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

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***Abstrak*— At the company PT. Delta Jaya Mas induction motors are very necessary to run machines in the production process. An induction motor consists of a rotor and stator with insulation resistance. Insulation Resistance (IR) is a measure of the ability of the insulation in the winding to withstand current. Insulation resistance testing is needed to determine the condition of the insulation which is influenced by humidity, environmental temperature and operating time. This test procedure is regulated in the IEEE Std 43-2000 standard. The use of an appropriate insulation tester and routine testing is important to maintain the insulation resistance value and prevent accidents and damage to 3-phase induction motors. Testing is carried out when the motor is turned off to avoid component damage. Polarization index data is taken by testing the insulation resistance for 1 to 10 minutes. The test was carried out on the insulation resistance of a three-phase induction motor with a power of 75 kW which showed a value of 515 MΩ to 602 MΩ when it was in a damaged condition with one phase having a value of 0 MΩ indicating a short or short circuit condition. After repair the motor has an insulation resistance of 2000 MΩ. After operating for 3 months the decrease in resistance that occurred per month was 11.6 MΩ and the polarization index test was 3.5 MΩ. An insulation resistance of 2000 MΩ can be expected to last for 14 years if degradation occurs consistently.**

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

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I. Introduction

One of the most important equipment in the industrial world is a 3-phase induction motor. Induction motors are tools commonly used in PT companies. Delta Jaya Mas. In operation, a three-phase induction motor consists of several constituent parts, namely the stator and rotor. This type of motor operates using three phases of alternating current (AC) [1],[2]. Checking induction motor reliability and safety is important to avoid accidents, such as explosions or fires. Insulation resistance testing, which indicates leakage current, is key to ensuring the motor remains safe and operational. When an electric motor operates, current will flow through the rotor and stator and leakage current will flow between them to the motor body due to the effect of insulation resistance. The smaller the insulation resistance, the greater the leakage current, if this is left unchecked it will result in failure of the electric motor's operation [3].

Previous research has been carried out by other researchers so that researchers who will carry out research will have the same relationship from the equations to the objects being observed. The main cause of electric motor failure is generally due to insulation failure. Insulation testing processes such as testing Insulation Resistance (IR), Polarization Index (PI) using direct DC voltage from the Insulation Tester or what can be called Magger [4], [5]. The decrease in insulation resistance is caused by the influence of humidity, operating time, environmental temperature and leakage current [6]-[8]. An electric motor that is used continuously will experience a decrease in performance so that it can be damaged very quickly. The decrease in the motor polarization index (PI) value is caused by dirty and damp winding conditions [9], [10].

Although motor stator windings are often coil-shaped with more improved insulation and inbuilt thermal sensors for thermal protection, stator-related failures, induced by greater electrical voltages, are nevertheless prevalent. Thermal stress on the MV motor. Similarly, because the rotor of a big MV motor is subjected to significant stress, including thermal, mechanical, and electrical stress, it is often more sensitive than that of a small motor [11], [12]. Stator insulation failure can be caused by heat, electricity, mechanics and environmental influences [13]. This weakened isolation between the windings will cause a short circuit between the windings and ultimately cause degradation of the windings to failure of the insulation of the entire winding [14],[15]. To avoid this, induction motor testing and maintenance must be carried out on a scheduled basis.

In this research, the use of insulation resistance value as the main parameter in estimating the life of a 3-phase induction motor is a specific and detailed approach. Insulation resistance is an indicator of the health of the winding insulation in a motor, which is a critical factor in the reliability of motor operation. Using insulation resistance as a basis for estimation provides focus on one of the main causes of motor failure.

II. Research Methods

This research is aimed at determining the value of insulation resistance and polarization index in a 3-phase induction motor. Measurements using the HIYOKI Insulation Tester. The object chosen in this research is a 3-phase motor with a power capacity of 75 kW located at PT. Delta Jaya Mas. This research is expected to determine the remaining life of a 3-phase induction motor by calculating the degradation value of insulation resistance in the induction motor.

A. 3-Phase Induction Motor Insulation Specifications

Data collection in this research was carried out at PT. Delta Jaya Mas Driyorejo. From the nameplate, it can be seen that this crane hoist motor has the specifications written 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 above it can be concluded that the motor power is 75 kW, frequency 50 Hz, isolation F, maximum rotation 1488 rpm, NEMA design C namely 3.55 kVA, cos φ 0.85, rated efficiency 85%, a motor with this specification is designed to handle the drive which is quite heavy, like on a calendar machine. The specifications shown show that this motor can provide quite large power with good efficiency, and is able to operate in the required rotation range.

B. Insulation Standards for 3-Phase Induction Motors

Data collection on insulation resistance and polarization index is carried out when the induction motor is off. This process ensures that measurements are carried out in safe and accurate conditions without any interference from operating voltage. Insulation resistance data is taken using an insulation tester which provides the insulation resistance value between the winding and the motor body phase.

Insulation resistance calculations are used to calculate the polarization index and remaining life of induction motors based on IEEE Standard No. 43 motor resistance usually has a value of several mega ohms (MΩ) as in Table 2. Use of appropriate insulation materials and regular testing is key to maintaining motor performance and preventing damage that can be 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)

Polarization Index (PI) is the ratio between resistance measured after 1 minute to 10 minutes of testing. This value provides a more in-depth indication of the condition of the insulation because it reflects the ability of the insulating material to maintain its insulating properties over a longer period of time. A high Polarization Index value indicates good insulation, while a low value can indicate degradation of the insulation. The following is the equation for the Polarization Index in a 3-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 value in a 3-phase induction motor by comparing it with IEEE standard No. 43 regarding the Polarization Index (PI) value. The following are the standard minimum Polarization Index (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

Regularly measuring the Polarization Index (PI) is an important part of a preventive maintenance program for 3-phase induction motors, as it can help detect potential problems before more serious motor failure occurs. The following is an interpretation of the Polarization Index (PI) value as a reference for determining the quality of an insulation resistance in a 3-phase induction motor.

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

Nilai PI	Keterangan
<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

Insulation class on motor is a class division for motor resistance at certain temperatures. The NEMA (The National Electrical Manufacture Association) standard divides Insulation Class into 4, namely A, B, F and H. Table 5 and Table 6 explain the criteria for increasing temperature 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]

Tabel 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. Penentuan Susut Umur Pada Motor Induksi 3-Fasa

Determining life loss in 3-phase induction motors is a process for estimating the service life or age of the motor based on operational and environmental conditions that affect motor performance. In determining the annual decrease in insulation resistance of a 3-phase induction motor, you can use the following equation.

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

Keterangan :

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

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

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

In testing electric motors with the specification listed in Table 1, the function is to determine the condition of the 3-phase induction motor regarding the insulation resistance between the phases and the phase with the induction motor body. In the maintenance process there are several components that we must check and maintain. One of them is the condition of the stator coil of the electric motor. Motor windings have different insulation resistance (IR) between one motor and another.

Poor insulation resistance can have a serious impact on electrical equipment. The impacts include causing the machine to become hotter, using more electricity than usual, and the risk of equipment not functioning due to a short circuit. The Institute of Electrical and Electronics Engineering (IEEE) has minimum standards for recommended insulation resistance values before damage occurs which are written in the IEEE guide, "Recommended practices for Testing Insulation Resistance of Rotating Machinery" which is described 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 carried out when the motor is turned off or off, with the black and red cables on the insulation tester to each phase winding of the 3-phase induction motor. The following is a test of the insulation 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 seen that the windings U1 – U2 and W1 – U2 have good insulation resistance values, while the insulation resistance values of V1 – W2 have very bad insulation resistance with 0 MΩ values, that's meaning a short circuit occurs when operating.

Tests carried out after repairs showed an insulation resistance value of 2000 MΩ when compared with IEEE standard No. 43, so this value is very good because all windings have a value above 100 MΩ. So the induction motor is safe when operated.

B. Motor Body-Phase Insulation Testing

Testing the insulation resistance between motor windings is carried out when the motor is turned off or off, with the red cable on the insulation tester to the phase winding and the black cable to the 3-phase motor body phase. The following is a test of the insulation 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 determine the insulation degradation value in a 3-phase induction motor which is measured over 1 to 10 minutes. The test was carried out 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) which is written in Table 13 and Table 14. From the results of the tests that have been carried out, it can be seen that the PI degradation value before repairs has a very bad value according to IEEE standard No. 43 which is explained in Table 13 and Table 14 with better conditions after repairs to the induction motor winding.

D. *Temperature Measurement*

Measuring the temperature of a 3-phase induction motor is an important process for monitoring performance and preventing damage caused by overheating. Excessive temperatures can cause damage to the insulation and other components, so regular temperature measurements on induction motors are very necessary. Temperature measurements are carried out when the induction motor is running a test. Temperature measurements are carried out every 15 minutes on a time scale of 1 hour or more. The results of temperature measurements on the motor are explained 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 3-phase induction motor with a power of 75 kW when the engine was operating at 01.00 PM to 02.00 PM reached a temperature of 36 - 56 °C, which means that the temperature is still safe according to NEMA standards, which at room temperature is 40 °C and 155 °C as a point of view. maximum temperature standards allowed for insulation class F.

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 is the worst standard value of resistance according to IEEE standard No. 43. monthly decrease of 11.6 MΩ. If the decrease in insulation resistance occurs continuously, then within 14 years and 3 months.

Insulation on electric motors functions to prevent leakage current between the windings and other parts of the motor. The quality of the insulation is critical to ensure safe operation and long life of the motor. Damage to the insulation can cause excessive leakage current, overheating, and ultimately motor failure. Low insulation resistance indicates degradation of the insulating material, which can be caused by factors such as humidity, contamination, high temperature and excessive electrical voltage. Future research could cover various important aspects to improve understanding and accuracy in estimating motor age. Furthermore, it is possible to develop mathematical models or machine learning algorithms to predict the lifetime of induction motors based on insulation resistance data collected periodically. Then, a study of the aging effects of the insulation material and how this affects the motor's lifespan.

IV. Conclusion

From the results of the research that has been carried out, it can be concluded that the average value of insulation resistance in 3-phase motors has been calculated and found to be 2000 MΩ. When compared with IEEE Standard No. 43 which confirms that the insulation resistance value must be more than 100 MΩ and the Polarization Index more than 4, this condition can be classified as excellent. Insulation resistance testing shows that the insulation on a 3-phase induction motor is in good condition and can operate with an appropriate level of insulation resistance to maintain safety. The motor with a power of 75 kW after repair shows an increase in insulation resistance to 2000 MΩ, which is predicted to last until 2038 from the initial repair in 2024. The motor is predicted to reach 5 MΩ in about 14 years if the room temperature remains within the range 36 – 56°C, which is still safe according to NEMA standards which set a room temperature of 40°C and 155°C as a standard reference for the maximum temperature for insulation class F.

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