Utilizing Artificial Intelligence for Enhanced Fault Detection in Electrical Systems

[1]N. VARATHARAJAN, [2] A. MOHAMED FAZI, [3] P. SAKTHIBALAN, [4]K. DEVARAJAN, [5]S.SIVAGNANAM

[1,2]UG Student, Department of ECE, [3,4,5]Assistant Professors, Annamalai University, India,

Abstract: In this paper, we introduce an innovative approach for identifying multi-cycle incipient faults occurring in underground cables. Leveraging direct circuit analysis methodology, we present a series of location algorithms designed specifically for pinpointing related faults in typical medium voltage underground cable setups. These algorithms rely solely on fundamental voltages and currents, recorded at a single end, typically within a substation. With the integration of a relay, users can easily detect faults. Simulation studies demonstrate that our proposed fault location scheme, combined with state estimation, consistently delivers robust performance across various load and fault scenarios.

Keywords: SCADA (Supervisory Control and Data Acquisition), UART (Universal Asynchronous Receiver and Transmitter) Machine Learning, Smart Grids, Power Distribution, Fault Diagnosis, Intelligent Monitoring, Deep Learning, Predictive Maintenance, Energy Networks.

I. Introduction

The power industry is undergoing significant transformation, characterized by restructuring and deregulation, leading to a challenging and competitive environment. This evolution necessitates electric utilities to streamline operating costs and optimize the usage and maintenance of electrical assets while maintaining the quality and reliability of power delivery to customers. Underground distribution systems, crucial assets for electric utilities, supply power to end customers at low voltages. However, many system components, particularly underground cables, experience failure over time, often due to the deterioration of insulating materials. Studies indicate that cable failure rates in power systems tend to worsen with cable age.

Traditionally, scheduled inspections and regular maintenance activities were employed to assess system condition and reduce failure rates. However, the imperative for improvement has prompted a shift from scheduled to condition-based maintenance. This transition necessitates the development of new tools and methodologies for prioritizing and conducting predictive fault diagnosis and condition assessments of underground distribution systems, including power cables. Beyond compromising system reliability, cable failures incur substantial costs for utilities, as cable replacement or repair is a costly endeavor. Early detection of cable faults would undoubtedly offer significant benefits to utilities, enabling them to prevent catastrophic failures, unscheduled outages, and subsequent revenue losses.

II. Components and Software Used

AI-Microcontroller, Relay, UART, ADC, Step down transformer, Current sensor, Voltage sensor, SCADA, LCD display, Power supply, Relay driver.

3. Block Diagram

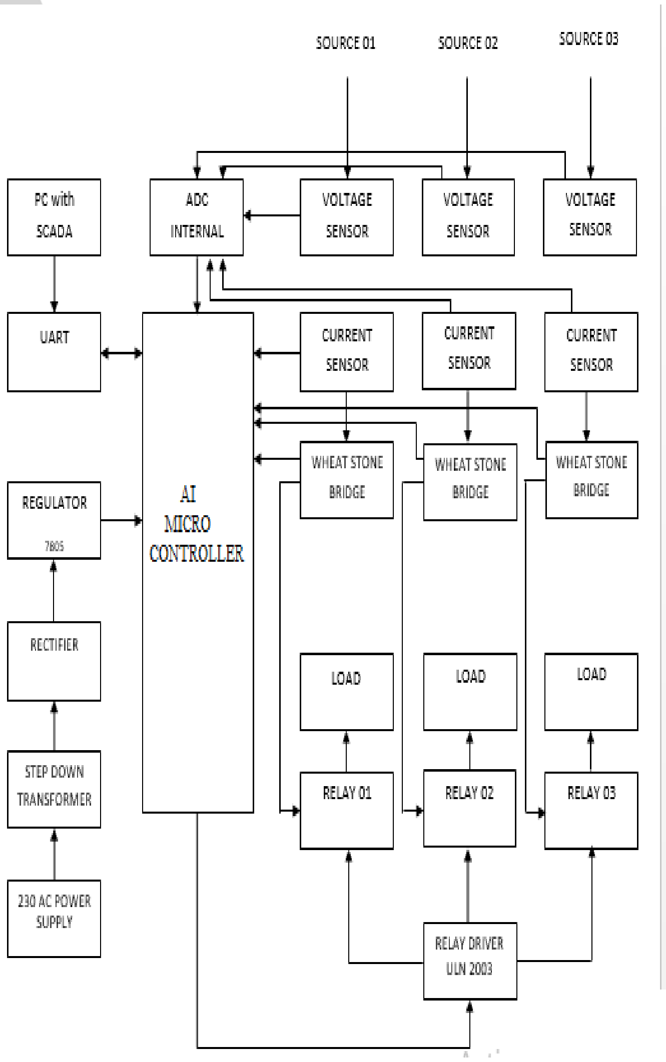

Figure 1: Block diagram of experiment

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4. Specification of Components

4.1 AT89s52 Microcontroller

Figure 2: AT89s52 Microcontroller

The AT89S52 microcontroller is a high-performance CMOS 8-bit chip with 8K bytes of in-system programmable Flash memory, designed for low-power operation. Manufactured using Atmel's advanced high-density nonvolatile memory technology, it adheres to the industry-standard 80C51 instruction set and pinout. Its on-chip Flash memory enables easy reprogramming either in-system or via a conventional nonvolatile memory programmer. With its combination of a versatile 8-bit CPU and in-system programmable Flash on a single chip, the AT89S52 offers a robust and cost-effective solution for numerous embedded control applications.

Standard features of the AT89S52 include 8K bytes of Flash memory, 256 bytes of RAM, 32 I/O lines, a Watchdog timer, two data pointers, three 16-bit timer/counters, a six-vector two-level interrupt architecture, a full duplex serial port, on-chip oscillator, and clock circuitry. Additionally, the AT89S52 employs static logic for operation down to zero frequency and supports two selectable power-saving modes. The Idle Mode halts the CPU while maintaining functionality of the RAM, timer/counters, serial port, and interrupt system. The Power-down mode preserves RAM contents but halts the oscillator, deactivating all other chip functions until the occurrence of the next interrupt or hardware reset

Features:

- Compatibility with MCS®-51 Products
- In-System Programmable (ISP) Flash Memory: 8K Bytes with Endurance of 1000 Write/Erase Cycles
- Operating Range: 4.0V to 5.5V
- Fully Static Operation: 0 Hz to 33 MHz
- Three-level Program Memory Lock
- Internal RAM: 256 x 8-bit
- Programmable I/O Lines: 32
- Timer/Counters: Three 16-bit
- Interrupt Sources: Eight

4.2 Current sensor

A current sensor is a device that detects electrical current (AC or DC) in a wire, and generates a signal proportional to it. The generated signal could be analog voltage or current or even digital output. It can be then utilized to display the measured current in an ammeter or can be stored for further analysis in a data acquisition system or can be utilized for control purpose.

Block diagram

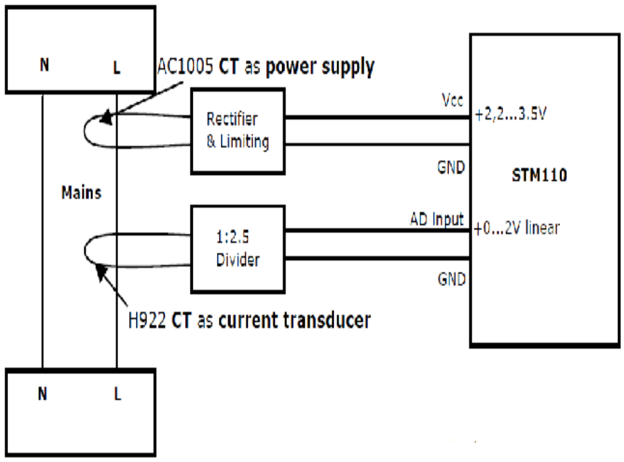

Figure 3: Block diagram for Current sensor

Specifications:

Ambient temperature range: -40°C to +85°C Storage temperature range: -40°C to +85°C Packaging trays temperature range: -40°C to +85°C Voltage tolerance: ±10%

Features:

- Measurement range: 1 to 10 Amps
- Termination material: Tin-silver over copper
- Minimum hole wall thickness: 0.5 mm
- Sensitivity can be improved by increasing primary turns

4.3 Voltage Sensor

Integrating various sensors with a controller like the Brain Stem GP 1.0 module usually entails conditioning or converting voltage levels to align with the controller's required range.

In numerous systems, A/D converters are employed to ensure the relevance of sensor values in program execution or data logging setups. These converters typically operate within a fixed voltage range, with 0-5V being the prevailing standard

Amplifying voltages:

Voltage amplification becomes necessary for sensors that generate small voltages, often as a result of converting physical energy such as acceleration or temperature into electrical signals. Due to the inefficiency of this conversion process, the resulting voltages may be minimal. To make these small voltages meaningful, they must be amplified to a usable level.

The process of amplification involves multiplying the sensor's output voltage to cover the full range of an A/D input or another interfaced circuit. For instance, if an accelerometer has a response of 312mV/g, and you aim to measure up to 2 gravity units (2g) using a 0-5V A/D converter, you would need to amplify the accelerometer's

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output voltage by a factor of approximately 16 to achieve the desired range and sensitivity in measurements.

One common method of voltage multiplication involves using an operational amplifier (Op Amp). The 741 Op Amp circuit, a widely available and easy-to-interface version, is commonly employed for this purpose.

Voltage Shifting:

Voltage shifting may be necessary for sensor data that are symmetrically generated about a common voltage, often ground. For instance, a motor acting as a generator might produce positive voltage when spinning in one direction and negative voltage when spinning in the other direction. Since most common A/D converters in microcontrollers operate within a 0-VCC range, sensors symmetric about the ground voltage reference must be shifted into this range.

Shifting involves adding or subtracting an offset from the original sensor voltage. For example, if a sensor produces -2 to 2V, adding 2V to the output would shift it into the 0-5V range suitable for reading with a common A/D converter.

Impurities in Conversion:

- The aforementioned conversions introduce impurities into the resulting signal, manifesting as noise, non-linearity, and other distortions of the original input voltage. It's crucial to minimize the number of stages and carefully sequence them to reduce errors. While testing and thoughtful design can mitigate these impurities to some extent, they cannot be entirely eliminated.
- A general rule of thumb applies to these introduced impurities: the more significant the change to the original voltage, the more impurities are introduced. For example, amplifying a signal by a factor of 100x would generally introduce more noise compared to an amplification of 2x

4.4 Relay:

Figure 4: Relay

A **relay** is an electrically A relay is an electrically operated switch. While many relays utilize an electromagnet to mechanically operate a switching mechanism, alternative operating principles are also employed. Relays find application where it's necessary to control a circuit using a low-power signal or where multiple circuits need to be controlled by a single signal. The earliest relays were utilized in long-distance telegraph circuits, where they repeated the incoming signal from one circuit and re-transmitted it to another. Relays were extensively employed in telephone exchanges and early computers for performing logical operations. A specific type of relay capable of handling the high power required for directly controlling an electric motor is known as a contactor. Solid-state relays manage power circuits without moving parts, instead utilizing semiconductor devices for switching.

Pin diagram:

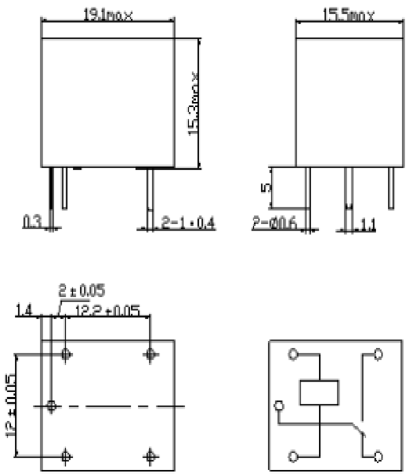

Figure 5: Pin diagram of Relay

Specification:

- Operating Voltage: 12 Volts DC Nominal.
- Current Draw: 30 milliamps.
- Minimum Pull-in Voltage: 9 Volts DC.
- Diode Protection Across Relay Coil.
- *Contact Ratings:*
- 7 Amps at 30 Volts DC
- 10 Amps at 125 Volts AC
- *Size: 1.1" X1.55 " (28mm X 39mm) Ea.*

Features:

- Switching capacity available up to 10A despite small size, designed for high-density PCB mounting.
- Recognized by UL, CUL, and TUV.
- Utilization of plastic material for high temperature resistance and improved chemical solution performance.
- Available in sealed types.
- Incorporates a simple relay magnetic circuit to meet low-cost mass production requirements.
- Characteristic impedance of 75 Ω.
- Bandwidth of 2.5 GHz.
- Insertion loss at 2.5 GHz less than 1.1 dB (typically less than 0.7 dB).
- VSWR at 2.5 GHz less than 1.6 (typically less than 1.3).
- Onboard relay counting feature.

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- Utilize NI Switch Executive for calibrating losses on each PXI-2558 channel.

4.5 LCD:

- Liquid Crystal Display (LCD) comprises rod-shaped tiny molecules sandwiched between a flat piece of glass and an opaque substrate. These rod-shaped molecules align into two different physical positions based on the electric charge applied to them.
- Application of electric charge causes them to align to block the light entering through them, while no charge results in transparency.
- The desired images appear when light passes through. This forms the fundamental concept behind LCD displays.
- LCDs are widely preferred due to their advantages over other display technologies. They are thin, flat, and consume minimal power compared to LED displays and cathode ray tubes (CRTs).
- Over recent years, LCDs have gained immense popularity for information display in numerous 'smart' appliances. They are typically controlled by microcontrollers, simplifying operation of complex equipment.

Pin diagram:

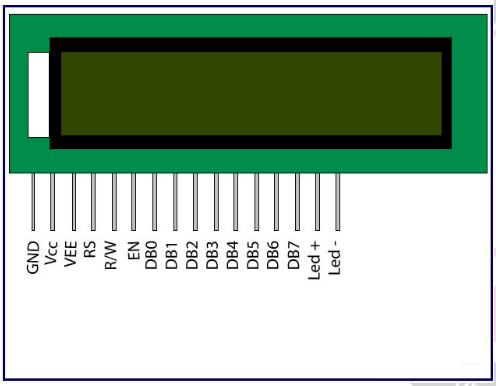

Figure 6: Pin diagram of LCD

Pin Description:

Pin No	Function	Name
1	Ground (0V)	Ground
2	Supply voltage; 5V (4.7V – 5.3V)	Vcc
3	Contrast adjustment; through a variable resistor	VEE
4	Selects command register when low; and data register when high	Register Select
5	Low to write to the register; High to read from the register	Read/write
6	Sends data to data pins when a high to low pulse is given	Enable
7	8-bit data pins	DB0
8		DB1
9		DB2
10		DB3
11		DB4
12		DB5
13		DB6
14		DB7
15	Backlight VCC (5V)	Led+
16	Backlight Ground (0V)	Led-

Table 1: Pin Description of LCD

Features:

- 16 Characters x 2 Lines.
- 5x7 Dot Matrix Character with Cursor.
- HD44780 Equivalent LCD Controller/Driver Built-In.
- 4-bit or 8-bit MPU Interface.
- Standard Type.
- Compatible with almost any Microcontroller.
- Competitive Pricing.
- Built-in controller (KS 0066 or Equivalent).
- +5V power supply (Also available for +3V).
- 1/16 Duty Cycle.
- Backlight (B/L) can be driven by Pin 1, Pin 2, Pin 15, Pin 16, or A.K (LED).
- Non-Volatile (N.V.) optional for +3V power supply.
- Contrast control.
- LCD backlight with current limiting.
- Overlay printed on both the top and the bottom

4.6 ADC:

Figure 7: ADC

The ADC0808 and ADC0809 data acquisition components are monolithic CMOS devices featuring an 8-bit analog-to-digital converter, an 8-channel multiplexer, and control logic compatible with microprocessors.

Pin diagram:

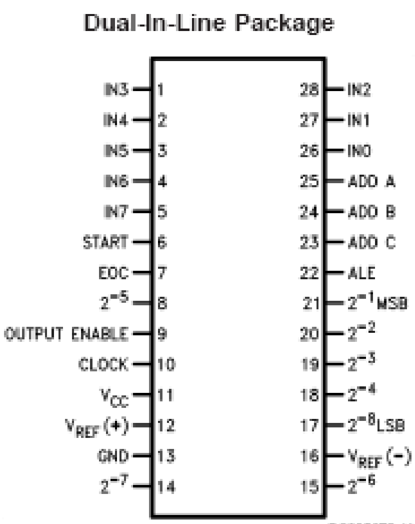

Figure 8: Pin diagram of ADC

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Features:

- Easy interface to all microprocessors
- Operates ratio metrically or with 5 VDC or analog span
- Adjusted voltage reference
- No zero or full-scale adjust required
- 8-channel multiplexer with address logic
- 0V to 5V input range with single 5V power supply
- Outputs meet TTL voltage level specifications
- Standard hermetic or molded 28-pin DIP package
- 28-pin molded chip carrier package
- ADC0808 equivalent to MM74C949
- ADC0809 equivalent to MM74C949-1.

Experimental setup for fault detection

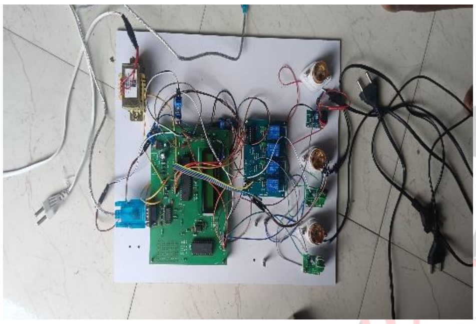
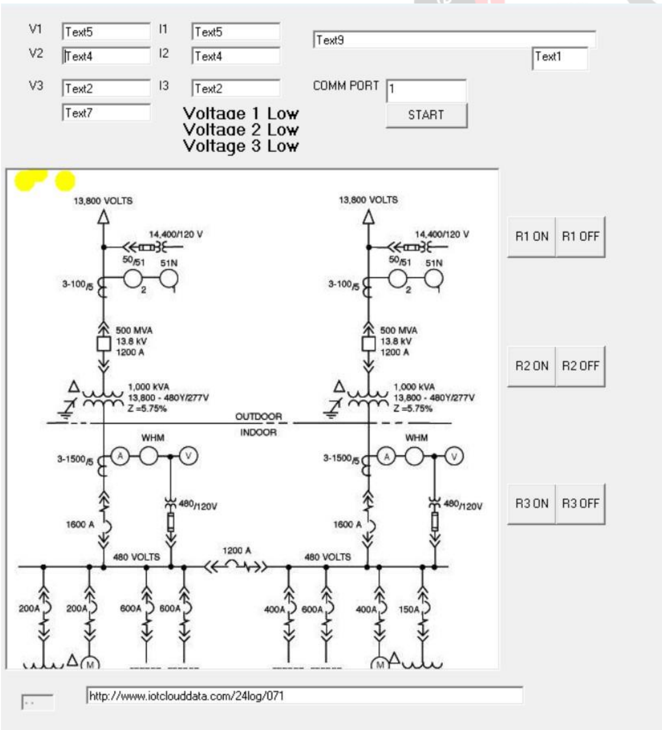
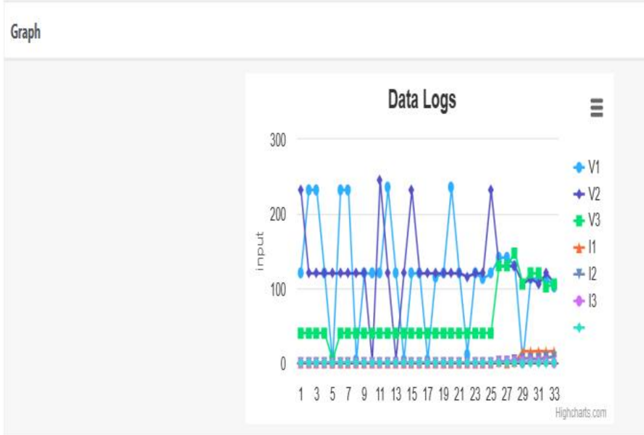


Figure 9: Experimental setup

III. RESULT ANALYSIS



In the above provided illustration, SCADA systems exhibit the capacity to oversee and regulate power distribution processes, encompassing the supervision of voltage and current levels within underground cables. Relay switches play a pivotal role in promptly and automatically addressing anomalies such as volta ge and current fluctuations, thereby upholding the integrity and dependability of the electrical infrastructure.



DATA	Logdate	LogTime
V1: 120 V2: 120 V3: 40 I1: 0 I2: 0 I3: 0 _Text13	04/27/2024	17:47:00
V1: 12 V2: 116 V3: 40 I1: 0 I2: 0 I3: 0 _Text13	04/27/2024	17:47:19
V1: 120 V2: 120 V3: 40 I1: 0 I2: 0 I3: 0 _Text13	04/27/2024	17:47:39
V1: 113 V2: 120 V3: 40 I1: 0 I2: 0 I3: 0 _Text13	04/27/2024	17:48:00
V1: 120 V2: 232 V3: 40 I1: 0 I2: 0 I3: 0 _Text13	04/27/2024	17:48:19
V1: 141 V2: 130 V3: 130 I1: 1 I2: 2 I3: 1 _Text13	04/27/2024	18:03:35
V1: 141 V2: 130 V3: 130 I1: 0 I2: 2 I3: 1 _Text13	04/27/2024	18:03:43
V1: 130 V2: 130 V3: 148 I1: 1 I2: 3 I3: 1 _Text13	04/27/2024	18:04:03
V1: 0 V2: 106 V3: 106 I1: 16 I2: 6 I3: 1 _Text13	04/27/2024	18:04:23
V1: 113 V2: 113 V3: 120 I1: 15 I2: 6 I3: 1 _Text13	04/27/2024	18:04:43

IV. CONCLUSION

Avoiding power outages requires prompt detection and resolution of issues with transmission lines. Utilizing machine learning (ML) for autonomous fault detection offers a direct and accurate approach to anticipate such failures. However, a major challenge in ML applications is the need for extensive training data, which is often difficult and costly to obtain, especially for accurate fault data. Moreover, the complexity of large data processing techniques poses challenges in identifying fault types. This study explores

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three distinct ML methodologies to address these challenges, all leveraging Kaggle data for training. These models are capable of detecting various types of faults. By comparing their performance, we can determine the most effective ML algorithm and its level of accuracy, which in turn can inform the development of improved fault detection methods in ML

V. FUTURE SCOPE

In the future scope, IoT technology is implemented to enable authorities to monitor and diagnose faults over the internet. The system detects faults utilizing a potential divider network installed along the cable. Whenever a fault occurs, causing a short between two lines, a specific voltage is generated based on the combination of resistors in the network. This voltage is then detected by the microcontroller and relayed to the user. The information provided to the user includes the corresponding distance to the fault. Furthermore, the microcontroller retrieves fault line data and displays it on an LCD screen, while simultaneously transmitting this data over the internet for real-time online display.

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