CONDITION MONITORING OF ELECTRIC MOTOR

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CONDITION MONITORING OF ELECTRIC MOTOR

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A thesis submitted in fulfillment of the
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To my caring and beloved husband,
Amir,

To my son,
Afiq

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ABSTRACT

Condition monitoring on electric motor is a preventive maintenance in order to avoid problems and hazard from happening to the machinery, also to prevent personal injury with the major factor is insulation resistance. In this thesis, to further discuss this issue, the developed experiment with the measuring technique of the condition of electric motor on insulation resistance is used. Then, the experiment rig was developed applied to Thrige Odense Denmark 3-phase induction motor for case study to observe the condition monitoring on insulation resistance. The validity of the data was then taken using the megohmmeter and temperature indicator. The experiment is to monitor the Denmark manufactured motor condition of insulation whether is good, fair, poor or bad by following the IEEE standard procedure. This preventive maintenance test can be done on a monthly, semiannual or annual basis as conditions demand. The data from the test is plotted to graph to get the trended data of the insulation. The theoretical and experiment studies include the effect of the humidity and temperature to the insulation. Tests rig for the experimental work are developed using IEEE Standard 43-2000, *IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery* and *A Guide To Diagnostic Insulation Testing Above 1kV by* Megger Ltd, Second Edition 2002. The results have been compared to the standard and analyses are presented in graph. From the developed procedure and methods prove that the temperature affects the insulation winding at 3-phase induction motor (2 speed : 2 winding). For case study, the motor has been soaked for three days to apply flooded condition. The result shows that the motor insulation condition is even better after comparison with the standard manufactured data at 821 MΩ and 893 MΩ change to more than 999 MΩ for both winding condition after drying out experiment.

ABSTRAK

Pengawasan keadaan ke atas motor elektrik merupakan penyenggaraan cegahan bagi mengelakkan masalah yang mengundang bahaya berlaku ke atas jentera serta mengakibatkan kecederaan ke atas manusia yang mana faktor penyumbang utama adalah rintangan penebatan. Dari itu, ujikaji dibangunkan berdasarkan teknik pengukuran keadaan rintangan penebatan motor elektrik. Pelantar ujikaji dijalankan ke atas motor aruhan 3 fasa Thrige Odense Denmark untuk kajian kes mencerap pengawasan keadaan terhadap penebatan rintangan. Data sah diambil menggunakan megohmmeter dan pengesan suhu untuk memantau keadaan penebatan motor buatan Denmark samada berkeadaan baik, memuaskan, lemah atau tidak memuaskan dengan mematuhi tatacara piawai IEEE. Ujian penyenggaraan cegahan boleh dilakukan samada sebulan sekali, enam bulan sekali atau setahun sekali. Data tersebut diplotkan ke dalam graf bagi mendapatkan '*trend*' terhadap penebatan. Pemelajaran dari ujikaji dan teori termasuklah kesan penebatan terhadap suhu dan kelembapan. Pelantar ujian bagi menjalankan kerja-kerja pengujian dibangunkan berdasarkan piawai IEEE 43-2000, *IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery* dan *A Guide To Diagnostic Insulation Testing Above 1kV* oleh Megger Ltd, edisi kedua 2002. Tatacara dan kaedah yang dibangunkan membuktikan bahawa suhu memberi kesan terhadap belitan penebatan pada motor aruhan 3 fasa (2 kelajuan:2 belitan).Untuk mengaplikasi keadaan banjir dalam kajian kes, motor telah direndam selama 3 hari. Hasil keputusan menunjukkan keadaan penebatan motor adalah lebih bagus selepas perbandingan dibuat dengan data piawai pengilang pada 821 MΩ dan 893 MΩ berubah lebih daripada 999 MΩ bagi kedua-dua keadaan belitan selepas ujikaji pengeringan.

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NOMENCLATURE

V	voltage

Greek letters

Ω	resistance, ohm
δ	loss angle
θ	phase angle

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CHAPTER 1

INTRODUCTION

1.0 Background of the Study

The normally quiescent state of electrical transmission and distribution system plant does not draw attention to incipient faults which may develop from the gradual deterioration of equipment. This fault may be detected during routine maintenance, but the ability to have detailed information on the state-of-health of transmission and distribution system equipment prior to carrying out maintenance work or alterations becomes a significant asset and adds an element of preventive maintenance to the operation of such assets.

Condition monitoring is a technique which may be adopted to reduce non-planned downtime and increase plant availability. To be successful it must be self sufficient and did not require manual intervention or detailed analysis. It must be capable of detecting gradual or sudden deterioration and trends and have predictive capabilities to permit alarming insufficient time to allow appropriate action to be taken and avoid major failure. It must be reliable and not reduce the integrity of the system, it must not require undue maintenance itself and must be a cost effective solution.

Condition monitoring may be formally defined as a predictive method making use of the fact that most equipment will have a useful life before maintenance is required. It embraces the life mechanism of individual parts of or the whole equipment, the application and the development of special purpose equipment, the means of acquiring the data and the analysis of that data to predict the trends .Certain key words are useful to recall from this definition: p*redictive, useful life, maintenance, application and development of special purpose of equipment, acquiring the data, analysis of that data, predict the trends [1].*

In more practical terms, the initial stage of a condition monitoring programmed consists of establishing the baseline parameter and then recording the actual baseline or fingerprints values. The next stage is the establishment of routine tours of equipment observing the running condition and assessing the parameter previously determined for the baseline. These readings are then compared with the fingerprint and the trends determined. The state of the present equipment condition can be determined from the absolute figures. The rate of degradation and an assessment of the likely time to failure can be estimated from the trend. The resources committed to monitoring the condition of equipment will depend on the numbers and on the service experienced and reliability.

1.1 Statement of Problem

Most of the electric motor around the world exceeding their designed life. Insulation is the major component, which plays an important role in the life expectancy of the electric motor. To determine the performance and aging of the asset, insulation behavior is a main indicator. In the absence of insulation monitoring and assessment, good number of electric motor failed due to insulations problems, before reaching to their designed technical life. A good number of aged electric motor are still performing well, it is important to monitor the insulation behavior rather than replacing with new one.

Table 1.1 : Specification for Thrige Odense Denmark 3-phase induction motor

Type	NAS 62
Horse Power	10
Rotor V	350 Y
RPM	1440
V	400A
A	14
Frequency	50Hz

Insulation failure can cause electrical shocks, creating a real hazard to personal and machinery. While there are cases where the drop in insulation resistance can be sudden, such as when equipment is flooded, it usually drops gradually, giving plenty of warning if tested periodically. A regular program of testing insulation resistance is strongly recommended to prevent this danger, as well as to allow timely maintenance and repair work to take place before catastrophic failure. Not only motor but new equipment, transformers, switch gears and wiring also should be tested before being put into service. This test record will be useful for future comparisons in regular maintenance testing.

Without a periodic testing program all failures will come as a surprise, unplanned, inconvenient also quite possibly very expensive in time and resources, therefore, money to rectify. For instance, take a small motor that is used to pump material, which will solidify if allowed to stand, around a processing plant. Unexpected failure of this motor will cost tens maybe even hundreds of thousands of ringgit to rectify if downtime of the plant is also calculated. However, if diagnostic insulation testing had been included in the preventive maintenance program it may have been possible to plan maintenance or replacement of the failing motor at a time when the line was inactive thereby minimizing costs. Indeed, it may have been that the motor could have been improved while it was still running.

If advanced insulation degradation goes undetected there is an increase in the possibility of electrical shock or even death for personnel: there is an increase in the possibility of electrically induced fires; the useful life of the electric motor can be reduced and/or the facility can face unscheduled and expensive downtime. Measuring insulation quality on a regular basis is a crucial part of any maintenance program as it helps predict and prevent electric motor breakdown.

For most motors, the expected life of a stator winding depends on the ability of the electrical insulation to prevent winding faults. That is the need for a stator rewind is almost always determined by when the electrical insulation is no longer able to fulfill its purpose, rather than, for example, being determined by a problem with the copper conductors. This follows from the fact that the electrical insulation has a large organic content, a lower melting temperature and a lower mechanical strength that the copper and the core steel.

Therefore, to implement this project the Thrige Odense Denmark 3-phase induction motor (Table 1.1) will be used as experiment rig to measure the insulation resistance. The insulation resistance test measures the resistance of the electrical insulation between the copper conductor and the core of the stator or rotor. Ideally the resistance is infinite. The purpose of the insulation is to block the current flow between the copper and the core. In practice, the insulation resistance is not infinitely high. Usually, the lower the insulation resistance, reveal more problem with the insulation.

Insulation resistance can be measured by nondestructive tests applied between the conductors and the framework of the apparatus. The resistance value can be read directly from a megohmmeter, called a megger or indirectly by calculation using the voltmeter-ammeter method. When properly made and evaluated, such tests assist in diagnosing impending trouble.

Moisture absorbed in the windings or condensed on the surface of insulation results in a decrease in the measured values of insulation resistance. Hence, for insulation measurements to be significant, the tests should be made immediately after shutdown. This avoids errors due to condensation of moisture on the windings. When the machine temperature is lower than the temperature of the surrounding air, moisture condenses on the windings and is gradually absorbed by the insulation. The insulation resistance values of DC machines are generally more sensitive to changes in humidity than are those of AC windings; this due to the greater number of leakage paths in the armature and fields of DC machines [1].

1.2 Objectives

The aims of this project are:

i. To understand the technique and to familiarize the measuring equipment in order to measure the insulation condition of electric motor.

ii. To develop the AC and DC method used for condition monitoring.

iii. To apply the learning technique and measurement method for case study using electric motor.

iv. To validate the condition of the electric motor being monitor using various testing.

1.3 Project Scope

The scopes that are set to achieve the main objectives are listed as follow:

i. To observe condition monitoring on insulation resistance of electric motor.

ii. It will be focused on AC and DC measurement method of insulation resistance test.

iii. To observe the validity of the data taken on electric motor using learning technique and measurement method.

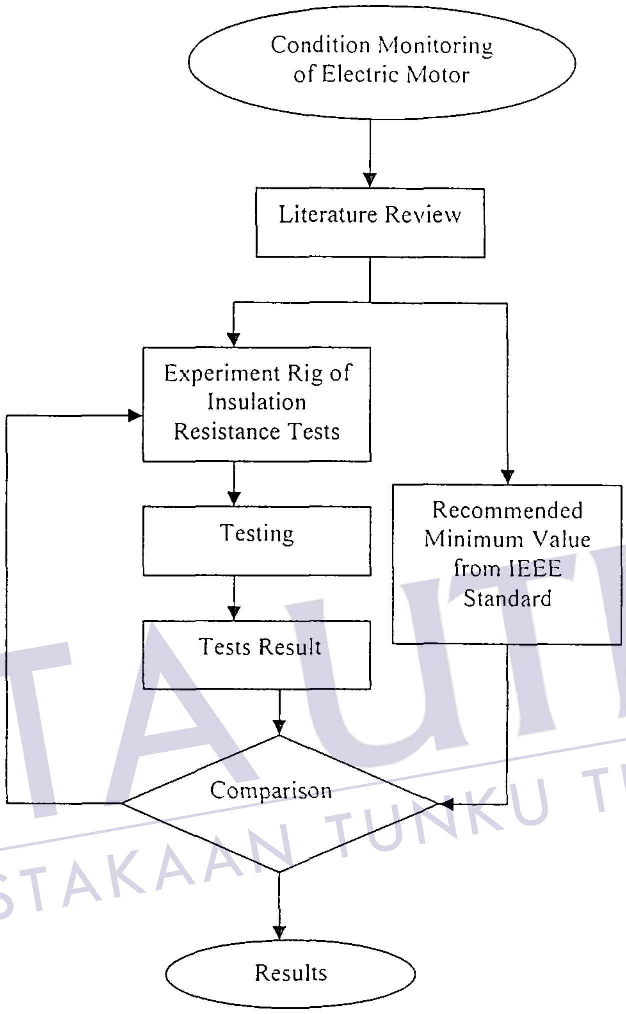

Figure 1.1 : Flow Chart Of The Research Methodology

Figure 1.1 shows a flow chart of the research methodology. For start, finding the project title is the most important thing. After the project title is fixed, objectives and scope of the project are identified. Next, proceed with the literature review. Using the information from the literature review, setup an experiment rig of insulation resistance tests. Then, continued with the testing followed the test procedures have been setup for experiment rig. From the tests result, comparison has been done with the recommended minimum value from IEEE standard. Finally, the test results are plotted in graphs. to get the trend of the insulation condition of the electric motor. Briefly explanation according to the experiments can be referred to Chapter 4 and 5.

1.4 Significance of the Study

The benefits of condition monitoring can be summarized as:

i. To reduce maintenance costs.

ii. The results provide quality control feature.

iii. Limiting the probability of destructive failures. this lead to improvements in operator safety and quality of supply.

iv. Limiting the severity of any damage incurred, elimination of the consequential repair activities and identifying the root causes of failures.

v. Information is provided on the plant operating life, enabling business decisions to be made either on plant refurbishment or replacement.

This study also useful as preventive maintenance from any hazardous to personnel and machinery.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter discusses and reviews previous studies from other researchers on condition monitoring on insulation resistance of electric motor which helps to provide more information and explanation especially on insulation resistance measurement method.

2.1 Condition Monitoring In Rotating Machinery

One of the most important insulation deterioration mechanisms in rotating machines is thermo-mechanical stresses during the machines life due to on-off-operations or load changes. With this load changes the insulation is thermomechanically stressed and ages because of the different thermal expansion coefficients of the materials involved and due to local and temporal gradients. When the load on the machine is rapidly increased, the temperature of copper raised quickly due to I^2R losses, while the temperature of the insulation increases more slowly. Along the length of a long stator bar, a considerable shear stress between the copper and insulation will occur. If the insulation system cannot resist this shear tear, the bond between the copper and insulation may break or the laminated layers in the ground wall may tear or fatigue. In additional, partial discharges will occur in the delaminated areas. The coefficients of thermal expansion in core stacks (steel), copper and insulating material may differ by a factor 10 or more [2].

In order to evaluate the condition of the insulation it is necessary to investigate the characteristic parameters, which are able to describe the ageing of the insulation system. Using these parameters the schedule and focus of required maintenance can be determined and a guess can be made concerning the residual lifetime of the insulation. Insulation resistance testing and related polarization index testing has formed the basis for determining operability and maintenance trending of motors for decades.

The insulation of high voltage rotating machine is able to resist permanent attack of partial discharge for long time. This is because of several small voids even in a new insulation PD values of some nC at operation voltage of rotating machine is normal. Larger insulation defects or premature aging, however, may cause PD with different characteristics. Therefore, the lifetime of an insulation system is strongly affected by the amount and intensity of partial discharges during operation. The partial discharge (PD) measurement and analysis are powerful tools for a reliable detection of locally confined insulation defects that often cannot be found by other dielectric methods [2]. The PD diagnosis can be applied both on-line and off-line. Other non-destructive methods like loss factor, insulation resistance and dielectric spectroscopy in time and frequency domain are typically off-line tests that give integral information on the insulation condition.

The dissipation factor is a valuable quantity, which with itself has integral information about the condition of the insulation. In electrical machines as in other electrical equipments, the dissipation factor measurement is used as a traditional diagnostic method. Once all voids become ionized and are discharging, the dissipation factor (tan δ) value, after attaining a local maximum, will commence decreasing with voltage. In good insulation system of high voltage rotating machines the change of tan δ is very small with increasing applied test voltage. But an increase in number and size of the voids or formation of delamination in the insulation system during its service life due to different stresses can lead to a large increasing of tan δ value with applied voltage.

2.2 Type Of Insulation Tests

Insulation testing is performed during acceptance test, factory routine test, pre-commissioning, preventive/predictive maintenance and after repair (breakdown maintenance). Insulation that has been worked on in any way should be tested before returning to service. A brief description of each type of test is as follows:

i. **Type Test:** Type tests are performed to the first unit manufactured by a vendor to a given specification. It is presumed that every such equipment would also comply with the type test, since its design is unique. Insulation type test are: full wave impulse withstand test, 1.2/50μs wave and switching impulse withstand test, 250/2500 μs wave. Switching impulse test is applicable for system voltages ≥220kV.

ii. **Special Tests:** Special tests correspond to particular service conditions or investigations. Chopped impulse wave withstand test and partial discharge test are insulation special tests.

iii. **Factory Routine Test:** Routine tests are carried out on every equipment without exception before shipment. Insulation routine tests are: measurement of insulation resistance (spot test and time-resistance), power frequency voltage withstand test and induced over-voltage withstand test.

iv. **Pre-commissioning Test:** These tests are conducted at site in accordance with an approved method statement before commissioning. Insulation pre-commissioning tests are: measurement of insulation resistance and polarization index, DC Hi-Potential Test and power frequency voltage withstand test at 80% of the values as Indicated in IEC 60298, Sub-clause 7.1 or at 75% as per ANSI standard. It is recommended that utilities, industrial and commercial clients should review and replace DC Hi-Potential test with VLF Hi-Potential test.

v. **Preventive Maintenance Test:** As an old age saying goes "A stitch in time saves nine", a regular periodic preventive maintenance may correct the situation in time and can eliminate the need of consequent major repair. For example, with good preventive maintenance and proper loading, a power transformer gives a service life of over forty years.

vi. **Predictive Maintenance Test:** It is a development of "Stitch in time" philosophy that uses data from testing and monitoring to adjust the maintenance activity in such a way that it is carried out at appropriate time whenever it is required instead of after a fixed interval of time.

2.3 Insulation Resistance

IEP-SAC Journal on Principles and Applications of Insulation Testing with DC by Engr. Mohammed Hanif (2005) discussed the basic initiators of insulation degradation, causes and effects of insulation failure as well as principles and applications of insulation testing. By applying insulations tests, deteriorated insulation can be identified before failure occurs. There are so many causes of insulation failure such as mechanical damage, pinholes, cracks, dielectric contamination, vibration, moisture and temperature cycling [4]. The principle concerns to be observed when testing with DC is the possibility of damaging otherwise good insulation. It also discussed on assessing the insulation quality with diagnostic insulation DC tests such as spot test, polarization index test, dielectric absorption ratio, step voltage test and DC high potential test. Dependent upon the measurement and response, some conclusions can be made about the condition of insulation .

Based on A New Approach for Electrical Machine Winding Insulation Monitoring by Means of High Frequency Parametric modeling (W.Liu, E. Schaeffer, D. Averty and L. Loron, 2006), investigations a new approach for electrical machine winding insulation diagnosis based on wideband parametric model identification. Experiments are carried out with a stator bar and coil taken from a 5 kV induction machine. A middle voltage pulse generator with extremely fast rise time allows the system excitation with respect to identification and industrial diagnosis constraints. It is shown that the moisture content in the insulation has closely relations with the parameter values of very simple diagnosis models [5]. The ignorance of temperature is the weakness of this method. As we know insulation monitoring are related to the temperature. Resistance drops markedly with an increase in the temperature.

From the IEEE STD.43-2000, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery, this document describes a recommended procedure for measuring insulation resistance of armature and field windings in rotating machines [6]. The document also describes typical insulation resistance characteristics of rotating machine windings and also it recommends minimum acceptable values of insulation resistance for ac and dc rotating machine windings. This paper also recommends uniform methods for measuring insulation resistance with precautions to avoid erroneous results and review the factors that effect or change insulation resistance characteristics.

Greg C. Stone, on his journal 'Recent Important Changes in IEEE Motor and Generator Winding Insulation Diagnostic Testing Standards' reviews the main insulation standards used for stator and rotor winding diagnostic testing and discusses the changes that have been made. Standards discussed include: IEEE 43, 56, 95, 286, 522 and 1434. for example. IEEE 43-2000 now requires a minimum insulation resistance of 100MΩ for new stator windings rated 2300V or more, rather than the 'kV+1' that was required in the past [7]. Furthermore, the interpretation for polarization index has changed such that a motor with a polarization index of 1 is no longer automatically classes as 'bad'.

CHAPTER 3

THEORY

3.0 Introduction

Insulation is one of the items on condition monitoring of electric motor. The first in-depth research on the characteristics of insulation, with particular emphasis on the effects of moisture and voltage on insulation resistance, was conducted by Sydney Evershed in the early 1990s in the England. Since then, insulation-resistance measurement has become an increasingly important part of electrical maintenance program.

3.1 Insulation

Every electric wire in a facility, whether it's in a motor, generator, cable, switch, transformer or whatever is covered with some form of electrical insulation. While the wire itself is a good conductor (usually made of copper or aluminum) of the electric current that powers electrical equipment, the insulation must resist current and keep the current in its path along the conductor.

The purpose of insulation around the conductor is much like that of pipe carrying water. As Figure 3.1(a), in a water pipe, there is some resistance to flow, but it is much less along the wire than it is through the insulation. As in Figure 3.1(b), with electricity, voltage is like the pump pressure causing electricity to flow along the copper wire. Therefore, with more voltage, the more current there will be. But with lower resistance, the more current for same voltage.

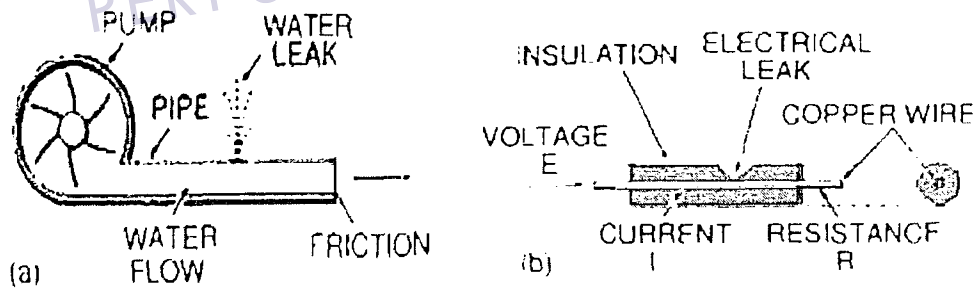

Figure 3.1 : Comparison of water flow (a) with electric current (b).

Understanding Ohm's Law, which is expressed in the following equation, is the key to understanding insulation testing:

$$E = I \times R \tag{3.1}$$

where

E = voltage in volts

I = currents in amperes

R = resistance in ohms

For given resistance, the higher the voltage, the greater the current. Alternatively, the lower the resistance of the wire, the more current will flows for the same voltage.

No insulation has infinite resistance, so some current does flow along or through insulation to ground. Such a current maybe insignificantly small for most practical purposes but it is the basis of insulation testing equipment. Therefore, good insulation means a relatively high resistance to current flow and has the ability to maintain a high resistance [8]. By measuring resistance can tell us how good the insulation but insulation can degrade. There are five basic causes for insulation degradation. They interact with each other and cause a gradual spiral of decline in insulation quality.

i.Electrical Stress

Insulation is designed for a particular application. Over voltages and under voltages will cause abnormal stresses within the insulation, which can lead to crack or delaminating of the insulation.

ii.Mechanical Stress

Mechanical damage such as hitting a cable while digging a trench is fairly obvious. But running a machine out of balance or frequent stops and starts also can cause mechanical stresses which the resulting vibration from machine operation may cause defects within the insulation.

iii.Chemical Attack

Other than affected by corrosive vapors, dirt and oil can also operate to reduce the effectiveness of insulation.

iv.Thermal Stress

When running a piece of machinery in excessively hot or cold conditions will cause insulation over expansion or contraction. This might result in cracks and failures. Thermal stresses are also incurred every time a machine is started or stopped. Unless the machinery is designed for intermittent use, where every stop and start will adversely affect the aging process of the insulation.

v.Environmental Contamination

Environmental contamination covers a multitude of agents ranging from moisture from processes, to humidity on a muggy day, and even to attack by rodents that gnaw their way into the insulation.

Insulation begins to degrade as soon as it is put in service. The insulation in any given application will have been designed to provide good service over many years under normal operating conditions. However, abnormal conditions may have a damaging effect which, if left unchecked, will speed up the rate of degradation and will ultimately cause a failure in the insulation. Insulation is deemed to have failed if it fails to adequately prevent electrical current from flowing in undesirable paths. This includes current flow across the outer or inner surfaces of the insulation (surface leakage current), through the body of the insulation (conduction current) or for a variety of other reasons.

3.2 Insulation Resistance

In general, the insulation resistance varies proportionately with the insulation thickness and inversely with the conductor surface area. The insulation resistance of insulation is defined as the resistance (in megohms) offered by the insulations to an impressed direct voltage. The resulting current is called insulation current and consists of two main components.

i)The current which flows within the volume of the insulation and is composed of :

i. capacitance current
ii. dielectric absorption current
iii. conduction current

ii)The current which flows in the leakage paths over the surface of the insulation and is termed leakage current.

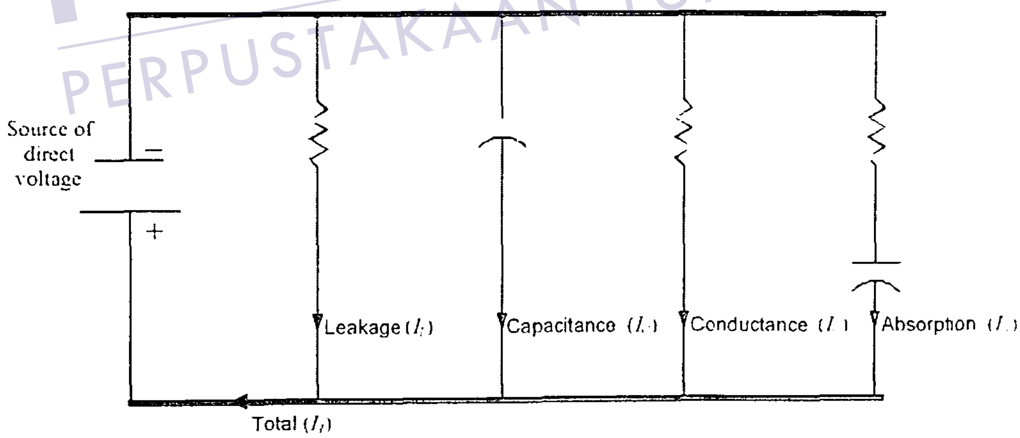

Figure 3.2 : Equivalent circuit showing the four currents monitored during an insulation resistance test.

The capacitance current (I_C) usually does not affect the measurements because it disappears by the first reading is taken at 1 min. The absorption current (I_A) or polarization current decays at a decreasing rate. The current vs. time relationship is a power function, shown in Equation (3.2). It may be plotted on a log-log graph as a straight line.

$$I_A = Kt^{-n} \tag{3.2}$$

where

I_A is absorption current,
K is a function of the particular insulation system and applied test voltage,
t is time of applied direct voltage,
n is a function of the particular insulation system.

The absorption current has two components. The first component is due to the *polarization* of the impregnating materials because the organic molecules, such as epoxy, polyester, and asphalt, tend to change orientation in the presence of a direct electric field. Since these molecules have to strain against the attractive forces of other molecules, it usually takes several minutes after application of the electric field for the molecules to become reoriented, and, thus, for the current-supplied polarizing energy to be reduced to almost zero. A second component of the absorption current is due to the gradual drift of electrons and ions through most organic materials [6]. These electrons and ions drift until they become *trapped* at the mica surfaces commonly found in rotating machine insulation systems. Usually, for clean and dry rotating machine insulation, the insulation resistance between about 30 s and a few minutes is primarily determined by the absorption current.

Since the absorption current is a property of the insulation material and the winding temperature, a specific absorption current is neither good nor bad. In insulation systems manufactured since about 1970 (usually thermosetting polyester or epoxy bonded), the value of the exponent n of the absorption current, $I_A = Kt^{-n}$, is different from the older thermoplastic (asphalt or shellac bonded) materials. This does not imply that more modern insulation materials are *better* because the absorption current is lower and the resulting insulating resistance is higher. For example, polyethylene has essentially no absorption current, yet because of its thermal limitations, it would be completely unsuitable for application in most rotating machines.

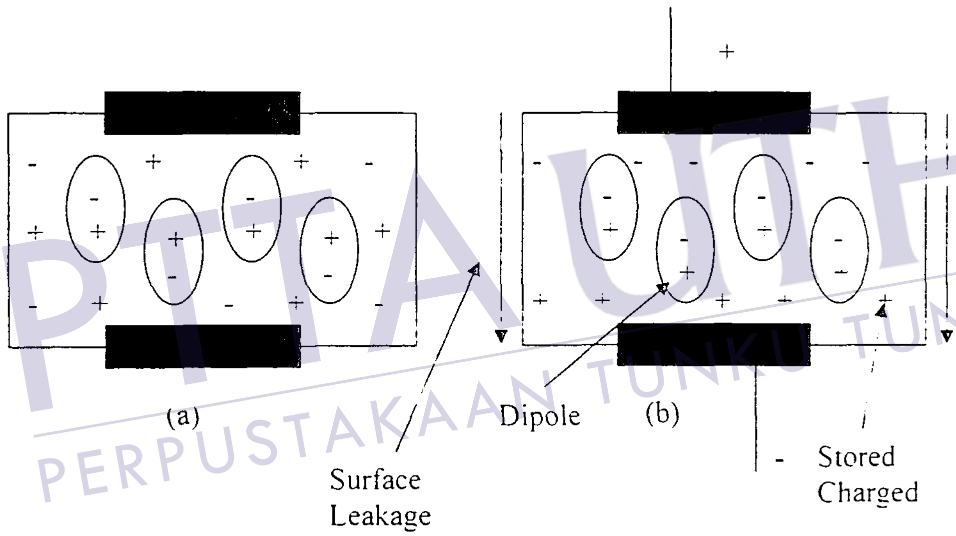

Figure 3.3 : Alignment of Polarized Molecules

The conduction current (I_G) in well-bonded polyester and epoxy-mica insulation systems is essentially zero unless the insulation has become saturated with moisture. Older insulation systems, such as asphaltic-mica or shellac mica-folium may have a natural and higher conduction current due to the conductivity of the tapes that back the mica.

The surface leakage current (I_L) is constant over time. A high surface leakage current, example, low insulation resistance, is usually caused by moisture or some other type of partly conductive contamination present in the machine.

3.3 Insulation Current-Time Characteristic

The insulation current-time curve for relatively good insulation is shown in Figure 3.4a And the component currents that result in this behavior are illustrated separately in Figure 3.4b, 3.4c and 3.4d. For clarity, the direction of the current is shown as actual electron flow (− to +) rather than the conventional (+ to −).

The leakage component, shown in Figure 3.4b, passes through or across the surface of insulation. The magnitude of this leakage current depends on the resistance of the leakage path and the value of the driving voltage: it is an Ohm's law relationship. For good clean-dry insulation, only a very small amount of leakage current occurs.

The capacitive component, shown in Figure 3.4c, is caused by the capacitance between the wiring and the metal frame of the apparatus, and it is typical of the charging current to a capacitor. This component of test current starts high but drops rapidly, reaching almost zero in a very short time (five time constants). Because the duration of this current is very brief, it has very little effect on the indicated values of insulation resistance for motors, generators and transformers.

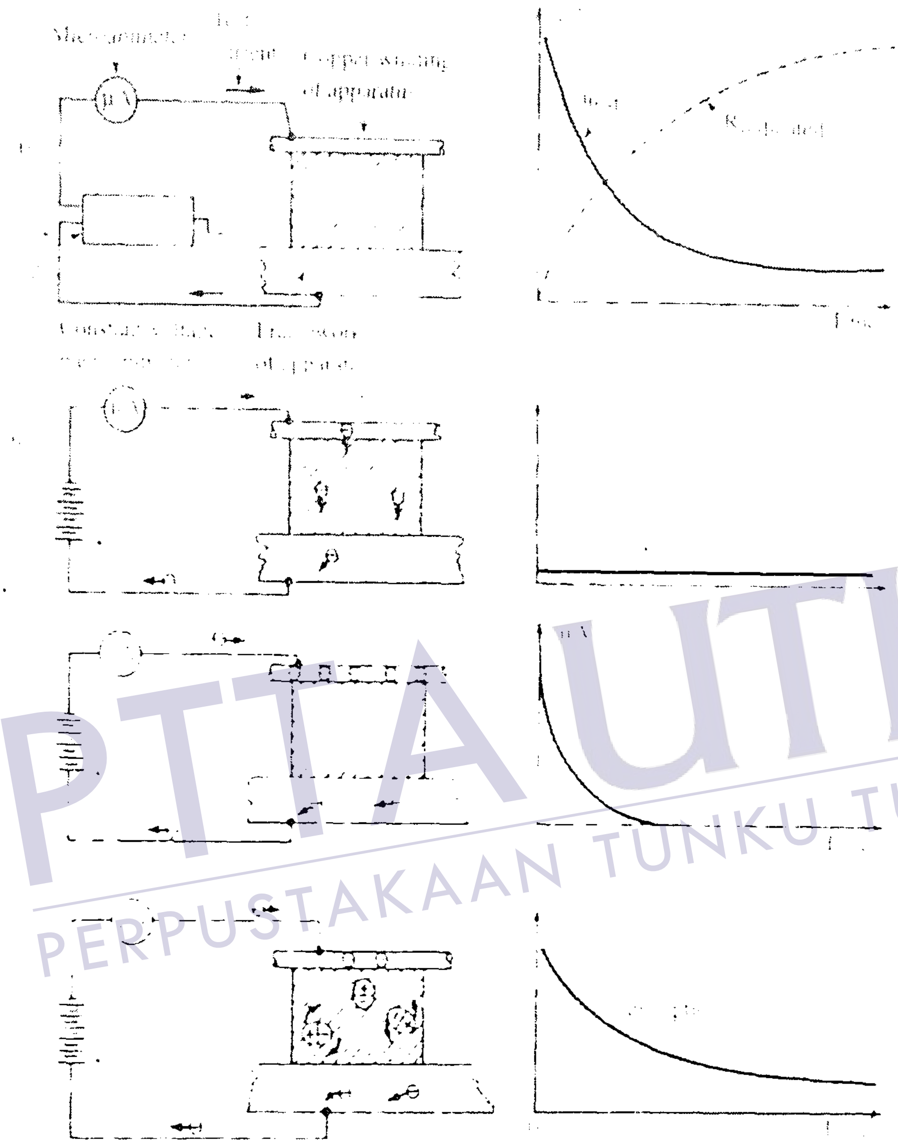

Figure 3.4 : Current-time curves for relatively good insulation.

The absorption component, shown in Figure 3.4d, converts electric energy to stored energy in the form of molecular strain in the insulating material. Although each molecule is electrically neutral (the positive charge is equal the negative charge), its positive and negative charges form an electric dipole. In the presence of an applied voltage, the positive end of the dipole is twisted towards the positive terminal. Thus each electric dipole not already aligned in the direction of the applied voltage experiences a torque that tends to position it parallel to the line of action of the applied voltage. This behavior, called dielectric absorption, is a relatively slow process that may take many hours or days to complete. When the applied voltage is removed, and the wiring grounded, the molecules return slowly to their unstressed equilibrium position [8].

The dielectric-absorption characteristic of electrical insulation makes it both difficult and time consuming to obtain an absolute measurement of insulation resistance. The insulation resistance indicated by the megger, at any instant of time, is the ratio of the megger voltage to the megger test current (Ohm's law):

$$R_{indicated} = \frac{V_{megger}}{i_{megger}} \tag{3.3}$$

Assuming a constant megger voltage, the indicated insulation resistance depends solely on the test current. If the test current high, the indicated resistance will be low, if the test current is low, the indicated resistance will be high. Because the test current in relatively good insulation starts high and gradually decreases with time, as shown in Figure 3.4a, the indicated resistance starts low and increases with the continued applications of test voltage. Higher leakage current through and across the surface of relatively poor insulation permits less accumulation of stored energy within the insulating material; this reduces the dielectric-absorption effect, causing both the current and resistance curves at Figure 3.4a to flatten faster.

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