Simulation study of Conventional Control versus MTPA-Based for PMSM Control

Mohamed Taha Elsayed, Osama Ahmed Mahgoub and Sherif Ahmed Zaid
Department of Electrical Power and Machines
Cairo University
Giza, Egypt 12613
Mohamd.taha@gmail.com

Abstract— in this paper, an analytical analysis for the permanent magnet synchronous motor (PMSM) control strategies will be provided and verified using the MATLAB program. A comparison between the conventional control (zero direct current) and the Maximum Torque per Ampere (MTPA) will be provided and verified on MATLAB. The target of this study is to verify that using the MTPA method is to be the proper choice for those applications require efficient driver to minimize the total power loss of the system. Electrical vehicle is one of those applications requires efficient motor drive to optimize the overall system performance.

Index Terms – PMSM, MTPA, IPMSM.

I. INTRODUCTION

Due to the advantages of the Permanent Magnet Synchronous Motors (PMSM) the application of Permanent Magnet Synchronous Motors (PMSM) has greatly broadened [1]. The zero rotor copper loss is that results in higher efficiency, the high torque and output power per volume that results in compact design and the simplicity in construction and maintenance are some of the PMSM advantages. Robotics, aerospace, power tools, generation with renewable energy source, various medical equipments and electric/hybrid vehicles etc are some of the applications that can be established based on the PMSM. Because of its many advantages, the permanent magnet machines are preferred over other traditional machines such as brush commutated DC motor, synchronous motor and induction motor especially for highly efficient servo and variable speed drive applications [1]. PMSM control can be controlled using different approaches; scalar control and vector control are possible methods for PMSM motors control [2]. PMSM can be controlled using sensor [3] or sensorless method [4]. PMSM are widely used in traction application because the wide range of the flux weakening control [5, 10].

II. PM MACHINES CONFIGURATIONS

In a Permanent Magnet (PM) machine, the field excitation comes from the permanent magnet pole pieces. Depending on working principles, the PM machine can be categorized broadly into three main groups; Brush commutated PMDC machines, Brushless PMDC machine and Brushless PMAC or PM Synchronous Machine (PMSM). The brush-commutated PMDC machine is the DC machine in which electromagnetic field has been replaced by the permanent magnet field. In such machines, permanent magnet poles are situated on the rotating part and the stator consists of three-phase windings that are fed with square waveforms from three-leg converters. The switching of the converter is controlled in such a way that at one time only two phases conduct. This electronic commutation scheme is functionally equivalent to the mechanical brush commutation of the DC machine. Hence, this type of PM DC machines is known as brushless PMDC machine or square-wave PMDC machine. The brushless PM DC machine is preferred for many applications because of its low maintenance, high efficiency and relatively simple switching scheme. The brushless PM AC machine also has permanent magnet poles in the rotating part and the stator or armature consists of the three-phase, sine-distributed windings. The machine operates with the principle of synchronous rotating magnetic field, hence, they are also known as PM Synchronous Machine (PMSM) [5].

III. PMSM ROTOR CONFIGURATIONS

The PM synchronous machines are built with a number of rotor configurations. Among them, interior and surface magnet rotors are the two most commonly used configurations. In the interior permanent magnet (IPM) structure, magnet poles are buried inside the rotor where as in the surface magnet rotor, the magnet poles are glued to the rotor surface as shown in the Fig. 1 (a) and (b).

Interior magnet rotor structure has the following important features:

Very small air-gap, consequently, flux weakening can be achieved by negative armature reaction

Its inverse saliency i.e. the q-axis inductance L_q is larger than the d-axis inductance L_d. Consequently; it has an additive reluctance torque component which can be exploited to extend constant power operation during flux-weakening.

Additionally, in the IPM rotor, the effect of centrifugal force over the pole magnet during very high speed application is minimal; hence, it is mechanically robust compared to surface magnet rotor structure.
IV. MATHEMATICAL MODEL OF AN IPMSM

The mathematical model of an IPMSM drive can be described by the following equations in asynchronously rotating rotor d-q reference frame as [2-5]:

\[ v_d = R_d i_d + \frac{d\psi_d}{dt} - \omega_L \psi_q \]  
(1)

\[ v_q = R_q i_q + \frac{d\psi_q}{dt} + \omega_L \psi_d \]  
(2)

And

\[ \psi_d = (L_{sd} + L_{md} i_d + \psi_{PM} \]  
(3)

\[ \psi_q = (L_{sq} + L_{mq} i_d) i_q = L_{iq} i_q \]  
(4)

Where:

- \( R_d \) : Stator winding resistance [Ω]
- \( i_d, i_q \) : d and q axes currents [A]
- \( v_d, v_q \) : d and q axes voltages [V]
- \( \psi_d, \psi_q \) : d and q axes stator flux linkage [Wb]
- \( L_{sd}, L_{sq} \) : d and q axes leakage inductance [H]
- \( L_{md}, L_{mq} \) : d and q axes magnetizing inductance [H]
- \( L_{dq} \) : d and q axis stator inductances [H]

The well-known electro-magnetic torque equation of the electric machine in the d-q synchronous reference frame is

\[ T_e = \frac{3}{2} p(\psi_d I_q - \psi_q I_d) \]  
(5)

This equation can be expressed in terms of machine parameters of the PM machine as:

\[ T_e = \frac{3}{2} p[\psi_{PM} I_q + (L_{dq} - L_{d}) I_d I_q] \]  
(6)

Equation 6 can be reduced to:

\[ T_e = k * I_q \]  
(7)

Where,

\[ k = \frac{3}{2} p[\psi_{PM}] \]  
(8)

V. CONVENTIONAL METHOD (I_d^*)

Based on Fig. 2, \( I_d^* \) will be set to zero. The previous scheme has been examined on MATLAB and the results in Fig. 4 have been obtained. The test was applying no load until time 0.3 sec. 2.5 Nm load has been applied. The motor parameters used in the simulation are listed in table 1 as [9].

VI. MTPA METHOD

In this method, the main idea is to provide a combination of \( I_d^* \) and \( I_q^* \), this combination resulting in the maximum torque per ampere. To get the MTPA Eqn. 6 can be differentiating by \( I_q \) and equating to zero. This procedure resulting in the following equation;

\[ i_q = \frac{\psi_{PM}}{2(L_q - L_d)} + \sqrt{\frac{\psi_{PM}^2}{4(L_q - L_d)^2} + i_q^2} \]  
(9)

The previous equation can either be normalized as [9] to simplify the experimental work or can be used as it is for the simulation to get the most accurate results. Figure (3) shows the MTPA control scheme.

The previous scheme has been examined on MATLAB and the results in Fig. 5 have been obtained. The test was applying no load until time 0.3 sec. 2.5 Nm load has been applied. The motor parameters used in the simulation are listed in table 1 as [9].
Fig. 4. Simulation results for Conventional control scheme (Id=0).

Fig. 5. Simulation results for MTPA control scheme.
Table 1
Motor parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor rated power Rated</td>
<td>3-phase, 1 hp</td>
</tr>
<tr>
<td>voltage</td>
<td>208 V</td>
</tr>
<tr>
<td>Rated current</td>
<td>3 A</td>
</tr>
<tr>
<td>Rated frequency</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Pole pair number (P)</td>
<td>2</td>
</tr>
<tr>
<td>d-axis inductance, L_d</td>
<td>42.44 mH</td>
</tr>
<tr>
<td>q-axis inductance, L_q</td>
<td>79.57 mH</td>
</tr>
<tr>
<td>Stator resistance, R</td>
<td>1.93Ω</td>
</tr>
<tr>
<td>Motor inertia, J_m</td>
<td>0.003 kgm²</td>
</tr>
<tr>
<td>Friction coefficient, B_m</td>
<td>0.001 Nm/rad/sec</td>
</tr>
<tr>
<td>Magnetic flux constant, ( \Psi_{PM} )</td>
<td>0.311 volts/rad/sec</td>
</tr>
</tbody>
</table>

VII. SIMULATION RESULTS

Simulation results in Fig.4 and Fig.5 show that; the motor provided the required torque (2.5Nm) and the required speed (1500 rpm) in both techniques. However the required torque is provided in both techniques, in the MTPA the total stator current is less. Stator current reduction can be seen from Fig. 6. A total reduction of about 5% has been obtained as the MTPA applied. \( I_q \) in MTPA technique less than \( I_q \) in the conventional technique. However \( I_q \) in the conventional technique is always zero. \( I_d \) in the conventional technique is variable with the time. The \( I_d - I_q \) Plan for both control techniques are shown also. These \( I_d - I_q \) Plans show the main difference between the conventional control concept \((I_d = 0)\) and the MTPA concept. \( I_q \) is the main variable in the conventional control technique while \( I_d \) is always zero. In the MTPA technique \( I_q \) and \( I_d \) both are variables, the proper combination between \( I_q \) and \( I_d \) values is the main target to be achieved in the MTPA technique.

VIII. CONCLUSIONS

The simulation study in this paper verified that using MTPA technique motor can deliver same torque and speed delivered by the motor in case of the conventional control technique \((I_d=0)\), but the stator current is less. As the stator current reduced using the MTPA, it is clear that working with MTPA optimizes the drive efficiency as the electrical power loss is minimized. This increase in the drive efficiency, based on the MTPA, increases the prospect of using the MTPA in many important applications like the electric vehicle, where the drive efficiency is one of the important factors affecting the overall system performance.

REFERENCES


