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Economic and Technical Analysis of the Use of High-Performance Motor in Mining in Vietnam

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Abstract

Reducing the cost of using electricity in mining to improve production efficiency is one of the most urgent tasks not only for other industries but also for the mining industry in Vietnam today. In the past years, the mining industry has applied many technical solutions to save energy in mining, such as using inverters to adjust the working process, using soft starts, and using a power metering monitoring system. The electric motor is the most energy-intensive driving device, accounting for about 70-80 % of the mine's electricity consumption. The use of high-performance motors to directly replace traditional induction motors with low-performance ones in mining will bring about high efficiency. The content of the article presents the possibility of using a line-start permanent magnet synchronous motor (LSPMSM) to replace traditional three-phase induction motors. At the same time, the article aims to analyze the economics and techniques of applying LSPMSM in mining to develop a reasonable investment plan to improve the use of electricity in mining.

Keywords: mining, high-performance motor, electricity.

1. Introduction

Currently, the capacity and depth of mining are increasing, leading to more and more machines being used in mining to replace human labor (Ranjith et al., 2017). Ha Lam mine in Vietnam is equipped with a mechanized longwall with a capacity of 1.2 million tons of coal and a mechanized furnace with a capacity of 600,000 tons of coal (Nguyen et al., 2020). Nui Beo mine is equipped with a synchronous mechanized longwall with a capacity of 600,000 tons of coal per year (Vu, 2022). The mechanization of mining leads to an increasing use of electricity in mining, making the proportion of electricity cost per ton of mined coal increasingly large.

Reducing the cost of using electricity in mining to improve production efficiency is one of the urgent tasks not only for other industries but also for the mining industry in Vietnam today. In the past years, the mining industry has applied many technical solutions to save energy in mining, such as using inverters to adjust the working process, using soft starts, and using a power metering monitoring system (Do et al., 2022a).

The above solutions have also been partly promoted and are effective in using energy efficiently. However, the majority of the electricity consumed in mining goes to electric drive systems (Semenov et al., 2019). An electric motor is a driving device used to generate the drives for

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mining operations. In mining in Vietnam, the electrical energy consumed by the electric drive accounts for about 70-80 % of the total electricity consumed by the mine (Bui et al., 2022; Do et al., 2022a; Do et al., 2022b; Maraaba et al., 2018). The use of high-performance motors as a direct replacement for low efficiency traditional induction motors in mining has not yet been implemented. The content of the article goes into an economic and technical analysis of the application of high-performance motors in mining.

2. High-performance motor

According to the IEC 60034-30 standard motor efficiency is classified into classes: IE1 – Standard Efficiency (IE1 – Standard Efficiency), IE2 – High Efficiency, IE3 – Premium Efficiency, IE4 – Super Premium Efficiency, IE5 – Ultra Premium Efficiency. According to (IEC, 2014) the efficiency levels from IE1 to IE5 of the motor depending on the power are shown in Figure 1.

Traditional motors used in mining are squirrel cage rotor induction motors (IM). This type of motor has many advantages such as: simple structure, high durability, large starting torque, low cost (Putro et al., 2023). However, the major disadvantage of these types of motors is that it is difficult to improve efficiency because there is still power loss on the rotor during operation (Dursun et al., 2018). It is really difficult to improve IM performance to IE2, IE3 level according to IEC60034-30 standard.

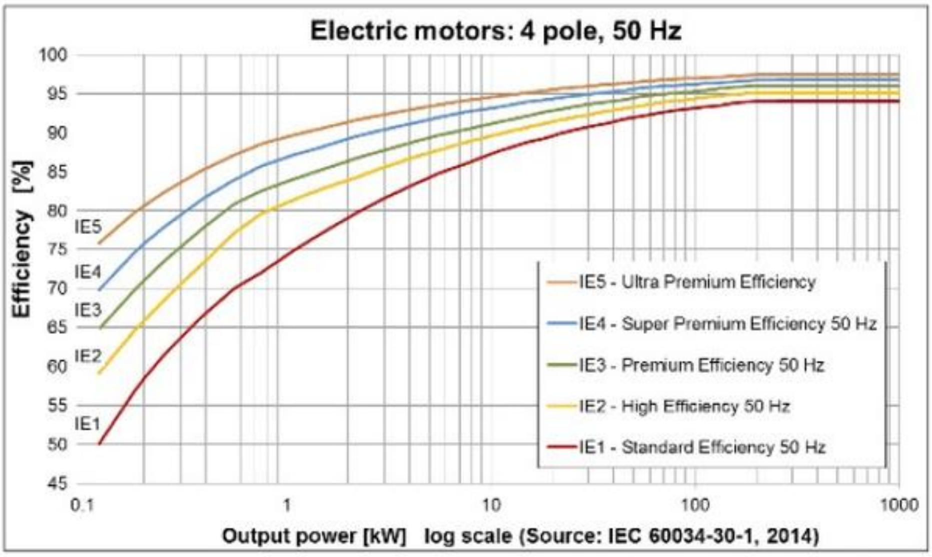

Fig. 1. Dependency between efficiency level and motor power

Nowadays, with the development of rare-earth magnet materials, many types of high-performance motors such as the line-start permanent-magnet synchronous motor (LSPMSM) are created (Ugale et al., 2014). LSPMSM has the advantages of high-performance, large power factor and does not need a starter, but has the disadvantage of low starting torque, so it is only suitable for technological stages with small starting torque requirements (Behbahanifard et al., 2015; Ganesan et al., 2019).

To be able to use LSPMSM to replace traditional three-phase induction motors, It is necessary to have in-depth studies on technical factors and economic efficiency when applying this type of motors in mining practice.

3. Results and discussion

3.1. Technical analysis

As analyzed above, LSPMSM has the advantages of high-performance, large power factor, direct starting without the need for an attached controller. However, the disadvantage of this motor is the small starting torque.

The use of high-performance LSPMSM motors as an alternative to IM is of great significance when applied to power-intensive technology stages and technically appropriate. According to the report on electricity use in underground mining, currently, electricity is mainly used in the following stages: mining, ventilation, water pumping, excavation and transportation. For technological stages of transportation, excavation or mining, the speed of the replacement motor must be exactly the same as that of the previously designed motor. In addition, these loads often have large starting torques, so they are not suitable for LSPMSM motors. However, the ventilation and water pumping stages are the major power consumers and the small starting torque can replace the LSPMSMs for the IMs in use (Bui et al., 2022; Do et al., 2022a; Do et al., 2022b; Maraaba et al., 2018).

Analysis of technical characteristics of LSPSMSM with speed of 3000 rpm, rated power of 15kW, rated voltage of 660/1140V used with load as a local exhaust fan in mining. The simulation results are shown in Figures 2, 3, 4.

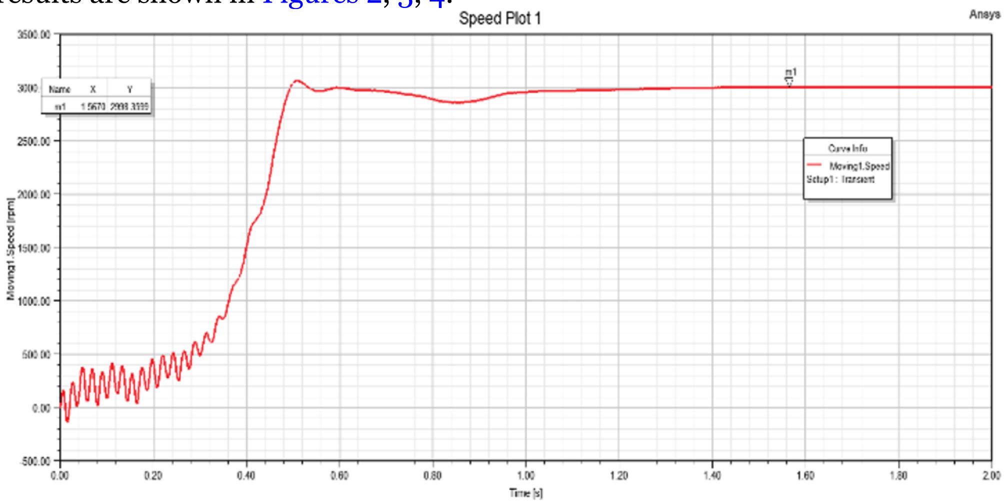

Fig. 2. Rated load starting characteristics of LSPMSM with power 15kW and speed 3000 rpm.

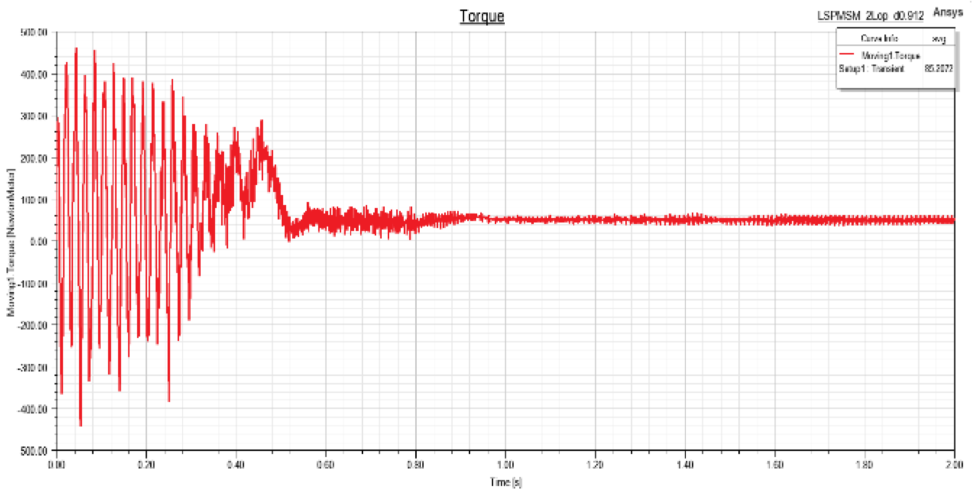

Fig. 3. Starting torque characteristics with rated load of LSPMSM

The results shown in Figure 2 show that the LSPMSM can be completely started with the blower loads, the motor's starting time is 1s. Figure 3 shows that the starting torque does not fluctuate. The motor current characteristics indicate that the starting current of the motor is small (Figure 4).

Thus, from the above specification analysis, it is found that it is possible to use high-performance LSPMSM to replace traditional IMs in the ventilation and water pumping stages of mining. This is the technology that uses the most electricity. The replacement can bring high economic efficiency, reduce power use and improve the power factor of the network.

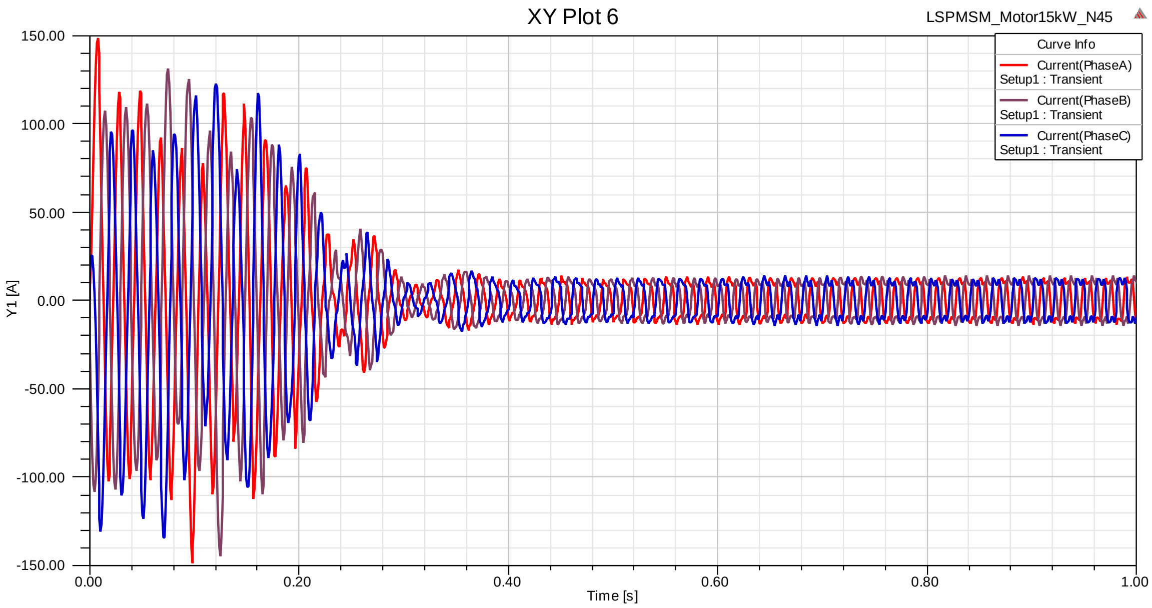

Fig. 4. Start-up current characteristics with rated load of LSPMSM

3.2. Economic analysis

The investment in high-performance motor will increase the initial cost, but will be recovered from the cost of saving energy during operation. In order to replace IM in mining with the high-performance LSPMSM, economic efficiency needs to be further considered.

Assume the mining powertrain is upgraded from IM with IE1 efficiency to using a motor with high efficiency IE_n (with n = 2, 3, 4). According to (Toda et al., 2014) the operating cost saved each year when using high-performance motor instead of IE1 efficiency motor is calculated according to the formula.

$$S = P_{out} \cdot C \cdot T \left[\frac{100}{E_1} - \frac{100}{E_n} \right] \quad (1)$$

where: P_{out} – motor power (kW); C – Electricity price (VND/kWh); T – number of working hours per year (hours); E_n, E_1 – is the standard motor efficiency, respectively IE_n and IE_1.

The initial cost difference between two high-performance IEn and IE1 motors is determined by the formula (Toda et al., 2014):

$$\Delta C = m \cdot Y \quad (2)$$

where: m – Differences in mass, material; Y – unit price difference.

The payback period is calculated as follows:

$$T_c = \Delta C / S \quad (3)$$

From the above base, the study conducted to compare the economic efficiency obtained for local exhaust fans in underground mines, using the IM with IE1 efficiency and the LSPMSM with IE3 high-performance. Motors with specifications as shown in Table 1.

Table 1. Specifications of IM and LSPMSM

TT	Parameters	IM	LSPMSM
1	Power (kW)	15kW	15kW
2	Voltage (V)	660/1140	660/1140
3	Frequency (Hz)	50	50
4	Speed (rpm)	2960	3000
5	Motor efficiency (%)	89 (IE_1)	93.2(IE_3)

According to the document (Toda et al., 2014), the mass of the electromagnet required for the LSPMSM with power 15kW is about m_{PM}=1.85kg, magnet sale price NdFeB is P_{PM}=250$/kg equivalent 5.75 million VND/kg. Cost difference using high flux density steel foil for LSPMSM with power 15kW is m'_{PM}=4.5kg, selling price difference P'_{PM}=12$/kg equivalent to about 0.276 million VND/kg.

From formula (2) determine the initial cost difference between the high-performance LSPMSM and the standard IM as:

$$\Delta C=[m_{PM}\cdot P_{PM}+m'_{PM}\cdot P'_{PM}]=[1.85\cdot 5.75+4.5\cdot 0.276]=11.88 \text{ million VND} \quad (4)$$

Operational cost savings per year when replacing LSPMSM for IM with the formula:

$$S = P_{out}\cdot C\cdot T\left[\frac{100}{E_2}-\frac{100}{E_1}\right] = 15\cdot 1600\cdot 5000\left[\frac{100}{89.3}-\frac{100}{93.2}\right] = 5.6\ million\ VND \quad (5)$$

where, electricity price C=1600 VND/kWh; Mining factory works three shifts T=5000h/year.

The payback period when replacing LSPMSM for IM of the local exhaust fan is determined by formula (1):

$$T_c=\Delta C/S=11.88/5.6=2.12 \text{ year} \quad (6)$$

Due to the energy saving during use, the replacement of the LSPMSM with power 15kW for the IM with power 15kW brings high economic efficiency, short payback period of about 2.12 years. In addition, the improvement of the power factor helps to reduce the loss on the transmission line, because the LSPMSM motor has a power factor of 0.95 or more compared to the IM with a power factor of about 0.85.

4. Conclusion

From the above economic-technical analysis, it is found that LSPMSM-type high-performance motors are technically suitable to replace the traditional low efficiency IMs used for exhaust fan or water pump loads. According to the analysis of economic profit, with the replacement of this high-performance motor, the payback period is more than 2 years, not to mention the benefits of power transmission lines and power sources.

In addition, the fan and water pump loads are the loads with the highest proportion of electricity usage in mining, accounting for over 30 % of the total electricity used in the whole mine. So this replacement will have a breakthrough in the efficient use of energy in mining.

5. Acknowledgments

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