# White Paper

## Insulation monitoring on common grounding methods in the pulp and paper industry

**Abstract** – This paper provides an overview of the benefits of using a low voltage insulation monitoring system on loads grounded with the three most common grounding methods. Premature motor failures caused by moisture will be discussed. Introduction to the concept of continuous offline monitoring will be discussed as well as its safety benefits. The advantage of using a low voltage monitoring signal will be explored.

**Index Terms** — Insulation Monitoring Device (IMD), ground detector, Residual Current Detector (RCD), offline monitoring, online monitoring, high resistance grounding.

## I. INTRODUCTION

Unplanned outages due to electrical insulation degradation can result in considerable costs in industrial processes as well as create safety hazards. The root causes of insulation degradation can be moisture, dust, thermal ageing, or other forms of mechanical damage such as vibration and rodent damage. This paper discusses basic motor insulation and a few failure modes. The paper also discusses the application of online- and offline-insulation monitoring and ground-fault detection devices while considering the different methods of grounding. Several applications are discussed to show benefits of insulation resistance monitoring and highlight some of the risks associated with not continuously monitoring insulation.

## II. INSULATION MONITORING ON SYSTEMS

### A. Common Insulation Problems with Motor Design and Construction

Today's industrial environments rely heavily on the use of efficient electrical motors and drives. While there is a huge variety of motor types, they all have a few things in common. They operate by producing a rotating magnetic field that forces a rotor into a rotating motion. Usually, the field will be established by insulated copper coils wound around poles within a stator made up of laminated flat metal mounted inside a housing. The coils will be energized by alternating current. Dominant is the three phase induction motor which may or may not be controlled by a variable frequency drive. The induction or squirrel cage motor consists of a relatively simple and robust design. The stator houses the stator pack, which is an assembly of laminated silicon steel rings with slots as shown in Fig 1. The magnetic properties differ for various types but the general-purpose steel M-19 is sometimes used. The slots will house the copper windings (coils) that will be arranged in patterns to achieve the desired speed and torque properties. Various slot quantities in multiples of 3 are possible, 36 and 48 being common for small machines; larger designs use 96, 108, etc. up to 312. The slots are metal and need to be covered with insulation strips, available in different temperature classes to insulate the coils from the stator steel when coils are the enameled type with no groundwall.

The copper wire (magnet wire) is insulated by a thin layer of polymer film material. In electric motors and transformers, insulation material is available with specific NEMA defined temperature ratings as shown in Table 1.

Table 1 NEMA Standards Publication Condensed MG 1-2007 shows temperature ratings of insulation [1]

**Table 46**
**WINDING TEMPERATURES UNDER RUNNING LOAD CONDITIONS [MG 1 Table 12-8]**

| Insulation System Class | Maximum Winding Temperature, Degrees C |
|---|---|
| A | 140 |
| B | 165 |
| F | 190 |
| H | 215 |

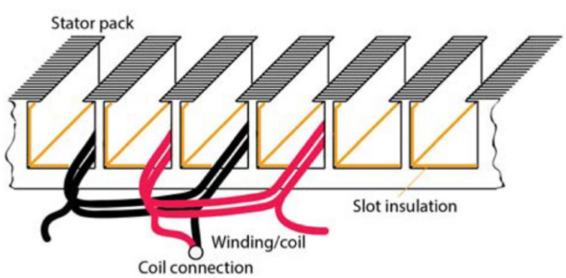


*Fig. 1 Stator coil construction drawing*

The coils are usually placed into the slots by hand. Here, utmost care is needed because the slot opening is very narrow and for mush wound coils it lets only 2-3 wires pass through at a time. The slots ends can be sharp and can easily scratch the wire insulation. The nicked wire is usually buried in the bundle, pressed against insulation which causes the damage to go unnoticed as shown in Fig. 2. Occasionally, two wires with scratched insulation are aligned and short two windings together. If additional shorts occur these become shorted windings that draw additional current creating heat and subsequently more damage between the windings until the entire coil fails.

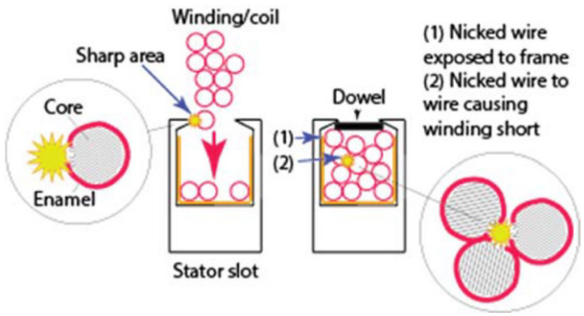


*Fig. 2 Damaged wire insulation in stator slots*

The above mentioned issues with wire insulation can go unnoticed for a long time. The varnishing process after laying the coils will also mask or may partially compensate for the damage caused during manufacturing. Varnish however does not always encapsulate the entire coil and is not an adequate remedy for these motor insulation problems. Measuring or pre- warning for these problems is virtually nonexistent because as long as there is some barrier left to the stator the insulation seems intact. The one factor that will change this insulation value rapidly is moisture ingress.

Water will create a conductive path to the stator via a couple of ways:

1. At the coil connection points where there is only a sleeve or piece of shrink tube covering the connection. See Fig.3.

The coil connections are typically made by braiding the bare copper wire ends together. An insulated sleeve is then pushed over the bare connections to provide insulation. Even after application of varnish these insulating sleeves may be susceptible to moisture. This presents another potential area for water or condensation induced insulation failure.

2. Any damaged point of insulation such as the nicks mentioned above where water can bridge the gap to the stator frame.

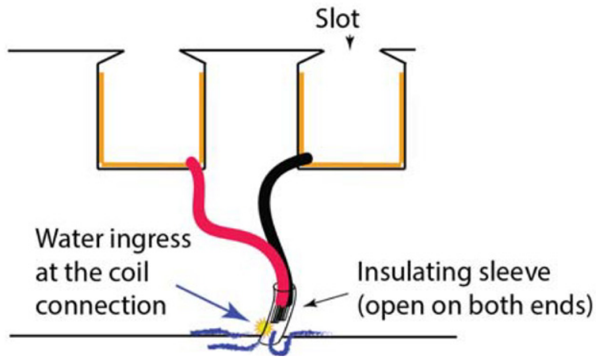


*Fig. 3 Water ingress via insulating sleeve*

As soon as such pathway is established the overall insulation value between the windings and frame will drop significantly, reducing the value from Megaohms to Kilohms. An insulation monitor connected between the motor terminals and the stator as shown in Fig. 4 will be able to accurately measure the breakdown of insulation and alert operations. It is not necessary for the motor to be energized for this to work, which makes it ideal for offline measurement before energizing a motor that may have a fault. These are also known as a lookahead monitor.

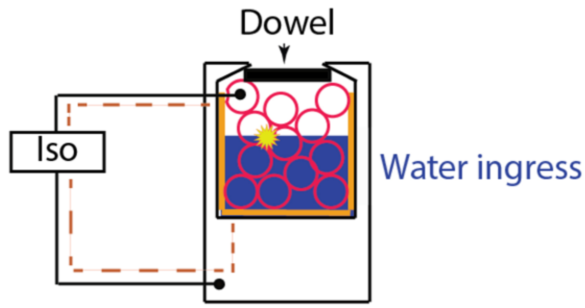


*Fig. 4 Monitoring coil winding insulation in water*

**B. Insulation Monitoring**

1. Grounding System types: Insulation resistance plays a crucial role when it comes to the protection against electrical hazards and unplanned downtime. The insulation of live parts ensures basic protection in electrical systems. Fault protection is achieved by protective equipotential bonding and coordinated electrical protection automatic de-energization in the event of a fault. Design engineers can choose between different system grounding types. Those systems differ in the type of ground connection at the power source. There have been a plethora of papers describing the basic system grounding methods including [2], [3], [4] etc. In the solidly grounded (TN) systems, the neutral point is directly connected to ground and the exposed conductive parts of the electrical installation are connected to ground via protective ground conductors (also referred to as equipment grounding conductors).

In another form of solidly grounded system called TT system, the transformer neutral is connected to earth at one location. In ungrounded systems (IT), all energized parts are isolated from ground. In the case of the resistance grounded system (also defined as an IT system by IEC) one point is connected to ground through an impedance. The impedance is mostly used for measuring and controlling the flow of current. The exposed conductive parts of the electrical system are either grounded individually, collectively or in groups (See IEC 60364- 4-41) [5].

If a low-resistance insulation fault occurs in a solidly grounded (TN or TT) system, high fault currents flow which cause the overcurrent protective device to trip. At the point of fault, high energy release can cause fire risk and an arc-flash hazard, resulting in a risk to personnel and equipment. Due to the high current flowing through the protective conductor, a high touch voltage is generated. In an ungrounded (IT) system, a first insulation fault results in a small fault current. The amount of current is determined by the system charging capacitance. If a second insulation fault occurs, the system must be de- energized immediately, as this is now a phase-to-phase fault with the potential for much higher fault current levels. Note that while some ungrounded and resistance grounded systems are used in an alarm-only operating mode the facility should have adequate procedures in place to use the alarm as a call-to-action. In many cases, operations are set up so that faults are required to be located and cleared within 48 hours.

2. Code Requirements and Beyond: One of the driving reasons for installing ground-fault protection is meeting local electrical code requirements such as the National Electrical Code (NEC). The code is a minimum requirement and the experienced engineer often sees advantages for installing equipment beyond the minimum requirement

For low voltage applications on ungrounded systems NEC Article 250.21 (B) requires installation of ground detectors. It is stated as such [6]: "Ground detectors shall be installed in accordance with 250.21(B)(1) and (B)(2). (1) Ungrounded ac systems as permitted in 250.21(A)(1)through (A)(4) operating at not less than 120 volts and at 1000 volts or less shall have ground detectors installed on the system.

(2) The ground detection sensing equipment shall be connected as close as practicable to where the system receives its supply.

Ground-fault detectors used in North America are often voltage indicating lights. Indication of a ground fault occurs when one of the lights goes dim (faulted phase) and the other two unfaulted phases appear brighter due to the increased voltage (approximately 1.73 times the line-to-ground voltage for a bolted fault). There is always the potential for ignoring a fault or not noticing the fault since the ground detectors are typically mounted near the supply and not the load. Most devices do not include remote indication. Another downside to this method is that it can also look like a fault if one of the bulbs is burned out or otherwise faulty. There have been many advances in this voltage indicating equipment including extremely long life devices, LED bulbs, being used in place of older incandescent bulbs. Even with that improvement and remote output there are still limitations to their capabilities

**C. Protection of Drives**

The use of frequency converters on ungrounded systems is common and one advantage is that high-frequency leakage currents do not flow back to the source via the neutral. Drive technology used on solidly grounded systems often includes isolation transformers and the secondary windings are often ungrounded. As long as the drive output remains ungrounded insulation monitors are useable. If the drive output is grounded alternate methods of leakage detection would need to be used. According to the product standard IEC 61557-8 [7] an insulation monitoring device must be installed which issues an alarm if the insulation level falls below a value that is critical for the installation. A typical critical insulation value is 500 ohms/volt. It must detect symmetrical and non-symmetrical insulation faults. Measuring the voltage unbalance or using ground detectors which react to the voltage unbalance is not a suitable measurement method for modern installations. In many parts of the world these are not considered adequate protection because symmetrical faults are not detected [7]. System charging capacitances tend to balance line-to-ground voltages. The larger the capacitance value, the more severe a ground has to be to cause a detectable voltage shift. Most bridge based detectors can therefore only alarm on solid (very low impedance) single phase ground faults and are known simply as unbalance monitors. These are passive type ground- fault detectors. Depending on the equipment used and the type of power supply, according to IEC 61557-8 [7] the insulation monitoring device can work with different measurement methods. In simple AC systems, where no DC components such as frequency converters and switched-mode power supplies are available, an insulation monitoring device with a DC measurement method can be used. It superimposes the AC system with a DC measuring voltage and measures the current flowing through an insulation fault. The insulation monitoring device can calculate the level of the insulation resistance via the measured current. This kind of insulation monitoring devices can be easily recognized by the AC symbol on the name plate.

Frequency converters and switched-mode power supplies are used in modern installations and systems to control motors in terms of speed, torque or position and to supply controls and sensors. Motors and controls are the heart of today's installations. Other equipment such as switched power factor correction can also distort the waveform from being sinusoidal. Since frequency converters and switched-mode power supplies have a DC link and are often operated with different output frequencies, they are referred to as mixed AC/DC systems. AC/DC systems cannot be monitored with a superimposed DC measuring voltage since insulation faults downstream of rectifiers or on a converter output side can lead to a false measurement result and false tripping or no tripping at all. The measurement methods used here are based on pulsed measuring voltages which are superimposed on the system. Due to the changes in polarity and transient reaction, mixed systems can also be monitored and accurately detect insulation deterioration. Such insulation monitoring devices can be easily recognized by the AC/DC symbol on the name plate. By using analog and digital filters, modern insulation monitoring devices can also reliably monitor such systems. An insulation monitoring device suitable for use in applications with slowly rotating drives or low frequency converter output frequencies should also show the frequency data of the nominal system frequency. (Example: fn = 0.1 … 460 Hz). By selecting the correct insulation monitoring device, an entire non-transformer isolated drive system can be monitored for insulation, starting from the transformer secondary through the rectifier in a frequency converter over the DC link to the converter output side. Various investigations into failure of drive systems concluded that failures in the order of 26 % [9] or even. 36 % [10] are due to insulation faults in stator windings. As mentioned previously, the root causes can be anything from moisture, dust, thermal ageing, and other forms of mechanical damage such as vibration.

Many modern insulation monitoring devices (IMD's) are capable of storing insulation resistance measurements at set time intervals and displaying the insulation resistance over time or communicating this information over a network. A graphical display of the insulation resistance over time as shown in Fig 5, can be very helpful to show a downward trend in system performance. It can be seen that the insulation resistance is very dynamic.  As loads are cycled on an ungrounded system insulation resistance changes. A slowly developing fault can be noticed and monitored and this can help with maintenance planning.

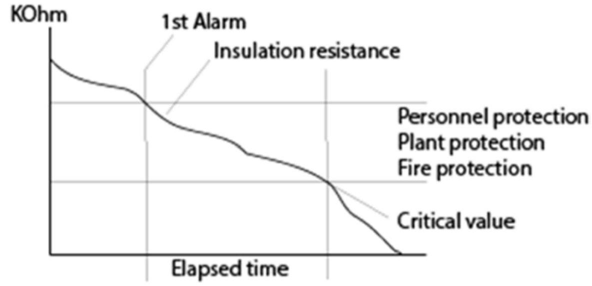


*Fig. 5 Insulation resistance vs time*

On a grounded system the insulation breakdown causes ground-fault current to flow back to the source. Insulation monitoring devices that measure resistance are not typically used during online operation. Users typically measure the current leakage to earth using a zero-sequence current transformer connected to a ground-fault relay or in Europe they also use residual current detectors (RCD's). Typically current sensors are used that are sensitive to low levels of leakage – and provide indication of the mA of leakage current. These can be combined with Insulation monitoring devices to provide protection for systems when they are de-energized while the ground-fault relays or RCD's provide online monitoring. Modern RCD's as discussed in reference [8] can be selected that are capable of both ac and dc fault detection.

**D. Pulp and Paper Applications**

Operations in pulp and paper and similar industries has shown that a common cause of motor and transformer insulation failure is moisture. Common loads such as motors over 250 hp need special attention. For example, vacuum pumps and fans that are taken offline during planned maintenance are subject to moisture buildup. A common step that is often done at the end of many planned outages is an insulation test. These are time consuming and can be replaced by a safer low voltage continuous insulation monitoring system. High voltage testers stress the system and can just deliver an instantaneous value.

For ungrounded systems, it has been mentioned that ground detectors are required by NEC. IMD's provide more than just simple code compliance serving as a ground detector. They also provide the ability to monitor insulation while the system is energized or de-energized. If anti-condensation equipment is not in place or has failed they can provide indication of insulation degradation due to moisture. They are also safer in two ways:

1. The user is much less likely to close into a fault if they know the insulation is degraded before they energize the breaker, or contactor, on startup.
2. Commonly available IMD's often use a low voltage signal that is safe for individuals in contact with the de- energized conductors.

In addition to the monitoring of systems in operation, there is also the possibility to monitor disconnected loads.

There are many critical loads that rarely operate but should work when needed (critical applications). For example, drainage pumps, emergency generators, emergency lighting, fire pumps. If the insulation is degraded for any reason and a fire pump cannot reliably operate it can have disastrous effects. Insurance companies often provide guidelines for recommended routine maintenance on such equipment. Such loads can generally be used in grounded and ungrounded systems. If all poles of the loads are disconnected, they can be continuously monitored, regardless of the system type. The frequently carried out recurrent tests during which a single insulation measurement is performed provide an instantaneous value. But what happens if one day after the recurrent test a rodent damages a cable so severely that the overcurrent protective device trips immediately the next time the load is turned on? With continuous insulation monitoring, critical systems can be monitored and load faults can be immediately reported.

Using the IMD as an interlocking mechanism can further prevent a faulty load from being energized. Insulation resistance measurements can be transferred via communications to a monitoring system and displayed graphically. This will help diagnose areas for future planned maintenance or additional testing.

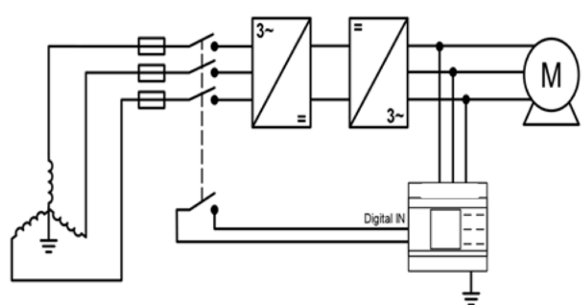


*Fig. 6 IMD connection on a solidly grounded system*

With a modern insulation monitoring device, disconnected loads can be reliably monitored and the insulation resistance can be recorded over time. An integrated web server allows viewing the history and starting scheduled maintenance. Internal decoupling switches can disconnect the device in operating mode.

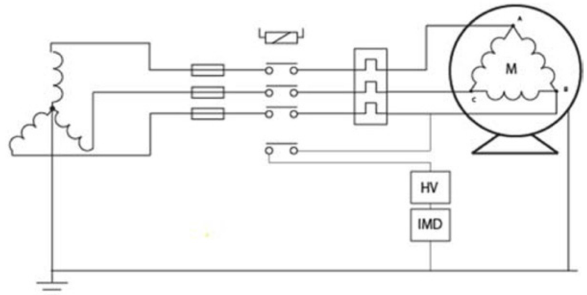


*Fig 7. IMD shown connected via a coupling device*

Modern insulation monitoring devices can be used in combination with coupling devices to monitor disconnected loads up to 7.2 kV. The connection between the coupling and the load is usually interrupted when the load is energized.

## IV. CONCLUSIONS

There are many causes of insulation failure. As discussed, motor design and damage caused during installation can be a cause of premature insulation breakdown, especially in the presence of moisture. Proper selection and application of appropriate protection devices for the load, while taking into consideration the system grounding method, provides enhanced information of the electrical system. Early indication of insulation problems, such as those caused by moisture, and subsequent appropriate action can prevent outages and make the system safer and more reliable.

Continuous monitoring, in conjunction with routine testing, provides the system information needed to allow better predictive maintenance. The use of a low voltage insulation monitoring signal makes the offline monitoring safer.

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## VI. VITAE

**Dale Boyd** has a Bachelor of Science degree in Electrical Engineering Technology degree from Old Dominion University. He spent the first (14) years in the Pulp & Paper Industry as a Project Design Engineer, and spent several years as Chairman of the Global Power Committee for a major consumer products paper company. He has also worked with various electrical manufacturers. His roles have included power consulting, national accounts manager and regional sales director. Dale is a member of IEEE, and active in the pulp & paper IEEE Group. He has developed power system solutions with many end customers, ranging from electrical distribution system upgrades to ground-fault solutions.

Dipl.-Ing. **Jörg Irzinger** has a Diploma degree in Electrical Engineering from the University of Applied Sciences Giessen Friedberg with the focus automation engineering. He has worked in the electrical automation market with a manufacturer for linear synchronous motors and handling systems. His roles have included application engineer and sales engineer. Joerg is currently serving as Product Manager in industrial business development with a main focus on insulation monitoring devices and insulation fault location systems.

**Jeff Glenney,** P.Eng. has a Bachelor of Science degree in Electrical Engineering from the University of Saskatchewan and is a registered Professional Engineer in Saskatchewan. He has worked in the electrical protection relay market with various manufacturers since 1995. His roles have included sales engineer, U.S. sales engineering manager, vertical market manager for fuses and relays and now as a product manager. Jeff is a member of IEEE and co-authored "Type B Ground-Fault Protection on Adjustable Frequency Drives". He has worked with many end customers and design engineers to assist in applying protective relays to meet their system needs.

**Torsten Gruhn** started out as a certified electrical motor rewinder in Germany. He graduated from trade school and worked on everything electrical that can turn, produce or transform power. After his mandatory military service, he obtained a Bachelor of Science degree in electrical engineering from the University GH in Paderborn, Germany with the emphasis on power generation, transmission and distribution. Torsten is a member of IEEE and co-authored "Type B Ground- Fault Protection on Adjustable Frequency Drives". Torsten is currently serving as Head of the EV division at Bender Inc.

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