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Vector Control of Permanent Magnet Synchronous Motor Connected to a Photovoltaic System

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Abstract

This manuscript describes the design of three phases of permanent magnet synchronous motor (PMSM) speed and torque using vector control. The mathematical model of PMSM using the simulation modeling capabilities of Matlab/Simscape is accomplished. PMSMs are very common in many applications. The PMSMs are more reliable than DC motors because there is no commutator. The PMSM also has advantages when compared to an AC induction motor. The PMSM generates the rotor magnetic flux with rotor magnets, achieving higher efficiency. Therefore, the PMSM is used in high-end white goods (refrigerators, washing machines, dishwashers, etc.), high-end pumps, fans, and other appliances requiring high reliability and efficiency. For the increasing of solar power output, an interleaved CUK converter with fuzzy logic-based MPPT control is studied, and in order to convert the DC output of the converter for the required form of motor input, the three-phase inverter has been used for running the PMSM. The concept of this manuscript is to design control of PMSM connected to the photovoltaic system.

Keywords: Vector control, PMSM, Photovoltaic, PV Module, MATLAB/ Simulink/Simscape

I Introduction

Permanent magnet synchronous motors are commonly used in industrial automation for traction, robotics, and aerospace. Compared with other motor types, Permanent magnet synchronous motor (PMSM) has better dynamic performance, smaller size, and higher efficiency [1].PMSM is a nonlinear system. The output torque and stator current present a complicated function relation. It was easier to implement vector control [2]. Vector control is a premium method of controlling the permanent magnet synchronous motor (PMSM), where vector control theory maintains space vectors of magnetic flux, voltage, and current. It is possible to set up the coordinate system to decompose the vectors into a torque generating and an electromagnetic field generating part. Both components can be controlled separately after decomposition. Then, the motor controller's structure (vector control controller) is almost like a separately excited DC motor, which simplifies the control of a PMSM. The vector control technique was developed to achieve the same superior, dynamic performance of the PMSM [3]. The PMSM motor application uses the encoder for rotor speed measuring and position sensing. The quadrature encoder output consists of three signals A, B, and an index pulse defines the zero position. PMSM's are widely used in pump applications. In [4], the authors present a perturb and observe algorithm to control the PMSM connected to the PV system. However, using this algorithm, the speed fluctuating of the pump can't be ignored. Another application is presented in [5]. The refrigerator compressor is also controlled by tying it to the power grid. Therefore, the phase-locked loop (PLL) is used, which increases the complexity of the control. In this paper, vector control is used to control the speed and torque of the PMSM connected to the PV system. In Section II, general descriptions of the PMSM is introduced. The vector control technique is depicted in Section III. In Section IV, the proposed PV system properties are described in detail. The proposed system's simulation results are studied and analyzed in Section V. Finally, the conclusion is described in Section VI.

II Permanent magnet synchronous motor

The permanent magnet synchronous motor is a cross between a brushless DC motor and an induction motor. Like a brushless DC motor, it has a permanent magnet rotor and windings on the stator. However, the stator structure with windings constructed to produce a sinusoidal flux density in the machine's air gap resembles that of an induction motor. PMSM power density is higher than induction motors with the same ratings since no stator power is dedicated to magnetic field production. The PMSM can generate torque at zero speed, it has a high-efficiency operation, but it requires a digitally controlled inverter for operations. PMSM consists of the stationary member of the machine called a stator. Stator laminations for axial air gap machines are often formed by winding continuous strips of mild steel. Various parts of the laminations are the teeth slots, which contain the armature windings. Yoke completes the magnetic path. Lamination thickness depends upon the frequency of the armature source voltage and cost. Armature windings are generally formed in double layers (two coil sides per slot). Individual coils are connected to form phase groups. Phase groups are joined together in series/parallel combinations to create a star or delta [6]. The vector control is usually used to control the PMSM. A good performance can be achieved by this control method enormously because the parameters of PMSMs do not vary as much depending on the operating situation as the parameters of other machine types do [7].

III Vector control

Vector control describes how torque and speed control are directly based on the electromagnetic state of the motor, similar to a DC motor. Vector control is the first technology to control the real motor control variables of torque and flux. Decoupling between the stator current components: magnetizing flux and torque, the torque producing element of the stator flux can be controlled independently. Vector control consists of controlling the stator currents represented by a vector. This control method is based on transforming a three-phase time and speed-dependent system into a two-coordinate (d and q coordinates) time-invariant system. Two constants are needed as input references: the torque component (aligned with the q coordinate) and the flux component (aligned with the d coordinate).In this way, the ease of reaching constant reference (torque component and flux component of the stator current) and applying direct torque control is possible. If the permanent magnets are installed on the rotor surface, and the iron parts of the rotor are symmetrical, the direct-axis and quadrature-axis inductances of the machine are approximately equal, Ld = Lq. In the steady-state, the torque equation can be expressed in the form:

$$T_e \approx 3/2\, P[\psi_{PM} i_{sq}] \quad (1)$$

Here,

T_e: Torque, P: Number of pole pairs, ψ_{PM}: *the* permanent magnets' magnetic flux, i_{sq}: Amplitude of the current in quadrature axis.

It is clear from the above equation that the direct-axis current id does not affect the torque, and the minimum stator current is reached at a constant torque when id = 0. This creates the basis for the id = 0 control. The control

method is straightforward to implement as long as the real-time information of the rotor angle is available for the control. The torque control is implemented similarly as in a fully compensated DC machine – the torque is directly proportional to the stator current [8].
It is evident that the PMSM needed electric power to operate, and as a result of the rapid development and widespread of the photovoltaic (PV) systems, it was necessary to consider using them to provide the PMSM with the essential electrical power. Because of the PV maximum extracted power on irradiance and temperature, a controller is necessary for PV performance optimization. In fact, different maximum power point tracking (MPPT) algorithms are required to keep the PV module working at its maximum power.

IV Photovoltaic System

The entire PV system is divided into several independent functional modules such as PV module, MPPT module, and DC-DC converter module. The PV module consists of a PV array with an open-circuit voltage (Voc) is equal to 220 VDC. The fuzzy logic controller is implemented to obtain the maximum power point (MPP). Fuzzy logic controller-based MPPT tracks the power continuously with less fluctuation and has less overshoot with fast-tracking time than the other MPPT algorithms. Cuk converter is used because the Cuk's input current is continuous and usually can draw a ripple-free current from the PV array that is important for efficient maximum power point tracking. PV system is connected to the inverter because its output current is direct current (DC). Three phases inverting DC into alternating current (AC) to operate the PMSM.

V Simulation results

Simscape is a physical modeling language used to present mathematical models of physical components. It provides basic blocks from different physical domains such as electrical, mechanical, hydraulic, pneumatic, thermal, etc. [9, 10]. PMSM module is a built-in Simscape environment to simulate the exact behavior of a real one.
The adopted PV system has five PV modules with 225 V and current equal 8 A. According to the proposed vector control of PMSM simulation model, run in MATLAB/Simscape, using the motor parameters are as follows: DC voltage Vdc = 220 V, Stator winding resistance Rs = 0.013 Ω, stator winding inductance Ls = 0.0002 H, the rotor magnetic flux λm = 0.03 Wb, the pole number P = 6, reference speed = 200 RPM. Set the total simulation time t = 1s.

The proposed system illustrated in Figure 1 is composed of the PV system as a DC power supply, a three-phase inverter to convert the DV voltage to AC, the PMSM controller, an encoder to measure the speed of PMSM, and the PMSM.

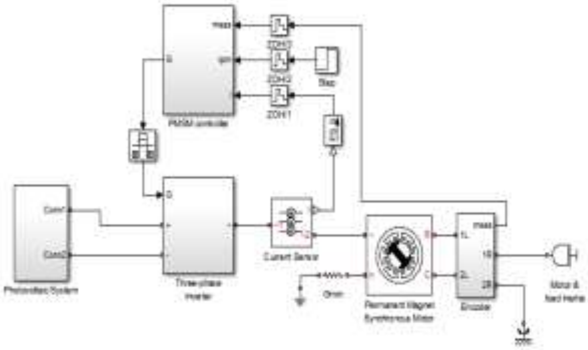

Figure 1. Matlab/Simscape Model of PMSM connected to the PV system.

The PV system includes the MPPT, and the DC/DC Cuk converter is evident in Figure 2. However, the MPPT control algorithm is investigated in [11, 12], while the Cuk converter is used to increase or decrease the output voltage to a specific value regarding the PMSM nominal voltage [13].

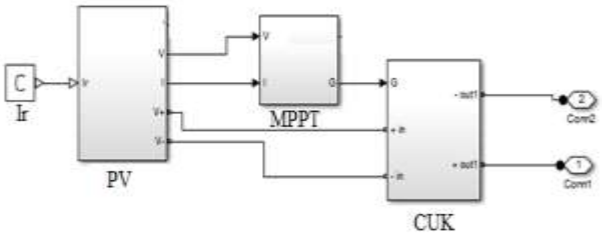

Figure 2. The components of the PV subsystem.

The vector control of the PMSM scheme with all detail is shown in Figure 3.

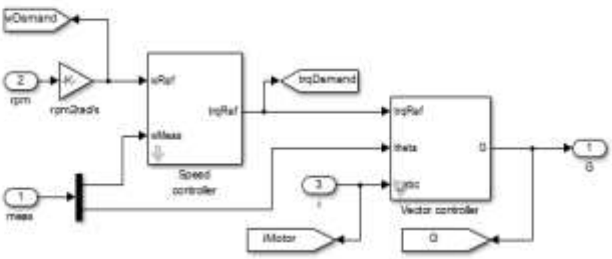

Figure 3. The components of the PV subsystem.

The PMSM is switching on at t=0.1 s. For that, the current response curve of PMSM is shown in Figure 4. The starting current is relatively high during the first half-second. Then, the current response is stable, and almost zero with no load appears.

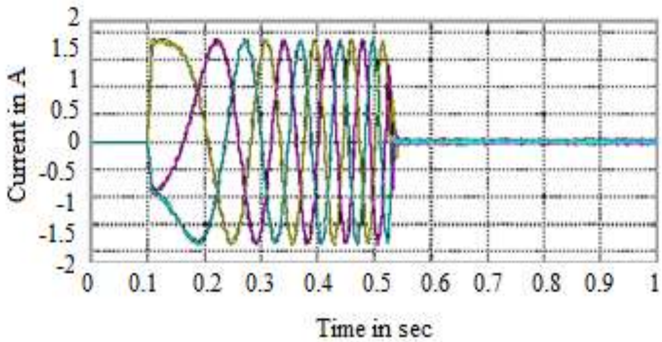

Figure 4. The current response curve of PMSM.

The demanded and achieved Torque plot of PMSM is illustrated in Figure 5. The achieved torque is similar to the demanded torque and has a stable response after 0.5 sec.

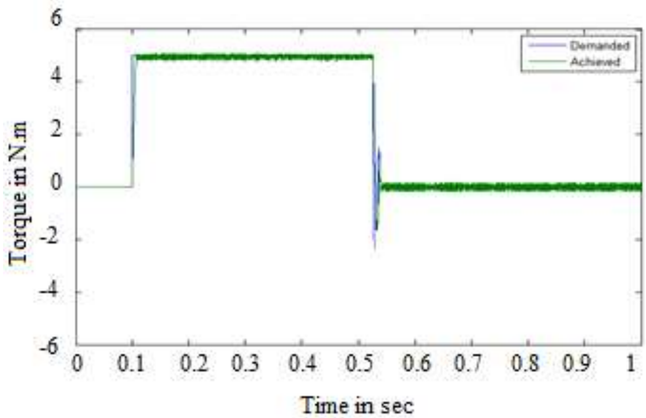

Figure 5. Demanded and achieved torque of PMSM.

The demanded and achieved speeds plot of PMSM is illustrated in Figure 6. However, the PMSM takes about 0.4 sec to reach its nominal speed, which is accepted in many applications. On the other hand, this duration is relatively high for some applications. Thus, the control parameters in figure 3 can be adjustable to decrease this duration.

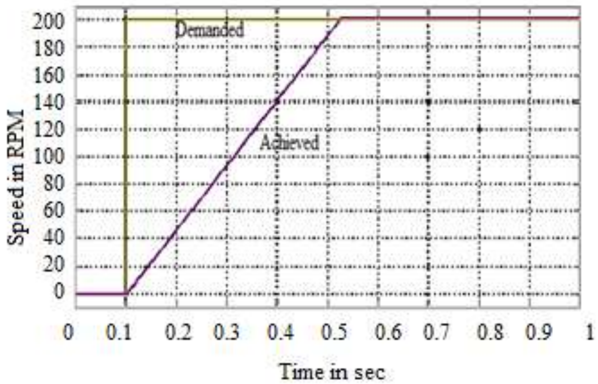

Figure 6. Demanded and achieved speeds of PMSM.

The previous results are depicted in the no-load case. However, it's recommended to study the system behavior in the load case and investigate the PV system's capability to deal with the load cases successfully. Indeed, the PMSM is driving a load at t=0.8 sec.

The current response of the PMSM is shown in Figure 7. The three phase-current is increasing at t=0.8 sec to about 0.5 A, which means the PMSM consumes about 330 W.

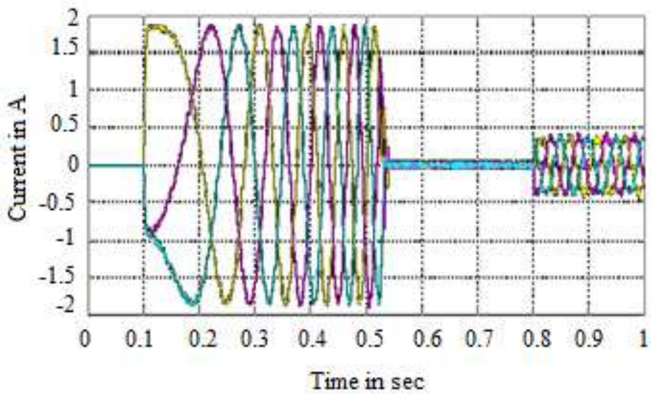

Figure 7. The current response curve of PMSM with additional load at T= 0.8s.

The torque response of the PMSM after driving the load is illustrated in Figure 8. However, the torque is about 1 N.m, which is almost the same torque calculated using Eq. 1. Moreover, the vector control forces the PMSM to attain the desired speed even in the load cases. Figure 9 illustrates that at t=0.8 sec, the PMSM speed still equal to 200 RPM and relatively doesn't affect by adding the load.

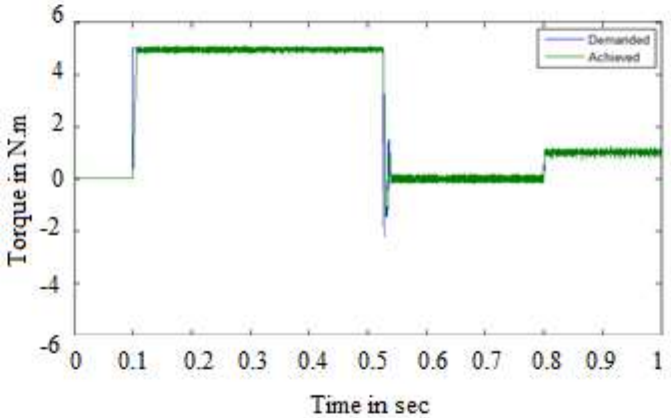

Figure 8. Demanded and achieved torques of PMSM with additional load at T=0.8s.

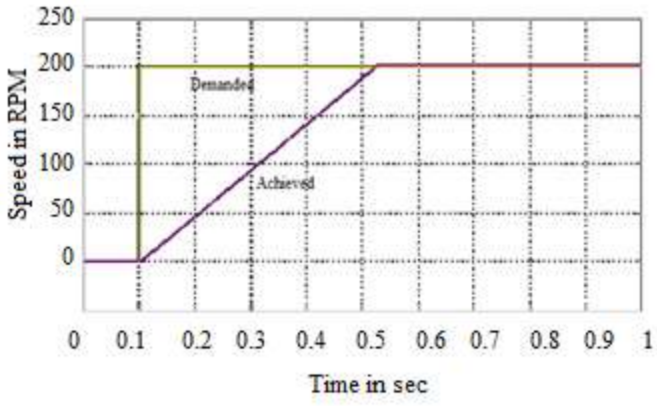

Figure 9. Demanded and achieved speeds of PMSM with additional load at T=0.8s.

VI Conclusion

In this paper, the Vector control of a permanent magnet synchronous motor connected to the photovoltaic system has been proposed and simulated. The

time-varying a,b,c currents are made stationery using Reverse Park Transformation. The vector control technique enables the operation of the drive at zero direct axis stator current. Therefore, it permits the process at minimum armature current. In this situation, it is obtaining maximum torque per ampere as well as maximum efficiency.
Simulation results show that the performance of vector control is fast and reliable, at a time equal to 0.8 s, the additional load is connected to the PMSM, but the speed of PMSM is approximate doesn't affect.

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