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IMPLEMENTATION OF DISTANCE PROTECTION RELAY USING PROGRAMMABLE LOGIC CONTROLLER FOR POWER SYSTEM FAULT DETECTION

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ABSTRACT

This paper presents the implementation of a distance protection relay using a programmable logic controller (PLC). Power systems widely use distance relays to detect and isolate faults based on the impedance between the relay and the fault location. By leveraging a PLC, the design benefits from flexibility, real-time processing, and integration with a monitoring system. The paper is mostly about using voltage and current inputs to figure out impedance, finding fault zones, and putting protection logic into place using the Function Block Diagram (FBD) in PLC programming environments. The proposed system is reliable, cost-effective, and easy to modify for various protection schemes.

KEYWORDS

Protection, Distance relays, PLC, Zone, FBD, and Impedance.

1. INTRODUCTION

Transmission lines are crucial in the electrical distribution system, transferring power between generation and load. Tightly interconnected, they operate at voltage levels ranging from 66 kV to 765 kV. However, factors such as deregulation, economics, and environmental requirements force utilities to operate near their limits. Transmission protection systems aim to detect and isolate faults (Henna et al. 2013). Distance protection is the most widely used method to protect transmission lines. Three generations of protective relays have primarily evolved in the industry: electromechanical (EM), solid-state (SS), and digital (A. Norouzi, 2022). Moving pieces that sensed abnormal changes in voltage or current produced the mechanical torque of EM relays. Static substitutes for EM relays were SS relays, which were based on analogue electronic components, including transistors, diodes, and other electronic parts. Digital numeric relays, which are based on microprocessor technology and sequential software programmability, currently make up the majority of commercial relays (Mia, Shojib, et al, 2025), (Alaa, Ruqaya, et al 2024), and (Alhusseny, Ahmed, et al, 2024). The operational speed of the designs is intrinsically limited by the sequential nature of software architecture. A distance relay based on PLC combines the traditional concept of distance protection with modern automation technologies. The PLC is used to implement and control the logic needed for distance protection in this work. This gives the power system protection scheme more flexibility, programmability, and control.

2. RELATED WORKS

There are many previous studies and research on the implementation of the digital distance relay based on variable controllers: The authors of (F. M. A. Hussain et al., 2003) present an algorithm for short transmission line protection using a microprocessor-based distance relay. The relay's characteristic is determined by comparing voltage and current at the relay location, determining the impedance between the relay and fault point. The signal is converted to digital and used to decide if a fault exists. The authors of (Henna et al., 2013) describe a new method that uses logic controls to stop events that are caused by zone 3 elements of faraway relays being overloaded on the transmission line. The paper (Wang et al., 2013) suggests using the field-programmable gate array (FPGA) to implement a digital distance protective relay that is real-time and low-latency. Utilizing the FPGA's intrinsic hard-wired architecture, the suggested hardware distance relay design is completely pipelined and paralleled to achieve minimal latencies in a variety of relay modules that are written in the textual VHDL language. In (M. R. D. Zadeh et al., 2009), the implementation of a distance protective relay in a field-programmable analogue array (FPAA) is illustrated. (Priyanka D. et al., 2023) introduce a microcontroller-based relay hardware that enables real-time fault detection and isolation of faulty sections in transmission line simulator models. Key features include zone selection, adjustable set point values, and accurate display of fault types.

The PLCs are designed for industrial applications; they possess the requisite certifications and environmental standards, and they are dependable, scalable, and adaptable. Consequently, PLC technology is regarded as a superior option for protective systems, exhibiting great dependability, programming flexibility, and robust adaptability to various severe conditions (Ahmed, 2022), and (Omar et al., 2025). Motivated by the preceding literature review, this study presents a revolutionary low-cost distance relay controller, constructed and theoretically studied on PLC.

3. DISTANCE PROTECTION

Distance protection is a widely used method for protecting transmission lines, based on local voltage and current measurements and the relay's response to the fault location. Local voltage and current measurements provide the basis of distance relaying's basic idea, in which the relay reacts to the impedance between the relay terminal and the fault location as shown in Fig. 1.

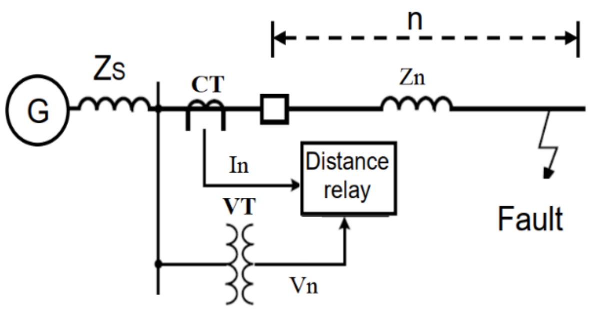


Fig. 1. Distance relay connected to line through instrument transformer

Line impedance is the main factor for the setting of distance relays operating zones as shown in Fig. 2. During a fault, the impedance reduced to the tripping zone and as a consequence, the relay will send trip signal (E. Henna, 2015). Each zone has its own time delay, and distance relays are generally designed to provide protection in multiple forward zones and one reverse zone. Transmission line faults are meant to be cleared by circuit breakers based on their location zones and after their zone delayed time. Through instrument transformers, a power line is connected to the distance relay (Kamal et.al, 2024).

Distance relays have one or more time-delayed zones in addition to instantaneous directional Zone 1 protection. Zone 1 is designed to cover only 80–85% of the protected line since the tripping signal it produces is quick and shouldn't extend as far as the busbar at the end of the first line. busbar at the very end. The remaining 20–15% offers a margin of safety to guard against mistakes brought about by the line impedance calculations and the current and voltage transformers. Operating in t2 seconds, Zone 2 protects the 20–15% at the end of the line. At least 120% of the protected line impedance should be the reach level for Zone 2 protection. Zone 3 was set to reach 100% of the impedance of the first two lines and 20% of the third line and to operate the Zone 3 element with time delay t3 (Abdallah. R. Alzyoud, et.al. 2022), (Ayache Mati et al., 2015).

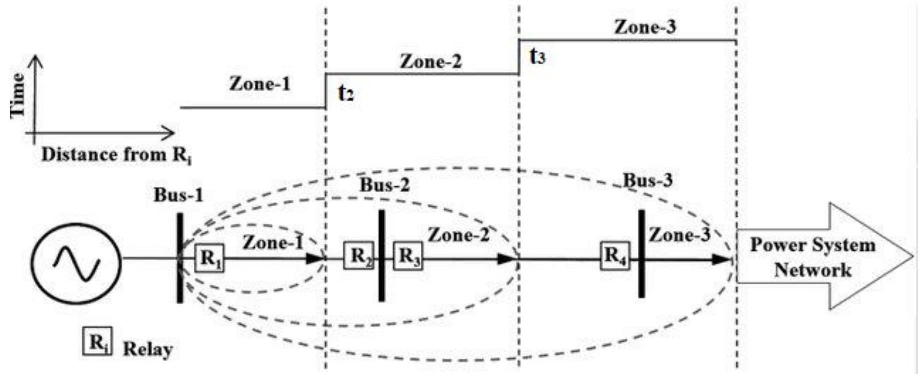


Fig. 2. Zones of the distance relay

4. ARCHITECTURE OF THE PROPOSED WORK

Fig. 3 shows the block diagram of the proposed system. It has four main parts: the first two are CT and VT; the second is signal conditioning circuits that change current and voltage signals into voltage signals that can be fed into the PLC unit; the third is the PLC itself; and the fourth is the CB.

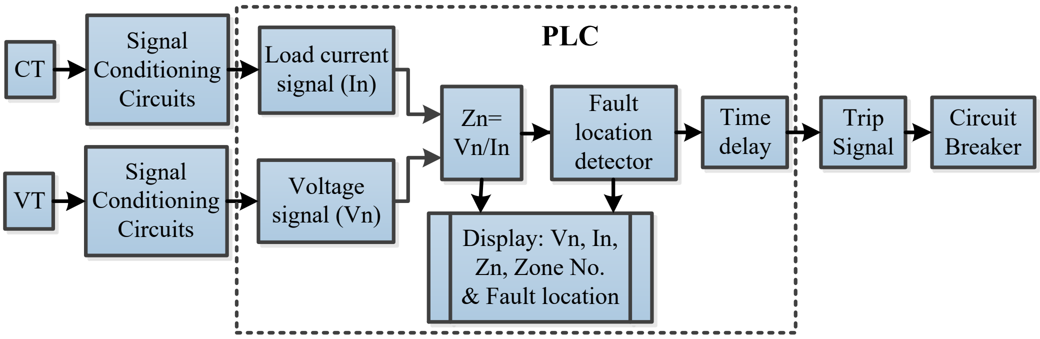


Fig. 3. General block diagram of the proposed protection scheme

CT develops a lowered current that is precisely proportional to the high current in the power supply. Actually, the PLC cannot detect the current signal. So, a shunt resistor (Rsh) (also known as a burden resistor) is connected across the CT's secondary windings. This resistor will not only complete the closed loop but will also transform the CT's current signal to a voltage signal in accordance with Ohm's Law. Therefore, the voltage signal results from dividing the primary load current by the turn's ratio and multiplying it by the resistor's value. Signal conditioning circuits are used to normalize the CT and VT converter voltage signals to the PLC analogue voltage range that will be measured. Each signal conditioning circuit includes a precision rectifier circuit based on operational amplifiers see Fig.4. The first operational amplifier rectifies the AC voltage, which is subsequently amplified by the second operational amplifier. This circuit offers a precise way for generating a DC signal from an AC source, addressing potential difficulties such as diode voltage drops, temperature, and current variations.

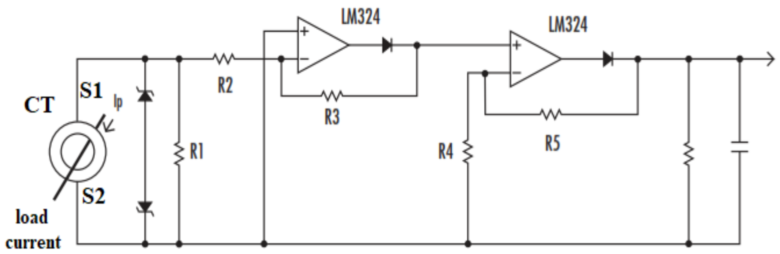


Fig. 4. Signal conditioning circuit for CT

5. SOFTWARE IMPLEMENTATION OF THE PROPOSED ALGORITHM

To represent the function block diagram for a distance relay based on PLC, visualization of the sequence of operations and interactions between the components of the system is required, so the flowchart of the proposed control system of the distance relay shown in Fig. 5 was employed to implement the controller.

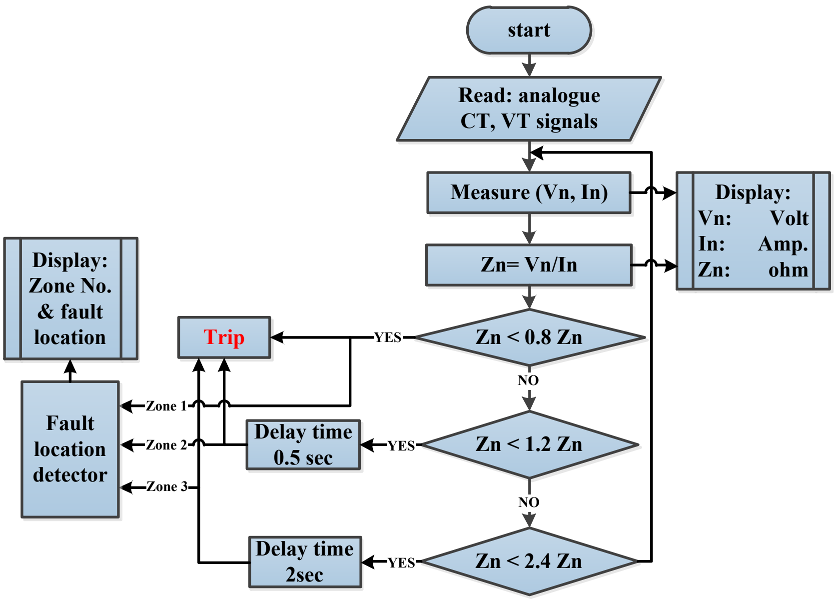


Fig. 5. Flow chart of proposed distance relay

The FBD typically focuses on the logic implemented within the PLC, showing how input signals are processed to perform distance protection (see Fig. 6). 'LOGO! Soft Comfort V8.3.0' software environment was employed in the implementation of the work.

- Two of the PLC's input modules (AI3 and AI4) were utilized; they are of the analog type, each one used for receiving the calibrated signal from VT and CT, respectively.

- Two of the mathematic instruction blocks (B005, and B012) were employed for calibrating the signals of the VT and CT to the terminal voltage (Vn) and load current (In) values. Then, a mathematical instruction block (B013) was used to determine the impedance by dividing the Vn by In.
- Two of the analogue threshold trigger blocks (B008, B026, and B028) were employed for selecting the zone fault operation depending on the value of the measured impedance.
- Output block Q1, which represents one of the output terminals of LOGO!, was used as the trip signal of the distance protection relay when the fault occurs.
- The mathematical instruction block B004 was employed for detected fault location according to the impedance value.
- Two of the retentive on-delay blocks (B031 and B032) were used to delay the trip signal 0.5 sec when fault in zone 2 detected and 2 sec when fault in zone 3 detected.
- Four of the message text blocks (B007, B010, B001, and B011) were used for displaying the measuring parameters (In, Vn, and Zn) in the first one and the fault distance for zones 1, 2, and 3 in the other blocks, respectively.
- The digital input module I2 was used to manually reset the distance relay.
- There are many other blocks that were used as auxiliary blocks to accomplish the proposed control system.

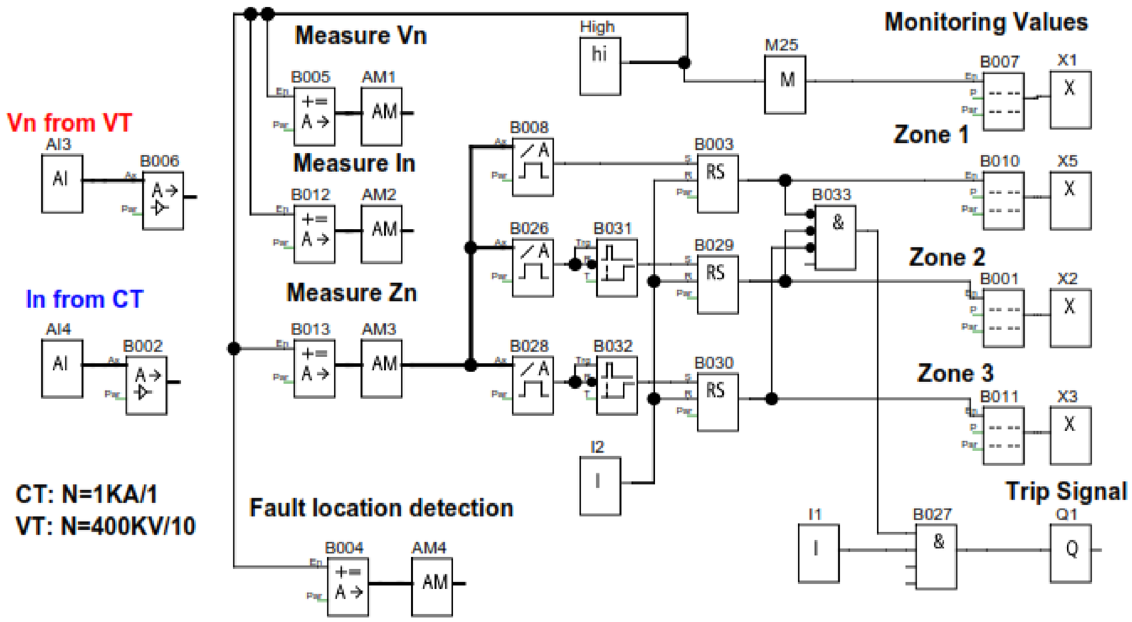
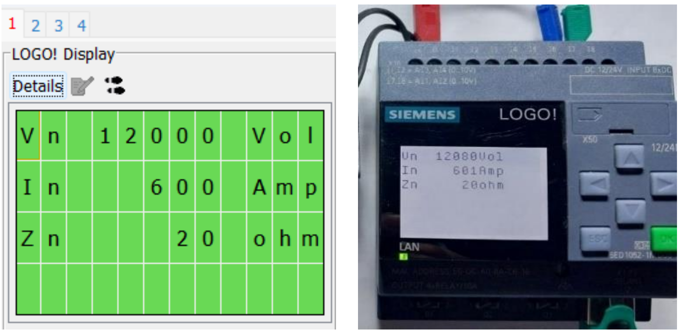


Fig. 6. Function block diagram for implementation the proposed controller of distance relay

6. EXPERIMENTAL RESULTS:

The suggested functional diagram language program underwent testing with the LOGO! Soft Comfort Simulation feature prior to being downloaded to the LOGO! 8. The instantaneous data of the instrument transformers of the distance relay, including the measured terminal voltage Vn via voltage transformer, load current In via current transformer, and the impedance of the transmission line, was displayed in the first message text and is shown in the PLC display unit as shown in Fig. 7. This data for the line under normal operation before occurring any faults (terminal voltage of the transmission line (nominal): Vn=12KV, the load current is 600A, thus the total line impedance is equal to 20 Ω. The transmission line length is 100 km (Impedance per km: 0.2 ohm/Km).



Simulation **(b) Experimental**

Fig. 7. The text message for normal operation condition

There are three types of faults at each of the fault zones that are listed in three case studies:

Case study 1: The load current increased up to 750 A, thus the fault impedance (up to the fault point): 12 kV/ 750 A= 16 ohms. Fault location (DS) equal to 16 ohms /0.2 ohms/km = 80 km (in Zone 1) as shown in Fig. 8 and Fig. 9. The time of the trip was zero sec.

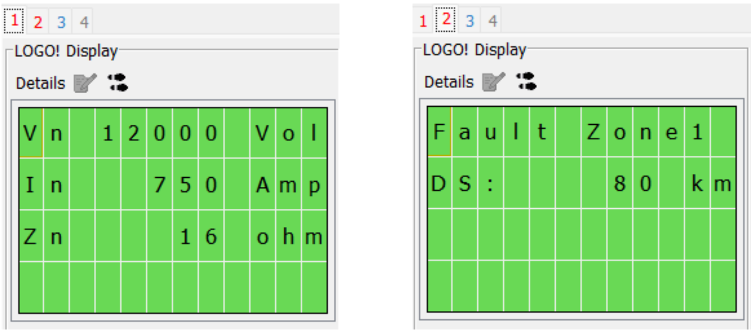


Fig. 8. Simulation Results: Text message of the faults that occur in Zone 1

Fig. 9. Experimental Results: Text message of the faults that occur in Zone 1

Case study 2: In this case, the load current increased up to 497 A, thus the fault impedance (up to the fault point) is equal to 24 ohms. Fault location DS is equal to 16 ohms /0.2 ohms/km = 120 km (in Zone 2) as shown in Fig. 10, and Fig. 11. The time of the trip was 0.8 sec.

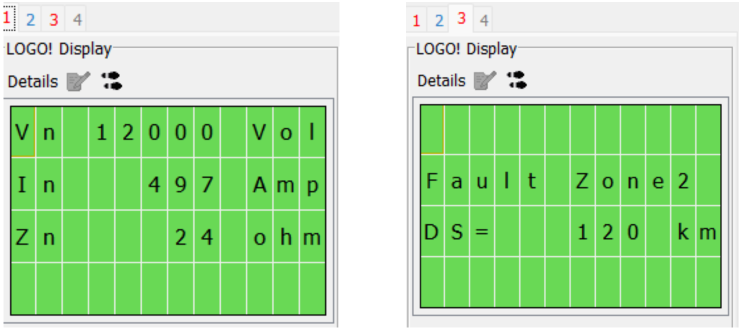


Fig. 10. Simulation Results: Text message of the faults that occur in Zone 2

Fig. 11. Experimental Results: Text message of the faults that occur in Zone 2

Case study 3: Current increased: 252 A, Fault impedance (up to the fault point): 12 KV/ 250 A= 48 ohms, Fault location (DS): 48 ohms /0.2 ohms/km = 240 Km (in Zone 3) as shown in Fig. 12, Fig. 13. The time of the trip: 2 sec.

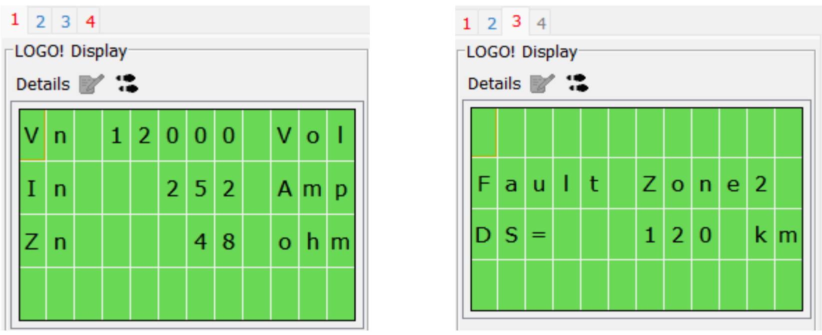


Fig. 12. Simulation Results: Text message of the faults that occur in Zone 3

Fig. 13. Experimental Results: Text message of the faults that occur in Zone 3

The value of the protection relay in zone 1 from 5km to 99km, the value of zone 2 from 101 km to 199km, and the value of the protection relay in zone 1 from 201 km to 240 km.

7. CONCLUSIONS

The FBD represents a simple and effective way to implement distance relay protection using a PLC system, giving operators flexibility and control over power system protection. Future work can easily expand on the proposed PLC-based work by incorporating another feature into the control design. In addition, the time and calibrated setting of the zones in the proposed design can easily be changed. Also, a new version of PLC, the Step 7 series, can be used to implement the other types of distance relay.

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8. REFERENCES

A. Norouzi, (2022) 'The shape of a zone: distance relaying technology from electromechanical to digital,' in IEEE Industry Applications Magazine, Vol. 28, no. 2, pp. 78-88, March-April 2022, https://doi.org/10.1109/MIAS.2021.3114662

Abdallah. R. Alzyoud, et.al. (2022), 'Modeling and simulation of distance protection for transmission lines with different grounding methods', International Journal of Power Systems, Vol. 7, pp. 86-100.

Ahmed M. T. Ibraheem, (2022), 'Design an industrial robot arm controller based on PLC' PRZEGLĄD ELEKTROTECHNICZNY, Vol. 2022, No 7, PP 105-109. https://doi.org/10.15199/48.2022.07.18

Alaa, Ruqaya, et al. "Object Detection Algorithms Implementation on Embedded Devices: Challenges and Suggested Solutions". *Kufa Journal of Engineering*, vol. 15, no. 3, Aug. 2024, pp. 148-69, https://doi.org/10.30572/2018/KJE/150309.

Alhusseny, Ahmed, et al. "Graphite Foam Structures as An Effective Means to Cool High-Performance Electronics". *Kufa Journal of Engineering*, vol. 15, no. 2, May 2024, pp. 39-60, https://doi.org/10.30572/2018/KJE/150204.

Ayache Mati, and BEGBAGUI Merouane, (2015) 'Digital distance relay modeling and testing using LabVIEW and MATLAB/Simulink', M.Sc. Thesis in Electrical and Electronic Engineering, University of Boumerdes, https://doi.org/10.13140/RG.2.1.2013.4647

E. Henna, Mohamed Younes, Sayed A. Nagy, & Ahmed Fahmy M. Bendary, (2015) 'Using logic controls in cascaded events prevention for pilot distance relay zone three.' CiiT International Journal of Programmable Device Circuits and Systems, Vol. 7, No. 6, pp. 178-184.

F. M. A. Hussain, N. Khan, N. Mariun and S. Mahmod, (2003), 'Microprocessor-based distance relay,' Proceedings. National Power Engineering Conference. PECon 2003., Bangi, Malaysia, 2003, pp. 43-46, https://doi.org/10.1109/PECON.2003.1437414

Henna, Mohamed Younes E., and Sayed A. Nagy, (2013) 'Prevention of cascaded events of distance relay zone three using logic controls.' Conference Papers in Science. Vol. 2013. no. 1. Hindawi Publishing Corporation. http://dx.doi.org/10.1155/2013/198021

Kamal Mohammed Mejdhab, Ali N. Hamoodi "Design and Simulation of Three Zones Distance Protection Scheme", NTU-JET, vol. 3, no. 4, pp. 26–34, Dec. 2024, https://doi.org/10.56286/ntujet.v3i4.1064.

M. R. D. Zadeh, T. S. Sidhu, and A. Klimek, (2009), 'Field-programmable analog array-based distance relay,' IEEE Trans. Power Del., vol. 24, no. 3, pp. 1063–1071. https://doi.org/10.1109/TPWRD.2009.2013403

Mia, Shojib, et al. "Integrating Renewable Energy with Internet of Things (IoT): Pathways to a Smart Green Planet". *Kufa Journal of Engineering*, vol. 16, no. 1, Feb. 2025, pp. 361-04, https://doi.org/10.30572/2018/KJE/160121.

Omar A. Younis, and Ahmed M. T. Ibraheem, (2025)'Implementation of an MPPT Technique for Solar PV Systems Based on a Programmable Logic Controller', IOP Conference Series: Earth and Environmental Science, Vol. 1440, RERA 2024, Thi-Qar, Iraq, 2025, https://doi.org/10.1088/1755-1315/1440/1/012003

Priyanka Deshpande, Amaraja Dhamangaonkar, and Vikram Sathe, (2023) 'Hardware development of microcontroller based impedance relay with interconnection to TLS',YMER , Vol. 22, No. 1.

Wang, Yifan, and Venkata Dinavahi (2013), 'Low-latency distance protective relay on FPGA.' IEEE Transactions on Smart Grid, Vol. 5, issue 2, pp. 896-905, 2013. https://doi.org/10.1109/TSG.2013.2278697