Design an Electronic System to Detect, Analysis and Prevent Fault during 3 Phase Power Transmission using WSN Technology

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***Abstract*— The complexity of the electric power system is escalating due to rising electricity demand, yet the current control systems are inadequate for ensuring safety, efficiency, and reliability. Transmission lines, which carry power over vast distances from generating stations, are frequently plagued by faults caused by lightning strikes, short circuits, insulation failures, operational errors, human mistakes, and overloads. These issues often result in significant damage to critical electrical components. To maintain an uninterrupted power supply and minimize damage to the system's infrastructure, it is imperative that we detect these faults swiftly. Identifying and locating faults quickly is crucial for maintaining a healthy power system operation. A robust protection scheme should efficiently pinpoint fault locations and isolate only the affected sections to reduce overall impact. Despite advancements in microcontroller-based systems for fault analysis and protection through wireless sensor network technology (WSN), there remains much room for improvement. This research project attempts to address these challenges by proposing a cutting-edge monitoring system using cloud-supported Zigbee technology that provides real-time data on transmission line conditions. The proposed solution has been tested with Proteus software simulations but still relies heavily on theoretical models.**

Keywords— 3-Phase Fault Detection, Analysis, WSN Technology, 8051 controllers etc.

I. INTRODUCTION

The electrical transmission line that supplies power to the consumer experiences failures due to faults, which can be either temporary or permanent. These faults cause significant damage to the power system. Faults exist in different types, each affecting the power system in various ways. This project primarily aims to detect faults as quickly as possible. Therefore, it studies different techniques for detecting and analyzing faults, along with protection using an overcurrent relay. It utilizes wireless sensor network technology with a microcontroller for fault detection and employs a simple overcurrent relay to protect each phase individually from overcurrent [1]. A fault is generally defined as an unwanted but inevitable incident that temporarily disturbs the stable condition of the power system, occurring when the system's insulation fails at any point along the line [2]. Furthermore, if a conducting object comes into contact with an exposed power conductor, a short circuit or fault is said to have occurred. The causes of faults are numerous, including lightning, human error, wind damage, trees falling onto transmission lines, vehicles or aircraft colliding with transmission towers or poles, birds short-circuiting lines, or acts of vandalism.

Electrical equipment is susceptible to disturbances introduced by faults in the system, such as overloading and short circuits. These faults, in turn, cause damage to power equipment within the power system and at the consumer’s end. Their impact can result in short- or long-term losses in the electric power system. Prompt attention to power transmission faults is crucial in preventing harm and ensuring system stability. To address these challenges, a power transmission monitoring and fault detection system using Wireless Sensor Network (WSN) technology is proposed. Several existing systems are available, but each has its own limitations when applied to electrical systems. Therefore, WSN technology is selected to provide a cost-effective, durable, and robust communication framework that enhances transmission speed regardless of distance. The system monitors breaches in the pre-set short circuit limit by comparing current and voltage levels. When a fault or short circuit occurs, the microcontroller sends a signal to trip the relay, disconnecting the system. Otherwise, the system remains operational. If the short circuit limit is exceeded, a fault detection signal is displayed on the LCD screen. This setup enables near real-time monitoring. However, the power sector, from generation to distribution, experiences significant power losses. It is crucial to protect equipment such as transformers, relays, and panels. When power transmissions are disrupted by faults, unless they are critical, they often go unnoticed. Even minor faults can damage power system components and pose a threat to human life. To mitigate these risks, a WSN-based monitoring and fault detection system is proposed to continuously monitor power transmission parameters. By incorporating fault detection, the system can promptly isolate itself from even the slightest fault occurrence. Consequently, maintenance costs are effectively reduced to a considerable extent.

In the last few decades, different techniques have been developed to protect three-phase systems from overcurrent and other faults. The author Yang et al. [3] presents a wireless monitoring system for a transmission line. This paper describes a smart grid application for monitoring the condition of the transmission line system using wireless sensor networks. ZigBee and GPRS (General Packet Radio Service) technology are utilized in this system to ensure the normal transmission of signals, even in remote areas without telecommunication services, allowing data to be transmitted over long distances. Additionally, the system provides early warnings before damage caused by meteorological disasters occurs, ensuring the security of the transmission line.

The author Gopal et al. [4] presented a new and efficient fault detection and routing scheme to manage a large-scale wireless sensor network. In this project, the EFDR scheme employs three linear cellular automata to manage the transmitter circuit, battery condition, receiver circuit fault, and sensor circuit fault representation. A wireless sensor is utilized for monitoring environmental conditions and other parameters. The microcontroller is responsible for data transmission and reception using the WSN technique. It can efficiently detect faults within a short time, as the sensor provides its own status, can be easily replaced, and is simple to operate. The author K. R. Krishnanand et al. [5] proposed a pattern recognition approach for current differential relaying of power transmission lines. The current differential method utilizes spectral energy information derived from a newly developed fast Discrete S-Transform. This technique incorporates various types of frequency scaling, band-pass filtering, and interpolation methods to reduce computational costs and eliminate redundant information. This scheme evaluates the current differential protection of a transmission line fed from both ends under various fault conditions, fault resistance levels, inception angles, and significant noise disturbances using computer simulations. In paper [6], the authors presented a brief review of different hardware techniques for power monitoring, power management, and remote power control at both the household and transmission levels. The study also discusses the suitability of ZigBee for establishing the required communication link. The monitoring hardware consists of a current or voltage measurement circuit, a microcontroller unit, a relay, and ZigBee communication. The current/voltage measuring circuit transmits data to the microcontroller, which detects abnormalities in the power system and sends the information to a home server, where a database is maintained through ZigBee. For control purposes, a relay is integrated into the monitoring hardware. In case of an emergency detected by the microcontroller, the relay disconnects the power supply to the electrical appliances. A graphical user interface software is employed as an interface between the user and the device. In paper [7], the authors proposed a method to enhance the functionality of power grid overcurrent relays, which protect against interphase faults and single-phase-to-ground faults. The proposed method relies on locally accessible measurements and does not require online information or communication facilities regarding varying short-circuit levels caused by distributed energy resources. This method is robust and employs a least-squares algorithm. The evaluation results indicate that the Thevenin's equivalent-based method improves the relay's tripping time. In papers [8] and [9], the authors proposed a three-phase fault analysis for both temporary and permanent faults based on a microcontroller. This study describes the use of a step-down transformer to manage low-voltage conditions of 12V. In addition to the transformer, a rectifier circuit and fault switches are used to simulate faults. LEDs indicate the fault status, while the microcontroller converts analog values into digital values and displays the results on an LCD screen. In paper [10], the authors discussed the use of overcurrent relays for microgrid protection against earth faults. This study focuses on

overcurrent relay coordination based on earth and phase overcurrent protection functions in the formulation of the OCR coordination problem. This approach minimizes damage and unintentional feeder disconnections. Furthermore, the paper proposes an optimal and unified protection scheme suitable for all fault types, based on single-line-to-ground fault calculations.
In paper [11], the author Mohammad Y. Suliman et al. presented a study on protective relays designed using different technologies, including electromechanical, solid-state, and numerical devices. Speed and reliability are identified as the two most important characteristics of a protective relay, while other capabilities, such as monitoring and recording, are considered secondary priorities. The modeling and simulation of a protected system using Simulink are described, along with the hardware implementation using Field Programmable Analog Arrays (FPAAs). Practical tests for various fault conditions are conducted, demonstrating the effectiveness of the proposed protection system. The experimental results confirm the relay's ability to respond promptly to steady-state fault conditions and accurately achieve different types of time-current characteristics.

In papers [12], [13], and [14], the author Antonio E. C. Momessoa presented a model and time-domain simulation of a directional overcurrent relay (DOR) with an adaptive pick-up current (Ip) provided by a fuzzy system. In this study, the protection scheme is incorporated as a performance enhancer. A comparison of the processing time between conventional relays, optimally coordinated using the evolutionary particle swarm optimization (EPSO) meta-heuristic algorithm while considering stability constraints, and the proposed adaptive method has been conducted. This paper also considers the calculation of the critical stability time using the bisection method and the potential energy boundary surface (PEBS) method.

This research primarily aims to detect and analyze faults swiftly and cost-effectively while focusing on over temperature and Line-to-Ground fault. Through an extensive review of journal papers, it acquires comprehensive knowledge of various fault detection techniques. The project employs a wireless sensor network to monitor transmission line conditions from urban centers to remote areas where traditional communication methods fail.

II. THEORY AND DISCUSSION

2.1 Transmission line faults:

An abnormal condition occurs due to various natural factors such as lightning, wind, short circuits, natural disasters, and human error. It results in an excessive flow of current beyond the normal value. As a consequence, several electrical apparatuses, including transformers and transmission lines, are affected due to overheating, short circuits, and insulation failures. Transmission line faults primarily occur when conductors come into physical contact or when phase wires break and fall to the ground. These faults are broadly classified into two types: unbalanced (asymmetrical) faults and balanced (symmetrical) faults. Examples include L-G, L-L, L-L-G, and L-L-L faults, respectively. Such faults typically arise due to insulation failure and the falling of tree branches on transmission lines.

2.1.1 Single Line to ground fault:

This type of fault occurs when a conductor falls to the ground or comes into contact with the neutral wire. It may also result from tree branches falling during a winter storm. Figure 2.1 illustrates a single-line-to-ground fault.

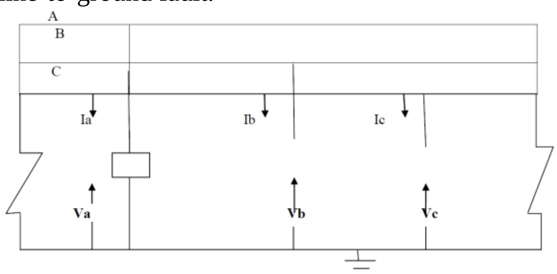

Fig. 2.1 Single line to ground fault

2.1.2 Line to Line fault:

The second type of fault occurring in a transmission line is the line-to-line fault. It is an unsymmetrical fault that occurs when two conductors are short-circuited. In this case, the fault is located between lines B and C, making it symmetrical with respect to the reference phase A, which remains unaffected, as shown in Figure 2.2.

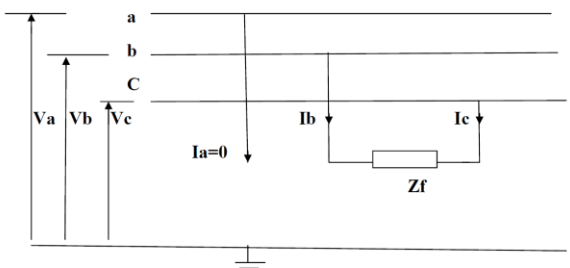

Fig. 2.2 Line to Line fault

2.1.3 Double line to ground fault:

The third type of transmission line fault is the double-line-to-ground fault. This fault occurs when two phases of the power circuit are short-circuited to the ground.

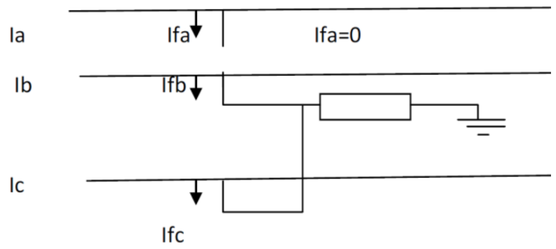

Fig. 2.3 Double line to ground fault

2.2 Need of transmission line protection:

A power transmission line protection system is a crucial component of the electrical system. The transmission system serves as the link between generating stations and distribution centers. Several techniques are used to protect transmission lines, with distance relay protection and overcurrent protection being the most common methods. The primary purpose of a transmission protection relay is to identify the location of a fault. Additionally, these relays help determine the type of fault occurring in transmission lines. Transmission line protection systems primarily rely on relays, with various relay mechanisms employed for fault detection. Among them, overcurrent relays are the most commonly used to safeguard transmission lines from faults.

2.2.1 Over current relay:

Overcurrent is defined as any current that exceeds the rated capacity of an apparatus or conductor. It may result from overload, short circuits, insulation failure, or ground faults. When current flows through a conductor, it generates heat. Under faulty conditions, excessive current leads to overheating, which can damage electrical components. To prevent such damage, overcurrent relays are used. The current from the transmission lines is supplied to the overcurrent relay through a current transformer. Under normal conditions, the relay remains in a closed state, whereas in the event of an overcurrent fault, it switches to an open state.

2.2.2 Types of over current relay:

i) Instantaneous Overcurrent Relay: This type of relay operates immediately, without any delay, when the input current exceeds the preset value. It functions within a definite time and is primarily used on outgoing feeders.

ii) Definite Time Overcurrent Relay: This relay operates when two conditions are met: the input current exceeds the relay's set value, and the predefined time delay is reached. Its operation is independent of the fault current level and solely depends on the preset time delay.

iii) Inverse Time Overcurrent Relay: In this type of relay, the operating time is inversely proportional to the magnitude of the fault current. It responds faster to high fault currents and more slowly to lower fault currents.

III. METHODOLOGY

The wireless sensor network system is used for fault detection and analysis in circuits efficiently and at a low cost by utilizing a microcontroller. In this research work, a microcontroller is interfaced with an LCD display and a ZigBee module, which is used to transmit and receive data. When a fault occurs in the transmission line phase, the microcontroller sends data via the ZigBee module, and the receiver forwards this data to the LCD display, indicating the fault phase and its exact location.

An overcurrent relay protection circuit is implemented to trip the circuit when excessive current flows or a short circuit occurs in a phase. Normally, the relay remains closed, but it opens when a fault is detected. Figure 3.1 illustrates the block diagram of this research work.

In this system, a step-down transformer is connected to the power source. The transformer reduces the voltage to 12V AC. After the transformer, a full-wave bridge rectifier converts AC power into DC, as the main components operate on DC. The rectifier provides 12V DC as output. Since the microcontroller cannot operate at such a high voltage, a 7805 voltage regulator is used to step down the voltage to 5V DC, which is then supplied to the microcontroller.

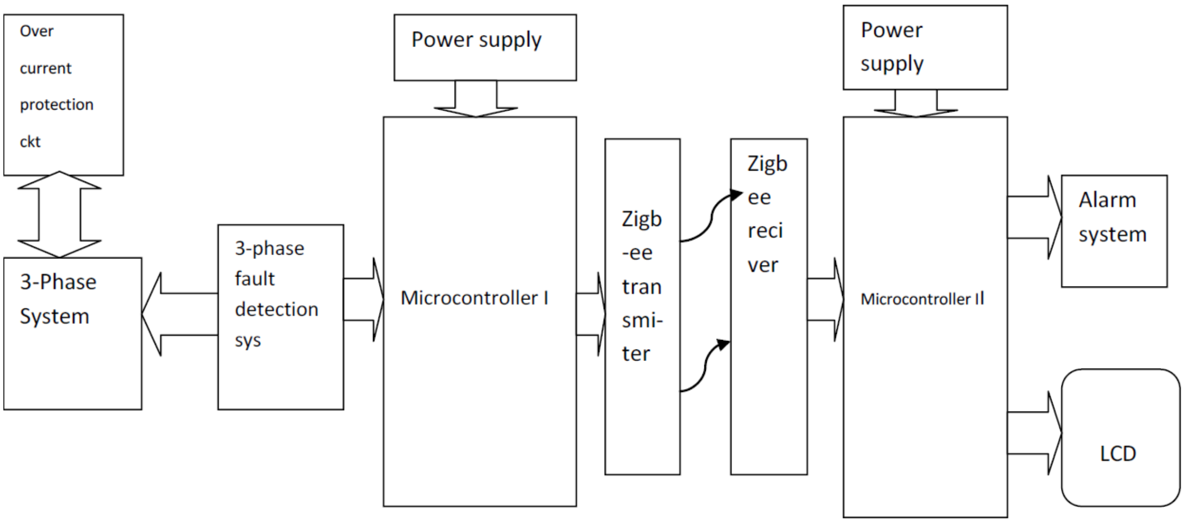

Fig. 3.1 Block Diagram

The microcontroller receives input from an operational amplifier (op-amp), which functions as a comparator. The comparator plays a crucial role in the system. When the reference voltage at the inverting terminal exceeds that at the non-inverting terminal, the op-amp generates a high response. On the receiving side, the microcontroller is interfaced with a ZigBee module. When the op-amp produces a high response, it signals the microcontroller, indicating a system change or fault. The ZigBee module transmits this data to the receiver-side ZigBee module, which then displays the status of the transmission line on the LCD screen.

The protection circuit consists of an overcurrent relay, a voltage-to-current converter, and a MOSFET, which is used for triggering purposes. A potentiometer is included to indicate voltage variations. Adjusting the potentiometer changes the voltage, which in turn affects the current. When the current exceeds the reference value set for the overcurrent relay, the relay trips and interrupts the circuit.

The flowcharts of the algorithms programmed in the controllers of the transmitter and receiver units are shown in Figure 3.2 and Figure 3.3, respectively.

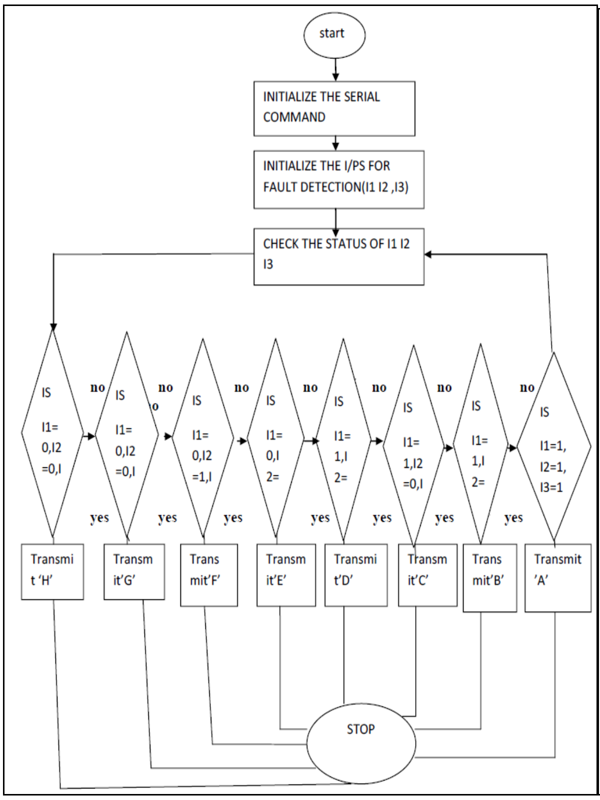

Fig. 3.2 Flowchart of algorithm for Transmitter Unit

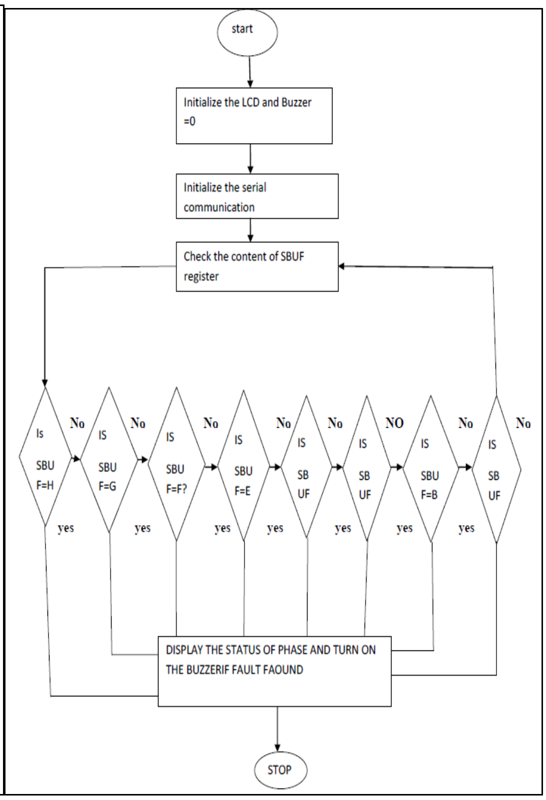

Fig. 3.3 Flowchart of algorithm for Receiver Unit

The key components essential for constructing the electronic circuit include step-down transformers, rectifier circuits, 8051 controllers, LCD displays, and Zigbee WSN Tx and Rx modules. Refer to Fig. 3.4 for the detailed schematic circuit diagram of the system.

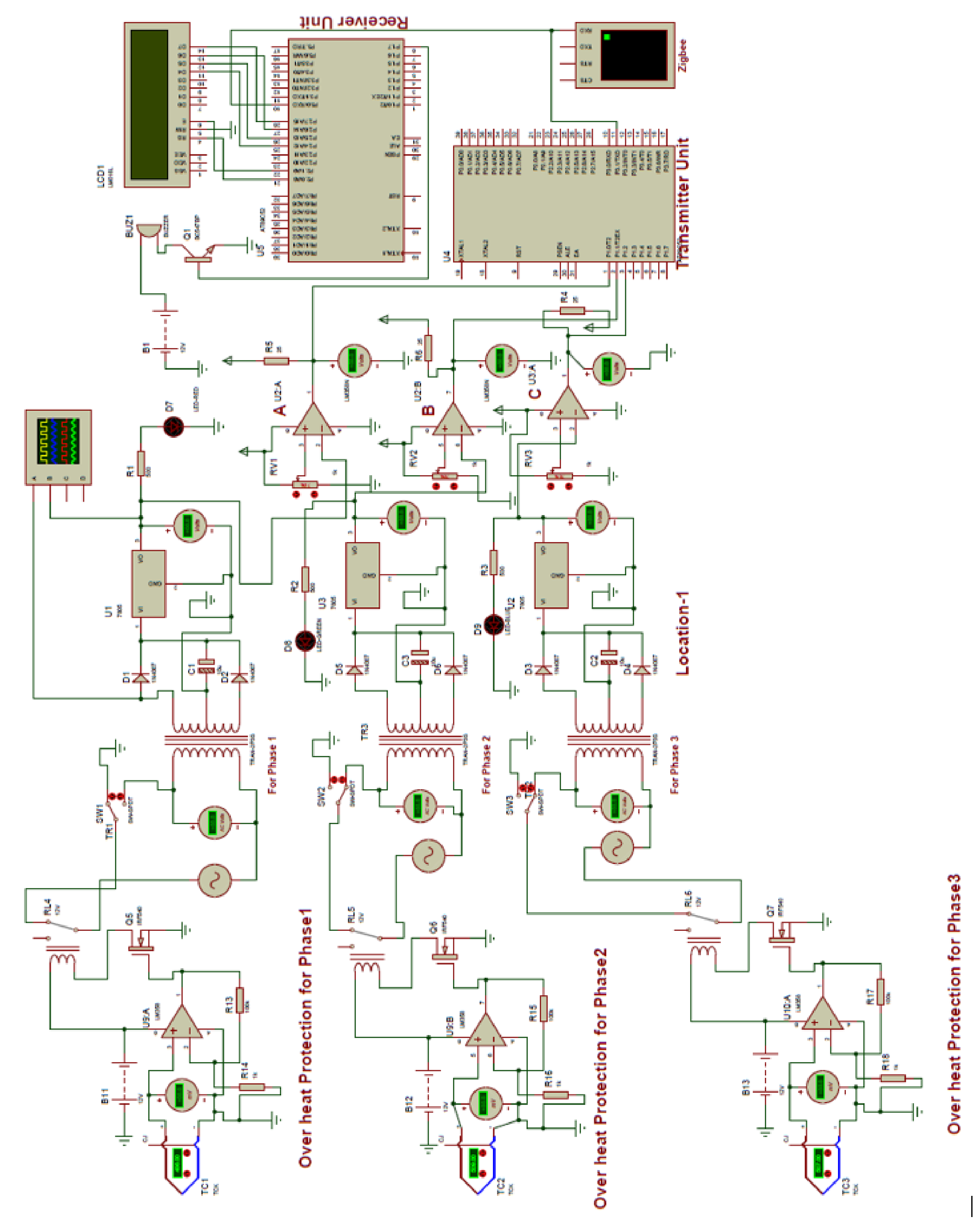

Fig. 3.4 Schematic Circuit Diagram

The microcontroller receives input from an operational amplifier (op-amp), which functions as a comparator. The comparator plays a crucial role in the system. When the reference voltage at the inverting terminal exceeds that at the non-inverting terminal, the op-amp generates a high response. On the receiving side, the microcontroller is interfaced with a ZigBee module. When the op-amp produces a high response, it signals the microcontroller, indicating a system change or fault. The ZigBee module transmits this data to the receiver-side ZigBee module, which then displays the status of the transmission line on the LCD screen.

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Three thermocouples are strategically deployed within the circuit to provide essential protection against overcurrent situations, safeguarding the system from potential damage. The output generated by each thermocouple is meticulously processed through a signal conditioning circuit, ensuring that the readings are accurate and reliable. To amplify these signals effectively, an operational amplifier (OPAMP) is configured as a non-inverting amplifier, serving as a critical component of the readout circuit. This setup not only enhances signal strength but also preserves the integrity of the original data. In addition to these components, an LCD display is incorporated into the receiver section to facilitate instant monitoring and real-time visualization of any faults that may arise within the power grid station. This allows operators to quickly identify issues and take appropriate action before they escalate into more serious problems. Furthermore, a buzzer is integrated with the receiver unit as an alert system, providing audible notifications that draw immediate attention to any irregularities. Together, these elements create a robust monitoring system designed to ensure safety and reliability in power grid operations.

IV. EXPERIMENTAL RESULT

For designing the fault detection circuit, a center-tapped step-down transformer is used with the main power source. An SPDT switch is interfaced between the ground and the transformer to manually create faults. The transformer's output is then fed into a full-bridge rectifier to convert AC into DC. Figure 4.1 illustrates the waveform of the rectifier circuit. The input is a sinusoidal wave, while the output is a pure DC signal.

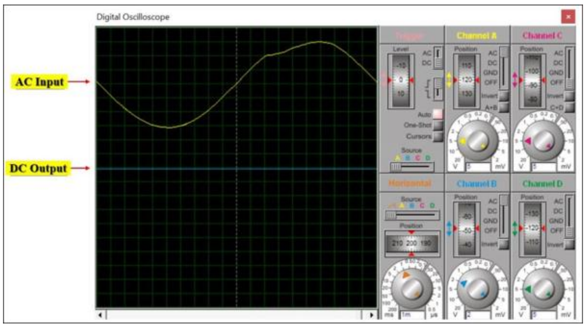

Fig. 4.1. Response of rectifier circuit

Three operational amplifiers (designated as A, B, and C) are strategically employed at the output stage of the rectifier circuit, as illustrated in figure 3. 4. These OPAMPs function effectively as comparators, whose output responses are dynamically adjusted based on the specific faults occurring within the electrical phase. In the event of a Line to Ground fault—an essential failure mode that can significantly impact system performance—the output response will alter almost instantaneously, reflecting the urgency and severity of such an event. This immediate change in output is critical for prompt fault detection and mitigation strategies. The range of possible output responses generated by this configuration is comprehensively summarized in Table 4.1, which delineates various scenarios and their corresponding outputs to facilitate a clear understanding of system behaviour under fault conditions.

Table 4.1: Response of an OP-AMP based on L-G fault

Phase 1	Phase 2	Phase 3	Phase Status	Transmission Character
NF	NF	NF	No Fault	A
NF	NF	L2G	Phase 3 fault	B
NF	L2G	NF	Phase 2 fault	C
NF	L2G	L2G	Phase 2 & 3 fault	D

L2G	NF	NF	Phase 1 is fault	E
L2G	NF	L2G	Phase 1 & 3 fault	F
L2G	L2G	NF	Phase 1 & 2 fault	G
L2G	L2G	L2G	Phase 1, 2, 3 are fault	H

According to the OPAMP response, the microcontroller at the transmitter end issues a specific command to the receiver end microcontroller via a Zigbee WSN device. Upon receiving this command, the receiver's microcontroller determines what should be displayed on the LCD. Refer to Table 4.2 for details on characters transmitted by the transmitter's microcontroller and Table 4.3 for LCD status under various fault conditions. Additionally, Table 4.4 outlines the buzzer status clearly and concisely.

Table 4.2: Transmission character through Zigbee base on the phase status:

Phase 1	Phase 2	Phase 3	Phase Status	Transmission Character
NF	NF	NF	No Fault	A
NF	NF	L2G	Phase 3 fault	B
NF	L2G	NF	Phase 2 fault	C
NF	L2G	L2G	Phase 2 & 3 fault	D
L2G	NF	NF	Phase 1 is fault	E
L2G	NF	L2G	Phase 1 & 3 fault	F
L2G	L2G	NF	Phase 1 & 2 fault	G
L2G	L2G	L2G	Phase 1, 2, 3 are fault	H

Table 4.3: LCD status base on fault condition

Phase1	Phase 2	Phase 3	LCD Status			
NF	NF	NF	P1	P2	P3	LOC
			NF	NF	NF	1
NF	NF	L2G	P1	P2	P3	LOC
			NF	NF	L2G	1
NF	L2G	NF	P1	P2	P3	LOC
			NF	L2G	NF	1
NF	L2G	L2G	P1	P2	P3	LOC
			NF	L2G	L2G	1
L2G	NF	NF	P1	P2	P3	LOC
			L2G	NF	NF	1
L2G	NF	L2G	P1	P2	P3	LOC
			L2G	NF	L2G	1
L2G	L2G	NF	P1	P2	P3	LOC
			L2G	L2G	NF	1
L2G	L2G	L2G	P1	P2	P3	LOC
			L2G	L2G	L2G	1

Table 4.4: Buzzer status base on fault condition

Phase1	Phase 2	Phase 3	Buzzer Status
NF	NF	NF	OFF
NF	NF	L2G	ON
NF	L2G	NF	ON
NF	L2G	L2G	ON
L2G	NF	NF	ON
L2G	NF	L2G	ON
L2G	L2G	NF	ON
L2G	L2G	L2G	ON

V. CONCLUSIONS

The increasing complexity of modern electric power systems necessitates advanced fault detection and protection mechanisms to ensure reliable and efficient operation. Transmission line faults pose significant risks to infrastructure and service continuity, making rapid identification and isolation of affected sections critical. While microcontroller-based fault analysis and wireless sensor networks (WSNs) have contributed to improving fault monitoring, existing solutions still face limitations in accuracy, scalability, and real-time responsiveness. This research introduces a cloud-supported Zigbee-based monitoring system designed to enhance fault detection in transmission lines. By leveraging real-time data acquisition and wireless communication, the proposed system aims to provide a more responsive and efficient approach to fault identification. Simulation results in Proteus demonstrate the system's feasibility; however, further validation through hardware implementation and field testing is essential to fully assess its practical viability.

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