

Analysis and Optimization of the High-Voltage Rewinding Process in Electric Motors and Generators to Improve Performance and Energy Efficiency

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ABSTRACT

Motors and generators play a very important role in the industrial sector. These machines often fail due to overload, poor power quality, or internal winding faults, which necessitate rewinding efforts. Analysis And Optimization Of The High-Voltage Rewinding Process In Electric Motors And Generators To Improve Performance And Energy Efficiency refers to the process of rewinding the coil windings in an electric motor or generator when the original winding is damaged, the insulation quality has deteriorated, or the machine experiences malfunction. This process should include analytical procedures that can predict and estimate the efficiency of rewound motors and generators, helping energy managers make more cost-effective decisions. The purpose of this study is to analyze the effect of the rewinding process on high-voltage electric motors and generators in relation to energy performance and efficiency, as well as to evaluate its impact on system reliability and operational performance. The research methodology for motors and generators includes several stages: testing, dismantling, data collection, repair, coil fabrication, coil testing, coil insertion, varnishing, oven curing, assembly, and final testing. After rewinding, efficiency and performance analyses were conducted during the no-load and load tests to compare conditions before and after the rewinding process of the motor and generator. The results indicate that after rewinding, performance targets were achieved, including improved energy efficiency and enhanced motor or generator performance, as demonstrated by test results before and after rewinding. Additionally, the no-load and load test results met acceptable standards for vibration, current (amperage), voltage, and power.

INTRODUCTION

Technological advances in the modern industrial era have led to an increased need for energy conversion, drive systems, and power generation systems with high reliability and optimal efficiency (Aghmadi & Mohammed, 2024; Boniface, 2026; Dhameliya, 2022; Elkelawy et al., 2024; Gidiagbaa et al., 2023; Nwokediegwu et al., 2024; Sahoo & Timmann, 2023). Electric motors and generators are the main elements in production processes across various industrial sectors, including power generation, mining, oil and gas, petrochemicals, and manufacturing (Chelliah et al., 2023; Rajendran et al., 2026; Shamoon et al., 2022; Wang et

al., 2024). The performance and stability of these electrical machines largely determine operational continuity; therefore, any disruption or decline in performance can trigger significant economic consequences (Nugraha et al., 2022).

The mechanisms of failures in motors and generators are typically categorized based on major components such as the stator, rotor, and bearings. Stator damage accounts for nearly 40% of failures and is commonly caused by short circuits in stator windings. These short circuits lead to reduced speed and increased heat, which in turn increases losses (Yulanda et al., 2023). More specifically, when the insulation resistance value of a generator is adequate, the insulation failure rate decreases. As the insulation failure rate decreases, the overall generator failure rate is also reduced, allowing the generator to operate optimally (Irianto, 2018). Electrical damage is primarily found in the coil windings; when a motor is overloaded and operates continuously, the coils may overheat and burn. When winding damage occurs in either the stator or rotor, the rewinding process becomes the most common and effective solution to restore machine functionality.

Motor rewinding is the process of replacing or repairing the wire windings in the stator or rotor of an electric motor. This is typically performed when there is winding damage such as broken conductors, short circuits, or insulation failure. Such conditions are often caused by overloading or continuous operation under excessive load, leading to thermal degradation of the windings (Fitriyanto & Fuad, 2023; Anisa Septiana, 2018).. In general, damage to electric motors can be caused by three main factors: environmental, mechanical, and electrical. Electrical damage is particularly common in winding systems (Suprianto & Syahril, 2023). However, in high-voltage machines, the rewinding process cannot be performed in a simplified manner, as insulation quality, material specifications, and high-voltage testing standards require highly precise procedures to restore machine performance to factory or improved conditions.

In practice, various challenges often arise during the repair process. Wire sizing and selection are critical; improper conductor sizing affects current-carrying capacity, where larger wire sizes can increase current capacity and torque output, while also influencing RPM and overall motor performance characteristics (Hendrick & Liliana, 2024). Inconsistencies in enamel wire specifications, errors in determining the number of turns, and poor oven curing control often lead to reduced electromagnetic efficiency, increased thermal losses, excessive vibration, and high inrush current. Repeated failures are also common, resulting in increased downtime and significantly higher operational costs.

Global demands for energy efficiency and system reliability have transformed the rewinding process from a simple restoration activity into a reconditioning process aimed at improving energy efficiency, insulation resistance, and the service life of electrical machines. International standards such as IEEE 43, IEEE 1415, IEC 60034, NEMA MG-1, and EASA guidelines provide clear direction for proper rewinding procedures. However, implementation in industry remains inconsistent due to limited facilities, variations in workshop practices, and insufficient monitoring of critical parameters during the repair process.

The urgency of this research is underscored by Indonesia's industrial energy consumption patterns, where electric motors account for approximately 50-60% of industrial electricity consumption. According to the Ministry of Energy and Mineral Resources, improving motor efficiency by just 2% could result in national energy savings of approximately 1.5 TWh

annually. In the context of the global energy transition and Indonesia's commitment to reducing greenhouse gas emissions by 31.89% by 2030, optimizing the performance of electric machines through improved rewinding processes represents a significant opportunity for energy efficiency improvement.

This condition highlights the need for more comprehensive research to analyze each stage of the rewinding process, starting from initial inspection, winding redesign, insulation material selection, slotting, varnish/resin impregnation, curing, to high-voltage testing, as well as identifying the factors that most significantly affect final machine performance. Furthermore, this research is expected to produce optimization strategies that improve energy efficiency, reduce electromagnetic losses, and significantly extend insulation lifespan.

Research on the analysis and optimization of the Analysis And Optimization Of The High-Voltage Rewinding Process In Electric Motors And Generators To Improve Performance And Energy Efficiency in high-voltage electrical machines has high urgency, as it directly supports improved industrial operational reliability and national energy efficiency. With increasing demands to reduce operational costs, minimize downtime, and support energy efficiency policies, this study is highly relevant and contributes strategically to the development of electrical machine maintenance technology in Indonesia and globally.

METHOD

The research methodology for motors and generators consisted of the following stages: testing, dismantling, data collection, repair, coil fabrication, coil testing, coil insertion, varnishing, oven curing, assembly, and final testing. After the rewinding process, efficiency and performance analyses were conducted during no-load testing by comparing data obtained before and after rewinding of the motor and generator.

Data Capture

The research began by determining the location of data collection, namely at PT. MESINDO TEKNINESIA at the street address. Rorotan IV No. 169 Cilincing North Jakarta 14140 The type of data taken in the study is motor/generator data before rewinding. To achieve the objectives of this study, stages will be carried out that are systematically and theoretically designed in the research flow diagram.

RESULT AND DISCUSSION

Analysis of Existing Winding Design

Number of Turns

The number of windings resulting from rewinding is different from *the existing* and will have a direct effect on:

1. Induction voltage
2. *Fluks magnet*
3. Working flow

Errors during *the rewinding* process are such as:

1. Too little circumference → rising current (*unbalanced amperes*)
2. Too much winding → *losses* increase

Analyze the bad test results before the rewinding process

Insulation Resistance Test (IR & P.I)

If the IR & P.I *test results* are not good, it will have an impact on the life of the *insulation of the coil* and the life of the motor/generator will be short and will result in a *short winding* because the *insulation* has been detected to be weak or degradation of the insulation due to long operation and very dirty *condition of the coil* (Mahendra et al., 2023; Wawoh et al., 2024).

The repairs that must be made are overhaul or cleaning the motor and generator so that the insulation resistance value can be high again (the impact of dirt on the insulation) but if the insulation strength is indeed weak or fragile, rewinding must be done immediately (Mahendra et al., 2023; Wawoh et al., 2024; Rosyidi & Baihaqi, 2020). *Winding Resistance Test*

If the winding *resistance results* are not good (*unbalance amperes*), it shows that the current below per phase is abnormal due to leaking current in one of the phases

The repairs that must be made are to check the connection per phase and repair or re-re-mailing, but if it has been done it is still the same as the ampere imbalance, then rewinding must be done (Suprianto & Syahrial, 2023; Rosyidi & Baihaqi, 2020).

Surge Test

If the *surge test* results are not good, it is by looking at an uneven wave graph showing a *short* between phases or *short* between *groundings*

The improvement that must be made is that if it is still *short* between phases, *partial rewinding* can be done for *phases* that are indicated *to be short*, but if it is short between grounds, then total *rewinding* must be done (Suparlan, 2010).

Elcid/core loss Test

If the *results of elcid/coreloss* are not good, it shows that there is an indication of heat in the body stator, especially in the core iron and will propagate to *the winding stator and cause high temperatures in the winding and can make the motor/generator burn or short winding*

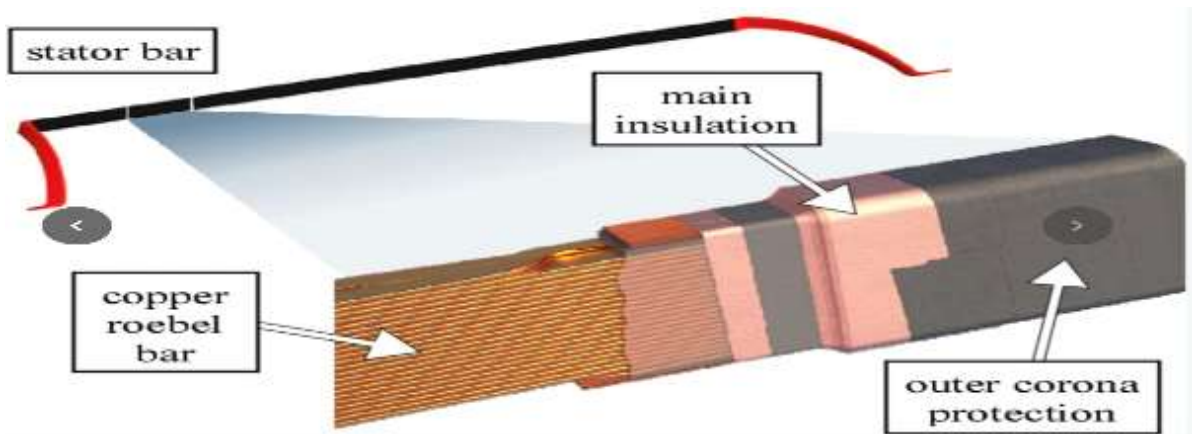
The repair that must be done *by repairing the* iron core from the stator is in the form of iron plates that number hundreds or thousands (depending on the size or size of the stator) and re-positioning is carried out for *the damaged core* (uneven surface of the *iron core*) (Gupta & Singh, 2025).

Partial Discharge Test

If the *partial discharge results* are not good, it shows that there is a leaking current in the *winding* and will result in a *short winding* The repair that must be made is to add liquid or *mica tape semi corona shield* (P 8003) to reduce the leakage current in *the winding* (Muhammad et al., 2021).



Picture 2. Coils that already use corona shield (P8003)



Picture 3. Coil insulation layer surface

From Picture 3 shows several layers of *high voltage insulation* on the coil such as *mica resin*, *anti-corona* and *kaptun*

Hardness/wedges Test

If the wedges test result is abnormal, there will be friction on the winding and the wedges and wedges as a coil protector will no longer be able to protect the surface of the coil and there will be vibration because the friction of the rotor with the stator wedges and winding stator will also be damaged and can cause short winding. The improvement that must be made is by making wedges with *NEMA G11 material* and according to the size of the exsiting.

Tan Delta Test

If the tan delta results are not good, it shows that there are *abnormalities* in the winding, such as the insulation is not dry and the layer is contaminated in the insulation which causes the life of the motor and generator to be *short winding* (Muhammad et al., 2021; Wawoh et al., 2024).

The repair that must be made is to *rewind the oven* so that the liquid in the insulation can dry if it is still high the tan delta value must be *rewinded*.

Comparative Analysis

Purpose of Comparative Analysis

After data collection and testing

This comparative analysis aims to:

1. Assess the effectiveness of *optimized high voltage rewinding* processes
2. Evaluating insulation quality improvement
3. Measuring the impact on electrical performance and energy efficiency
4. Compare test results before and after *rewinding*

1. Assess the effectiveness of the *optimized high voltage rewinding* process

For the effectiveness of *rewinding optimization*, what must be done is to use a machine to reduce human errors. That is, *the machine tapping process* during the inter-turn isolation process and for inter-phase isolation as well.

Disadvantages of using manual:

- a. For insulation strength depends on hand strength
- b. The insulation layer will have a *void* (air wave) in the insulation layer because it is uneven for the density of the insulation strength and causes *partial discharge*.
- c. The isolation process takes a long time because it relies on humans.

Advantages of using *a tapping machine* :

- a. For the strength of the insulation will be equal in the *winding insulation process*
- b. The insulation layer will not have a *void* (air bubble) because it is flat for the strength in the *winding insulation process*
- c. The process is also very fast because it uses *a tapping machine* instead of the speed of a human hand.



Picture 4. Machine *tapping process* for *winding insulation*

From Picture 4 is a machine for coil isolation so that it reduces air cavities if done with a machine instead of using a manual.

Insulation Quality Evaluation

The effectiveness of rewinding was assessed through insulation quality testing, especially using *tan delta*, *Insulation Resistance (IR)*, and *Polarization Index (PI)* tests.

1. The decrease in the value of the *tan delta* after *rewinding* showed a reduction in *dielectric losses* and an increase in insulation homogeneity.

2. Higher *IR* and *PI* values indicate the new insulation has better resistance to moisture and aging.
3. Insulation is the most important component for high-voltage electrical equipment to operate with a bail in an electrical system, such as a generator or motor, having a resistance system known as insulation to separate the energized part from the other energized part or the neutral part. To repair an equipment, the insulation quality of a particular piece of equipment must be considered. One way to find out if there is a leaking current in the winding insulation is to apply high voltage to the winding insulation. The test shows the insulation quality to the received working voltage. The leakage current value obtained during the test is used as an indicator of the resistance of the insulation quality to the accepted working voltage. The dissipation factor, also known as Tan Delta, is a parameter that indicates how efficiently the isolation is used. Insulation contamination can be detected very well with Tan Delta testing A decrease in insulation quality will lead to higher tan delta values (Wawoh et al., 2024).

Table 5. Insulation material class according to *temperature strength*

INSULATION MATERIAL CLASS AND TEMPERATURE	
<i>Class</i>	<i>Temperature</i>
<i>Y (formely O)</i>	<i>90 °C</i>
A	<i>105 °C</i>
E	<i>120 °C</i>
B	<i>130 °C</i>
F	<i>155 °C</i>
H	<i>180 °C</i>
G	<i>180 °C</i>

From table 5, it is explained that the type of insulation material as in the table above used for rewinding determines that it can withstand the maximum temperature of the coil insulation (Muhammad et al., 2021). These results prove that the application of a new insulation system and the vacuum pressure impregnation (VPI) process in rewinding has succeeded in improving the quality of high voltage insulation.



Picture 6. Condition of the stator after rewinding

From picture 6 is the image of the stator on the left showing after rewinding and on the right after removing the old coil.

CONCLUSION

The conclusion of this study is that the rewinding process in electric motors and high voltage generators has a very important role not only as an improvement, but also as an effort to optimize performance and energy efficiency. The rewinding process that is carried out precisely -- through the control of parameters such as winding design, selection of insulation materials, impregnation methods (such as VPI), and testing according to international standards -- has been proven to significantly improve engine performance. The systematic approach to rewinding, incorporating initial testing, design optimization, quality control during fabrication, and comprehensive post-rewinding testing, ensures that the rewound machine meets or exceeds original specifications. The results of this study demonstrate that energy efficiency increases after rewinding compared to previous conditions; energy losses can be reduced through the control of the winding resistance and quality; the quality of insulation improves, thereby reducing the risk of failures such as partial discharge and overheating; operational performance (current, voltage, vibration, temperature) becomes more stable and compliant; and the motor/generator life is longer, improving reliability and lowering operating costs.

For future research, this study suggests investigating the use of advanced insulation materials and nano-composite coatings to further improve the performance and reliability of high-voltage electric machines. The development of predictive maintenance models based on in-service monitoring of insulation parameters could enable proactive intervention before failure occurs, reducing downtime and maintenance costs. Additionally, research on the application of Industry 4.0 technologies, such as sensors, internet of things, and machine learning, to the rewinding process would enable enhanced monitoring and control, improving quality and consistency. Comparative studies of different impregnation methods and their impact on long-term insulation performance would also contribute to knowledge in this field. Finally, the economic analysis of optimized rewinding versus motor replacement would provide valuable guidance for decision-makers in industrial settings. In addition, this study states that without proper optimization, the rewinding process can actually reduce efficiency. Therefore, a systematic, standardized, and analysis-based approach is needed before and after rewinding to get maximum results. Overall, this research is expected to be a technical guideline for the industry in rewinding that not only improves function, but also improves the energy efficiency and long-term reliability of electric machines.

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