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Intelligent Fault Detection in Aerial Bunched Cables Using Partial Discharge Monitoring

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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 better voltage regulation and lower maintenance requirements in power distribution networks. Despite the enhanced safety and reliability offered by ABC systems compared to traditional overhead lines, they remain vulnerable to insulation degradation over time due to environmental and mechanical stress. Early detection 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 activity in aerial bunched cables. The leakage current produced due to insulation deterioration is first sensed and then amplified using an AD620 instrumentation amplifier, which is designed to accurately measure very small signals in electrically noisy environments. The amplified signal is then processed by a microcontroller and evaluated against predefined threshold levels to determine abnormal conditions associated with insulation degradation. A communication module is incorporated to transmit real-time fault alerts to a mobile application, enabling remote monitoring of the cable condition. Unlike traditional fault detection methods that rely on complex and costly protection schemes such as differential protection, the proposed system provides a cost-effective and real-time monitoring solution specifically designed for ABC networks. The methodology integrates precision signal amplification, microcontroller-based signal processing, and wireless communication 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 reliability compared to conventional bare conductors. These cables are particularly suitable for densely populated urban areas and environmentally sensitive locations where maintaining electrical safety and minimizing accidental contact are essential.

Although ABC systems offer several advantages, their insulation is still vulnerable to degradation over time. Factors such as thermal stress, moisture ingress, environmental aging, and electrical over-stress can gradually weaken the insulation material. One of the earliest indicators of insulation deterioration is the occurrence of partial discharge (PD). Partial discharge is a localized electrical breakdown within the insulation that does not completely bridge the insulating medium but progressively damages it, eventually leading to insulation failure if not detected in time.

Monitoring partial discharge activity is therefore an important method for assessing the health condition of cable insulation. Early detection of PD enables preventive maintenance and helps avoid unexpected failures in power distribution systems. One practical approach for detecting PD activity is by measuring the leakage current associated with insulation degradation. However, the leakage currents generated by partial discharge are typically very small, often in the microampere or milliamperere range, making direct measurement difficult using conventional microcontroller systems.

To address this challenge, signal conditioning techniques are required to amplify the weak leakage current signals before processing. In the proposed system, an AD620 instrumentation amplifier is used to amplify the leakage current signal obtained 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.

The amplified signal is then processed by a microcontroller that continuously monitors the leakage current and identifies abnormal conditions associated with partial discharge activity. 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.

The remainder of this paper is organized as follows. Section II explains the fundamental concept of partial discharge and its impact on insulation degradation in aerial bunched cables. Section III presents the proposed leakage current monitoring methodology, including the sensing circuit and signal conditioning stage implemented using the AD620 instrumentation 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 from the 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 important 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 and insulation defects contribute to the occurrence of localized dielectric breakdown, which eventually leads to insulation deterioration.

Standardized techniques for measuring partial discharge are provided by the International Electrotechnical Commission through the IEC 60270 standard [2]. This standard specifies the procedures, measurement circuits, and calibration methods required for reliable PD measurement in high-voltage systems, forming the basis for most experimental and monitoring studies in this field.

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

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 degradation 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 parameters to assess insulation condition.

Leakage current monitoring has been widely recognized as an effective method for evaluating insulation health. M. Luvuno and A. M. Abu-Mahfouz [6] discussed various leakage current monitoring techniques for condition assessment of power cables and emphasized their capability for early fault detection.

Sensor-based detection methods have also been explored for partial discharge monitoring. M. F. I. N. A. Arifin, N. Bashir, and Z. Zakaria [7] investigated the use of a Rogowski coil sensor for detecting partial discharge in medium-voltage aerial bundle cables. Their study demonstrated that non-invasive sensing techniques can effectively capture PD signals.

Condition monitoring of overhead transmission systems has also been addressed in earlier studies. R. K. Aggarwal, A. T. Johns, and J. A. S. B. Jayasinghe [8] provided an overview of monitoring techniques used for overhead lines and highlighted the importance of continuous monitoring for improving system reliability.

Industry-based technical guidelines also emphasize the importance of partial discharge testing. OMICRON [9] and Doble Engineering [10] provide detailed procedures and diagnostic approaches for online partial discharge measurements in power cable systems. M. Hoof and R. Patsch [11] further investigated 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] studied the effects of thermal aging on aerial bundled 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 monitoring 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 discharge in aerial bundled cables.

Overall, existing literature confirms that partial discharge and leakage current monitoring are reliable indicators of insulation degradation in cable systems. However, many reported approaches rely on offline testing or complex instrumentation. 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 that occurs within insulation defects such as voids, cracks, or at the interfaces between different dielectric materials. Unlike a complete dielectric breakdown, partial discharge does not fully 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 dielectric strength of the surrounding medium, particularly in gas-filled voids or weakened insulation regions. Under such conditions, short-duration electrical discharges occur, generating transient current pulses. These pulses propagate through the insulation structure and associated conductive paths, eventually reaching grounded or conductive components connected to the cable system. As a result, the discharge activity can be indirectly detected by monitoring the current signals associated with these pulses.

In practical monitoring systems, these discharge-related signals are extremely small and require amplification before further processing. Precision amplification circuits, such as the 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 represented as the time derivative of the apparent charge transferred during the discharge process, which is expressed as

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

In Aerial Bunched Cable (ABC) systems, leakage currents produced due to partial discharge activity tend to flow through the metallic screen and the messenger conductor toward ground. Monitoring these leakage currents provides a practical and non-intrusive approach for assessing the condition of cable insulation. By observing variations in leakage current, early indications of insulation degradation can be detected without interfering with the normal operation of the power conductors. In the proposed system, these small leakage current signals are sensed and amplified using the AD620 instrumentation amplifier before being processed by the monitoring unit. As insulation degradation progresses, the magnitude or frequency of partial discharge events generally increases, resulting in a corresponding rise in leakage current levels. Detecting such variations at an early stage enables timely identification of developing faults and facilitates preventive maintenance in aerial bunched cable 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 acquisition of leakage current signals, processes the measured data, and determines whether the system is operating under normal or abnormal conditions. The operational flow of the system is divided into two major stages: the setting stage and the monitoring stage. These stages enable the system to configure a suitable reference threshold value and continuously supervise leakage current behavior during operation.

A. Setting Mode

During the setting mode, the user is provided with the ability to define the reference threshold value for leakage current detection. This threshold represents the maximum permissible leakage current under normal operating conditions of the aerial 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 value is displayed on the LCD module so that the user can easily observe and modify the limit until an appropriate reference level is obtained. Once the desired threshold value is selected, it is stored in the microcontroller memory and used as the comparison reference during the monitoring stage.

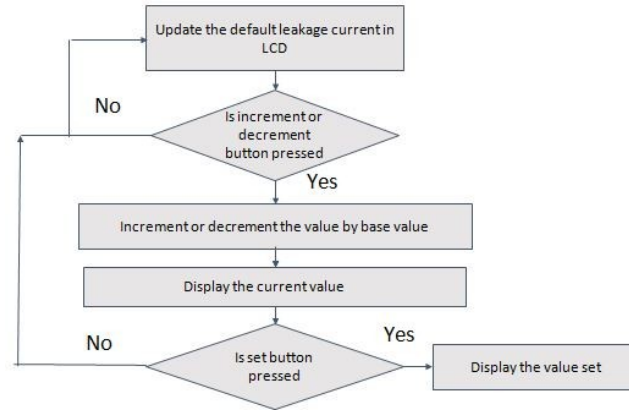


Fig. 1. Flowchart of setting mode in the proposed monitoring system.

The leakage current signal obtained from the sensing circuit is extremely small and therefore requires amplification before processing. In the proposed system, the AD620 instrumentation amplifier is used to amplify the leakage current signal and convert it into a measurable voltage level. This amplified signal can then be accurately processed by the microcontroller through its analog input interface. Proper selection of the threshold value is important because it determines the sensitivity of the fault detection system and helps prevent unnecessary false alarms.

After the threshold configuration is completed, the system automatically transitions to the monitoring stage. This sequence of operations involved in the setting stage is illustrated in Fig. 1.

B. Monitoring Mode

In the monitoring mode, the microcontroller continuously observes the leakage current signal to ensure reliable operation 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 microcontroller to estimate the corresponding leakage current value. This measured value is displayed on the LCD module, allowing 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.

If the measured leakage current remains below the specified threshold limit, the system interprets the condition as normal operation and continues monitoring without triggering any alerts. However, when the measured leakage current exceeds the predefined threshold, the system identifies it as a potential abnormal condition associated with insulation degradation or partial discharge activity within the cable.

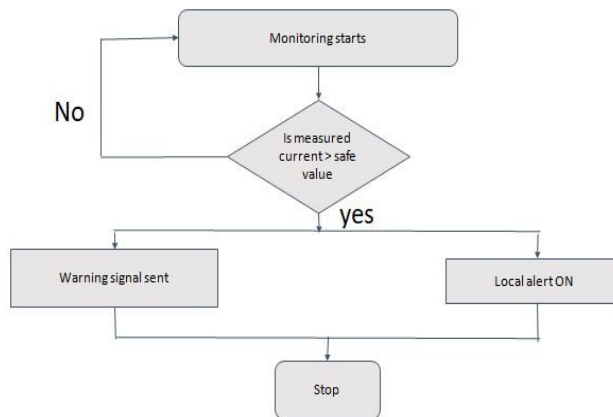


Fig. 2. Flowchart of monitoring mode in the proposed monitoring system.

In such cases, the microcontroller immediately activates the 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 module to inform maintenance staff. This continuous monitoring mechanism allows early detection of insulation faults and helps prevent severe failures in overhead distribution networks. The operational sequence of this monitoring stage is illustrated in Fig. 2.

V. PROPOSED METHODOLOGY

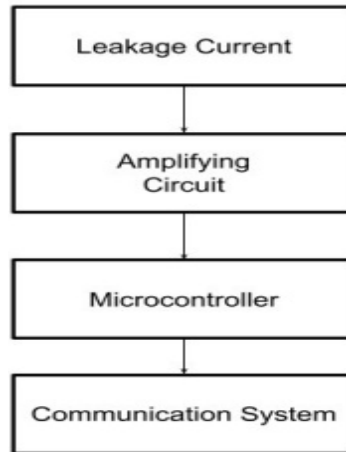


Fig.3. Block diagram of the intelligent fault detection system

The proposed monitoring system is designed to detect insulation degradation in aerial bunched cables by observing leakage current associated with partial discharge activity. In overhead power distribution networks, insulation deterioration may occur due to aging, environmental stress, or mechanical damage. Such degradation often produces small leakage currents 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 leakage current measurement without direct interference with 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 stage is required before measurement. In the proposed system, 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.

The leakage signal obtained from the sensing point is first applied to the AD620 amplifier, where it is amplified to a measurable voltage level. The amplified signal is then passed through a signal conditioning stage to ensure that the output voltage remains within the safe input range of the microcontroller's analog-to-digital converter (ADC). This conditioning stage also helps reduce the influence of electrical noise present in the distribution environment.

The conditioned analog signal is then sampled by the microcontroller through its ADC channel. The microcontroller processes the digital data to estimate the corresponding leakage current value and compares it with a predefined threshold level representing the safe operating condition of the cable insulation.

If the measured leakage current remains below the threshold 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 maintenance 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 system was evaluated under both safe and faulty operating conditions to verify its ability to detect leakage current associated with partial discharge activity.

A. Simulation Results

Figure 4 shows the simulation result obtained when the leakage current remains within the safe operating range. Under this condition, the amplified leakage signal processed by 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 current exceeds the predefined threshold value. This condition represents insulation degradation or partial discharge activity within the cable. Once the microcontroller detects that the measured leakage current surpasses the threshold, the system identifies it as an abnormal condition and activates the alert mechanism.

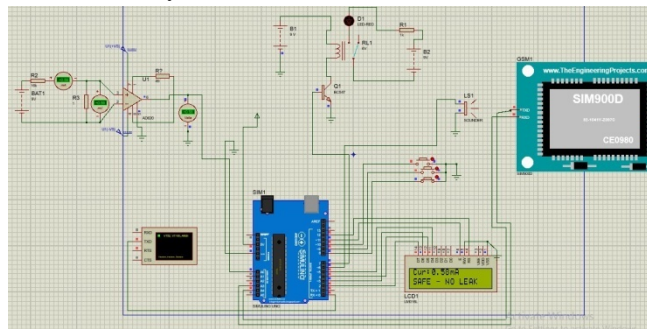


Fig.4.Simulation result under safe operating condition

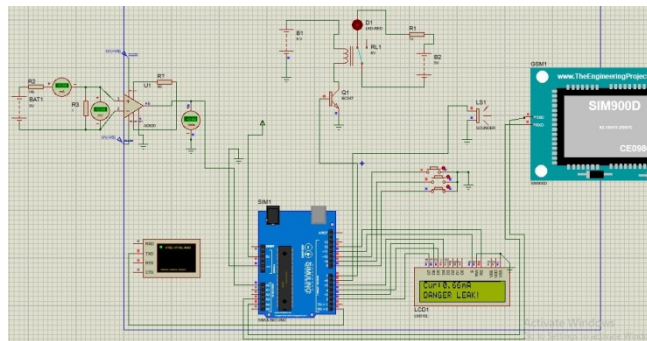


Fig.5.Simulation result under faulty condition

B. Hardware Results

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 in Fig.7, the microcontroller detects the abnormal current level and activates the warning indicators to alert the user. This early detection capability allows maintenance personnel to take corrective action before severe insulation failure occurs.

The experimental results demonstrate that leakage current monitoring provides a reliable and practical method for identifying early insulation degradation in aerial bunched cables. The proposed system offers a low-cost and efficient solution for real-time fault detection in overhead distribution networks.

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 distribution systems by observing leakage current variations associated with partial discharge activity. Aerial bunched cables are widely used in modern power distribution networks due to their safety and reliability; however, environmental conditions, aging, and mechanical stress can gradually weaken the cable insulation and lead to partial discharge, which is an early indicator of potential faults.

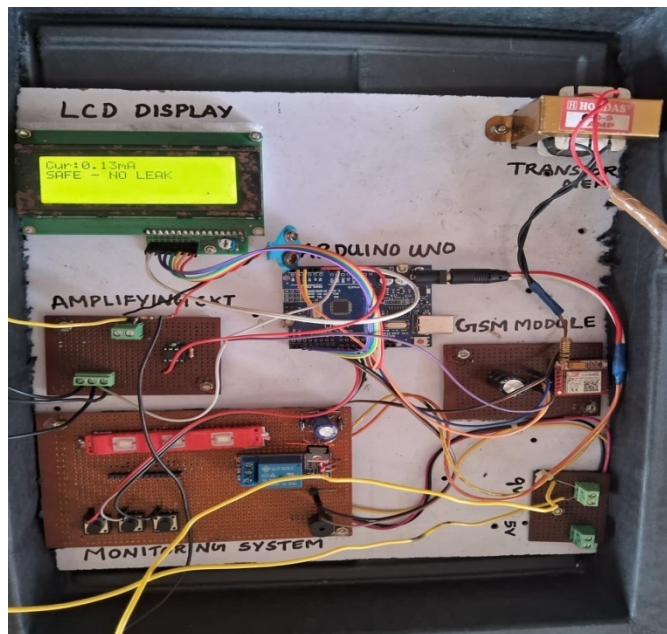


Fig.6.Hardware result under safe leakage current condition

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 is then supplied to a microcontroller, where it is converted into digital form using an analog-to-digital converter and continuously 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 as LEDs or buzzers are activated, and fault information can be transmitted through a communication module to alert maintenance personnel.

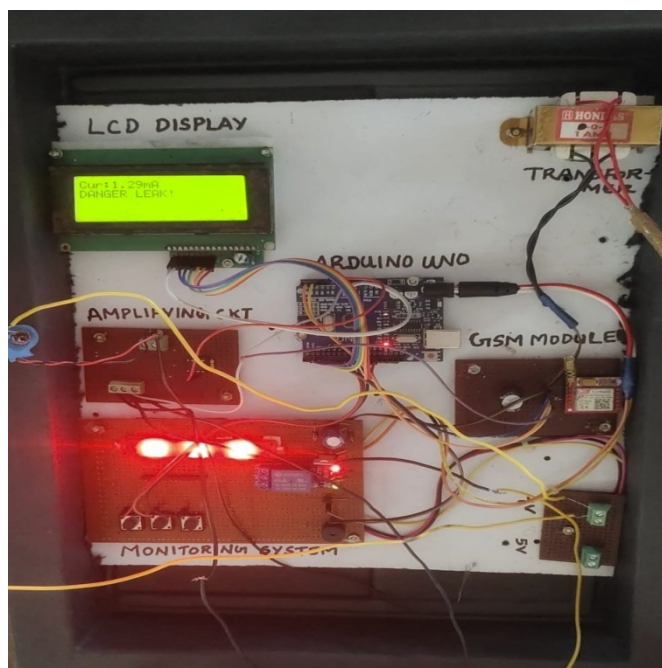


Fig.7.Hardware result under unsafe leakage current condition.

The results demonstrate that this monitoring approach can effectively detect abnormal leakage current levels at an early stage, thereby helping to prevent severe cable failures and improving the reliability of aerial bundled cable distribution networks. In addition, the proposed system is non-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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