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Performance Analysis of Permanent Magnet Synchronous Motor for Mining Applications – A Review

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Abstract

The features of Permanent Magnet Synchronous Motor (PMSM) makes it suitable for mining applications such as copper mining, mining floating machine, mining scraper conveyor, mine integrated machine, mining vacuum circuit breaker, mineral extraction in mines, coal mine belt conveyor system, mining truck and many more. This study focuses on performance analysis of permanent magnet synchronous motor for mining applications and performance analysis is the confirmation and analysis of parameters, various losses and efficiency at various loads. A comparative analysis of wound rotor synchronous motor, induction motor and permanent magnet synchronous motor confirmed the suitability of PMSM for various mining applications. Advanced technology of artificial intelligence integrated with permanent magnet synchronous motor also enhances the effectiveness and precision of the system.

Keywords: *Cooling Schemes, Mining Application, Mine Integrated Machine, PMSM, Sliding Mode Control*

1.0 Introduction

The researchers prove that the permanent magnet direct drive has high energy density, high response speed, stable operation and performs well in any difficult situations in mine. The accuracy and stability of the control system gets influenced by the recurrent switching of operational conditions in mine. The rotor position and rotor speed of the permanent magnet motor are estimated by sliding mode control. A direct drive with integrated machine uses sensor less vector control system[1]. In addition to the improvement in performance of the permanent magnet drive, a smart controller with fuzzy PID control shows the stronger reliability[2]. The geometrical dimensions and efficiency of permanent magnet axial flux synchronous motor are optimized. The cogging torque is reduced and the efficient drive is used for the concentration of copper minerals in copper mining industry[3]. The mining flotation machines uses the permanent magnet direct drive system with the vector control method based on field weakening. The proposed machine reduces the energy consumption[4]. The performance characteristics of the mining scraper conveyor are improved with the combination of permanent magnet machines driven system and composite sliding mode controller. The controller of the driven system with reference to the load profile improves the starting of the scraper conveyor, accuracy in the load torque estimation, reduces the frequent switching of the control system due to the changes in load[5]. The permanent magnet synchronous motor is one of the important motors to fulfill the required characteristics of mine integrated machines. In underground coal transportation, the problem faced by power switching device IGBT is the dissipation of heat which limits the consistent operation of the mine machine. Large overload capacity, low failure rate, high starting torque and high-

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power density are the features of the permanent magnet machines required to design mine integrated machine[6]. The permanent magnets used in actuators for mining vacuum circuit breakers detects the minute variations in voltage in main circuit at each instant. The presence of permanent magnet breaks the circuit on occurrence of low voltage fault with no any additional detection and control of apparatus[8]. The permanent magnet synchronous motor plays an important role for effective mineral extraction in mines. The precision and effective arm movement of robot in mines for mineral extraction is a challenge. This challenge is accepted and implemented with an advanced technology and innovative idea of integrating permanent magnet synchronous motor and artificial intelligence. The permanent magnet synchronous motor is used for robotic arm movement and artificial intelligence is used to manage the robotic arm motion. The system with artificial intelligence and robotic arm movement control by permanent magnet synchronous motor increases the efficiency of mineral extraction. The proposed system can be used in a variety of mining applications[10]. The permanent magnet synchronous motor with different stator conductors turns used in belt conveyor system of coal mine leads to rise in temperature. The temperature rises due to heat generated by different stator turns and magnets used for rotor. The motor is designed with concentrated and fractional slot winding to optimize the efficiency and power density[11]. The Induction motor, Wound rotor synchronous motor and permanent magnet synchronous motor are compared and concluded that the wound rotor (with no magnets) synchronous motor is the best for constant power and constant speed control over a wide range in mining dump truck. The limitations of constant flux in permanent magnet motor and more losses in induction motor are overcome by regulated flux in wound rotor synchronous motor with dc excitation to rotor[13]. The rotor speed of the permanent magnet synchronous motor can be precisely estimated using sensor less vector control method based on model reference adaptive system[14]. The exterior rotor permanent magnet synchronous motor experiences the temperature rise. The temperature rise can be within the limits by distribution of temperature of the motor through different modes of heat dissipation like air cooling and water cooling schemes. The effect of cooling and distribution of temperature rise by cooling schemes are compared and analyzed. The effect of heat sink on maximum temperature rise, effect of fillet at the back of the fluid channel and the effect of speed of water flow on maximum temperature rise is analyzed in air cooling and water cooling schemes[16]. The permanent magnet synchronous motor with high power density and multiphase for enhancing robustness and fault tolerance is the advanced motor in mining applications[18].

The primary objective of this study is to confirm the suitability of permanent magnet synchronous motor for mining applications such as mining scraper conveyor and electric drive mining truck. These two applications are studied for control scheme of PMSM and result analysis proves that the PMSM with composite sliding mode controller and speed sensor less vector control improves the system stability and enhances the efficiency.

2.0 PMSM for Mining Scraper Conveyor

2.1 Control Scheme

The equipment of coal mining has an important part scraper conveyor and its performance depends upon the drive working. The failure of drive affects the operation of scraper conveyor and hence the safety and efficiency of the system. PMSM drive system with sliding mode controller starts the scraper conveyor smoothly and makes its operation stable. Figure 1, shows the sliding mode control of PMSM. The soft switching sliding mode observer identifies the load torque of the PMSM; the output of the Soft Switching Sliding Mode Observer (SS-SMO) is then fed to the current regulator as an input. The Non-singular Terminal Sliding Mode Control (NTSMC) controls the speed of the PMSM due to sudden changes in load. The sudden changes in the load affect the performance

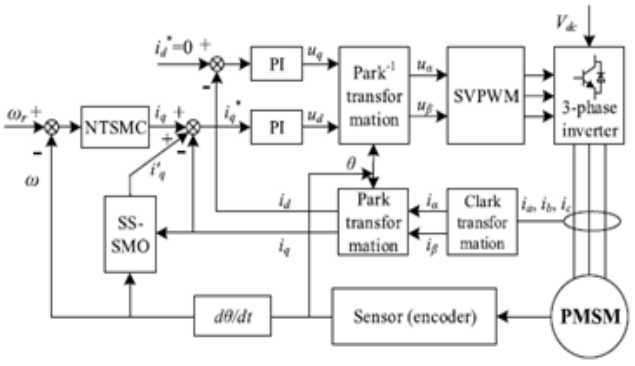


Figure 1. Composite sliding mode control scheme of PMSM[5].

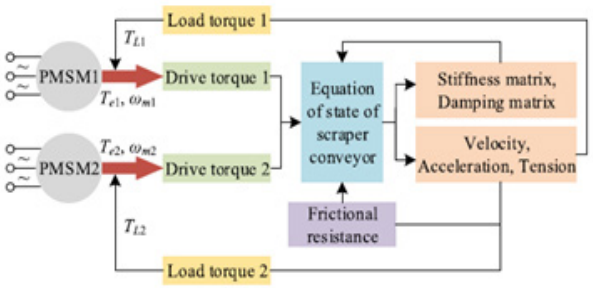


Figure 2. Schematic block diagram of electromechanical coupling model[5].

of the control system and can be effectively reduced by composite sliding mode controller. The composite sliding mode controller enhances the performance and stability of the system.

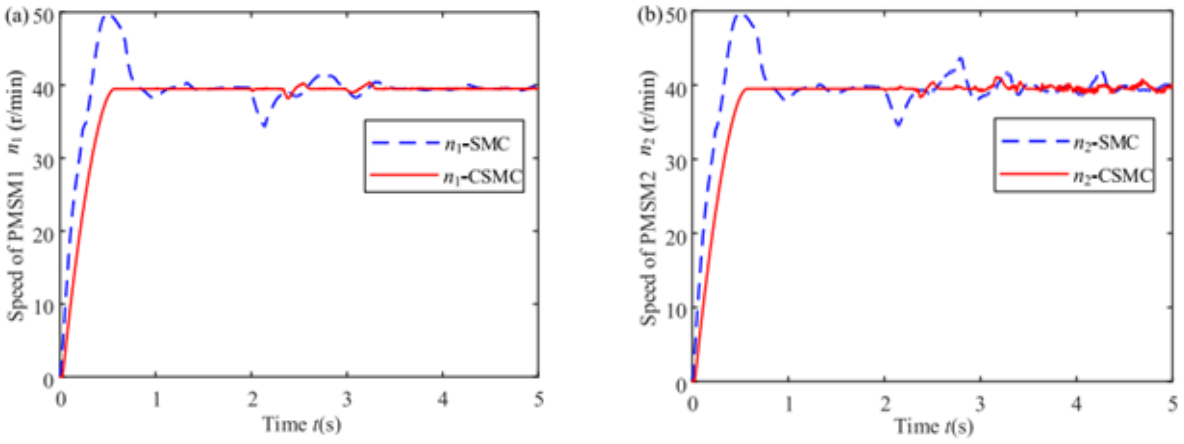


Figure 3. Simulation curves of the sliding mode controller and composite sliding mode controller (a. Speed of PMSM1, b. Speed of PMSM2)[5].

The scraper conveyor and PMSM drive can be correlated by the electromechanical coupling model as shown in Figure 2.

2.2 Result and Analysis

The composite sliding mode controller as shown in figure 3 improves the system stability and performance. Figure 3(a) shows the speed time curves of PMSM 1 with generalized sliding mode controller and composite sliding mode controller. It is clear that the composite sliding mode controller minimizes the overshoots and gives better stability of the system. Figure 3(b) shows the speed time curves of PMSM 2 with both the controller and composite sliding mode controller gives the better performance as compared with sliding mode controller.

3.0 PMSM for Electric Drive Mining Truck

3.1 Control Scheme

In surface mines, the coal and ore production is a continuous process; to carry the ore and coal more numbers of mining trucks are needed. Mechanical drive truck and electrical drive truck are the two categories of mining dump truck as shown in Figure 4.

The electric drive system has many advantages as compared to mechanical drive system with reference to

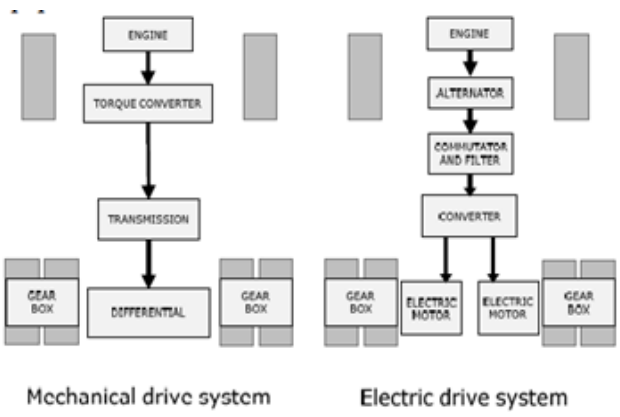


Figure 4. Mechanical drive system and Electrical drive system[14].

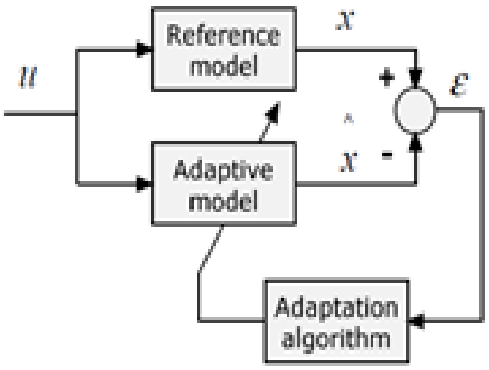


Figure 5. Model Adaptive Reference System[14].

3.2 Result and Analysis

The PMSM model is simulated with the specified values of dc voltage of PWM inverter, stator winding resistance, d axis and q axis inductances, pole pair number, and moment of inertia of the motor and given speed of 2000 revolutions per minute at no load. The speed time curves of estimated and measured speed are shown in Figure 7. The two curves show the fluctuations initially and then estimated and measured speed maintains the speed of 2000 revolutions per minute. In PMSM, there are two fields by stator current and permanent magnets. These fields develop the torque which is braking torque. The

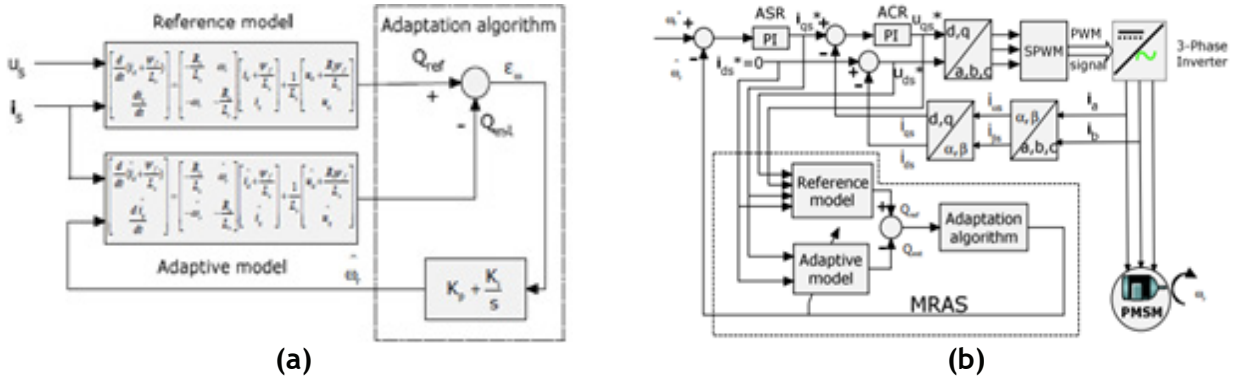


Figure 6. a) Adaptive Logarithm[14]. b) Speed Sensorless control for PMSM[14].

efficiency, energy saving, heavy duty and transportation cost. The structure and electromagnetic interference of the electric vehicle makes the mining truck to be driven by AC drive system. High efficiency, extensive speed range, high power density and high torque these are the characteristics of PMSM required for mining truck and hence AC drive system with PMSM is generally used now days for mining dump trucks.

Rotor position and rotor speed of PMSM are controlled by sensor less control technique which saves the cost and enhances the reliability. Model adaptive reference system estimates the PMSM speed on comparison of output by reference model and output by adaptive model in anticipation of the zero error. It is shown in Figure 5.

In model reference adaptive system, to design adaptation algorithm the system stability and estimated speed are considered. It is also necessary to verify the estimated and desired speed with reference to characteristics of the motor. The block diagram is shown in Figure 6(a&b).

motor torque gets affected due to this braking torque. The large value of braking torques than the traction torques causes the reduction in motor torque. It is as shown in Figure 8, the motor toque experiences large fluctuations upto 0.7 seconds because the stator magnetic field speed is more than the rotor speed. Hence the motor torque gets reduced initially before 0.7 second and afterwards the torque remains constant with minimum fluctuations.

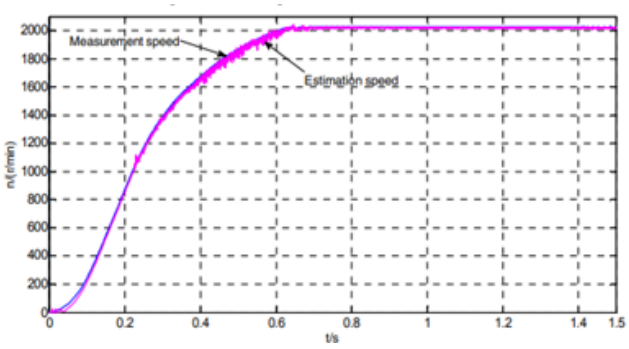


Figure 7. Measurement speed and estimation speed comparison[14].

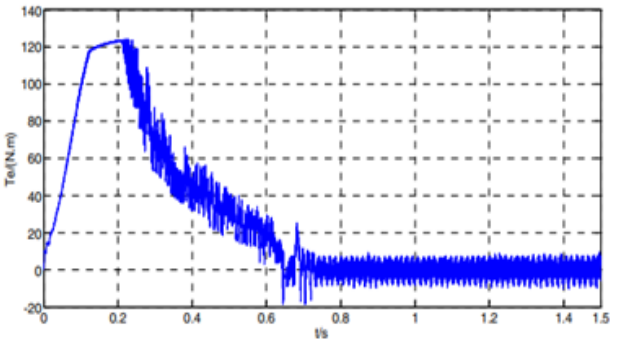


Figure 8. Torque Response Curve[14].

4.0 Conclusion

Permanent magnet synchronous motor is controlled by controller. Based upon the requirements, the parameters are controlled by using the appropriate controller. This study presents the control scheme and result analysis of PMSM for mining scraper conveyor and electric vehicle mining truck. The design, development and analysis of the permanent magnet synchronous motor are also studied for various mining applications. The study focuses on performance analysis; hence the PMSM and its control scheme are studied for two mining applications such scraper conveyor and mining truck.

The controller plays an important role in performance enhancement of permanent magnet synchronous motor. The composite sliding mode controller and speed sensor less vector controller are used to control the PMSM speed and torque parameters. The controller reduces the vibrations in speed maintaining the stability of the system and causes the increment in efficiency.

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