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Intelligent Fault Detection in Aerial Bunched Cables Using Partial Discharge Monitoring

Prof. Ashna Joseph, Prof. Elezabeth Paul, Sreeranjini VA, Athira Lal, Ajay Jojo, PS Sachin
Department of Electrical and Electronics Engineering Mar Athanasius College of Engineering Kothamangalam, Kerala, India

Abstract: ***Aerial Bunched Cable (ABC) is an innovative over- head power distribution system that uses insulated conductors bundled together, typically supported by a messenger wire. Unlike traditional bare conductor systems, ABC offers improved safety, reliability, and reduced power theft. It is particularly suitable for urban areas, congested spaces, and regions with challenging terrain. The use of ABC contributes to bettervoltageregulationandlowermaintenancerequirementsinpower distributionnetworks.Despitetheenhancedsafetyandreliability offered by ABC systems compared to traditional overhead lines, theyremainvulnerabletoinsulationdegradationovertime duetoenvironmentalandmechanicalstress.Earlydetection of such faults is crucial to prevent major failures and system outages. This project aims to develop a monitoring system that detects leakage current generated by partial discharge activityin aerial bunched cables. The leakage current produced due to insulationdeteriorationisfirstsensedandthenamplifiedusingan AD620instrumentationamplifier,whichisdesignedtoaccurately measure very small signals in electrically noisy environments. Theamplifiedsignalisthenprocessedbyamicrocontroller and evaluated against predefined threshold levels to determine abnormal conditions associated with insulation degradation. A communicationmoduleisincorporatedtotransmitreal-timefault alerts to a mobile application, enabling remote monitoring of the cable condition. Unlike traditional fault detection methods that relyoncomplexandcostlyprotectionschemessuchasdifferential protection, the proposed system provides a cost-effective and real-time monitoring solution specifically designed for ABC net- works.Themethodologyintegratesprecisionsignalamplification, microcontroller-based signal processing, and wireless communi- cation to provide continuous monitoring of the cable insulation condition. By enabling timely maintenance interventions, this solution significantly improves the operational reliability, safety, and maintainability of medium-voltage overhead distribution systems employing aerial bunched cables.***

I. INTRODUCTION

Aerial Bunched Cables (ABCs) are widely used in modern overhead power distribution networks due to their improved safety, reduced power theft, and enhanced operational relia- bilitycomparedtoconventionalbareconductors.Thesecables are particularly suitable for densely populated urban areas and environmentallysensitivelocationswheremaintainingelectri- cal safety and minimizing accidental contact are essential.

AlthoughABCsystemsofferseveraladvantages,theirinsu- lationisstillvulnerabletodegradationovertime.Factorssuch asthermalstress, moistureingress, environmentalaging,and electricaloverstresscangraduallyweakentheinsulationmate- rial. Oneoftheearliestindicators ofinsulationdeteriorationis the occurrence of partial discharge (PD). Partial discharge is a localized electrical breakdown within the insulation that does notcompletelybridgetheinsulatingmediumbutprogressively damages it, eventually leading to insulation failure if not detected in time.

Monitoring partial discharge activity is therefore an impor- tant method for assessing the health condition of cable insula- tion. Early detection of PD enables preventive maintenance and helps avoid unexpected failures in power distribution systems.OnepracticalapproachfordetectingPDactivity is by measuring the leakage current associated with insula- tion degradation. However, the leakage currents generated by partial discharge are typically very small, often in the mi- croampere or milliampere range, making direct measurement difficult using conventional microcontroller systems.

To address this challenge, signal conditioning techniques arerequiredtoamplifytheweakleakagecurrentsignalsbefore processing.Intheproposedsystem,anAD620instrumentation amplifierisusedtoamplifytheleakagecurrentsignalobtained from the sensing circuit. The AD620 amplifier is well suited for precision measurement applications due to its high input impedance, low offset voltage, high common-mode rejection ratio (CMRR), and adjustable gain using a single external resistor. By amplifying the small leakage current signals to measurable voltage levels, the system enables accurate data acquisition through the analog input of an Arduino-based monitoring unit.

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The amplified signal is then processed by a microcontroller that continuously monitors the leakage current and identifies abnormalconditionsassociatedwithpartialdischargeactivity. When the measured leakage current exceeds a predefined threshold value, the system can trigger alerts and indicate potential insulation faults, thereby improving the reliability and safety of aerial bunched cable networks.

Theremainderofthispaperisorganizedasfollows.Section II explains the fundamental concept of partial discharge andits impact on insulation degradation in aerial bunched cables. Section III presents the proposed leakage current monitoring methodology, including the sensing circuit and signal condi- tioningstageimplementedusingtheAD620instrumentation amplifier. Section IV describes the operational flow of the microcontroller and explains the different modes of system operation, including initialization, setting, and monitoring. Section V discusses the experimental results obtained fromthe developed system and analyzes the behavior of leakage current under different operating conditions. Finally, Section VI concludes the paper and highlights the effectiveness of the proposed monitoring system for early fault detection in aerial bunched cable networks.

II. LITERATURE REVIEW

Partial discharge (PD) is considered one of the most impor- tant indicators of insulation degradation in power cables. G. Li, J. Chen, H. Li, L. Hu, W. Zhou, and C. Zhou [1] proposed a novel model for the initiation of partial discharge in cable insulation systems. Their work explains how electrical stress andinsulationdefectscontributetotheoccurrenceoflocalized dielectric breakdown, which eventually leads to insulation deterioration.

Standardizedtechniquesformeasuringpartialdischargeare provided by the International Electrotechnical Commission through the IEC 60270 standard [2]. This standard specifies theprocedures,measurementcircuits,andcalibrationmethods requiredforreliable PD measurementinhigh-voltagesystems, forming the basis for most experimental and monitoring stud- ies in this field.

Research focusing on aerial bundled cables has highlighted the importance of environmental and operational factors in insulationdegradation.W.B.Yousuf,M.S.Alam,andM.

A. Al-Farooq [3] presented a remaining useful life prediction model for aerial bundled cables operating in coastal regions. Their study considered thermal and corrosion degradation mechanisms and demonstrated that environmental exposure significantly affects cable insulation reliability.

S. M. U. Talha, A. Ahmed, and M. S. Khan [4] proposed a recursive neural network-based method for estimating degra- dation trends in aerial bundled cables. Their approach enables predictive maintenance by analyzing long-term degradation patterns. Similarly, M. A. Shahid, A. R. Bhatti, and M. Q. Raza [5] developed a health diagnosis scheme for in-service low voltage aerial bundled cables, focusing on electrical pa- rameters to assess insulation condition.

Leakagecurrentmonitoringhasbeenwidelyrecognized as an effective method for evaluating insulation health. M. LuvunoandA.M.Abu-Mahfouz[6]discussedvariousleakage current monitoring techniques for condition assessment of power cables and emphasized their capability for early fault detection.

Sensor-baseddetectionmethodshavealsobeenexploredfor partial discharge monitoring. M. F. I. N. A. Arifin, N. Bashir, and Z. Zakaria [7] investigated the use of a Rogowski coil sensorfordetectingpartialdischargeinmedium-voltageaerial bundle cables. Their study demonstrated that non-invasive sensing techniques can effectively capture PD signals.

Conditionmonitoringofoverheadtransmissionsystemshas alsobeenaddressedinearlierstudies.R.K.Aggarwal,A.T. Johns, and J. A. S. B. Jayasinghe [8] provided an overview of monitoringtechniquesusedforoverheadlinesandhighlighted theimportanceof continuousmonitoringforimprovingsystem reliability.

Industry-based technical guidelines also emphasize the im- portanceofpartialdischargetesting.OMICRON[9]andDoble Engineering [10] provide detailed procedures and diagnostic approachesforonlinepartialdischargemeasurementsinpower cablesystems. M.HoofandR.Patsch[11]furtherinvestigated high-frequency current transformer based partial discharge detection techniques for cable condition monitoring.

Aging of cable insulation is another factor that significantly influences partial discharge activity. M. A. Salam and Q. M. Rahman[12]studiedtheeffectsofthermalagingonaerialbun- dled cables and demonstrated that prolonged exposure to high temperature accelerates insulation degradation. A. Cavallini and G. C. Montanari [13] analyzed the relationship between insulation aging and partial discharge activity, showing that the intensity of partial discharge increases as the insulation material deteriorates over time.

These studies highlight the importance of reliable moni- toring techniques for detecting early insulation degradation. Therefore, leakage current monitoring combined with signal amplification and microcontroller-based processing provides an effective approach for early detection of partial dischargein aerial bundled cables.

Overall, existing literature confirms that partial discharge and leakage current monitoring are reliable indicators of insu- lation degradation in cable systems. However, many reported approachesrelyonofflinetestingorcomplexinstrumentation. Therefore, a low-cost, real-time leakage-current-based PD monitoring system for Aerial Bunched Cables represents a practical and valuable contribution to early fault detection and preventive maintenance.

III. PARTIAL DISCHARGE THEORY

Partial discharge (PD) is a localized electrical phenomenon thatoccurswithininsulationdefectssuchasvoids,cracks,orat the interfaces between different dielectric materials. Unlike a completedielectricbreakdown,partialdischargedoesnotfully bridge the insulation between conductors. However, repeated PD activity gradually deteriorates the insulation material. Although individual discharge events may be small and may not immediately cause failure, continuous discharge activity accelerates insulation aging and may eventually lead to severe faults in power distribution systems.

Partial discharge typically initiates when the electric field within a localized region of the insulation exceeds the di- electric strength of the surrounding medium, particularly in gas-filled voids or weakened insulation regions. Under such conditions,short-durationelectricaldischargesoccur,generat- ing transient current pulses. These pulses propagate through theinsulationstructureandassociatedconductivepaths,even- tuallyreachinggroundedorconductivecomponentsconnected tothecablesystem.Asaresult,thedischargeactivitycanbe indirectlydetectedbymonitoringthecurrentsignalsassociated with these pulses.

In practical monitoring systems, these discharge-related signals are extremely small and require amplification before furtherprocessing.Precisionamplificationcircuits,suchasthe AD620 instrumentation amplifier, are commonly employed to amplify these weak signals so that they can be accurately measured and analyzed by electronic monitoring systems.

The current associated with partial discharge can be repre- sentedasthetimederivativeoftheapparentchargetransferred during the discharge process, which is expressed as

$$i(t) = \frac{dq(t)}{dt} \qquad (1)$$

In Aerial Bunched Cable (ABC) systems, leakage currents producedduetopartialdischargeactivitytendtoflowthrough themetallicscreenandthemessengerconductortowardground.Monitoringtheseleakagecurrentsprovidesapractical andnon-intrusiveapproachforassessingtheconditionofcable insulation.Byobservingvariationsinleakagecurrent,early indications of insulation degradation can be detected without interferingwiththenormaloperationofthepowerconductors. In the proposed system, these small leakage current signalsaresensedandamplifiedusingtheAD620instrumentation amplifierbeforebeingprocessed bythemonitoringunit. As insulation degradationprogresses, themagnitude orfrequency ofpartialdischargeeventsgenerallyincreases,resultingina correspondingriseinleakagecurrentlevels.Detectingsuch variationsatanearlystageenablestimelyidentificationof developingfaultsand facilitatespreventivemaintenancein aerial bunchedcable systems.

IV. MICRO CONTROLLER OPERATIONAL FLOW

The microcontroller plays a central role in managing the overall operation of the leakage current monitoring system developed for aerial bunched cables. It coordinates the acqui- sition of leakage current signals, processes the measured data, and determines whether the system is operating under normal orabnormalconditions.Theoperationalflowofthesystem is divided into two major stages: the setting stage and the monitoring stage. These stages enable the system to configure asuitablereferencethres holdvalueandcontinuouslysupervise leakage current behavior during operation.

A. Setting Mode

Duringthesettingmode,theuserisprovidedwiththeability to define the reference threshold value for leakage current detection. This threshold represents the maximum permissible leakagecurrentundernormaloperatingconditionsoftheaerial bunched cable system. The value can be adjusted using the push-button interface connected to the microcontroller.

The microcontroller continuously reads the button inputs and updates the threshold value accordingly. The selected valueisdisplayedontheLCDmodulesothattheusercan easily observe and modify the limit until an appropriate referencelevelisobtained.Oncethedesiredthresholdvalueis selected, it is stored in the microcontroller memory and usedas the comparison reference during the monitoring stage.

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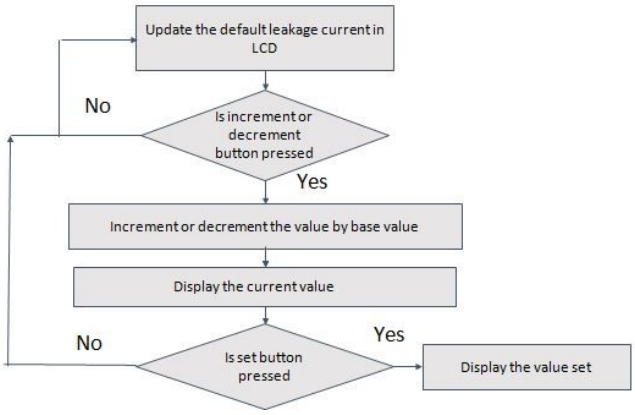


Fig.1.Flowchartofsettingmodeintheproposedmonitoringsystem.

Theleakagecurrentsignalobtainedfromthesensingcircuit is extremely small and therefore requires amplification before processing. In the proposed system, the AD620 instrumenta- tion amplifier is used to amplify the leakage current signaland convert it into a measurable voltage level. This amplified signalcanthenbeaccuratelyprocessedbythemicrocontroller through its analog input interface. Proper selection of the thresholdvalueisimportantbecauseitdeterminesthesensitiv- ityofthefaultdetectionsystemandhelpspreventunnecessary false alarms.
After the threshold configuration is completed, the system automaticallytransitionstothemonitoringstage.Thesequence ofoperationsinvolvedinthesettingstageisillustratedin Fig. 1.

B. MonitoringMode

In the monitoring mode, the microcontroller continuously observes the leakage current signal to ensure reliable op- eration of the aerial bunched cable system. The amplified signal produced by the AD620 instrumentation amplifier is periodically sampled through the analog-to-digital converter (ADC) of the microcontroller. Since partial discharge related leakage currents are typically very small, the amplification stage plays an important role in converting the weak current signal into a voltage level suitable for digital measurement.
The digitized voltage signal is processed by the microcon- troller to estimate the corresponding leakage current value. This measured value is displayed on the LCD module, allow- ing the user to monitor the system condition in real time. At the same time, the measured leakage current is continuously compared with the predefined threshold value stored during the setting stage.
Ifthemeasuredleakagecurrentremainsbelowthespecified threshold limit, the system interprets the condition as normal operation and continues monitoring without triggering any alerts. However, when the measured leakage current exceeds thepredefinedthreshold,thesystemidentifiesitasapotential abnormal condition associated with insulation degradation or partial discharge activity within the cable.

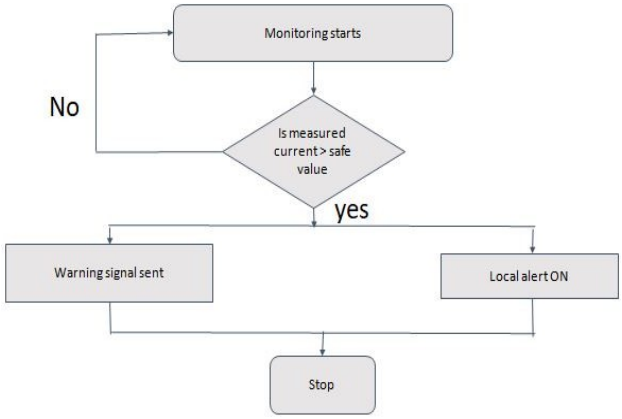


Fig.2.Flowchartofmonitoringmodeintheproposedmonitoringsystem.

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In such cases, the microcontroller immediately activatesthe alert mechanism. Warning indicators such as LEDs or buzzers are triggered to notify nearby personnel, and a fault notification can be transmitted through the communication moduletoinformmaintenancestaff.Thiscontinuousmonitor- ing mechanism allows early detection of insulation faults and helpspreventseverefailuresinoverheaddistributionnetworks. Theoperationalsequenceofthismonitoringstageisillustrated in Fig. 2.

V. PROPOSED METHODOLOGY

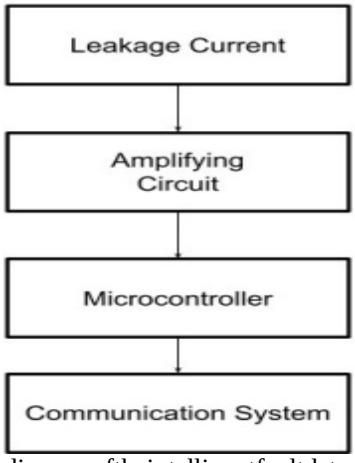


Fig.3.Blockdiagramoftheintelligentfaultdetectionsystem

The proposed monitoring system is designed to detect insulation degradation in aerial bunched cables by observing leakage current associated with partial discharge activity. In overheadpowerdistributionnetworks,insulationdeterioration may occur due to aging, environmental stress, or mechanical damage. Such degradation often produces small leakage cur- rents that can act as early indicators of potential insulation faults.

The monitoring technique adopted in this work is non- intrusive, as it utilizes the messenger conductor of the aerial bunched cable as the sensing path. This approach enables leakagecurrentmeasurementwithoutdirectinterferencewith the main power conductors, making the system suitable for practical distribution environments.

Since the leakage current produced during partial discharge events is extremely small, a precision signal amplification stageisrequiredbeforemeasurement.Intheproposedsystem, an AD620 instrumentation amplifier is employed to amplify the weak leakage current signal. The AD620 amplifier is well suited for this application due to its high input impedance, excellent common-mode rejection ratio (CMRR), low noise characteristics, and the ability to adjust the gain using a single external resistor.

Theleakagesignalobtainedfromthesensingpointis firstappliedtotheAD620amplifier,whereitisamplified to a measurable voltage level. The amplified signal is then passedthroughasignalconditioningstagetoensurethat theoutputvoltageremainswithinthesafeinputrangeof the microcontroller's analog-to-digital converter (ADC). This conditioningstagealsohelpsreducetheinfluenceofelectrical noise present in the distribution environment.

The conditioned analog signal is then sampled by the microcontrollerthroughitsADCchannel.Themicrocontroller processes the digital data to estimate the corresponding leak- age current value and compares it with a predefined threshold level representing the safe operating condition of the cable insulation.

Ifthemeasuredleakagecurrentremainsbelowthethreshold value, the system continues normal monitoring operation. However, when the leakage current exceeds the predefined limit, the system identifies a possible insulation fault and activates the alert mechanism. Warning indicators such as LEDs or buzzers are triggered, and a GSM communication module can transmit fault notification messages to mainte- nance personnel. This approach enables early detection of insulation degradation and helps prevent severe failures in aerial bunched cable distribution systems.

VI. RESULTS AND DISCUSSION

The performance of the proposed fault detection systemwas evaluated under both safe and faulty operating conditions to verify its ability to detect leakage current associated with partial discharge activity.

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A. Simulation Results

Figure 4 shows the simulation result obtained when the leakagecurrentremainswithinthesafeoperatingrange.Under thiscondition,theamplifiedleakagesignalprocessedby the microcontroller remains below the predefined threshold value. This indicates that the insulation condition of the aerial bunched cable is normal and no partial discharge activity is present. Therefore, the system continues monitoring without activating any warning signals.

Figure 5 illustrates the system behavior when the leakage currentexceedsthepredefinedthresholdvalue.Thiscondition represents insulation degradation or partial discharge activity within the cable. Once the microcontroller detects that the measuredleakagecurrentsurpassesthethreshold,thesystem identifiesitasanabnormalconditionandactivatesthealert mechanism.

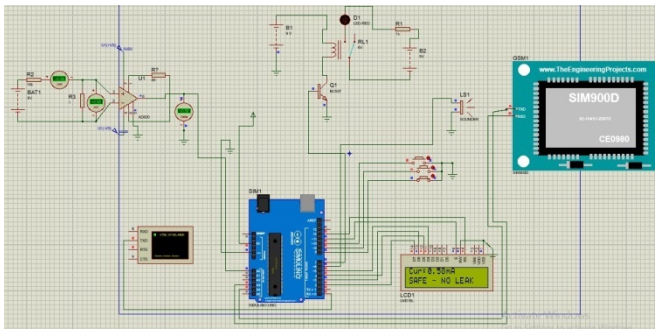


Fig.4.Simulationresultundersafeoperatingcondition

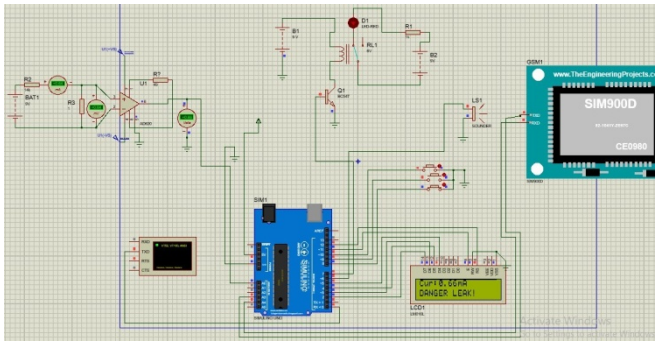


Fig.5.Simulationresultunderfaultycondition

B. HardwareResults

The hardware prototype of the proposed monitoring system was also tested to validate its practical performance. Figure 6 shows the experimental result obtained when the leakage current remains within the safe operating range. In this case, the measured current is below the threshold value, indicating healthy insulation behavior.

When the leakage current exceeds the predefined threshold, the system identifies a potential insulation fault. As illustrated inFig.7,themicrocontrollerdetectstheabnormalcurrentlevel and activates the warning indicators to alert the user. This earlydetectioncapabilityallowsmaintenancepersonneltotake corrective action before severe insulation failure occurs.

The experimental results demonstrate that leakage current monitoring provides a reliable and practical method for iden- tifying early insulation degradation in aerial bunched cables. The proposed system offers a low-cost and efficient solution forreal-timefaultdetectioninoverheaddistributionnetworks

VII. CONCLUSION

Intelligent Fault Detection in Aerial Bunched Cables Using Partial Discharge Monitoring is presented as an effective approach for identifying insulation degradation in overhead distributionsystemsbyobservingleakagecurrentvariations associated with partial discharge activity. Aerial bunched ca- bles are widely used in modern power distribution networks due to their safety and reliability; however, environmental conditions,aging,andmechanicalstresscangraduallyweaken thecableinsulationandleadto partialdischarge, which is an early indicator of potential faults.

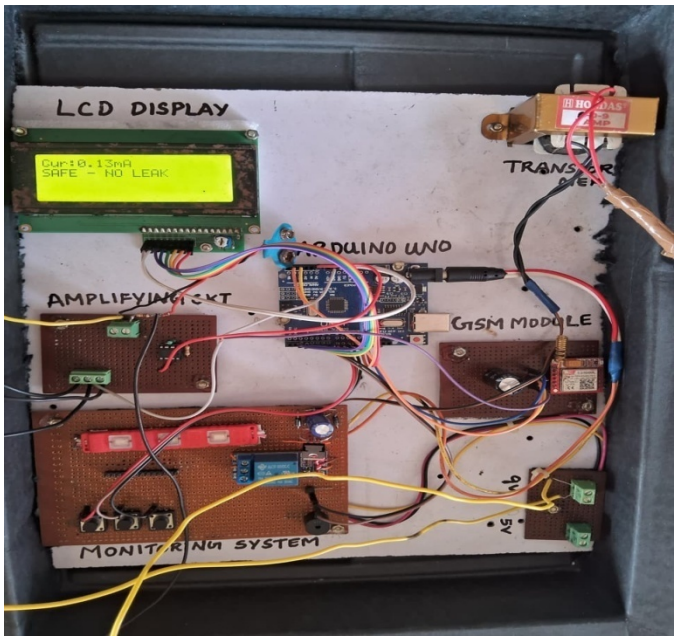


Fig.6.Hardwareresultundersafeleakagecurrentcondition

To monitor this condition, the leakage signal obtained from the messenger conductor is processed using a precision amplification circuit based on the AD620 Instrumentation Amplifier. Because the leakage currents produced during partial discharge events are extremely small, the AD620 instrumentation amplifier is used to accurately amplify these weak signals while maintaining high noise immunity and signal stability. The amplified signal isthensuppliedtoamicrocontroller,whereitisconvertedinto digital form using an analog-to-digital converter and contin- uously analyzed in real time. The microcontroller compares the measured leakage current with a predefined threshold value that represents the safe operating condition of the cable insulation. When the measured current remains below this threshold, the system indicates normal operation; however, if the leakage current exceeds the predefined limit, the system identifies it as a possible insulation fault caused by partial discharge activity. In such situations, warning indicators such asLEDs or buzzersare activated,and faultinformation canbe transmitted through a communication module to alert mainte- nance personnel.

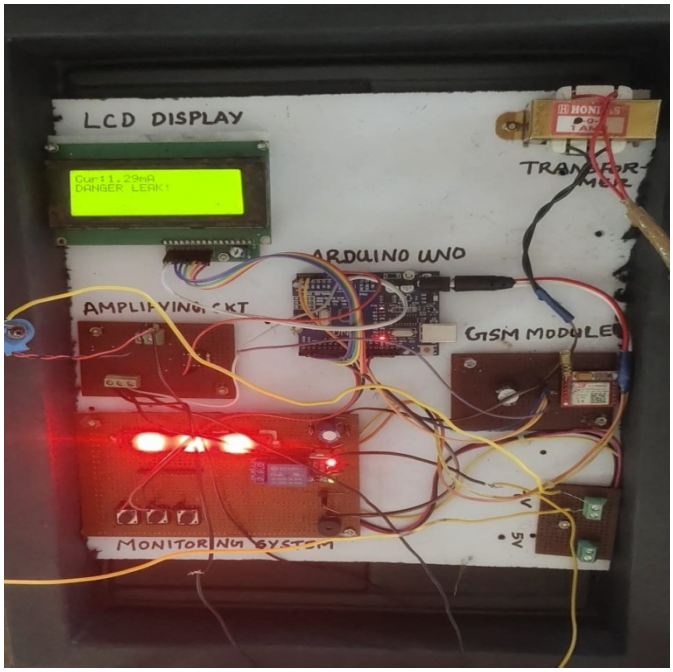
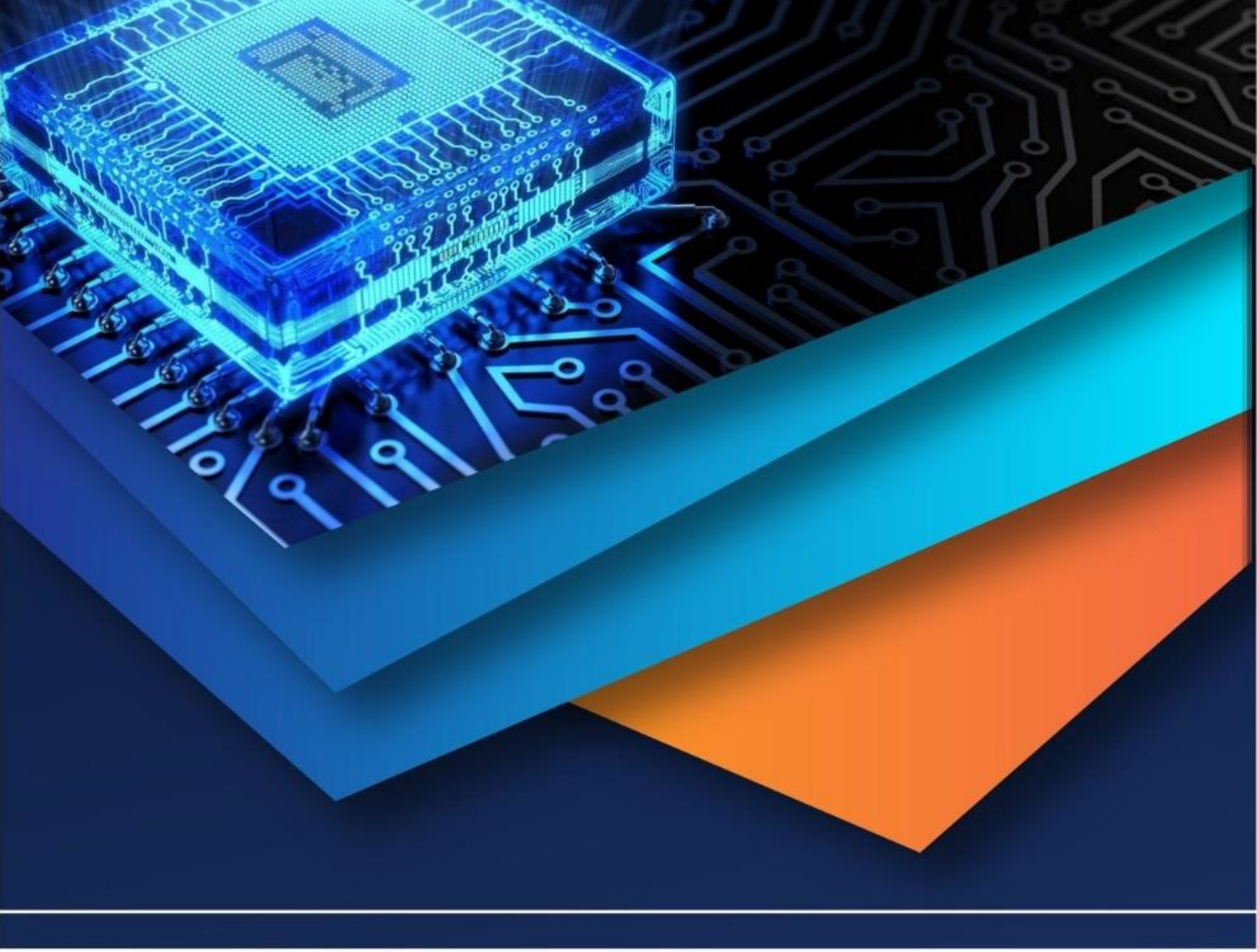


Fig.7.Hardwareresultunderunsafeleakagecurrentcondition.

The results demonstrate that this monitoring approach can effectively detect abnormal leakage current lev- els at an early stage, thereby helping to prevent severe cable failures and improving the reliability of aerial bundled cable distributionnetworks.Inaddition,theproposedsystemisnon- intrusive, cost-effective, and suitable for continuous real-time monitoring. Future improvements may include incorporating advanced signal processing methods and machine learning techniques to enhance fault classification accuracy and enable predictive maintenance for modern smart power distribution systems.

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