this end, the load torque applied between 0 and 0.04s was 3NM, and the load torque applied between 0.04 and 0.5s was equal to 1NM. The proposed trend can be employed easily for PMSMs with a load torque in low-load conditions.

Appendix: Motor parameters

parameters	Value	parameters	Value
Lq	0.0115 H	Vs	200 V
Ld	0.0115 H	Ns	2000 rpm
λaf	0.283	B	0.0005416
P	4	J	0.0000144
Rs	6.8 Ω	f	60 hz

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