

Analysis Process Of Insulation Test On Buzios P 80 Module

Muhammad Thoha Al-Haqqi¹

¹Jurusan Teknik Elektro, Prodi Teknik Elektronika manufakur Politeknik Negeri Batam, Batam, Indonesia

*Email: muhammadthoha1922@gmail.com

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Abstract— The Búzios P-80 FPSO (Floating Production Storage and Offloading) construction project requires a rigorous electrical quality testing process to ensure system reliability, one of which is the insulation test. This study aims to analyze the process of conducting insulation tests on the Búzios P-80 module, as well as evaluating the suitability of its implementation against international standards such as IEC 60364. The method used is direct observation of the test implementation, documentation of measurement results, and analysis of the causes of test results that do not meet the standards. The results showed that most of the process had been carried out according to the procedure, but there were some obstacles such as high humidity and less than optimal grounding that affected the insulation resistance value. The conclusion of this study shows the importance of controlling environmental conditions and maintaining test equipment to ensure the accuracy of test results.

Keywords: Insulation test, Búzios P-80, resistansi isolasi, IEC 60364, FPSO

I. INTRODUCTION

Floating Production Storage and Offloading (FPSO) is a key solution in the offshore oil and gas industry for the production, storage and delivery of hydrocarbons from offshore oil fields to onshore facilities. FPSOs are used as floating facilities that can receive crude oil from subsea wells, process it, store it, and then transfer it to tankers or through pipelines to land.

The main advantage of FPSOs is their flexibility in various environmental conditions without the need for fixed infrastructure on the seabed. Because they operate in extreme marine environments and for long periods of time, the electrical systems on FPSOs must be designed with high levels of reliability, efficiency and safety. Failure of the electrical system can lead to production interruptions, fire hazards, and major economic and environmental losses.

Electrical systems on FPSOs are required to meet international standards such as IEC 61892 (for electrical installations on offshore units), IEC 60364 (for low-voltage installations), and IEEE 45 (marine ship electrical system standards). These standards cover power distribution design, system protection, grounding, cable selection, distribution

panels, and insulation system testing to prevent leakage current and short circuit faults.

In data collection, not all levels were measured due to the limited scope of work that had been determined, so data collection was only focused on Level 1 Electrical Equipment Room, Level 2 Electrical Equipment Room, and Level 5 Main Deck. Level 1 and Level 2 Electrical Equipment Rooms are areas where the main and supporting electrical equipment used in the distribution and control of the electrical power system are located. These rooms contain electrical panels, cable installations, and control devices that operate continuously, requiring evaluation of the insulation condition to ensure the reliability and safety of the system. Meanwhile, the Level 5 Main Deck is the main deck that serves as the distribution route for various electrical installations and is more exposed to environmental conditions and operational activities. Therefore, data collection at this level was carried out to assess the environmental impact on insulation resistance values and to ensure that electrical installations remain safe and operational.

II. METHOD

A. Procedure of before Insulation testing

Figure 1. illustrates the pre-insulation testing procedure, starting with literature studies, followed by insulation testing, result recording, verification against standard limits, and defect cause analysis when nonconformities are identified.

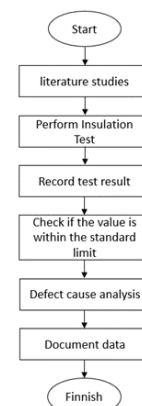


Figure 1. Flowchart of before Insulation testing

➤ Literature Studies

The initial stage involves reviewing relevant literature, standards, and references related to insulation testing. This aims to understand theoretical foundations, testing procedures, and standard values that serve as the benchmark for evaluation.

➤ Perform Insulation Test

The next step is conducting the insulation test on the equipment or system under study. This test measures the insulation resistance to determine the quality and reliability of electrical insulation.

➤ Record Test Result

All test results are documented accurately, including measurement values, environmental conditions, and testing parameters. This ensures traceability and supports subsequent analysis.

➤ Check if the Value is within the Standard Limit

The recorded data are compared with standard limits or reference criteria (IEC or IEEE standards) to determine whether the insulation condition meets acceptable requirements.

➤ Defect Cause Analysis

If any deviation or abnormality is found, a defect cause analysis is carried out to identify potential sources of insulation failure, such as contamination, aging, or mechanical damage.

➤ Document Data

The final step involves compiling all results and analyses into a comprehensive report. The documented data serve as a reference for evaluation, maintenance planning, and further research.

B. Procedure Insulation test

Figure 2. shows the insulation testing procedure, including tool preparation, equipment de-energization, insulation measurement, corrective repair when results are unacceptable, documentation, and residual voltage discharge.

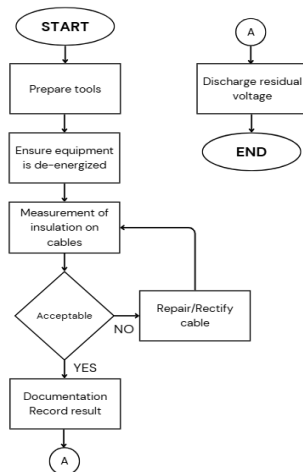


Figure 2. Flowchart Insulation Test Process

- Start, The proces starts when insulation testing work is scheduled and has been approved to be performed.
- Prepare Tools, All the tools needed for the test are prepared. This includes an insulation tester (e.g.

megger), test leads, and PPE (personal protective equipment).

- Ensure Equipment is De-energized, An important step for safety: ensure that the equipment to be tested is completely de-energized (isolated from the power source).
- Measurement of insulation on cables, Select the test voltage according to the standard and type of equipment (e.g. 500V, 1000V, 5000V depending on the rating). Connect the test leads to the appropriate terminals (e.g. inter-phase, phase-to-ground). Measure the insulation resistance and record the results.
- Check Results - “Acceptable?” Check whether the measurement results comply with the minimum standard ($\geq 100 \text{ M}\Omega$ as per IEC 60034). If not compliant (NO), proceed to the correction step. If compliant (YES), proceed to documentation.
- Repair Ferulle On Cable, Check and Take Corrective Action if the Measured Resistance is Still Below the Standard ValueIf the result is not good, perform re-inspection, cleaning, drying, or other actions. Then repeat the testing process.
- Documentation - Record Result, If the results are correct, record the test results in a report for technical documentation and archives.
- Discharge Residual Voltage, After the test, discharge the residual voltage from the equipment to ensure safety.
- END, The test process is complete.

C. Cable Types and Insulation Materials

TABLE 1.
CONSTRUCTION CHARACTERISTICS

No	Construction Characteristics	Type
1	Conductor Material	Copper
2	Conductor Shape	Circular solid (RE)
3	Insulation	XLPE (chemical)
4	Outer Sheath	HFFR (Halogen Free Flame Retardant)
5	With smaller neutral conductor	No
6	Conductor Flexibility	Solid Class 1
7	Core Identification	Blue,Brown,Green/Yellow
8	Sheath Colour	Black
9	Halogen Free	IEC 60754-1

Based on the table above, the cable shown uses a circular solid (RE) copper conductor with a Solid Class 1 classification in accordance with the IEC 60228 standard, making it suitable for fixed installations. The insulation used is XLPE, which is the result of a chemical cross-linking process, and has a thermal

resistance of up to 90°C during normal operation and high dielectric strength.

The outer sheath uses HFFR (Halogen Free Flame Retardant) material that meets the IEC 60754-1 standard, so it does not produce toxic or corrosive gases in the event of a fire. This cable does not use smaller neutral wires, meaning that all cores have the same cross-sectional area. Core identification follows the international standard color code, namely blue, brown, and green/yellow, with a black outer sheath that provides additional protection against environmental exposure.

Overall, this cable is designed for low-voltage power distribution systems that require fire safety, electrical reliability, and permanent installation.

TABLE 2.
DIMENSIONAL CHARACTERISTICS

No	Dimensional Characteristics	Type
1	Number Of Cores	3
2	Conductor cross-section	4 mm ²
3	Neutral conductor section (when smaller)	- mm ²
4	Approximate weight	260 kg/km
5	Nominal outer diameter	12.0 mm

Based on the Dimensional Characteristics table above, the cable has a 3-core configuration with a conductor cross-sectional area of 4 mm² each. There is no neutral conductor with a reduced size, so all cores have a uniform cross-section. This cable weighs approximately 260 kg/km and has a nominal outer diameter of 12.0 mm, indicating compact dimensions suitable for low-voltage power distribution installations in three-phase systems with medium current capacity.

TABLE 3.
ELECTRICAL CHARACTERISTICS

No	Electrical Characteristics	Type
1	Rated Voltage U ₀ /U (Um)	0,6/1 kV
2	Max. DC resistance of the conductor at 20°C	4.61 Ohm/km
3	Perm current rating in air 30°C	42 A
4	Permissible current rating buried/direct 20°C	39 A

Based on the Electrical Characteristics table, the cable has a rated voltage U₀/U (Um) of 0.6/1 kV, making it suitable for low voltage distribution systems. The maximum conductor resistance value at 20°C is 4.61 Ω/km, which reflects the electrical resistance characteristics of copper conductors with that cross-sectional area. The allowable current carrying capacity is 42 A for overhead installations at an ambient temperature of 30°C, and 39 A for direct burial installations at a soil temperature of 20°C. This difference shows the effect of cooling conditions on the current carrying capacity of the cable.

TABLE 4.
USAGE CHARACTERISTICS

No	Usage Characteristics	Type
1	Operating temperature, range	-20 ... 90 °C
2	Short-circuit max. conductor temperature	250 °C
3	Bending factor when laying	8 (xD)
4	Smoke density	IEC 61034-2
5	Gases corrosivity	IEC 60754-2
6	Flame retardant	IEC 60332-3 Cat. C
7	Max. conductor temperature in service	90 °C

Based on the Usage Characteristics table, the cable is designed to operate in an ambient temperature range of -20°C to 90°C, with a maximum conductor temperature during a short circuit reaching 250°C. Under normal operating conditions, the maximum conductor temperature is limited to 90°C, in accordance with the XLPE insulation characteristics.

The bending factor during installation is 8 × the outer diameter of the cable (8D), which indicates the minimum bending radius to maintain mechanical integrity and insulation. From a fire safety perspective, the cable complies with IEC 61034-2 for low smoke density, IEC 60754-2 for low gas corrosivity, and IEC 60332-3 Category C for flame propagation resistance. These specifications confirm that the cable is suitable for installations that require stable electrical performance and a high level of fire safety.

Electrical cables serve as a medium for conducting electrical energy while also protecting against mechanical and environmental disturbances. In offshore installations, cables are required to have high resistance to moisture, salt, temperature, and vibration.

Cable types such as N2XH or XLPE insulated cable are widely used because they have:

- High insulation resistance
- Low smoke & halogen free properties
- Good thermal resistance

Nexans Kukdong TI cables are equipped with insulation that prevents current leakage and maintains electrical system safety. The insulation material is capable of withstanding working voltage and environmental influences. Nexans Kukdong TI cables are fire-resistant and halogen-free, and are equipped with electromagnetic shielding. These cables are typically used in lighting systems, distribution panels, and MCC motor control panels. For low voltage (LV) cables, the general rating is 0.6/1 kV.

D. Configuration Of The Insulation Test

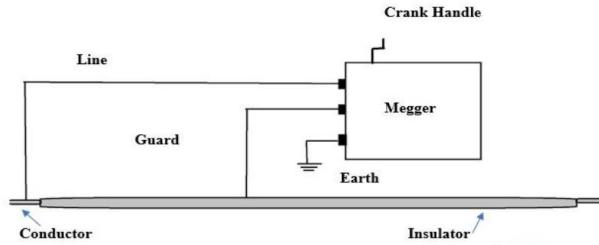


Figure 3. Conguration process insulation test

Based on the image above, in this configuration, the Line (L) terminal is connected to the core conductor of the cable to be tested, while the Earth (E) terminal is connected to the ground or a reference metal part. The Guard terminal (G) is installed on the surface of the insulator to eliminate surface leakage current, so that the measured current mainly comes from leakage through the insulating material (volume leakage current).

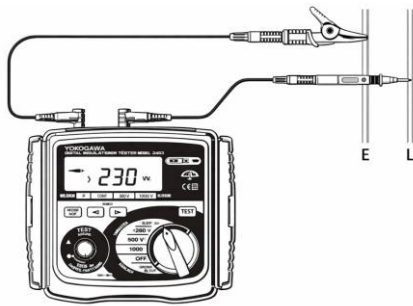


Figure 4. Configuration Settings and Operation of Insulation Tester

Based on the image above, In this procedure, the test device is first ensured to be in the appropriate measurement mode and the system is in a de-energized state. After the test button is pressed, the device generates a specific DC voltage (500 V, or 1000 V according to the system voltage standard). This voltage is applied between conductors L and E, creating an electric field in the conductor insulation layer.

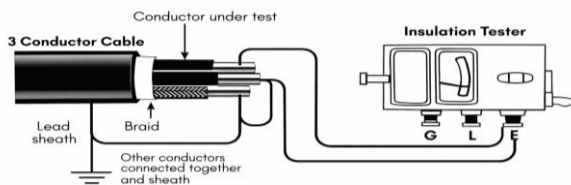


Figure 5. Configuration of Megger Connection Stages to Cables in Insulation Tests

Based on the image above, leakage current flowing through insulating material due to its dielectric resistivity will be detected by the device, then converted into an insulation resistance value displayed on a digital screen in Megaohms (MΩ). A high resistance value indicates good insulation conditions, while a low value indicates possible degradation, moisture, or contamination in the system.

With this configuration, insulation resistance testing serves as an initial diagnostic method to evaluate the operational feasibility and reliability level of electrical installation systems before they are re-energized.

This DC voltage produces a very small leakage current through the insulating material. Based on Ohm's law:

$$I = \frac{V}{R}$$

R = insulation resistance (Ω)

V = DC test voltage (Volts)

I = measured leakage current (Amperes)

Since leakage current is typically in the order of microamperes (μA) or nanoamperes (nA), the resulting resistance values are in the range of Megaohms (MΩ).

Physically, the measured current consists of three main components:

1. Capacitive charging current (dominant at the beginning of the test)
2. Absorption current (polarization current of the insulation material)
3. Steady-state leakage current (actual leakage current through the insulation)

The resistance value displayed on the digital screen is the stable result after the transient current subsides (generally after 30–60 seconds of testing).

The higher the insulation resistance value (100 MΩ for new LV installations), the better the insulation quality. Conversely, a low value indicates:

- Insulation degradation
- Moisture contamination
- Mechanical damage
- Carbon tracking or partial discharge potential

This test is crucial for power systems, distribution panels, electric motors, and offshore cables, as insulation failure can cause ground faults, short circuits, and even flashovers.

This test aims to determine the condition of electrical equipment insulation. A high insulation resistance value indicates that the insulation is still in good condition and safe to operate, while a low value indicates a potential current leak.

In the Búzios P-80 Module, which operates in an offshore environment, this test is very important because humidity and salt exposure can accelerate insulation degradation. Therefore, the Insulation Resistance Test is used as an indicator of the operational feasibility and safety of the electrical system before and during module operation.

If the value meets the standard, the residual charge is discharged to ground, the test results are documented, and the process is declared complete. However, if the value does not meet the standard, an investigation or corrective action is taken, and the status is reevaluated until it meets the specified criteria.

Overall, this diagram illustrates a systematic procedure for testing insulation resistance to ensure the safety and reliability of electrical systems.

Algoritma Process Insulation Test

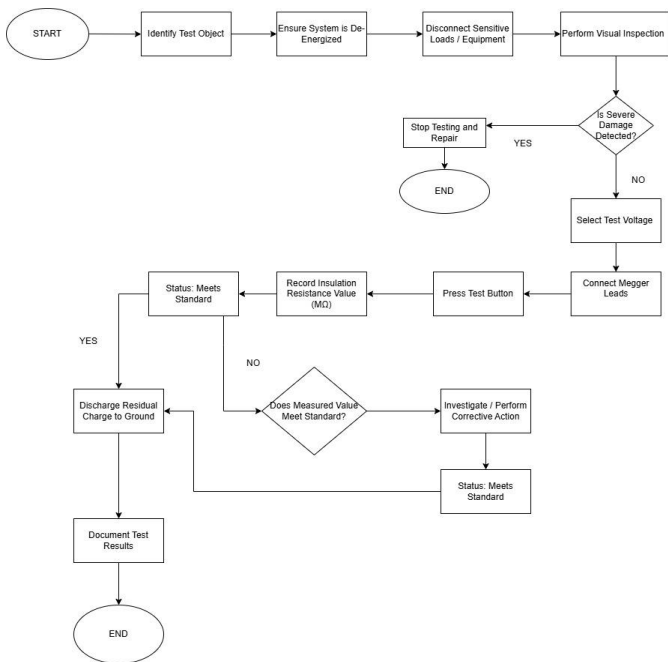


Figure 6. Algorithm of the insulation test process

Based on the image above, the testing process begins with the identification of test objects, such as motors, cables, panels, or lighting systems. Next, it is ensured that the system is de-energized (not live) to ensure work safety. After that, loads or sensitive equipment are disconnected from the circuit to prevent damage during testing.

A visual inspection is carried out to detect physical damage, moisture, or contamination. If serious damage is found, the test is stopped and repairs are carried out first. If not, the process continues with the selection of the test voltage according to system standards.

Next, the megger is connected to the test object, then the test button is pressed to measure the insulation resistance value (MΩ). The measurement results are recorded and compared with the applicable standards ($\geq 100 \text{ M}\Omega$ for certain low-voltage installations).

Blog Diagram Insulation Test

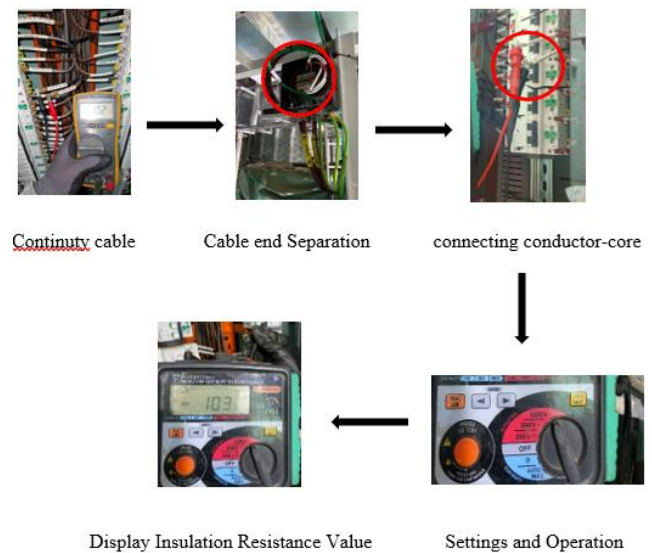


Figure 7. Blog Diagram of the insulation test process

Based on the flowchart in the figure, the Insulation Test process begins with a continuity cable check. This stage aims to ensure that the cable cores are still properly connected and have not broken before the insulation resistance test is performed. The continuity check is an important first step to ensure that the results of subsequent tests are valid.

Once the continuity of the cable has been confirmed to be in good condition, the process continues with cable end separation. At this stage, each cable core is separated from one another and kept away from the sheath or grounding. This separation is done to prevent short circuits between cable cores during testing.

The next stage is connecting the conductor cores. The cable cores to be tested are connected to the Line (L) terminal on the megger, while the other cable cores and the cable sheath are connected to the Earth (E) or ground terminal. This connection is carried out in accordance with standard insulation resistance testing procedures.

Once the connections are properly installed, the device is set up and operated. At this stage, the megger is set to the specified test voltage, then the device is operated by turning the crank (on an analog megger) or pressing the test button (on a digital megger).

The final stage is the reading and display of the insulation resistance value. The insulation resistance value is displayed on the screen or megger scale and recorded as the test result. This value is then used to assess the condition of the cable insulation, whether it is still suitable for use or requires repair and replacement.

E. The standards have been established.

Tabel 1. Prior to conducting insulation testing, the test equipment settings must be adjusted in accordance with the applicable standards and the nominal voltage rating of the equipment under test. The testing standards applied are presented in Table 1. Equipment rated at 250 V is tested using a DC test voltage of 500 V with a minimum insulation resistance requirement of 100 MΩ. Meanwhile, equipment rated at 600 V is tested using a DC test voltage of 1000 V, maintaining the same minimum insulation resistance criterion of 100 MΩ.

TABEL 1.
TESTING STANDAR

Voltage Nominal Rating of Equipment in Volts	Dc test voltage	IR minimum (MΩ)
250 V	500 V	100
600 V	1000 V	100

Based on insulation resistance testing standards, the minimum acceptable resistance value for cables with operating voltages below 1 kV is 100 MΩ, while for higher voltages, the minimum value increases proportionally. Measurement results with values above this limit are categorized as “OK”, indicating good insulation conditions, while values below the standard are classified as “Reject”, indicating a possible deterioration in insulation quality due to moisture, contamination, or physical damage. This standard is used as a reference in assessing the reliability of insulation systems and ensuring the safety and reliability of electrical systems in FPSO installations.

A. Figure Fishbone Method

Figure 3. illustrates the Fishbone method applied to analyze the root causes of defects or low insulation resistance, focusing on factors related to measurement, machine, human, material, environment, and method.

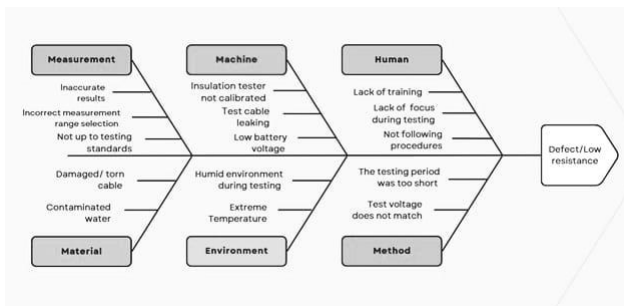


Figure 4. Fishbone Method

- **Human**
 - Lack of training:** The operator does not fully understand the insulation testing procedure.
 - Lack of focus during testing:** Reduced attention can affect data validity, especially when procedures are not carefully followed according to operational standards.
 - Failure to follow procedures:** Errors in setting test voltage or test duration may lead to inaccurate results.
- **Machine**
 - Uncalibrated test equipment:** Lack of proper calibration may produce inaccurate insulation resistance values.
 - Worn or damaged test cables:** Can cause current leakage or poor electrical contact, leading to unreliable readings.
 - Low battery voltage:** If the tester’s power is insufficient, it may cause unstable or fluctuating measurement results.
- **Method (Procedure)**
 - Insufficient testing duration:** Testing for too short a period may result in unstable readings, especially when assessing insulation resistance over time.
 - Test voltage not compliant with standards:** For instance, applying only 250V when 500V is required can produce invalid or misleading results.
- **Material**
 - Damaged or torn cable insulation:** Compromised insulation can lower resistance readings and create potential safety hazards.
 - Moisture or water contamination:** Presence of water significantly reduces insulation resistance values.
- **Environment**
 - High humidity or wet conditions:** Moist environments can decrease insulation resistance.
 - Extreme temperature conditions:** Very high or low temperatures can affect measurement accuracy.
- **Measurement**
 - Faulty or uncalibrated megger:** Inaccurate or unstable readings may occur due to poor calibration or damaged instruments.
 - Incorrect measurement range selection:** Choosing the wrong range may cause incorrect readings or prevent detection of actual resistance values.
 - Non-compliance with testing standards:** Tests performed outside standard procedures may yield unreliable or non-valid results.

B. Metode FMEA

Based on observations in the FPSO module, there were failures in insulation testing. There fore, a plan is needed so that insulation testing can be carried out optimally. FMEA (Failure Mode and Effect Analysis), is a systematic method for analyzing potential failures in a process or system. In the context of Insulation Resistance test, a test used to ensure there is no leakage of electric current. The aim is to determine the feasibility of

equipment and improve system reliability before, after installation, maintenance and repair.

1. Table 2. To evaluate the severity of the impact of each failure mode, the Severity (S) parameter is used in the Failure Mode and Effects Analysis (FMEA) method. Severity assessment is carried out to determine the seriousness of the consequences of failure on system performance, operational processes, and service outcomes.

TABLE 2.
FMEA SEVERITY INDIKATOR

Value	Description Severity Level	Detailed Explanation Impact
1	No Impact	No Impact on production or service systems or service products or outcomes.
2	Very Small	Very little impact on system performance.
3	Small	Minor impact on system product performance or service outcome
4	Low	Service yield decreased but did not require repair.
5	Medium	Service results are declining but can still be improved.
6	Signifikan	Product yield decreases because certain functions may not be operational or - Service yield performance decreases because convenience functions are not fulfilled.
7	Mayor	Slightly disrupt the smooth running of the Insulation Tester process or the results are not perfect but can still be functioned or the service results are not satisfactory but still acceptable to the client.
8	Ekstrem	Disrupting the smoothness of the insulation test process The tool cannot be operated (100%).
9	Seriously, Failure occurs with misreading	Not up to the specified standard.
10	Danger, Failure occurs when cable damage	Standard values not achieved - Doing work that slows down progress.

2. Table 3. Occurrence (O) is a parameter in the Failure Mode and Effects Analysis (FMEA) method used to assess the level of possibility or frequency of a failure mode occurring during the operational process. The occurrence value is determined based on standardized O parameter criteria.

TABLE 3.
FMEA OCCURANCES INDIKATOR

Value	Description Severity Level	Possible Failure Rate
1	Failure is almost impossible	1 of 1,500,000
2	Very Low	1 of 150,000
3	Low	1 of 15,000
4	Relatively Low	1 of 2000
5	Medium	1 of 400
6	Medium to high tendency	1 of 80
7	Relatively High	1 of 20

8	High: repeated failures	1 of 8
9	Very high; failure is related to a previously failed process	1 of 3
10	Very high and extreme; failure almost inevitable	1 of 2

3. Table 4. Detection (D) is a parameter in the Failure Mode and Effects Analysis (FMEA) method used to assess the system's ability to detect or control failure modes before their effects occur. Detection assessment is based on the effectiveness of available controls, including testing methods and monitoring systems.

TABLE 4.
FMEA DETECTION INDIKATOR

Value	Description Severity Level	Criteria Based on Current Control Design
1	Almost Certainly	There is a permanent isolation sensor with automatic alarm
2	Very High	There is routine testing and real-time monitoring using sensors
3	High	There are regular tests with calibrated measurement methods and standardized records
4	Somewhat High	There is regular testing with analysis of insulation degradation trends
5	Medium	There is insulation testing with standard tools
6	Low	There is periodic but not thorough insulation testing
7	Very Low	There is insulation testing but it is not documented/not calibrated
8	Small	There is insulation testing only when a fault occurs
9	Very Small	There was testing during commissioning, without procedures
10	Almost Impossible	No insulation testing performed

4. RPN (Risk Priority Number).

The Risk Priority Number (RPN), calculated as the product of Severity (S), Occurrence (O), and Detection (D) ratings (1–10), ranges from 1 to 1000. In FMEA/FMECA, RPN serves as a key indicator for identifying, evaluating, and prioritizing potential failure modes. Higher RPN values signify higher risk levels, guiding engineers to focus on critical areas and implement effective preventive or corrective actions aligned with the philosophy of “prevention before failure.”

III. RESULT AND DISCUSSION

A. Data Analysis

Overmelt Root Cause Analysis

Several possible causes of Reject Overmelt have been outlined based on an understanding of the production process and historical data. Preventive measures have also been implemented to reduce the Reject potential. However, to ascertain which factors are frequent or the main cause of reject overmelt. So, a root cause analysis was conducted. This process is accompanied by regular inspection of the machine to narrow the focus of the analysis to the most influential factors.

Table 5. The verification results of the factors that are suspected to be the main root causes of Overmelt rejects. The

symbol (✓) indicates that the factor has been confirmed as the main cause, while (X) indicates that the factor does not have a significant impact on the occurrence of Overmelt rejects.

TABLE 5.
ROOT CAUSE

Category	Potential	Confirmed Root Cause (✓/×)	Corrective Actions
Machine	Insulation tester not calibrated	✓	Calibrate tester regularly according to IEEE 43-2000 standards
	Damaged test leads or probes	✓	Replace and inspect test cables periodically
	Internal megger battery voltage low	×	Ensure sufficient battery before testing
Human	Lack of Operator Training	✓	Conduct formal training on insulation testing procedure and safety
	Misreading instrument readings	✓	Conduct operator retraining and assessment
	Inconsistent application of SOP	✓	Enforce checklist-based procedures during insulation testing
Method	Incorrect duration for IR/PI measurement	✓	Ensure timing procedure (1-min and 10-min) is followed strictly
	Not correcting IR value for temperature	✓	Apply standard correction to 40°C reference value
	Incorrect connection during test (wrong terminals)	✓	Recheck all terminal connections before energizing tester
Material	Damp or contaminated winding insulation	✓	Perform drying procedure (blow dryer or oven drying per IEEE recommendations)
	Poor insulation quality of winding	✓	Use certified-quality insulating materials, verify with supplier
	Dust, oil, or moisture on surface	✓	Clean surface before testing using lint-free cloth and alcohol-based cleaner
Environment	High ambient humidity during testing	✓	Maintain dry test room conditions (RH < 60%) using dehumidifier
	Temperature variation during testing	✓	Perform test in controlled-temperature environment
	Dirty or unclean test terminal	✓	Clean and ground testing station properly before initiating test

Measurement	Test duration was inconsistent (IR t=1 and t=1 minutes)	✓	Ensure proper duration SOPs and Consistent recording
	Neglecting temperature corrections in IR results	✓	Apply temperature correction to the reference value (40 °C) using a standard graph or table.
	Test voltage does not match equipment rating	✓	Use voltage according to the winding rating (e.g., 500-1000 V for LV, up to 5 kV for HV)

A. FMEA Analysis Result

The FMEA analysis results show that insulation test failures in the FPSO module were mainly caused by human error, continuous equipment operation, and inadequate cooling systems. The dominant failure factors were related to machine and environmental conditions. Applying FMEA helped identify critical issues and establish corrective actions, improving insulation test reliability, system performance, and operational safety.

a. Result Severity

Table 6 The results of the severity analysis divide the risk severity level into four main categories, namely Low (1–3), Moderate (4–5), Significant (6–7), and Critical (8–10). The Low category indicates minimal impact on the system and does not require immediate action, while Moderate describes a decline in performance that can still be handled.

TABLE 6.
RESULT SEVERITY

Severity Value Range	Impact Category	General Description	Recommended Actions
1-3	Low (Minor Impact)	Very minor or almost no impact on the system or service results. The system continues to function normally.	No immediate action is required; periodic monitoring is sufficient.
4-5	Moderate Impact	There is a decline in service output or system performance, but it can still be repaired without stopping operations.	Perform root cause analysis and scheduled repairs
6-7	Significant (Major Impact)	Some functions do not work optimally or the service results do not meet customer satisfaction standards.	Immediate corrective action is needed to prevent further damage.
8-10	Critical (Severe/Danger Impact)	The system fails to operate, a reading error occurs, or a physical hazard risk arises.	Stop operations and perform emergency repairs; conduct a thorough root cause analysis.

b. Result Occurrence

Table 7. The occurrence analysis shows that failure probability increases with reduced system reliability. Low occurrence

values indicate stable performance, while high values require immediate corrective and preventive actions to maintain system reliability.

adequate but not optimal. without consistent documentation or calibration.

TABLE 7.
RESULT OCCURANCE

Occurance Value Range	Impact Category	General Description	Probability of Failure (Estimated)	Recommended Actions
1-2	Very Low	Failure is almost impossible. The system or process has a very high level of reliability.	1 in 150,000 to 1 in 1,500,000 occurrences	No special measures are required; standard preventive maintenance is sufficient.
3-4	Low	Failures are rare, and the possibility of process disruption is low.	1 in 2,000 to 1 in 15,000 occurrences	Monitor system performance and document rare anomalies.
5-6	Medium	Failures may occur periodically; attention should be paid to recurring causes.	1 in 80 to 1 in 400 cases	Perform routine inspections and calibrations to reduce the possibility of failure.
7-8	High	Failures began to occur frequently, and some processes showed instability.	1 in 8 to 1 in 20 occurrences	Conduct a thorough evaluation of the system and immediately implement preventive improvements.
9-10	Very High	Failures often occur or are almost inevitable; they are related to previous process errors.	1 out of 2 to 1 out of 3 occurrences	Take major corrective action, review procedures, and retrain operators.

7-8	High	Reactive detection	Testing occurs only when a disruption occurs.	High risk
9-10	Very High	Almost undetectable	Testing only during commissioning or not at all.	Very High risk

Table 9. shows that the highest value of 144 is in the high severity category, indicating the most significant level of risk. The other RPN values are in the range of 72–92, indicating a moderate level of risk that still requires further control and evaluation.

TABLE 9.
RPN RESULT

Value	Description Severity Level	S	O	D	RPN
1	Almost Certainly	8	4	3	92
2	Very High	6	4	3	72
3	High	9	4	4	144
4	Somewhat High	7	4	3	84
5	Medium	7	3	4	84

Table 10. This test is crucial for verifying the integrity of the electrical system and identifying potential insulation failures that could affect operational reliability. Insulation resistance values are recorded in MegaOhms, while conductor resistance is recorded in Ohms.

TABLE 10.
INSULATION TEST RESULT DC Test Voltage 1000V

No	Date	Cable ID	Equipment Tag From	Level	Equipment Tag To	Level	Continuity	Insulation Resistance Test	Description
1	03/02/25	217-CN-O-01	PL-5143017	2	CX-N-L-M17-001	1	0,2 Ω	412 MΩ	Cable OK
2	05/02/25	367-CE-M-01	PL-5148017	1	CX-E-L-M17-080	5	5,0 Ω	11 MΩ	Cable Reject
3	06/02/25	485-CE-M-	PC-C-5263	1	CX-E-L-M1	1	0,2 Ω	428 MΩ	Cable OK

Result Detection

Table 8. The detection analysis indicates that higher detection capability reduces the risk of failure. Systems with reliable and automatic detection have very low risk, while limited or reactive detection increases the possibility of undetected failures, requiring improvement in monitoring and calibration.

TABLE 8.
RESULT DETECTION

Detection Value Range	Impact Category	General Description	Control Category	Risk Of Failure
1-2	Very Low	An automatic and highly reliable detection system.	Permanent sensors and automatic alarms with real-time monitoring.	Very Low Risk
3-4	Low	Regular and calibrated detection.	Periodic testing and analysis of insulation trends.	Controlled risk
5-6	Medium	Detection is	Periodic testing	Moderate risk

No	Date	Cable ID	Equipment Tag From	Level	Equipment Tag To	Level	Continuity	Insulation Resistance Test	Description
		01-01	117-A		7-250				
4	07/03/25	217-CN-O-20-01	PL-5143-017	2	CX-N-L-M1-7-116	5	8,0 Ω	66 MΩ	Cable Reject
5	11/03/25	217-CN-O-02-01	PL-5143-017	2	CX-N-L-M1-7-009	1	0,4 Ω	269 MΩ	Cable OK
6	13/03/25	217-CN0-03-07	PL-5143-017	1	CX-N-L-M1-7-020	2	0,2Ω	455 MΩ	Cable OK
7	14/03/25	217-CN-O-04-03	PL-5143-017	1	CX-N-L-M1-7-022	2	0,5 Ω	305 MΩ	Cable OK
8	15/03/25	217-CN0-05-011	PL-5143-017	2	CX-N-L-M1-7-030	2	5,0 Ω	23 MΩ	Cable Reject
9	15/03/25	217-CN-O-07-07	PL-5143-017	2	CX-N-L-M1-7-053	2	1,1 Ω	80 MΩ	Cable Reject

Based on the table above, the cable testing table consists of several main columns, namely No, which indicates the serial number of the cable test data; Date, which indicates the date of the test to determine the sequence of time and period of cable condition evaluation; and Cable ID, which is a unique identification code for the cable used to track test history and facilitate cable identification in the field. The Equipment Tag From – Level column shows the equipment or panel where the cable originates, along with the level or floor where the cable installation begins, while the Equipment Tag To – Level column shows the equipment or panel where the cable terminates, along with the level or floor where the cable installation ends, so that the cable route and connectivity in the installation system can be clearly understood. The Continuity (Ω) parameter shows the measurement results of the cable conductor resistance, where a low value ($\leq 0.5 \Omega$) indicates that the conductor is still in good condition with no connection problems, while a high value ($> 1 \Omega$) indicates an increase in resistance which can be caused by cable degradation, loose connections, or internal damage. Meanwhile, the Insulation

Resistance Test (MΩ) shows the cable's insulation ability to withstand electrical leakage, with a high value ($\geq 100 \text{ M}\Omega$) indicating that the insulation is still good and safe to use, and a low value ($< 100 \text{ M}\Omega$) indicating a decline in insulation quality that could potentially cause leakage currents or system interference. The Description column is the final conclusion of the test results based on the continuity value. The Description column is the final conclusion of the test results based on continuity and insulation resistance values, where Cable OK indicates that the cable meets technical standards and is suitable for use, while Cable Reject indicates that the cable does not meet standards and replacement is recommended.

From all of the tests, 5 cables were declared to be in good condition (Cable OK) and 4 cables were declared unfit for use (Cable Reject).

Cables declared Cable OK generally have low continuity values, ranging from 0.2 to 0.5 Ω, and high insulation resistance values, above 250 MΩ. This condition indicates that the cable conductor is still in good condition and the insulation is still able to withstand current leakage optimally. Conversely, cables declared Cable Reject show high continuity values, ranging from 1.1–8.0 Ω, and low insulation resistance, even reaching 11 MΩ and 23 MΩ in some tests. These values indicate an increase in conductor resistance and a decrease in cable insulation quality, which could potentially cause operational disruptions and safety risks.

Rejection of cables tested at 1000 volts due to cable damage, ferrule damage, and moisture.

Cables that have suffered physical damage should be replaced with new cables, especially if the damage is not too severe and can be covered or hesring .

For damaged ferrules, the solution is to replace them with new ferrules of the appropriate size and crimp them using standard tools to restore the connection.

If the cable is exposed to moisture, the cable and termination area need to be dried, cleaned, and given additional protection such as heat shrink or insulation. In addition, ensure that the panel and cable route are protected from water ingress.

TABLE 11.
INSULATION TEST RESULT DC Test Voltage 500V

No	Date	Cable ID	Equipment Tag From	Level	Equipment Tag To	Level	Continuity	Insulation Resistance Test	Description
1	04/02/25	48-4-CE-S-03-01	PCC-5263-017B	3	CXE-L-M17-188	2	0,6 Ω	430 MΩ	Cable OK
2	08/03/25	48-4-CE-S-11	PCC-5263-017B	3	CXE-L-M17-236	5	0,8 Ω	226 MΩ	Cable OK

No	Date	Cable ID	Equipment Tag From	Level	Equipment Tag To	Level	Continuity	Insulation Resistance Test	Description
		-01							
3	09/03/25	483-CE-S-05-01	PCC-5263-017A	1	CXE-L-M17-121	3	0,8 Ω	320 MΩ	Cable OK
4	10/03/25	217-CE-S-12-01	PL-5143-017	2	CXN-L-M17-085	4	0,8 Ω	360 MΩ	Cable OK
5	12/03/25	217-CE-S-03-05	PL-5143-017	1	CXN-L-M17-019	2	0,7 Ω	326 MΩ	Cable OK
6	14/03/25	217-CE-S-06-023	PL-5143-017	2	CXN-L-M17-047	2	0,6 Ω	340 MΩ	Cable OK

Based on the table above, the continuity values obtained are in the range of 0.6–0.8 Ω, which indicates that the cable conductor resistance is still within acceptable limits and there are no indications of problematic connections or significant degradation of the conductor. Meanwhile, the insulation resistance test results show relatively high values, ranging from 226–430 MΩ, which indicates that the cable insulation is still in good condition and is able to withstand electrical leakage optimally.

Insulation resistance testing is one of the steps in electrical system maintenance. The main purpose of this test is to evaluate the insulation capacity of cables in withstanding leakage currents that can arise due to surface contamination or environmental influences such as temperature and humidity. By conducting tests, insulation conditions can be monitored so that potential electrical disturbances or equipment damage can be prevented early on.

The measurement data is displayed in the Insulation Test Results Table, showing the insulation resistance values from several test points in the field. Based on the test results, the insulation resistance values range from 11 MΩ to 455 MΩ, depending on the cable length and test location. These values provide an overview of the actual insulation condition.

Referring to the insulation resistance testing standard table, the minimum acceptance limit for cables with an operating voltage below 1 kV is set at 100 MΩ. Measurement results with values above 100 MΩ are categorized as “OK”, indicating that the insulation is still functioning properly and safely. Conversely, results with values below 100 MΩ are classified as “Reject,” as they indicate a potential decline in insulation quality that requires inspection or corrective action.

A comparison of the measurement data and the standard shows that most test points are in good condition, with insulation resistance values meeting the required limits. This indicates. Based on the results of insulation resistance testing that has been carried out, data shows that several measurement points indicate resistance values below the minimum standard of 100 MΩ. Further analysis of field conditions and physical inspection results shows that there are three main factors contributing to the decrease in insulation resistance values, namely ferrule damage, cable damage, and humidity.

Factors Affecting The Results Of Insulation Test

Figure 5. This malfunctioning ferrule was found at the cable termination connected to the terminal. In this condition, it directly contributed to an unstable connection and resulted in low resistance.



Figure 8. Ferrule Damage

The first factor is ferrule damage, which was found at the cable terminal connections. This damage was caused by improper installation and tool damage. These conditions resulted in imperfect electrical contact, increased connection resistance, and increased potential for leakage current, thereby reducing the effectiveness of the system insulation.

Figure 6. Identifies significant mechanical damage in the form of tears. These tears have penetrated the protective layer, exposing the conductor core insulation and even the copper conductor inside.



Figure 9. Cable Damage

The second factor is cable damage, which occurs due to physical damage to the cable insulation layer. This condition is generally caused by excessive pressure, repeated bending, or scratches from sharp objects. The effects of this condition include cracks, tears, or damage to the cable surface, which significantly reduces the insulation resistance value and increases the occurrence of leakage current.

Figure 7. Identifying moisture inside the junction box, which affects the cable ferrule and causes low resistance values.



Figure 10. Humidity

The third factor is humidity or high ambient moisture levels. Testing was conducted in areas with limited air circulation and humid conditions, which triggered the formation of a layer of water on the insulation surface. This layer is conductive and causes the insulation resistance value to decrease. Moisture also accelerates the corrosion process.

Table 11. is categorized as “Cable OK,” indicating that the corrective measures taken have successfully restored the

integrity of the insulation and the quality of the connection on the previously problematic cable segment.

TABLE 12.
AFTER ANALYSIS & RECTIFY

No	Date	Cable ID	Equipment Tag From	Level	Equipment Tag To	Level	Continuity	Insulation Resistance Test	Description
1	05/02/25	367-CE M-20-01	PL-5148017	1	CXE-L-M17-080	5	0,7 Ω	145 MΩ	Cable OK
2	07/03/25	217-CN O-20-01	PL-5143017	2	CXN-L-M17-116	5	0,6 Ω	167 MΩ	Cable OK
3	15/03/25	217-CN O-05-01	PL-5143017	2	CXN-L-M17-030	2	0,4 Ω	287 MΩ	Cable OK
4	15/03/25	217-CN O-07-07	PL-5143017	2	CXN-L-M17-053	2	0,5 Ω	265 MΩ	Cable OK

Based on Table 12 (After Analysis & Rectify), the results of cable testing after analysis and rectification are shown. Testing was conducted from February 5 to March 15, 2025, on four cables that previously required further evaluation.

The test results show that all cables tested have met the eligibility criteria and are declared in Cable OK condition. The continuity values were in the range of 0.4–0.7 Ω, indicating that the cable conductor resistance was within normal limits and there were no indications of faulty connections. Meanwhile, the insulation resistance test results showed values between 145–287 MΩ, indicating that the cable insulation quality had returned to good condition and was able to withstand electrical current leakage.

IV. Conclusion

The results of insulation testing on the FPSO electrical system show that most of the cable insulation conditions are still within acceptable standards, with resistance values exceeding 100 MΩ. However, there are several test points with values below the minimum limit, mainly due to ferrule damage, cable damage, and high humidity levels. These factors

contribute to a decrease in insulation effectiveness and the potential for leakage currents. After inspection and corrective action, all tested cables showed an increase in insulation resistance and met the specified standards. These results prove that the maintenance measures implemented are effective in restoring system reliability.

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