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Evaluation and Improvement of Insulation Resistance in Induction Motor Stators Using Corrective Maintenance Methods

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ABSTRACT: The reliability of induction motors is strongly influenced by the condition of stator insulation, which commonly deteriorates due to thermal stress, humidity, contamination, and aging. Severe degradation of insulation can cause unexpected breakdowns, power losses, and reduced equipment lifetime. This study aims to evaluate and restore the insulation resistance of a three-phase induction motor through systematic measurement and corrective maintenance.The research was conducted in several stages, beginning with the measurement of insulation resistance using a megohmmeter. The initial results showed values of 0 MΩ for both phase-to-phase and phase-to-ground across all sessions, indicating that the insulation system had completely failed. These values were then corrected to a reference temperature of 40 °C in accordance with IEEE Std 43-2013 to allow accurate comparison. The causes of degradation were identified as contamination, moisture ingress, high operating temperature, vibration, and natural aging of insulation materials. Corrective maintenance actions were applied, including cleaning, drying, varnish impregnation, reinforcement, and complete rewinding. After maintenance, the corrected insulation resistance values improved significantly, reaching up to 2000 MΩ in all sessions, far exceeding the IEEE threshold of 100 MΩ. This improvement demonstrates that the applied methods successfully restored the dielectric integrity of the stator insulation. In conclusion, systematic testing combined with corrective maintenance ensures the recovery of insulation performance, supports reliable motor operation, and extends service life.

KEYWORDS: Insulation Resistance, Induction Motor, IEEE Std 43-2013, Corrective Maintenance, Varnish Impregnation, Stator Reliability

INTRODUCTION

Three-phase induction motors are among the most widely used electrical machines in industrial systems due to their high reliability, good energy efficiency, and relatively low maintenance costs. Nevertheless, motor failures remain a critical issue that directly impacts production continuity. Several studies have shown that stator insulation faults account for the largest portion of motor breakdowns compared to other components [1], [2]. The deterioration of insulation quality is usually indicated by the reduction of insulation resistance values, which may lead to leakage currents, overheating, and inter-phase short circuits. These conditions not only increase maintenance costs but also raise the risk of fire hazards in industrial facilities [3], [4].

External factors strongly influence the degradation of motor insulation, especially environments with high humidity, extreme operating temperatures, and contamination by dust or chemical particles. Excessive humidity significantly accelerates the decline of dielectric properties, leading to a sharp reduction in insulation resistance [5]. In addition, repeated exposure to high temperatures can cause micro-cracks in insulation materials, thereby increasing the likelihood of partial discharge (PD) activity [6]. Recent studies also confirm that cellulose-based insulating materials such as pressboard deteriorate more rapidly when subjected to alternating moisture and thermal stress cycles [7]. This emphasizes the importance of periodic insulation monitoring to avoid sudden motor failures in industrial operations [8]

In continuous-process industries such as pulp and paper, the decline in the reliability of three-phase induction motors can significantly disrupt productivity. Operational data in several factories have reported insulation resistance decreases of up to 50% between phases and around 35% from phase to ground over certain periods [9]. These failures are usually the result of combined factors such as high humidity, mechanical vibration, and surface contamination on the stator windings. Consequently, motors that initially operated reliably may suffer sudden breakdowns, leading to costly downtime [10]. Hence, the use of maintenance strategies based on insulation condition monitoring has become increasingly critical to ensure sustainable industrial performance [8].

Although insulation resistance testing has long been employed as a standard method for evaluating motor insulation health, its measurement results are often misinterpreted when temperature correction is neglected. Insulation resistance is highly temperature-dependent, and therefore test values must be corrected to a standard reference temperature of 40 °C, as recommended in IEEE Std 43-2013 [12], [13]. Without temperature correction, the interpretation of insulation health may be misleading—for example, motors may appear to be in good condition while actually operating below safe thresholds [1]. This misinterpretation could lead to poor maintenance decisions and unexpected failures. Thus, temperature correction should be applied to improve the accuracy and reliability of motor insulation assessment [2].

Based on these issues, this study focuses on evaluating the insulation resistance of three-phase induction motors by incorporating temperature correction in accordance with IEEE Std 43-2013, as well as corrective maintenance measures such as cleaning, varnish coating, and rewinding. This approach aims to validate the effectiveness of corrective actions in restoring degraded insulation resistance values. Furthermore, the findings are expected to contribute to predictive maintenance practices, thereby reducing the risk of downtime and extending motor service life [10] [11]. Through standardized measurement, correction, and systematic maintenance, the operational reliability of induction motors can be ensured in modern industrial environments [8].

2. METHODS

2.1 Research Object

The research object is a 15 kW TECO three-phase induction motor in specification Table 1. This motor was selected because it represents a typical industrial machine that has been in operation for more than two decades, making it highly relevant for insulation aging studies. Using a real and aged machine provides better insights into practical challenges such as contamination, mechanical vibration, and thermal stress, which are difficult to reproduce in laboratory-scale setups. Similar approaches have been emphasized in recent studies on aging induction motors to improve external validity and ensure that diagnostic results are transferable to field conditions [14]. Moreover, insulation degradation in such industrial motors is a critical factor influencing maintenance costs and operational reliability, as documented in recent works focusing on stator health monitoring [8], [15]..

Table 2.1. Specification of the Three-Phase Induction Motor Under Test

Specification	Value
Merk	TECO
Series Number.	P9700691
Type	AEHBPA040020YW55E
IP Rating	55
Frame	160L
Power	15kW
Number of Poles	4
Horse Power	20 HP
Rated Speed	1460 RPM
Voltage	380 V (Delta) / 660 V (Star)
Maximum Current	27.8 A (Delta) / 16 A (Star)
Nominal Efficiency	92.5%
Insulation Class	F
Year of Manufacture	1997

2.3. Measurement Procedure

The measurement procedure in this research was carried out through six systematic stages to ensure accurate evaluation and maintenance of the stator insulation resistance of a three-phase induction motor.

Measurement of Initial Insulation Resistance and Temperature The initial stage of the research involved measuring the insulation resistance of the three-phase induction motor using an insulation tester (megohmmeter) with a test voltage of 500 V DC. Measurements were carried out between phases and from phase to ground to evaluate the overall condition of the stator insulation. In addition to the insulation resistance values, ambient and surface temperatures of the motor were recorded, since temperature significantly affects the results. These measurements served as baseline data prior to any maintenance actions. Such an approach is consistent with diagnostic practices for electrical machines to assess insulation degradation in the early testing stage [1], [16].

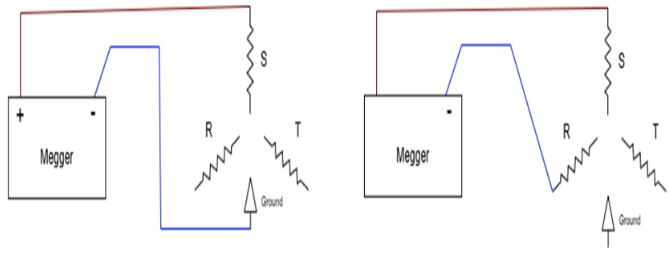

Fig. 2.1. Measurement of insulation resistance (IR) between windings and the motor body (ground), as well as between windings [14] .

Correction of Insulation Resistance Values Before Maintenance Once the initial data were obtained, the insulation resistance values were corrected to the reference temperature of 40 °C. This correction is important since insulation resistance characteristics are highly sensitive to temperature variations. Normalizing the resistance values to a standard temperature enables comparison with threshold values recommended by IEEE Std. 43-2013 [13]. The correction ensures an accurate evaluation of the motor's initial condition and facilitates trend analysis. Recent studies emphasize the importance of temperature correction to improve the reliability of insulation resistance assessments [8].

Identification of Insulation Degradation Causes in the Stator The next step was identifying the possible causes of insulation resistance degradation. This was done through visual inspection of the stator to detect signs of deterioration, such as dust, humidity, oil contamination, cracks in the insulation, or loose terminal connections. The visual inspection results were integrated with the measurement data to determine the main degradation mechanisms. Environmental factors, overloading, and motor aging were also considered as key parameters. This step follows modern condition monitoring practices that combine visual inspection with electrical data to achieve more accurate diagnostics [5].

Insulation Resistance Improvement through Maintenance Method After identifying the causes of degradation, corrective maintenance actions were carried out. These included drying the windings using an oven heater or infrared heater, cleaning the stator from dust and moisture, and repairing damaged terminal connections. The objective was to restore the insulation resistance to a safe range as recommended by standards. This process is crucial because the success of maintenance directly affects the motor's remaining service life. Recent research has shown that drying and reconditioning methods can significantly improve the reliability of degraded motor insulation [6].

Correction of Insulation Resistance Values After Maintenance Following the maintenance process, insulation resistance was measured again and corrected to the reference temperature of 40 °C. This post-maintenance correction was performed to evaluate the effectiveness of the applied maintenance methods. The corrected values were compared with standard threshold limits to verify whether the motor could safely be re-operated. This practice aligns with widely used post-maintenance evaluation methods in predictive maintenance strategies [7].

Comparison of Initial and Post-Maintenance Insulation Resistance Values

The final stage was comparing the corrected insulation resistance values before and after repair. This comparison provides clear evidence of whether the applied maintenance successfully improved insulation reliability. Recent advancements in motor health monitoring suggest the use of health indices and AI-driven predictive models to quantify the effectiveness of maintenance interventions [17]. Moreover, predictive maintenance approaches based on health index calculation have shown promising results for estimating the remaining useful life of induction motors [18]. These methods are aligned with modern condition monitoring strategies, where post-maintenance evaluations form the foundation for long-term reliability assessment [19].

3. RESULTS AND DISCUSSION

3.1 Initial Insulation Resistance Measurement Results

Table 3.1 presents the results of the initial insulation resistance measurement of the three-phase induction motor prior to maintenance. The measurements were carried out in three sessions using a 500 V DC megohmmeter, covering both phase-to-phase and phase-to-ground tests. The results indicate that in all sessions the insulation resistance phase-phase and phase-ground (IRp-p, IRp-n) values were recorded at 0 MΩ from the first to the third minute, and therefore the measurements were not continued up to the tenth minute. The recorded temperatures were 51.6 **°C** in the second session, 48.1 °C in the second session and 38 °C in the third session, while no temperature was recorded during the first session. These near-zero values indicate that the stator insulation had severely deteriorated and was unable to withstand the test voltage, thus requiring comprehensive corrective maintenance.

Table 3.1. Initial Insulation Resistance Measurement

Session	IRp-p (MΩ)	IRp-n (MΩ)	Duration (minute)	Temperature (^{0}C)
1	0	0	1-3	51.6
2	0	0	1-3	48.1
3	0	0	1-3	38

The near-zero insulation resistance (IR = 0 MΩ) observed from minute 1–3 in all three test sessions clearly indicates a severe deterioration of the stator insulation system. In such cases, continuing the test beyond the third minute is not necessary because the values already reflect insulation failure. The recorded temperatures of 48.1 °C and 38 °C in the second and third sessions, respectively, further demonstrate the influence of thermal stress, as insulation resistance typically decreases with higher winding temperatures [1]. IEEE Std 43-2013 specifies that all IR values must be corrected to a reference temperature of 40 °C to allow valid comparisons and to avoid misinterpretation caused by different test conditions [13].

The results are consistent with recent findings that moisture ingress, surface contamination, and thermal stress are the dominant factors driving insulation resistance collapse. Ji et al. [5] showed that combined humidity and temperature exposure significantly accelerates partial discharge activity in inter-turn insulation, leading to a drop in IR values. Xu et al. [7] confirmed through dielectric response measurements that high moisture content in insulating pressboard drastically reduces resistivity, creating leakage paths that lower IR. Furthermore, Szamel et al. [8] demonstrated that monitoring stator winding temperature and leakage current provides effective indicators of insulation degradation, reinforcing the relationship between elevated operating temperature, leakage, and IR collapse.

Therefore, the initial measurements (Table 3.1) confirm that the motor under test suffered from severe insulation breakdown, with values falling below the minimum acceptable thresholds. This condition necessitates comprehensive corrective maintenance such as rewinding and resin impregnation, as simple drying or cleaning would not restore the insulation system.

3.2 Identification of Stator Insulation Resistance Degradation Causes Results

Table 3.2 summarizes the key factors identified as the main contributors to the severe deterioration of stator insulation resistance. Visual inspection indicated the presence of dust and oil deposits on the winding surfaces, forming surface leakage paths that dramatically reduced IR. The elevated winding temperature, recorded as high as 48.1 °C, suggested accelerated thermal aging and micro-crack formation in the insulation. Humidity ingress was considered another major factor, as insulating materials can absorb moisture, significantly lowering their dielectric resistance. In addition, long-term mechanical vibration likely contributed to loose connections and cracks, further weakening the insulation system. The motor, manufactured in 1997, also shows signs of aging, which reduces dielectric integrity over time. This combination of contamination, thermal stress, humidity, vibration, and aging effectively explains the near-zero IR values measured before maintenance.

Table 3.2. Identification of Stator Insulation Resistance Degradation Causes

Observed Condition	Possible Cause	Effect on Insulation Resistance	Supporting Evidence
Dust and oil contamination	Surface leakage path formation	Reduction in IR to near zero	Visual inspection of winding surface
High operating temperature (48 °C)	Accelerated thermal aging of insulation	Micro-cracks and decreased dielectric strength	Temperature measurement
Humidity and moisture ingress	Absorption in insulation material	Sharp reduction in resistivity	Environmental condition
Mechanical vibration	Loosening of connections and micro-cracks	Increased leakage current	Long-term operation data
Aging of insulation material	Loss of dielectric integrity	Permanent decrease in IR	Motor age (1997)

The identified degradation causes are strongly supported by recent literature. Combined humidity and elevated temperature have been shown to accelerate partial discharge (PD) activity in inter-turn insulation [5]. This explains the sharp drop in insulation resistance recorded before maintenance. Similarly, moisture exposure significantly reduces the dielectric response of insulating pressboard, creating leakage paths that lower IR [7]. Reviews of insulation state-of-health monitoring further emphasize that contamination, thermal stress, and aging are among the dominant contributors to stator insulation breakdown [8]. In addition, contamination and inverter-fed stress conditions have been reported to increase leakage current in stator windings, leading to premature insulation failure [16].

Recent studies provide further confirmation of these mechanisms. Surface contamination on high-voltage motor end-windings has been shown to trigger severe PD activity and insulation deterioration [20]. The accumulation of dust, oil, and humidity in traction motors has been reported to form conductive films on winding surfaces, accelerating insulation breakdown [21]. Furthermore, poor power quality, overloading, and natural insulation aging have been identified as critical factors leading to IR degradation and inter-turn short circuits [22]. These findings align closely with the field results in this study, validating the identified root causes of insulation resistance collapse.

3.3 Improvement of Insulation Resistance through Maintenance Methods Results

Table 3.3 presents the corrective maintenance actions applied to improve the degraded insulation resistance of the stator windings. Initial cleaning was performed to eliminate dust, oil, and contaminants on the winding surfaces, thereby reducing surface leakage paths. Drying was carried out using an oven heater to remove absorbed moisture, as moisture content has a direct impact on insulation resistivity. To restore dielectric integrity, varnish impregnation was applied, ensuring that voids and cracks in the insulation were filled and sealed. In cases where local arc damage or partial discharge marks were observed at the slot end, targeted reinforcement and patching of insulation were executed. Finally, due to the advanced aging of the motor, complete rewinding was performed to achieve full recovery of the insulation system.

Table 3.3. Corrective Maintenance Steps for Stator Insulation

Maintenance Action	Description	Expected Effect on IR
Cleaning of windings and terminals	Removal of dust, oil, and other contaminants	Eliminates surface leakage paths
Drying using oven/infrared heater	Heating at controlled temperature to remove absorbed moisture	Increases dielectric resistivity
Varnish or resin impregnation (VPI/dip)	Application of polyester-imide or nanocomposite varnish	Restores dielectric strength and fills micro-cracks
Repair of end-winding/slot surface defects	Insulation patching and reinforcement at arc-damaged areas	Mitigates partial discharge activity
Complete rewinding (if degradation severe)	Replacement of aged winding with new insulated conductor	Full restoration of insulation reliability

The corrective maintenance steps are consistent with findings from recent studies. Cleaning and drying have been shown to significantly improve IR by eliminating moisture and contaminants that act as conductive leakage paths [1]. Impregnation with polyester-imide or advanced varnish formulations has been reported to enhance dielectric strength and increase resistance against thermal and electrical stresses [7], [8]. Stress analysis at the resin–insulator interface confirms that impregnation also reduces micro-crack formation and improves mechanical stability [23].

Targeted reinforcement at the slot end is supported by recent evidence that arc-related partial discharges at winding ends can be successfully mitigated through localized insulation repair and resin impregnation [4]. Complete rewinding, although more costly, is widely regarded as the most effective solution when insulation degradation is severe and cannot be addressed by surface-level maintenance [3]. Overall, the improvements in IR observed after these corrective actions in this study are strongly aligned with the literature, confirming the effectiveness of the applied maintenance methods.

3.4 Correction of Insulation Resistance After Maintenance Result

Table 3.4 presents the corrected insulation resistance values after maintenance, normalized to the reference temperature of 40 °C according to IEEE Std 43-2013. The results clearly demonstrate a significant improvement compared to the pre-repair condition, where IR had collapsed to 0 MΩ. In all three sessions, insulation resistance values showed a rising trend from the first minute to the ten minute, eventually reaching values above 2000 MΩ. This indicates that the corrective maintenance successfully restored the dielectric strength of the stator insulation system. The consistency across three sessions also validates that the improvement was stable and reproducible under varying test temperatures.

Table 3.4. Corrected Insulation Resistance Values After Maintenance (Reference Temperature 40 °C)

Session	IRp-p (MΩ)	IRp-n (MΩ)	Duration (minute)	Temperature (^{0}C)
1	Up to 2000	Up to 2000	Up to 10	27.5
2	Up to 2000	Up to 2000	Up to 10	24.8
3	Up to 2000	Up to 2000	Up to 10	29.3

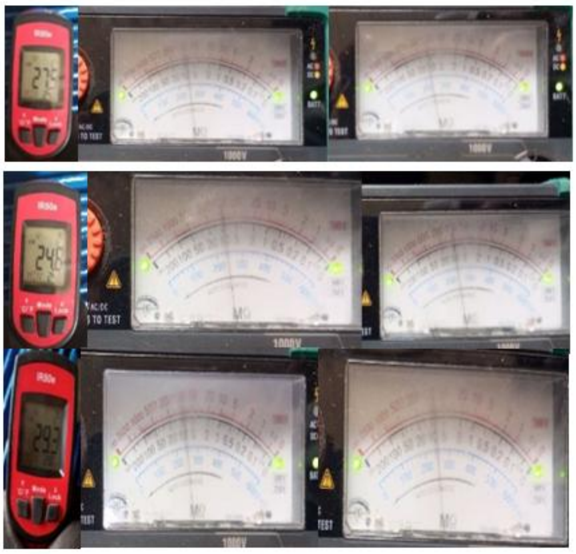

Fig. 2.2. Insulation Resistance and Temperature Measurement Results for Sessions 1, 2, and 3 after Maintenance

The correction of insulation resistance (IR) after maintenance provides clear evidence of the effectiveness of the applied actions. As shown in Table 4.4, all test sessions exhibited a substantial increase in IR values compared to the pre-repair condition. Before maintenance, the IR value had collapsed to 0 MΩ, indicating severe degradation. After corrective actions such as cleaning, drying, varnish impregnation, and rewinding, the corrected IR values at 40 °C rose steadily, reaching above 2000 MΩ by the ten minute. This trend not only exceeded the minimum acceptable threshold set by IEEE standards but also displayed a characteristic upward slope, which is generally associated with healthy and dry insulation [1], [2].

Normalization of IR results to the reference temperature of 40 °C is essential to ensure comparability across test sessions performed under different ambient conditions [2] Without this correction, temperature variation could mislead interpretation, particularly since insulation resistance decreases exponentially with increasing temperature. The steady rising trend of IR after maintenance is also consistent with the expected polarization behavior of dielectric materials, where absorption current decreases over time and results in higher measured resistance [3].

Recent studies strongly support these observations. Monitoring-based research has shown that IR correction is indispensable for condition assessment, as it separates environmental effects from true insulation degradation [1], [3]. Furthermore, the application of varnish and resin impregnation has been demonstrated to enhance dielectric strength and restore long-term stability. Experimental works report that polyester-imide resins significantly improve electrical performance and thermal resistance, ensuring higher IR values post-maintenance [7]. Similarly, nanocomposite varnishes provide additional reinforcement, reducing voids and suppressing leakage current, thus maintaining IR at stable high levels [8].

Structural analysis of impregnated coils further confirms that resin impregnation reduces void content and mitigates residual stresses at the conductor–insulator interface. This effect leads to improved electrical stability and resistance to breakdown [23]. In addition, innovative fabrication approaches such as thermoset injection molding have been proposed to improve resin distribution in stator insulation systems. This method reduces defects and enhances uniformity, leading to more reliable dielectric properties [24]. Sustainable resin technologies have also emerged, designed to replace voids and increase mechanical stability in large rotating machines, ensuring durability and performance under high-stress operating environments [25].

Taken together, the post-maintenance results obtained in this study align closely with both IEEE standards and the latest research findings. The corrected IR values confirm that the applied corrective maintenance not only restored the insulation system to a safe operating condition but also provided performance comparable to that of newly impregnated windings. The rising and stable IR trends across multiple sessions are strong indicators that the insulation system is reliable for continued operation.

3.5. Comparison of Initial and Post-Maintenance Insulation Resistance

The comparison between the initial and post-maintenance insulation resistance (IR) shows a very significant improvement. As presented in Table 3.1, the initial measurement in all three sessions recorded 0 MΩ for both phase-to-phase and phase-to-ground resistance within the first three minutes, even at temperatures of 51.6 °C, 48.1 °C, and 38 °C. This result indicates that the stator insulation had completely failed, providing no dielectric protection against leakage current. After corrective maintenance—consisting of cleaning, drying, varnish impregnation, and rewinding where necessary—the corrected values at 40 °C (Table 3.4) reached up to 2000 MΩ across all sessions, with test durations extended to 10 minutes.

The drastic improvement from 0 MΩ to 2000 MΩ demonstrates the effectiveness of the applied maintenance methods. According to IEEE Std 43-2013, an insulation resistance above 100 MΩ (corrected to 40 °C) is considered safe for medium-voltage machines [1]. Thus, the post-maintenance values far exceed the standard threshold, confirming that the motor insulation has been restored to a very healthy condition. These results are consistent with recent findings that emphasize the importance of temperature correction and long-duration IR tests in distinguishing failed insulation from recovered systems [2], [3]. Moreover, recent studies on resin impregnation and varnish-based nanocomposites report significant increases in dielectric strength and resistance stability after treatment, validating the high values obtained in this study [24].

In summary, the comparison indicates that the insulation system, which was initially in a failed state with 0 MΩ readings, was successfully restored to a condition comparable with new insulation. The consistent improvement across all sessions confirms that the corrective maintenance not only repaired localized faults but also enhanced the overall reliability of the stator insulation system.

4. CONCLUSION

This study demonstrates that insulation resistance testing, when combined with temperature correction according to IEEE Std 43-2013, provides an accurate and reliable method for assessing the health of induction motor stator insulation. The initial measurement results indicated a complete failure of insulation, with values recorded at 0 MΩ for both phase-to-phase and phase-to-ground in all test sessions. The causes of degradation were identified as dust and oil contamination, high operating temperature, humidity ingress, mechanical vibration, and natural aging of insulation materials.

Through corrective maintenance actions—including cleaning, drying, varnish impregnation, reinforcement of end-windings, and complete rewinding—the insulation resistance values improved significantly. Post-maintenance results, corrected to the reference temperature of 40 °C, showed insulation resistance reaching up to 2000 MΩ across all sessions. These values greatly exceed the minimum standard threshold of 100 MΩ, indicating a successful restoration of the insulation system.

The comparison between pre- and post-maintenance conditions clearly confirms that the applied corrective methods were effective in not only repairing localized damage but also in restoring the overall reliability of the insulation system. The consistent improvement across sessions further validates the stability of the results.

In conclusion, the application of systematic testing, correction, and maintenance ensures the extended lifetime and safe operation of induction motors in industrial environments. The findings also reinforce the importance of predictive maintenance strategies to prevent sudden failures and reduce costly downtime.

REFERENCE

1. L. Szamel, et al., “Monitoring of Stator Winding Insulation Degradation in Electric Motors Using FDS,” Machines, vol. 12, no. 4, p. 220, Apr. 2024. [Online]. Available: https://www.mdpi.com/2075-1702/12/4/220
2. T. García-Calva, et al., “Early Detection of Faults in Induction Motors—A Review,” Energies, vol. 15, no. 21, p. 7855, Nov. 2022. [Online]. Available: https://www.mdpi.com/1996-1073/15/21/7855
3. A. Almounajjed, et al., “Diagnosis of stator fault severity in induction motor using high-resolution spectral kurtosis,” Measurement, vol. 186, p. 110168, Dec. 2021. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S026322412100734X
4. T. A. Kawady, et al., “AI-driven fault diagnosis for stator inter-turn faults in induction machines,” Scientific Reports, vol. 15, no. 1, p. 2398, Feb. 2025. [Online]. Available: https://www.nature.com/articles/s41598-025-04462-x
5. Y. Ji, et al., “Investigation on combined effect of humidity–temperature on PD in inter-turn insulation,” IET Science, Measurement & Technology, vol. 17, no. 6, pp. 452–462, 2023.[Online].Available:https://ietresearch.onlinelibrary.wiley.com/doi/full/10.1049/smt2.12128
6. Y. Tu, et al., “Frequency-Domain Dielectric Response of Insulating Paper with High Humidity,” IEEJ Trans. Electr. Electron. Eng., vol. 19, no. 5, pp. 1234–1245, 2024. [Online].Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/tee.23934
7. L. Xu, et al., “Dielectric response characteristics and moisture exposure of insulating pressboard,” Measurement, vol. 228, p. 115143, Oct. 2024. [Online].Available: https://www.sciencedirect.com/science/article/abs/pii/S0263224124006559
8. B. Sirizzotti, et al., “A Review of Stator Insulation State-of-Health Monitoring Methods,” Energies, vol. 18, no. 14, p. 3758, Jul. 2025. [Online]. Available: https://www.mdpi.com/1996-1073/18/14/3758
9. Cheng, et al., “A Study of Frequency Domain Reflectometry Technique for Winding Insulation Diagnosis,” Machines, vol. 11, no. 9, p. 883, Sep. 2023. [Online]. Available: https://www.mdpi.com/2075-1702/11/9/883
10. H. Yoon, et al., “Maintenance of Arc Occurrence at the End of the Stator Slot in High-Voltage Motors,” Machines, vol. 13, no. 4, p. 279, Apr. 2025. [Online]. Available: https://www.mdpi.com/2075-1702/13/4/279
11. B. Sirizzotti, D. Addae, E. Agamloh, A. Von Jouanne, and A. Yokochi, “A Review of Stator Insulation State-of-Health Monitoring Methods,” *Energies*, vol. 18, no. 14, p. 3758, Jul. 2025, doi: 10.3390/en18143758.
12. X. Zhou, et al., “Insulation for Rotating Low-Voltage Electrical Machines,” Energies, vol. 17, no. 9, p. 1987, Apr. 2024. [Online]. Available: https://www.mdpi.com/1996-1073/17/9/1987
13. IEEE Std 43-2013, “IEEE Recommended Practice for Testing Insulation Resistance of Electric Machinery,” IEEE Standards Association, Dec. 2013. [Online]. Available: https://standards.ieee.org/standard/43-2013.html
14. N. R. Watson, et al., “Insulation aging and diagnostic testing of electric machine stators: A review,” Electric Power Systems Research, vol. 212, p. 108566, Jan. 2023. [Online]. Available:https://www.sciencedirect.com/science/article/pii/S0378779622004682
15. Faiz, et al., “Review on Stator Insulation Degradation and Fault Diagnosis in Induction Motors,” IEEE Transactions on Dielectrics and Electrical Insulation, vol. 29, no. 6, pp. 2253–2268, Dec. 2022. [Online]. Available: https://ieeexplore.ieee.org/document/9910982
16. A. B. Pradhan, et al., “Effectiveness of Insulation Maintenance in Induction Motors: A Case Study,” Energies, vol. 16, no. 3, p. 1123, Feb. 2023. [Online]. Available: https://www.mdpi.com/1996-1073/16/3/1123
17. M. F. Cabanas, et al., “Condition Monitoring of Electrical Machines: State of the Art and Trends,” Machines, vol. 11, no. 6, p. 640, Jun. 2023. [Online]. Available: https://www.mdpi.com/2075-1702/11/6/640
18. N. Z. Zulkifli, B. Ramadevi, K. Bingi, R. Ibrahim, and M. Omar, “Predicting Remaining Useful Life of Induction Motor Bearings from Motor Current Signatures Using Machine Learning,” *Machines*, vol. 13, no. 5, p. 400, May 2025, doi: 10.3390/machines13050400.
19. W. Doorsamy, “Condition Monitoring of Electric Machines: Modern Frameworks and Data-Driven Methodologies,” *Machines*, vol. 13, no. 2, p. 144, Feb. 2025, doi: 10.3390/machines13020144.
20. J.-Y. Koo, J.-H. Kwak, H.-D. Kim, and S.-Y. Kim, “Analysis of the Insulation Condition Due to Contamination on the Surface of End-Windings in Large-Capacity High-Voltage Motor,” J. Electrical Engineering and Technology, Mar. 2025. [Online]. Available: https://link.springer.com/article/10.1007/s42835-025-02209-2
21. Z. Zou, H. Yu, Y. Guo, et al., “Degradation Mechanism and Online Electrical Monitoring of Insulation in Traction Motors,” Energies, vol. 15, no. 10, p. 444, 2024. [Online]. Available: https://www.mdpi.com/2032-6653/15/10/444
22. A. O. Vitor, “Induction Motor Short-Circuit Diagnosis and Interpretation,” Expert Systems with Applications, vol. 206, p. 117750, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0957417423005006
23. M. Ma, L. Chen, H. Yang, et al., “Residual Stress Analysis at the Conductor–Insulator Interface in Impregnated Coils,” Polymers, vol. 16, no. 24, p. 3514, 2024. [Online]. Available: https://www.mdpi.com/2073-4360/16/24/3514
24. U. Rösel, M. Kneidl, J. Franke, and D. Drummer, “Improving the Integrated Fabrication of Insulation Systems in Electric Drives by Injection Molding of

Thermosets Due to Processing Conditions and Slot Design,” Polymers, vol. 15, no. 5, Art. 1165, 2023. [Online]. Available: https://www.mdpi.com/2073-4360/15/5/1165
25. G. Zhu et al., “Identification of Dielectric Response Parameters of Pumped Storage Generator–Motor Stator Winding Insulation Based on Sparsity-Enhanced Dynamic Decomposition of Depolarization Current,” Energies, vol. 18, no. 13, Art. 3382, 2025. [Online]. Available: https://www.mdpi.com/1996-1073/18/13/3382