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Estimated Life Loss of a 3-Phase Induction Motor Based on Insulation Resistance Test at PT. Delta Jaya Mas

Reza Sarwo Widagdo[1*], Puji Slamet[1], Aris Heri Andriawan[1], Mochamad Rama Firmansyah[1]

[1]*Department of Electrical Engineering, Universitas 17 Agustus 1945 Surabaya, Indonesia*
[*]rezaswidagdo@untag-sby.ac.id

***Abstract*— Induction motors play a crucial role in the production process at PT. Delta Jaya Mas, making insulation resistance (IR) testing essential for maintaining operational reliability. IR is a key parameter that measures the ability of motor winding insulation to withstand electrical current, influenced by factors such as humidity, environmental temperature, and operating time. This study evaluates insulation resistance degradation in a 75 kW three-phase induction motor following IEEE Std 43-2000 guidelines. Testing was conducted while the motor was de-energized to prevent component damage. Polarization index data was recorded over a 10-minute interval. Initial testing on a damaged motor revealed insulation resistance values between 515 MΩ and 602 MΩ, with one phase measuring 0 MΩ, indicating a short circuit. After repairs, insulation resistance improved to 2000 MΩ. However, after three months of operation, resistance decreased at an average rate of 11.6 MΩ per month, with a polarization index of 3.5 MΩ. The findings suggest that, under consistent degradation rates, the insulation resistance can be expected to remain within acceptable limits for approximately 14 years. Regular IR monitoring and preventive maintenance are critical to ensuring motor longevity and reducing the risk of electrical failures. This study highlights the importance of systematic insulation testing in industrial environments to enhance safety and efficiency in motor-driven systems.**

Keywords—3-Phase Induction Motor, Insulation Resistance, Life Loss

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I. Introduction

One of the most important pieces of equipment in the industrial world is the three-phase induction motor. This type of motor is commonly used in PT. Delta Jaya Mas. During operation, a three-phase induction motor consists of several main components, namely the stator and the rotor. It operates using three phases of alternating current (AC) [1],[2].

Checking the reliability and safety of an induction motor is crucial to preventing accidents such as explosions or fires. Insulation resistance testing, which indicates leakage current, is essential for ensuring the motor remains safe and operational. When an electric motor is in operation, current flows through both the rotor and the stator, while leakage current flows to the motor body due to insulation resistance. The lower the insulation resistance, the higher the leakage current. If left unchecked, this can lead to motor failure [3].

Previous research has been conducted by other researchers, providing a foundation for future studies to establish a relationship between equations and observed objects. The primary cause of electric motor failure is generally insulation failure. Insulation testing processes, such as Insulation Resistance (IR) and Polarization Index (PI) testing, are carried out using direct DC voltage from an insulation tester, commonly known as a Megger [4], [5]. The decrease in insulation resistance is influenced by factors such as humidity, operating time, environmental temperature, and leakage current [6]-[8]. An electric motor that operates continuously will experience a decline in performance, leading to potential damage over time. A decrease in the motor's Polarization Index (PI) value is caused by dirty and damp winding conditions [9], [10].

Although motor stator windings are often coil-shaped with improved insulation and built-in thermal sensors for thermal protection, stator-related failures induced by high electrical voltages remain prevalent. Thermal stress affects medium-voltage (MV) motors. Similarly, because the rotor of a large MV motor is subjected to significant thermal, mechanical, and electrical stress, it is often more sensitive than that of a smaller motor [11], [12]. Stator insulation failure can be caused by heat, electrical stress, mechanical factors, and environmental influences [13]. Weakened insulation between the windings can lead to short circuits, ultimately causing the degradation of the windings and the complete failure of the insulation system [14], [15]. To prevent this, scheduled testing and maintenance of induction motors must be carried out.

In this research, the use of insulation resistance value as the main parameter for estimating the lifespan of a three-phase induction motor is a specific and detailed approach. Insulation resistance serves as an indicator of the health of the winding insulation in a motor, which is a critical factor in ensuring reliable motor operation. Using insulation resistance as the basis for estimation focuses on one of the primary causes of failure.

II. RESEARCH METHODS

This research aims to determine the insulation resistance and polarization index values in a three-phase induction motor. Measurements are conducted using the HIYOKI Insulation Tester. The selected object in this study is a three-phase motor with a power capacity of 75 kW, located at PT. Delta Jaya Mas. This research is expected to estimate the remaining lifespan of the induction motor by calculating the degradation of its insulation resistance.

A. 3-Phase Induction Motor Insulation Specifications

Data collection for this research was conducted at PT. Delta Jaya Mas Driyorejo. Based on the nameplate, the specifications of this crane hoist motor are listed in Table 1.

Table 1. Performance and Insulation Specifications of Motor

Power	75 [kW]
Frequency	50 [Hz]
Voltage	380 [Volt]
Class Insulation	F
Current	136 [Ampere]
Maximum Rotation	1480 [rpm]
Cos φ	0.85
Efficiency	85%

From the Table 1, it can be concluded that the motor has a power of 75 kW, a frequency of 50 Hz, insulation class F, a maximum rotation speed of 1488 rpm, and a NEMA Design C with a rating of 3.55 kVA, a power factor (cos φ) of 0.85, and an efficiency of 85%. A motor with these specifications is designed to handle heavy loads, such as in a calendar machine. These specifications indicate that the motor can deliver substantial power with good efficiency and operate within the required speed range.

B. Insulation Standards for 3-Phase Induction Motors

Data collection on insulation resistance and polarization index is conducted when the induction motor is turned off. This process ensures that measurements are taken under safe and accurate conditions, without any interference from operating voltage. Insulation resistance data is obtained using an insulation tester, which measures the insulation resistance between the winding phases and the motor body.

Insulation resistance calculations are used to determine the polarization index and estimate the remaining lifespan of induction motors based on IEEE Standard No. 43. Motor resistance typically has a value of several megaohms (MΩ), as shown in Table 2. The use of appropriate insulation materials and regular testing is key to maintaining motor performance and preventing damage caused by insulation degradation.

Table 2. Insulation Standards Based on IEEE std. 43

Insulation Resistance Standar	**Insulation Level**
< 2 MΩ	Danger
2 – 5 MΩ	Very Bad
5 – 10 MΩ	Bad
10 – 50 MΩ	Enough
50 – 100 MΩ	Good
> 100 MΩ	Very Good

C. Polarization Index (PI)

The Polarization Index (PI) is the ratio of resistance measured after 10 minutes to the resistance measured after 1 minute of testing. This value provides a more in-depth indication of the insulation condition, as it reflects the ability of the insulating material to maintain its properties over time. A high Polarization Index value indicates good insulation, while a low value may indicate insulation degradation. The following equation represents the Polarization Index for a three-phase induction motor:

$$PI = \frac{IR\ Measurement\ for\ 10\ Minutes}{IR\ Measurement\ for\ 1\ Minutes} \quad (1)$$

where,

PI = Polarization Index

IR 10 mins = Insulation resistance during 10 minutes

IR 1 min = Insulation resistance during 1 minute

The PI value calculation is used to determine the degradation level of a three-phase induction motor by comparing it with IEEE Standard No. 43, which defines the Polarization Index (PI) values. The following are the standard minimum PI values:

Table 3. Minimum PI Value According to IEEE std. 43

Thermal Class Rating	**Minimum PI**
Class A	1.5
Class B	2.0
Class F	2.0
Class H	2.0

Regular measurement of the Polarization Index (PI) is a crucial part of a preventive maintenance program for three-phase induction motors, as it helps detect potential issues before serious motor failures occur. The following is an interpretation of PI values, serving as a reference for assessing the quality of insulation resistance in a three-phase induction motor.

Table 4. Interpretation Values of the Polarization Index (PI)

PI Value	Classification
<1.0	Danger
1 – 1.5	Very Bad
1.5 – 2.0	Bad
2.0 – 3.0	Enough
3.0 – 4.0	Good
> 4.0	Very Good

D. Classification of 3-Phase Induction Motor Insulation Types

The insulation class of a motor refers to the classification of motor resistance at specific temperatures. The National Electrical Manufacturers Association (NEMA) standard categorizes insulation classes into four types: A, B, F, and H. Tables 5 and 6 provide details on the criteria for temperature rise and hotspot margins.

Table 5. Rise Temperature Classification

Thermal Class Rating	**Maximal Temperature**
Class A	60 [^{0}C]
Class B	80 [^{0}C]
Class F	105 [^{0}C]
Class H	125 [^{0}C]

Table 6. Hotspot Margins Classification

Thermal Class Rating	**Maximal Temperature**
Class A	5 [^{0}C]
Class B	10 [^{0}C]
Class F	10 [^{0}C]
Class H	15 [^{0}C]

E. Determination of Lifespan of 3-Phase Induction Motors

Determining the life loss of a three-phase induction motor is a process of estimating its service life based on operational and environmental conditions that impact motor performance. The annual decrease in insulation resistance of a three-phase induction motor can be calculated using the following equation.

$$\Delta IRm = \left(\frac{IR_0 - IR_1}{3}\right) \tag{2}$$

Where,

ΔIR_m = Decreased value of insulation resistance per month

IR_0 = Initial operating insulation resistance value (new/after rewinding/reinsulation)

IR_1 = Insulation resistance value at the time of testing

3 = Testing period (months)

The following is the equation to determine the annual decrease in insulation resistance of a 3-phase induction motor

$$Life\ loss = \left(\frac{IR_0 - 5\ \mathrm{M\Omega}}{\Delta IRm}\right) \tag{3}$$

Where,

IR_0 = Initial operating insulation resistance value (*new/after rewinding/reinsulation*)

5 MΩ = Minimum limit insulation resistance in IEEE std. 43

ΔIR_m = Decreased value of insulation resistance per month

III. Result and Analysis

Testing electric motors with the specifications listed in Table 1 serves to determine the condition of the three-phase induction motor by measuring the insulation resistance between phases and between each phase and the motor body. During the maintenance process, several components must be checked and maintained, one of which is the condition of the stator coil. Motor windings exhibit varying insulation resistance (IR) values depending on the motor type and condition.

Poor insulation resistance can have a serious impact on electrical equipment. These impacts include increased machine temperature, higher electricity consumption, and the risk of equipment failure due to short circuits. The Institute of Electrical and Electronics Engineers (IEEE) has established minimum recommended insulation resistance values to prevent damage, as outlined in the IEEE guide, *Recommended Practices for Testing Insulation Resistance of Rotating Machinery*, which is detailed in Table 7.

Table 7. Minimum *Insulation Resistance (IR)*

No.	**Minimum IR Value (MΩ)**	**Induction Motor Spesification**
1	IR = kV + 1	For all types of windings whose year of manufacture is less than 1970, or which are not mentioned below.
2	IR = 100	For the majority of AC and DC coils, the year of manufacture was over the 1970s (from wound coil).
3	IR = 5	For most machines with random wound stator coils and wound coil forms the rating is below 1kV.

A. Insulation Testing Between Motor Windings

Testing the insulation resistance between motor windings is conducted when the motor is turned off. The black and red cables of the insulation tester are connected to each phase winding of the three-phase induction motor. The following is a test of the insulation resistance between motor windings.

Table 8. Inter-Phase Insulation Resistance Test Before Repair

Time (mins)	Insulation Resistance Value (MΩ)		
	U1 – V2	V1 – W2	W1 – U2
1	515	0	509
2	567	0	516
3	580	0	534
4	570	0	533
5	572	0	546
6	561	0	561
7	570	0	567
8	577	0	573
9	592	0	597
10	610	0	602

Table 9. Inter-Phase Insulation Resistance Test After Repair

Time (mins)	Insulation Resistance Value (MΩ)		
	U1 – V2	V1 – W2	W1 – U2
1	577	575	580
2	710	2000	2000
3	935	2000	2000
4	1176	2000	2000
5	1881	2000	2000
6	2000	2000	2000
7	2000	2000	2000
8	2000	2000	2000
9	2000	2000	2000
10	2000	2000	2000

It can be observed that the windings U1 – U2 and W1 – U2 have good insulation resistance values, while the insulation resistance of V1 – W2 is extremely poor, with a value of 0 MΩ. This indicates that a short circuit occurs during operation.

Tests conducted after repairs showed an insulation resistance value of 2000 MΩ. When compared to IEEE Standard No. 43, this value is considered excellent, as all windings have resistance values above 100 MΩ. Therefore, the induction motor is safe for operation.

B. Motor Body-Phase Insulation Testing

Testing the insulation resistance between motor windings is conducted when the motor is turned off. The red cable of the insulation tester is connected to the phase winding, while the black cable is connected to the motor body of the three-phase motor. The following is a test of the insulation resistance between the windings and the motor body.

Table 10. Body-Phase Insulation Resistance Test Before Repair

Time (mins)	Insulation Resistance Value (MΩ)		
	U – Body	V – Body	W – Body
1	270	0	637
2	277	0	639
3	280	0	702
4	283	0	733
5	272	0	736
6	281	0	741
7	330	0	742
8	347	0	757
9	392	0	762
10	392	0	766

Table 11. Body-Phase Insulation Resistance Test After Repair

Time (mins)	Insulation Resistance Value (MΩ)		
	U – Body	V – Body	W – Body
1	530	433	557
2	610	687	732
3	735	734	945
4	876	854	1066
5	981	987	1378
6	1007	1050	1690
7	1330	1133	1812
8	1842	1715	2000
9	2000	2000	2000
10	2000	2000	2000

Table 13. Polarization Index (PI) Testing on Induction Motor with a Power of 75 kW Before Repair

PI (*Polarization Index*) Test				**IEEE std. No. 43**	**Condition**
Phase to Phase		***Phase to Body***			
U1 – V2	1,1	U - *Phase Body*	1,4	2,0	**Bad**
V1 – W2	0	V - *Phase Body*	0		**Bad**
W1 – U2	1,1	W - *Phase Body*	1,2		**Bad**

Table 14. Polarization Index (PI) Testing on Induction Motor with a Power of 75 kW After Repair

PI (*Polarization Index*) Test				**IEEE std. No. 43**	**Condition**
Phase to Phase		***Phase to Phase Body***			
U1 – V2	3,4	U - *Phase Body*	3,7	2,0	**Good**
V1 – W2	3,4	V - *Phase Body*	4,6		**Good**
W1 – U2	3,4	W - *Phase Body*	3,5		**Good**

C. *Polarization Index (PI) Testing*

The Polarization Index (PI) calculation is used to assess insulation degradation in a three-phase induction motor by measuring insulation resistance over a period of 1 to 10 minutes. The test was conducted using a megohmmeter, as shown in Figure 1.

Figure 1. Insulation testing with a megohmmeter

Based on Equation (1) for testing the Polarization Index (PI), the results are presented in Table 13 and Table 14. From the test results, it can be observed that the PI degradation value before repairs was very poor according to IEEE Standard No. 43, as explained in Table 13 and Table 14. However, after repairs to the induction motor winding, the PI value improved significantly.

D. *Temperature Measurement*

Measuring the temperature of a three-phase induction motor is an essential process for monitoring performance and preventing damage caused by overheating. Excessive temperatures can degrade insulation and other components, making regular temperature monitoring crucial. Temperature measurements are taken while the induction motor is running a test, with readings recorded every 15 minutes over a period of one hour or more. The results of the temperature measurements are presented in Table 15.

Table 15. Results of Temperature on Motor Components

Temperature when the motor is running			
Operation Time	***Shaft Bearing***	***Body***	**Condition**
01.00 PM	36 [°C]	48,6 [°C]	**Good**
01.15 PM	36,6 [°C]	51,5 [°C]	**Good**
01.30 PM	36,6 [°C]	52,3 [°C]	**Good**
01.45 PM	39,9 [°C]	53,1 [°C]	**Good**
02.00 PM	39,9 [°C]	56,3 [°C]	**Good**

The results of temperature measurements on a three-phase induction motor with a power of 75 kW, taken while the motor was operating from 1:00 PM to 2:00 PM, showed a temperature range of 36–56°C. This indicates that the temperature is still within a safe range according to NEMA standards, where the ambient temperature is 40°C, and the maximum allowable temperature for insulation class F is 155°C.

E. *Calculation of Decreased Insulation Resistance (IR)*

Calculation of the reduction in insulation resistance using equation (2) using table data on insulation resistance after repairs.

$$\Delta IRm = \left(\frac{2000\ \text{M}\Omega - \ 1965\ \text{M}\Omega}{3}\right)$$

$$\Delta IRm = 11{,}6\ \text{M}\Omega$$

From the results of the calculations above, it can be seen that the decrease in insulation resistance every month is 11.6 MΩ.

F. Prediction of Remaining Life of a 3 Phase Induction Motor

From the previous data, it is obtained that ΔIRm = 11.6 MΩ every month and to find out the remaining life of a 3 phase electric motor you can use equation (3).

$$Life\ loss = \left(\frac{2000\ \text{M}\Omega\ -\ 5\ \text{M}\Omega}{11{,}6\ \text{M}\Omega}\right)$$

$$\Delta IRy = 171{,}9\ \text{M}\Omega\ /\ Month$$

$$\Delta IRy = 171{,}9\ /\ 12$$

$$\Delta IRy = 14{,}3\ \text{Year}$$

The calculation above is used to determine the remaining life or loss of life of a three-phase electric motor. The value of 2000 MΩ is taken from the initial insulation resistance after repair, while 5 MΩ represents the worst-case resistance standard according to IEEE Standard No. 43. The monthly decrease in insulation resistance is 11.6 MΩ. If this decline continues consistently, the insulation resistance will reach the critical threshold in approximately 14 years and 3 months.

The insulation in electric motors serves to prevent leakage current between windings and other motor components. The quality of the insulation is crucial to ensuring safe operation and extending the motor’s lifespan. Insulation failure can lead to excessive leakage current, overheating, and ultimately, motor failure. Low insulation resistance indicates insulation degradation, which can be caused by factors such as humidity, contamination, high temperatures, and excessive electrical voltage. Future research could explore various aspects to enhance the understanding and accuracy of motor lifespan estimation. This includes developing mathematical models or machine learning algorithms to predict the lifetime of induction motors based on periodically collected insulation resistance data. Additionally, further studies on the aging effects of insulation materials and their impact on motor lifespan could provide valuable insights for improving motor reliability and maintenance strategies.

IV. Conclusion

The research concludes that the average insulation resistance of the three-phase motor is 2000 MΩ, exceeding the IEEE Standard No. 43 requirement of 100 MΩ and a Polarization Index above 4, classifying it as excellent. After repairs, the 75 kW motor showed improved insulation resistance, expected to last until 2038. If the decline continues at the same rate, the insulation resistance is predicted to reach 5 MΩ in 14 years, assuming a room temperature of 36–56°C, which remains within NEMA standards for insulation class F.

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