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METHODS FOR ANALYZING HEAT GENERATION AND ENERGY CONSUMPTION IN VARIABLE-SPEED ASYNCHRONOUS PUMP DRIVES

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Abstract
Variable-speed asynchronous pump drives are widely used to improve operational flexibility and energy efficiency in modern pumping systems. However, changes in operating speed significantly affect both heat generation and energy consumption, which may influence system reliability and service life. This article analyzes methods for assessing heat generation and energy consumption in asynchronous pump drives operating under variable-speed control. The study is based on analytical evaluation of electrical and mechanical losses, thermal balance considerations, and energy performance indicators at different operating regimes. The results show that integrated analysis of thermal and energy characteristics enables identification of optimal operating conditions that minimize overheating and reduce power losses. The proposed approach supports the development of reliable and energy-efficient control strategies for variable-speed pump systems.

Keywords. Variable-speed drive; asynchronous motor; pump systems; heat generation; energy consumption

Materials and Methods

This study adopts an analytical approach to evaluate heat generation and energy consumption in variable-speed asynchronous pump drives. The analysis focuses

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on identifying relationships between operating speed, loss components, and thermal behavior under different load conditions.

The object of investigation is an asynchronous electric motor coupled with a centrifugal pump and controlled by a variable frequency drive (VFD). The operating regimes considered include low-speed, nominal-speed, and high-speed conditions. For each regime, electrical, magnetic, and mechanical loss components were analyzed to determine their contribution to total heat generation.

Electrical losses were evaluated based on stator copper losses, which depend on current magnitude and load, while magnetic losses in the motor core were assessed as functions of supply frequency and voltage. Mechanical losses associated with friction and ventilation were also considered, particularly their variation with rotational speed. Energy consumption was analyzed using power balance equations and pump affinity laws to assess changes in power demand under variable-speed operation.

Thermal analysis was performed using steady-state thermal balance equations, taking into account heat generation and heat dissipation through motor cooling mechanisms. Comparative evaluation was conducted across different operating regimes to identify conditions associated with increased thermal stress or excessive energy consumption.

As this research is based on analytical modeling and theoretical assessment, no experimental testing or human subjects were involved. Therefore, ethical approval was not required.

Results

The analysis of variable-speed asynchronous pump drives revealed a strong relationship between operating speed, heat generation, and energy consumption. The results indicate that both thermal and energy characteristics are highly sensitive to changes in motor speed and load conditions.

At low-speed operation, electrical losses increased due to higher current demand relative to torque production, while cooling efficiency decreased as a result of reduced airflow. This combination led to elevated temperature rise in the stator

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windings, despite relatively low overall power consumption. Such operating conditions were identified as thermally critical for prolonged operation.

At nominal-speed operation, a balanced relationship between heat generation and heat dissipation was observed. Electrical, magnetic, and mechanical losses remained within acceptable limits, resulting in stable thermal behavior and efficient energy use. This operating regime was found to be optimal for continuous operation of pump systems.

At high-speed operation, magnetic and mechanical losses increased significantly, leading to higher total heat generation. Although cooling performance improved due to increased rotational speed, the overall energy consumption rose sharply. The results suggest that sustained high-speed operation may compromise energy efficiency and increase thermal loading if not properly managed.

Overall, the findings demonstrate that integrated analysis of heat generation and energy consumption is essential for identifying optimal operating regimes in variable-speed asynchronous pump drives.

Discussion

The results of this study emphasize the importance of simultaneously analyzing heat generation and energy consumption in variable-speed asynchronous pump drives. While variable-speed control offers significant advantages in terms of energy efficiency and operational flexibility, it also introduces thermal challenges that can affect system reliability if not properly addressed.

Low-speed operation was shown to be thermally sensitive due to reduced cooling efficiency and increased electrical losses. In practical applications, this regime is often encountered during partial-load operation or flow regulation. Without adequate control strategies or auxiliary cooling measures, prolonged low-speed operation may lead to excessive thermal stress and accelerated insulation aging.

High-speed operation, although beneficial for meeting peak demand, was associated with increased magnetic and mechanical losses, resulting in higher energy consumption and elevated temperatures. These findings highlight the necessity of defining safe and efficient operating speed limits. Simply increasing speed to improve performance may compromise both energy efficiency and thermal stability.

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The discussion underscores the need for integrated control strategies that consider both thermal constraints and energy performance. Incorporating temperature monitoring, adaptive speed control, and loss-minimization algorithms can significantly enhance system reliability and efficiency. Such approaches enable the identification of optimal operating regimes that balance energy savings with thermal safety, contributing to the sustainable operation of variable-speed pump systems.

Conclusion

The study demonstrates that effective analysis of heat generation and energy consumption is essential for the optimal operation of variable-speed asynchronous pump drives. The results show that operating speed has a significant impact on both thermal behavior and energy performance. Low-speed operation, while energy-efficient, may lead to increased thermal stress due to reduced cooling efficiency, whereas high-speed operation results in elevated energy consumption and additional heat generation.

An integrated analytical approach that considers electrical, magnetic, and mechanical losses enables the identification of operating regimes that ensure thermal stability and energy efficiency. The findings highlight the importance of optimized control strategies, including speed limitation, thermal monitoring, and adaptive regulation, to prevent overheating and minimize power losses. Overall, the proposed analysis methods contribute to improving the reliability, efficiency, and service life of modern variable-speed pump systems.

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