Testing and Simulation of Motor Insulation System under Some Artificial Environmental Conditions

I Made Yulistya Negara, Dimas Anton Asfani, Daniar Fahmi, Siti Sudatul Aisyah N.

Electrical Engineering Department, Faculty Of Industrial Technology

Institut Teknologi Sepuluh Nopember

Surabaya, Indonesia

Email: yulistya@ee.its.ac.id

Abstract— **This study deals with the effect of humidity and contamination of salt on insulation resistance and polarization index. It investigated experimentally and is also analyzed by using its equivalent circuit. Surface leakage and absorption currents were measured to interpret the quality of insulation winding of a motor. The result shows that in all conditions, the value of absorption current is constant during the testing, meanwhile due to effect of humidity and contamination the leakage current is much larger than normal conditioned motor. Data obtained from insulation resistance test are used to calculate the resistance to ground (RTG) and capacitance to ground (CTG). RTG and CTG are then used as value of components on equivalent circuit for simulation matter. The simulation result using equivalent circuit is reasonable agree with the experiment done.**

Keywords—insulation resistance test; polarization index; equivalent circuit; resistance to ground (RTG); capacitance to ground (CTG)

I. INTRODUCTION

In general, the aim of maintenance of electrical equipment is to maintain its condition. On maintenance of a motor, insulation resistance test and polarization index measurement are common parameters used to judge its insulating quality. Such routine test is expected to reduce sudden failure of the motor and finally reduce the maintenance cost.

In the fact, some extreme environmental condition can lead to deterioration of winding insulation of an electric motor [1]. Humidity of environment results in the presence of moisture on the surface or between the winding insulation of an electric motor. Within the time it can damage the insulation winding. As well as humidity, contamination such as salt, conductive particle and oil on winding insulation can damage the insulation winding of motor and finally lead to failure of motor.

The deterioration of winding insulation affected by environmental condition can be detected and simulated by using equivalent circuit insulation resistance standard IEEE 43-2000 [2]. The circuit monitors some direct current during insulation resistance testing. Those currents are capacitance current (IC), conductance current (IG), surface leakage current (IL), and absorption or polarization current (IA). The characteristics of those current within the time are shown in
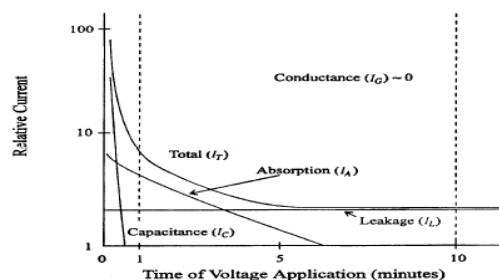

Fig. 1. Direct current curve is Measured Current Insulation Resistance Testing [2]

TABLE I. EXPLANATION THE RATIO OF VALUES POLARIZATION INDEX [3]

Polarization Index Value	Insulation Condition
<1.0	Dangerous
1 – 1.4	Poor
1.5 – 1.9	Questionable
2.0 – 2.9	Fair
3.0 – 4.0	Good
>4.0	Excellent

Figure. 1. It can be clearly shown in the figure that all the current decrease with the time, but leakage current has a small constant value. In this study, insulation resistance will be measured in normal condition, conditioned humidity, and under salt contamination. Data obtained from insulation resistance testing is used to determine polarization index (PI), and RTG and CTG. Moreover, those data are used as component parameter on equivalent circuit [4]. PI is then used to interpret the insulation quality according to Table 1 [3].

II. EXPERIMENTAL SETUP

Three conditions of experiments are performed in this study in order to investigate the quality of insulation winding of an electric motor. In all condition motor was running 14 days and 10 hours each day. Insulation resistance was measured offline every day by using Mega-Ohm meter. Temperature of winding was also measured for future investigation. In detail those conditions are explained as follows.
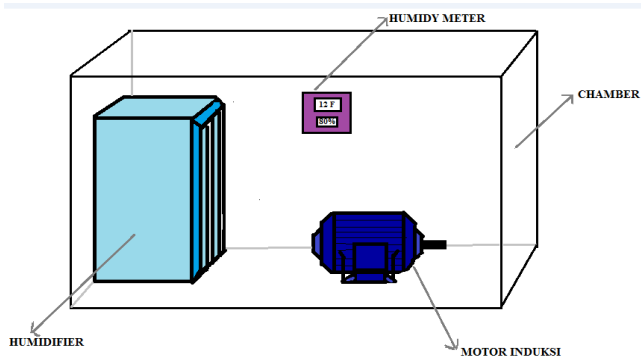
Fig. 2. Schematic diagram of experimental setup

A. Normal Environmental Condition

It is to understand that normal condition means motor was run under natural laboratory condition. Phase to ground insulation resistance was measured, namely phase U-Ground, V-Ground, and W-Ground. The data obtained is used to calculate polarization index, RTG and CTG. As explained before the value of RTG and CTG will be used in the equivalent circuit to simulate the condition of insulation winding.

B. Humid Environmental Condition

In order to investigate the effect of humidity on insulation resistance, motor was placed in a chamber together with humidifier and humidity meter. The humidity during the experiment was 95%. Schematic diagram of the experimental setup is depicted on Figure 2 [5]. The experimental procedure is similar to normal environmental condition.

C. Contaminated Environmental Condition

In this case motor was also placed in chamber similar to humid environmental condition. However liquefied salt was filled up in humidifier so that it blew salty humid air. The concentration of liquefied salt is about 56 kg/m3 or equal to 0.954 Mol. Such concentration of pollution is a very heavy pollution category [6]. The measured parameter is similar to normal as well as humid environmental condition.

III. RESULT AND DISCUSSION

In these discussions, the measurement data of U phase to ground is used as a representative to determined polarization index, RTG and also CTG. Using the other phases to calculate all parameters needed gave reasonable similar result. The insulation resistance was measured on the day of 14.

A. Normal Environmental Condition

The insulation resistance is higher than the minimum value of insulation resistance which is $I_{Rmin} = (V_{max} +1) \times 100$ MΩ = 138 MΩ [2]. It indicates that the insulation winding was not broken. As shown on the table, the insulation resistance

minute	U-Ground (MΩ)	V-Ground (MΩ)	W-Ground (MΩ)	Explanation
1	495.7	446.68	368.7	Measurement: SANWA MG100) "Digital Insulation Tester" Ambient Temperature: 31ºC Reference Temperature: 75ºC
2	665.9	620	440	
3	784	745	687	
4	926	950	845	
5	1908.1	1267	1096.1	
6	2028	1768.5	1785	
7	2521	1946	1956	
8	2756	2524	2450	
9	3621	3512	3565.8	
10	2995.4	3997.8	3996.7	
PI	8.06	8.95	10.84	

TABLE II. DATA TESTING INSULATION RESISTANCE OF NORMAL CONDITIONS

increased within the measurement time. The polarization index is determined by using following equation:

$$PI = \frac{R_{10min}}{R_{1min}} \qquad (1)$$

where,

PI = Polarization Index

R_{10mins} = Insulation Resistance at 10 minutes

R_{1min} = Insulation Resistance at 1 minute

Using equation 1, the polarization index becomes 8.06. According to Table 1 polarization index of 8.06 was much higher than 4. That is the quality of insulation is excellent. Graphically, insulation resistance with the time under normal environmental condition is depicted on Figure 3.

The results on Table 2 are then used to determine parameters on insulation resistance equivalent circuit. RTG and CTG are determined as following [4].

$$RTG = RT \cdot Kt \qquad (2)$$

where,

RTG = Resistance to ground (resistance to ground) in MΩ
Kt = insulation resistance temperature coefficient at temperature° C
RT = measured insulation resistance at temperature° C (MΩ)

$$CTG = \sqrt{Z^2 - RT} \qquad (3)$$

where,

CTG = Capacitance to ground (nF)
Z = impedance of the motor insulation system

RTG and CTG value of this condition are 1055.97 MΩ and 1323.9 nF. Figures 4 and 5 show the equivalent circuit and its result under normal condition [7].This result has good agreement with IEEE standard that the current detected is only absorption current that decreases with the time.
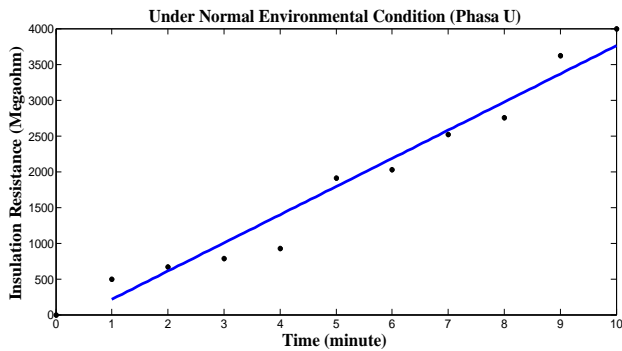
Fig. 3. Insulation resistance with the time under normal environmental condition
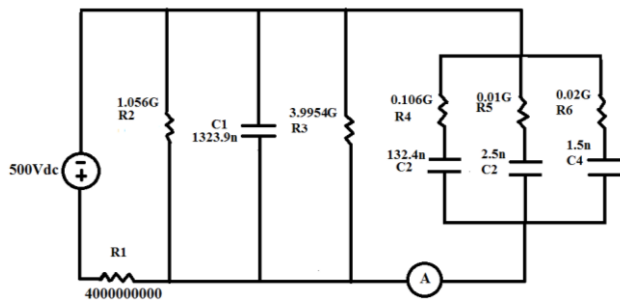
TABLE III. DATA TESTING INSULATION RESISTANCE OF HUMID ENVIRONMENTAL CONDITIONS

minute	U-Ground (MΩ)	V-Ground (MΩ)	W-Ground (MΩ)	Explanation
1	230	318.7	315.9	Measurement: SANWA MG100) "Digital Insulation Tester" Ambient Temperature: 31°C Reference Temperature: 75°C
2	321.5	480.8	459	
3	465.6	429.1	590.3	
4	599.3	542.6	645.3	
5	556.7	656.1	792.6	
6	697.4	765.7	745.1	
7	760.1	718.4	899.3	
8	863.1	878.1	956.6	
9	799	784.1	974.4	
10	704	656.5	780.4	
PI	3.06	2.06	2.47	

TABLE IV. RESULT POLARIZATION INDEX, RTG, AND CTG UNDER HUMID ENVIRONMENTAL CONDITION (U PHASE)

IR min (MΩ)	Polarization Index		RTG	CTG
	Value	Insulation Quality		
138	3.06	good	321.43	403

Fig. 4. Insulation resistance equivalent circuit under normal conditions

Fig. 5. Simulation results of insulation resistance equivalent circuit under normal conditions

Fig. 6. Insulation resistance with the time under humid environmental condition

B. Humid Environmental Condition

The data of insulation testing under humid environmental condition were mined on days 14. The results are shown on Table 3.

By using similar equation as under normal condition, the results of PI, RTG and CTG are shown on Table 4. Graphically, insulation resistance with the time under humid environmental condition is depicted on Figure 6.

The equivalent circuit of insulation resistance under humid environment is shown on Figure 7. Differ from under normal condition under given humidity condition ac source was added to leakage current and absorption current branches [7].

Ac sources represent the effect of humidity or moisture because in the fact humidity and moisture as well as contaminant has most influence on absorption and leakage currents. Furthermore ac sources also represent the variability of polarization and movement influence either on the surface as well as inside the insulation system itself. The value of sources
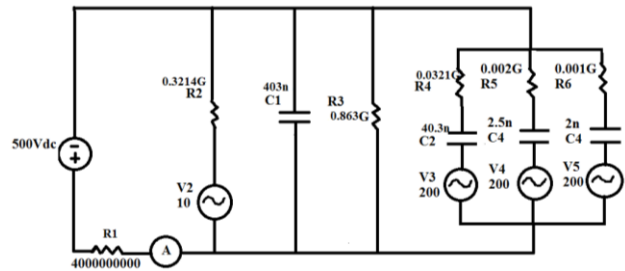

Fig. 7. Insulation resistance equivalent circuit under humid environmental condition
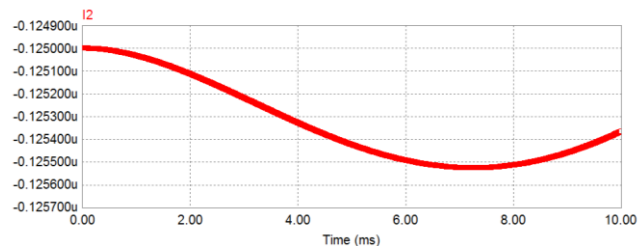

Fig. 8. Simulation results of insulation resistance equivalent circuit under humid environmental conditions

TABLE V. DATA INSULATION RESISTANCE OF CONTAMINATED ENVIRONMENTAL CONDITION

minute	U-Ground (MΩ)	V-Ground (MΩ)	W-Ground (MΩ)	Explanation
1	287.4	322.6	303	Measurement: SANWA MG100) "Digital Insulation Tester" Ambient Temperature: 31°C Reference Temperature: 75°C
2	340.8	340.8	467	
3	490.3	490.3	566	
4	556	556.3	684	
5	608.1	608.1	652	
6	686.1	696.1	674	
7	656.7	666.7	784.1	
8	747	757.1	884	
9	796.8	766.8	867	
10	686.9	654.9	702.9	
PI	2.39	2.03	2.32	

is randomly chosen due to immeasurable level of humidity on insulation itself. The result under humid environmental condition is shown on Figure 8. The result shows good agreement with the measurement one shown in Figure 6. They should be seen that resistance is inversely proportional to the current.

C. Contaminated Environmental Condition

The results of insulation resistance under contamination on day 14 are shown on Table 5 and graphically are shown on Figure 9. By using similar method as before, the value of PI, RTG, and CTG under contaminated environmental condition are shown on Table 6.

The equivalent circuit of insulation resistance under contamination of salty humid environmental and its result are shown in Figures 10 and 11. The result under salty humid environmental condition is shown on Figure 11. The result shows good agreement with the measurement one shown by Figure 9. They should be seen that resistance is inversely proportional to the current. Under humidity without salt the insulation had a higher polarization index, compare to the salty humidity environment. It means contamination of salt significantly reduces the insulation quality.

IV. CONCLUSION

The paper discusses about the effect of humidity and contamination in the motor. Under normal condition, the PI was higher than 4 indicating that insulation has good quality meanwhile under humid and contaminated condition the PI was similar to or lower than 3 which indicate that the quality of insulation decrease by the time under such condition. Therefore, a good agreement was found between measurement result and simulation result, even though they should be seen that resistance is inversely proportional to the current.

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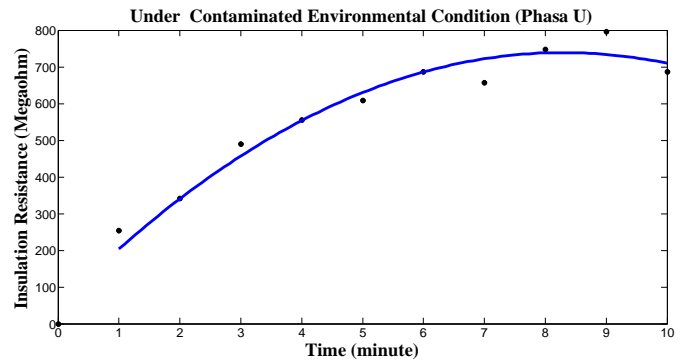

Fig. 9. Insulation resistance with the time curve under contaminated environmental condition

TABLE VI. RESULT POLARIZATION INDEX, RTG, AND CTG UNDER CONTAMINATED ENVIRONMENTAL CONDITION (U PHASE)

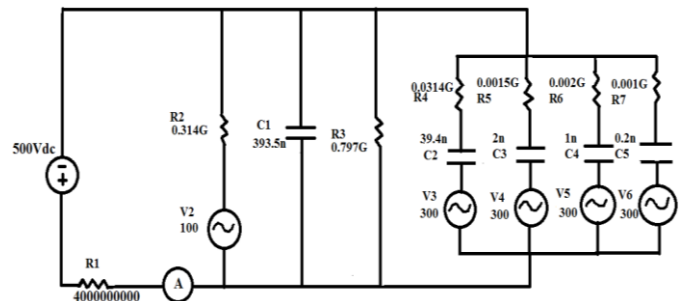| IR min (MΩ)	Polarization Index		RTG	CTG
	Value	Insulation Quality		
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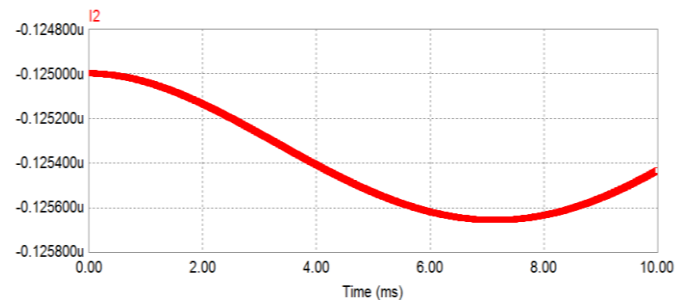Fig. 10. Insulation resistance equivalent circuit under contaminated environmental condition (U phase)

Fig. 11. Simulation results of insulation resistance equivalent circuit under contaminated environmental condition (U phase)