CALCULATION OF PERFORMANCE INDICATORS FOR IMPROVING MONITORING AND CONTROL SYSTEMS OF INDUCTION MOTORS UNDER UNBALANCED OPERATING CONDITIONS

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Abstract. *Unbalanced operating conditions in induction motors can significantly affect electrical performance, increase energy losses, and reduce operational reliability. Variations in voltage and current distribution may lead to overheating, efficiency reduction, and accelerated degradation of motor components. Therefore, accurate calculation of monitoring and control indicators is essential for improving motor performance and ensuring stable operation. This study analyzes the calculation of key performance indicators for enhancing monitoring and control systems of induction motors operating under unbalanced conditions. The investigation focuses on the relationship between electrical parameters, energy losses, and operational characteristics used for monitoring purposes. Theoretical analysis was applied to evaluate the influence of parameter variations on control effectiveness and predictive assessment of motor behavior. The findings indicate that integrated monitoring of electrical and operational indicators may improve fault detection capability, reduce energy losses, and contribute to the optimization of induction motor control systems under unbalanced operating conditions.*

Keywords: *induction motor; unbalanced operating conditions; monitoring system; control system; performance indicators; energy losses; predictive monitoring; operational reliability; electrical parameters; motor efficiency.*

Introduction. Induction motors are among the most widely used electrical machines in industrial systems due to their reliability, simple construction, and high adaptability to various operating conditions. They are extensively applied in pumping stations, manufacturing processes, transportation systems, and automated industrial facilities. Since induction motors account for a significant share of industrial electricity consumption, improving their operational efficiency and reliability remains an important engineering challenge. Under unbalanced operating conditions, variations in electrical parameters such as voltage, current, and power factor may negatively affect motor performance. These disturbances often lead to increased energy losses, overheating, reduced efficiency, and accelerated degradation of motor components. Consequently, inaccurate assessment of operational parameters may decrease the

effectiveness of monitoring and control systems and limit their capability to prevent abnormal operating conditions.

Modern monitoring technologies increasingly rely on calculated performance indicators to evaluate motor condition, estimate energy efficiency, and support predictive control strategies. The selection and calculation of appropriate indicators are essential for identifying deviations from normal operation and improving decision-making processes within control systems. However, many existing approaches focus primarily on fault detection or parameter measurement while providing limited attention to integrated indicator-based assessment for improving monitoring and control under unbalanced operating conditions. Therefore, the calculation and analysis of performance indicators associated with electrical losses, operational efficiency, and monitoring parameters become important for optimizing control strategies of induction motors. Improved indicator-based evaluation may enhance monitoring accuracy, increase operational reliability, and contribute to reducing energy losses in industrial applications. The aim of this study is to analyze the calculation of performance indicators for improving monitoring and control systems of induction motors operating under unbalanced conditions and to evaluate their significance for enhancing predictive monitoring and control effectiveness.

Methodology. The study applied a theoretical analysis approach to evaluate performance indicators used for improving monitoring and control systems of induction motors under unbalanced operating conditions. The analysis focused on the influence of variations in electrical parameters, including current, voltage, power factor, and energy losses, on motor operational performance.

Power losses in motor windings were assessed using the relationship:

$$P_{loss} = I^2R$$

where P_{loss} is the power loss, III is the phase current, and R is the winding resistance.

Motor efficiency was estimated using:

$$\eta = \frac{P_2}{P_1} \times 100\%$$

where P_2 represents output power and P_1 denotes input power.

The selected performance indicators included current variation, efficiency, power factor, and thermal loading. Their interrelationships were analyzed to determine their significance for predictive monitoring and optimization of induction motor control systems under unbalanced operating conditions.

Results and Analysis

The theoretical analysis indicated that unbalanced operating conditions significantly influence the performance indicators used in monitoring and control

systems of induction motors. Variations in current and voltage distribution increase electrical losses, which directly affect motor efficiency and operational reliability.

According to the relationship between current and power losses:

$$P_{loss} = I^2R$$

an increase in phase current leads to a quadratic growth of losses in motor windings. This effect may contribute to higher thermal loading and reduced efficiency during long-term operation. The analysis also showed that changes in performance indicators such as current, power factor, and efficiency can serve as important monitoring variables for identifying deviations from normal operating conditions. A decrease in efficiency is generally associated with increased energy losses and deterioration of motor performance. Furthermore, the evaluation of multiple indicators simultaneously improves the capability of monitoring systems to detect abnormal conditions at an early stage. Integrated assessment of electrical parameters may therefore support more effective control decisions and enhance predictive monitoring strategies for induction motors operating under unbalanced conditions. The obtained theoretical findings suggest that indicator-based monitoring approaches can contribute to reducing energy losses, improving operational reliability, and optimizing control system performance in industrial applications.

Conclusion. This study analyzed the calculation of performance indicators for improving monitoring and control systems of induction motors operating under unbalanced conditions. The theoretical assessment demonstrated that variations in electrical parameters, particularly current and efficiency, significantly affect energy losses and overall motor performance. The findings indicate that integrated evaluation of performance indicators can enhance monitoring accuracy, support early detection of abnormal operating conditions, and improve control effectiveness. Indicator-based approaches may therefore contribute to increasing operational reliability and reducing energy losses in induction motor systems. The practical significance of the study lies in the potential application of calculated performance indicators for optimizing predictive monitoring and developing more efficient control strategies for industrial induction motors.

References

1. Lee, C.-Y. (1999). Effects of unbalanced voltage on the operation performance of a three-phase induction motor. *IEEE Transactions on Energy Conversion*, 14(2), 202–208. https://doi.org/10.1109/60.766984

2. Wang, Y.-J. (2001). Analysis of effects of three-phase voltage unbalance on induction motors with emphasis on the angle of the complex voltage unbalance factor. *IEEE Transactions on Energy Conversion*, 16(3), 270–275. https://doi.org/10.1109/60.937207

3. Pillay, P., Hofmann, P., Manyage, M. (2002). Derating of induction motors operating with a combination of unbalanced voltages and over or undervoltages. *IEEE Transactions on Energy Conversion*, 17(4), 485–491. https://doi.org/10.1109/TEC.2002.805205
4. Faiz, J., Ebrahimpour, H., Pillay, P. (2004). Influence of unbalanced voltage on the steady-state performance of a three-phase squirrel-cage induction motor. *IEEE Transactions on Energy Conversion*, 19(4), 657–662. https://doi.org/10.1109/TEC.2004.837304
5. Krause, P.C., Wasynczuk, O., Sudhoff, S.D., Pekarek, S. (2013). *Analysis of Electric Machinery and Drive Systems* (3rd ed.). Wiley-IEEE Press.
6. Chapman, S.J. (2012). *Electric Machinery Fundamentals* (5th ed.). McGraw-Hill Education.
7. Boldea, I., Nasar, S.A. (2010). *The Induction Machines Handbook*. CRC Press.
8. IEC 60034-26. (2006). *Rotating Electrical Machines – Part 26: Effects of Unbalanced Voltages on the Performance of Three-Phase Cage Induction Motors*. International Electrotechnical Commission (IEC).
9. Konuhova, M., et al. (2025). Induction motor dynamics regimes: A comprehensive investigation and experimental validation of mathematical models. *Applied Sciences*, 15(3), 1527. https://doi.org/10.3390/app15031527
10. Fathabadi, F.R., Molavi, A. (2019). Black-box identification and validation of an induction motor in an experimental application. *European Journal of Electrical Engineering*, 21(2), 255–263.