

Smart Transmission Line Protection System with Transformer Monitoring and Power Theft Detection

Md Shawon^{a,*}, Md Al Araf^a, Sohan Molla^a, Supto Kumar Ghosha, Utsa Sen^a, Md Sajib Nowjha^a

^aBangladesh University of Business and Technology (BUBT), Dhaka, Bangladesh.

Keywords:

Power theft, current sensor, ACS712, Arduino, GSM modules

* Corresponding author:

Md Shawon 
E-mail: shawon.bubt.bd@gmail.com

Received: 4 September 2024

Revised: 10 October 2024

Accepted: 18 November 2024



ABSTRACT

The rapid expansion of power distribution networks demands robust transmission line protection systems to maintain a continuous electricity supply and safeguard infrastructure. This project proposes an integrated system that combines transformer protection with an innovative power theft detection approach. It enhances power grid reliability by offering real-time monitoring of transformers and transmission lines, allowing quick fault detection and isolation to prevent large-scale outages. Additionally, the system addresses power theft, a growing concern that leads to significant financial losses and grid instability. Using current and voltage sensors, it identifies abnormal conditions such as short circuits and overcurrent, and incorporates an intelligent theft detection algorithm to track unauthorized usage by analyzing discrepancies between power recorded at substations and end-user consumption. Upon detecting a fault or theft, the system triggers an alarm and isolates affected segments, thus enhancing safety and reducing equipment damage. This solution is cost-effective, scalable, and suitable for urban and rural applications, improving grid security and operational efficiency. By tackling both technical faults and non-technical issues like theft, this system provides reliable, real-time fault management and theft prevention, setting the stage for future enhancements in grid optimization and resilience.

© 2025 Journal of Sustainable Development Innovations

1. INTRODUCTION

In modern power grids, efficient energy transmission and the prevention of system faults are critical. Transmission lines, responsible for long-distance energy transfer, require robust protection against faults such as

short circuits and overloads. Additionally, power theft in Bangladesh remains a pervasive issue, contributing to financial losses and degraded power quality [1]. This study aims to design a system that integrates fault detection, transformer protection, and real-time power theft detection to improve the overall efficiency

of the electric grid [2]. Estimating the annual losses due to transmission inefficiencies and power theft in Bangladesh requires analyzing both technical losses (caused by inherent issues in transmission systems) and non-technical losses (such as theft). Technical losses include energy dissipation in the form of heat due to the resistance of transmission lines, transformers, and other equipment. The typical range of transmission and distribution (T&D) losses in developing countries is between 8-15% of the total electricity generated. Global Estimates according to the World Bank, T&D losses in Bangladesh were approximately 12% in 2021(Report) [3]. Impact on Bangladesh with an annual electricity generation of 82 TWh (terawatt-hours) in 2022, a 12% loss means 9.84 TWh of electricity was lost due to technical inefficiencies. Non-technical losses (NTLs), primarily caused by power theft, meter tampering, and illegal connections, are more difficult to measure but contribute significantly to total losses. Power Theft studies suggest that power theft contributes between 5-10% of total electricity losses in Bangladesh. If we take a conservative estimate of 7%, this would account for an additional loss of 5.74 TWh annually. Combining both technical and non-technical losses, Bangladesh's power sector loses approximately 20-22% of its total generated electricity each year. In 2022, this amounts to around 15.58 TWh of electricity, which represents a significant financial loss. Given that the cost of electricity in Bangladesh is around \$0.09 USD per kWh, the financial loss from these inefficiencies and theft is approximately: $15.58 \text{ billion kWh} \times \$0.09 = \$1.4 \text{ billion USD}$ annually [4]. Given the high level of technical and non-technical losses, the development and deployment of systems like the Transmission Line Protection System with Transformer and Power Theft Detection can significantly mitigate these losses. Such systems can, detect faults and theft in real-time using current sensors and GSM modules, these systems can immediately alert operators to issues, allowing for quicker responses to minimize energy loss. Improve transformer protection transformer monitoring can reduce the frequency of costly failures and extend equipment life. Prevent power theft the real-time detection of power theft through anomalies in current flow and voltage drops can help curb unauthorized usage and reduce revenue losses. The hardware components

include current sensors, which detect magnetic fields or voltage drops induced by current flow through a conductor and produce an output signal proportional to the current, often processed to determine the current value [5]. The IC 7805 module, incorporating the LM7805 voltage regulator and additional components like capacitors for stability and noise reduction, is widely used in electronic projects to provide a reliable +5V power supply for microcontrollers, sensors, and other 5V components. Control devices, such as relays or circuit breakers, disconnect faulty sections, while remote terminal units (RTUs) enable remote monitoring and control. A centralized SCADA system offers centralized monitoring, control, and user interaction via Human Machine Interfaces (HMI). Power supply continuity is maintained with Uninterruptible Power Supply (UPS) systems, especially during outages. Alarms and notification devices alert operators in case of faults or power theft. Temperature sensors, essential in applications ranging from industrial processes to consumer electronics, provide accurate temperature monitoring, often requiring calibration for precise control [6] [7]. The "Transmission Line Protection System with Transformer and Power Theft Detection" is designed to address critical issues in modern power distribution networks, including equipment safety, fault detection, and power theft prevention. By integrating sensors, microcontrollers, and communication modules, the system monitors the condition of transformers and transmission lines, identifying faults like short circuits and overloads in real-time. It also combats power theft by detecting discrepancies in energy usage patterns. When issues such as theft or faults occur, alarms are triggered, and the system isolates the affected segment to minimize damage and downtime. This solution improves both the security and efficiency of power grids, particularly in regions like Bangladesh where power theft is a significant challenge.

2. LITERATURE REVIEW

The literature on transmission line protection systems and power theft detection highlights significant advancements in ensuring reliable energy distribution. Studies emphasize the need for real-time monitoring and response mechanisms, with a focus on mitigating

technical losses such as short circuits and overloads, as well as non-technical losses like power theft. We have demonstrated the financial impacts of power theft, particularly in developing countries. Existing systems, such as those incorporating IoT and SCADA technologies, provide essential fault detection and theft prevention capabilities, though cost-efficiency and scalability remain key challenges. Innovations such as smart meters, current sensors, and automated response systems have contributed to more effective grid management by identifying and isolating faults and unauthorized power usage in real time [8]. Despite these advances, there is ongoing research into improving the cost-effectiveness and accuracy of such systems, with a focus on incorporating machine learning and predictive algorithms for enhanced grid protection and efficiency. The field of transmission line protection and power theft detection has evolved significantly with the integration of advanced technologies like IoT, smart sensors, and real-time monitoring systems. Several studies have addressed the critical issues of technical and non-technical losses in power grids, with particular focus on developing countries where power theft remains a major concern. According to integrating fault detection mechanisms with power theft detection offers a more comprehensive approach to safeguarding power networks. Traditional methods, such as manual inspections and basic circuit protection, have proven insufficient for managing modern, complex power grids. The literature suggests that the incorporation of current and voltage sensors, combined with automated systems like SCADA and GSM modules, can enhance fault detection accuracy and theft identification [9]. The highlighted the importance of identifying power consumption discrepancies as a means of detecting theft, proposing the use of smart meters that communicate anomalies directly to control centers. Other studies have proposed the use of machine learning algorithms to predict faults before they occur, which could further improve response times and reduce the frequency of outages. The overall trend in the literature points to the need for scalable, cost-effective solutions that can be easily deployed in both urban and rural areas, with a focus on improving energy efficiency, reducing financial losses, and ensuring the stability of power grids [10].

3. METHODOLOGY

The system for transmission line protection and power theft detection consists of several key components. Sensors deployed along transmission lines monitor electrical parameters like current and voltage, while transformer sensors track temperature, oil levels, and winding currents. Power theft detection is enabled by smart meters and current sensors that detect unauthorized consumption. Data collected from these sensors is sent to a microcontroller (Arduino), where it is processed and analysed to detect faults such as short circuits or abnormal current flow. The system can also pinpoint the location of faults for quick isolation. Transformer protection includes temperature and oil monitoring, with alerts triggered when conditions exceed safe limits. Power theft is detected through current discrepancies, with alerts sent to authorities and displayed on an LCD. The system uses an Arduino and GSM module for control and communication, with relays isolating faulty sections or disconnecting power when necessary. Automated responses such as fault isolation and transformer cooling are triggered in critical situations. All operational data is logged for analysis, and real-time alerts are sent to operators for quick action. The hardware setup includes current sensors, Arduino Uno, temperature sensors, an LCD display, and relays to manage the system.

3.1 SYSTEM FLOWCHART

The flowchart illustrates the program's algorithm, with the system flowchart presented in Figure 1. Software design is essential for the system's functionality, as it cannot run without it. An algorithm was created to allow Arduino controllers to process inputs and react appropriately. The project uses C as its programming language, with the C compiler facilitating communication between the current sensor, Arduino, PC, and other interfaces within the system. The Arduino, powered by the programmed software, functions as the system's brain, comparing the necessary values in its specific language.

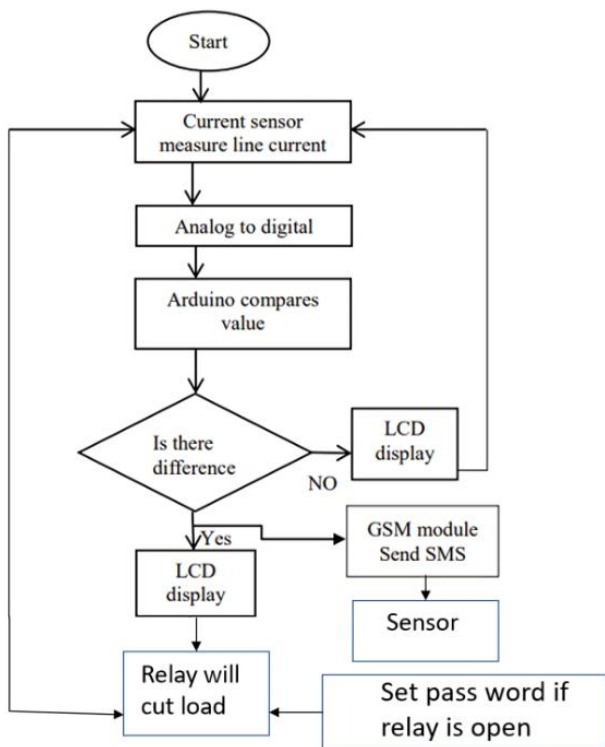


Fig. 1. Flowchart description of the system.

3.2 SYSTEM DESIGN

The system design for the transmission line protection and power theft detection in Bangladesh includes a power supply that powers the control unit (Arduino AT mega 328), which manages data from sensors monitoring critical parameters like current and voltage. The sensor data is compared by the comparator circuit to detect discrepancies such as voltage drops or unauthorized consumption. A voltage change detection block identifies issues like theft or faults, while a display unit shows real-time system status. The system monitors and protects two electrical loads (Load-1 and Load-2), taking corrective action when irregularities are detected [11].

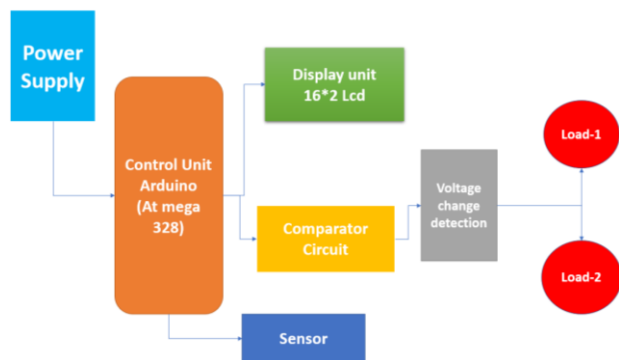


Fig. 2. Block diagram of the system.

The system design diagram for the transmission line protection system with transformer and power theft detection in Bangladesh can be explained as follows. The system consists of several key components working together to ensure efficient monitoring and protection of electrical loads. The power supply provides energy to the entire system, enabling components like the Arduino AT mega 328 control unit to function. This control unit acts as the central processor, managing tasks such as reading sensor data, analyzing it, and controlling other elements like the display unit and comparator circuit. The sensor monitors vital metrics like voltage and current on the transmission line, helping to detect irregularities such as voltage drops or theft. A comparator circuit compares the sensor data to predefined thresholds to identify discrepancies. The voltage change detection block further monitors for fluctuations that may signal power theft or faults. Real-time system information, including voltage levels and alerts, is shown on a 16x2 LCD display. The system monitors two electrical loads (Load-1 and Load-2), taking necessary action to protect them if any irregularities are found. This design aims to detect power theft and protect the transmission lines by monitoring parameters and ensuring that corrective actions are taken in response to irregularities [12]. The working principle of a "Smart Transmission Line Protection System with Transformer & Power Theft Detection" involves the integration of various sensors, communication systems, and control mechanisms to ensure the reliable and secure operation of electrical power transmission lines. A 3-phase transmission line we are used a 220v power supply and also used three single-channel relay modules. These modules are commonly used to control high-voltage devices with low-voltage signals, such as those from a microcontroller like an Arduino. The relay acts as a switch, allowing an external circuit to control higher power devices such as motors, lamps, or other electrical loads while maintaining electrical isolation between the control signal and the load. Transmission Line Sensors, Current and voltage sensors are deployed along the transmission lines to continuously monitor the electrical parameters. Transformer Sensors, Sensors on transformers monitor parameters like temperature, oil level, and winding currents. Power Theft Detection Sensors, Sensors or smart meters are used to monitor power consumption patterns and identify anomalies.

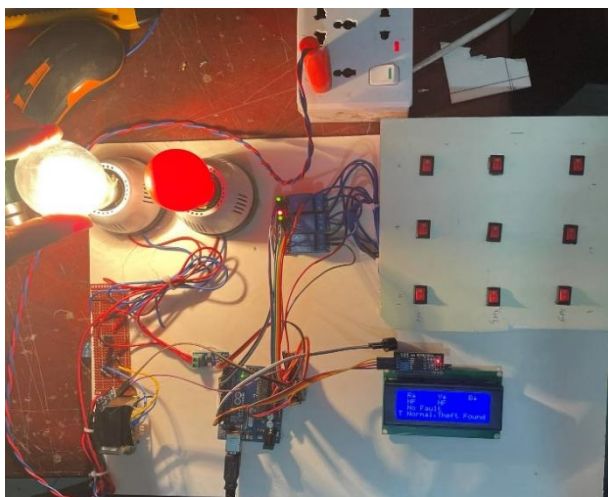


Fig. 3. Hardware set up “Transmission line protection system with Transformer & power theft detection”.

The sensors collect real-time data, which is then sent to microcontrollers or PLCs for processing. Arduino processes the acquired data to identify normal operating conditions and detect any abnormalities or faults. Algorithms analyze the processed data to detect faults on the transmission line. This could include short circuits or abnormal variations in current and voltage. The system determines the location of the fault by comparing the data from different sensor points. In the case of potential issues with transformers, the system triggers early warnings or automatic responses. This may involve adjusting load distribution, activating cooling mechanisms, or isolating the transformer to prevent further damage. Algorithms analyze power consumption patterns to identify anomalies that may indicate power theft. If power theft is detected, the system sends alerts to the central control system for further action. The processed data, fault alerts, and power theft notifications are transmitted to a central control system using communication modules such as GSM-module, GPRS, or IoT. The central control system, often implemented through SCADA, receives and monitors the real-time data. Operators can view the status of the transmission lines, transformers, and power consumption patterns through a graphical user interface (HMI). In critical situations, the system may trigger automated responses, such as isolating faulty sections of the transmission line or disconnecting power in the case of power theft. The system generates regular reports on the health of the transmission lines, transformer status, and instances of power theft. Data

analytics tools may be used to analyze historical data, identify trends, and predict potential issues. Alarms and notifications are generated for operators to take immediate action in the event of a fault or power theft. This working principle ensures the continuous monitoring, early detection of faults, protection of transformers, and identification of power theft, ultimately contributing to the reliability and efficiency of the power transmission system. The model of the proposed system is as shown in figure. Here 0 W bulb will represent the extra load used to do the power theft. When the normal power is consumed, whenever the 100W bulb is on it will indicate that there is no power theft but whenever someone tries to do direct hooking to make a power theft then that extra load will be detected with the help of the 0W bulb. Current sensor will sense the amount of flow of current and then the current sensor output will be given as the input to relay in-order to count the current pulses and the other output will be given to the 5V of the microcontroller. Hence, the power theft detection will take place depending upon the rate at which the current pulses are counted and that will get displayed on the LCD as “Power Theft” and simultaneously the alert indicator “Power Theft” will glow. In-order to monitor the health of the transformer the temperature sensor and the oil level detection sensors are used to indicate the low oil level and high temperature. When temperature of the transformer goes high then that information will get displayed on LCD and then the respective indicator will glow.

4. RESULTS AND DISCUSSION

During the prototype testing, the system demonstrated reliable detection of unauthorized power tapping and accurate reporting of transformer conditions. The GSM module successfully alerted the control room in the event of anomalies. This real-time monitoring capability proved to be crucial for quickly isolating faults, reducing downtime, and preventing extensive damage to the transmission infrastructure. The following figures 4 shows the outcome upon implementation on a board. Heart of the project is the microcontroller ATMEGA 328P. In general, the normal distribution phase voltage is 220 V, in this project we used a step-down transformer 220/12 V for converting the phase voltage from 220 V to 12 V.



(a)



(b)



(c)



(d)



(e)



(f)

Fig. 4. Output Display Unit (16*2) Lcd Different Condition.

The steps for conduction are as follows the figure 4 (a) Initially, when the power is switched ON, in order to activate the microcontroller. In this display no fault condition, normal temperature & no over load connection. If the temperature of the transformer is going abnormal, the temperature sensor gets activated and the message “TEMPERATURE HIGH”. The temperature value is displayed on LCD display. Also, no line fault and no overload fault. So, temperature of the transformer goes high then that information will get displayed on LCD figure 4 (b).

This step is Line to Ground fault also temperature & overload connection is normal figure 4 (c). A Single Line-to-Ground Fault occurs when one of the power lines comes into direct contact with the ground or any other low-impedance path. And Figure 4 (d) shows as a line-to-line fault is one where short circuiting occurs between two phases of a system. In this system Line to Line Fault is Blue & Yellow line but red line is no fault condition. LCD display is also showing temperature is normal and no overload because no theft found. Line to ground (LG) and line to line (LL) faults are two of the most common types of faults that occur in power systems. A line to ground fault occurs when one of the conductors of a three-phase system comes into contact with the ground or any other grounded object. This type of fault is also known as a single-phase fault or a ground fault in figure 4 (e). A line-to-line fault, on the other hand, occurs when two conductors of a three-phase system come into contact with each other. Red and Yellow line is Line to Line fault and also blue and yellow line is Line to

Ground fault. This condition Temperature and Theft detection is normal. And also figure 4 (f) The 60W bulb is on it will indicate that there is no power theft but whenever someone tries to do direct hooking to make a power theft then that extra load will be detected with the help of the 100W bulb. Here is Theft Found.

5. CONCLUSION

The development of a smart transmission line protection system with integrated theft detection offers a promising solution to several challenges faced by power sector. By minimizing technical and non-technical losses, this system ensures more efficient power distribution and reduced operational costs. Future enhancements could involve integrating advanced machine learning algorithms to predict faults before they occur and scaling the system for larger, more complex grid networks. The development of a comprehensive transmission line protection system, combined with transformer monitoring and power theft detection, marks a significant advancement in improving the reliability and efficiency of power distribution networks. This system not only safeguards electrical infrastructure from faults but also effectively addresses the issue of power theft, which is a major source of financial loss and inefficiency in power grids. By incorporating real-time monitoring with current and voltage sensors, temperature controls, and theft detection mechanisms, the system ensures quick fault isolation and resolution. The use of GSM modules for remote alerts further enhances the responsiveness of the network, minimizing downtime and preventing damage to critical components. The successful prototype testing demonstrates that this system can significantly reduce technical and non-technical losses. Future improvements could focus on integrating advanced predictive algorithms, such as machine learning, to foresee potential faults and optimize grid management. Additionally, scaling this system to accommodate more extensive and complex power grids could yield even greater improvements in power management and theft prevention. This solution offers a practical, scalable, and cost-effective approach to modernizing power grids, ensuring a more sustainable and efficient energy supply for urban and rural areas alike.

REFERENCES

- [1] T. B. Smith, "Electricity theft: a comparative analysis," *Energy Policy*, vol. 32, no. 18, pp. 2067–2076, Dec. 2004, doi: 10.1016/S0301-4215(03)00182-4.
- [2] C. J. Bandim et al., "Identification of energy theft and tampered meters using a central observer meter: a mathematical approach," in *2003 IEEE PES Transmission and Distribution Conference and Exposition* (IEEE Cat. No.03CH37495), Dallas, TX, USA, 2003, pp. 163–168, doi: 10.1109/TDC.2003.1335175.
- [3] L. Powanga and P. A. Kwakwa, "Determinants of electricity transmission and distribution losses in South Africa," *J. Renew. Energy*, vol. 2023, pp. 1–9, May 2023, doi: 10.1155/2023/2376449.
- [4] Department of Telecommunication Engineering, BMSIT, S. I G, S. M S, T. S, and S. R. Gondkar, "Wireless power theft monitoring and controlling unit for substation," *IOSR J. Electron. Commun. Eng.*, vol. 9, no. 1, pp. 10–74, 2014, doi: 10.9790/2834-09131074.
- [5] G. F. Nama, D. Despa, and Mardiana, "Real-time monitoring system of electrical quantities on ICT Centre building University of Lampung based on embedded single board computer BCM2835," in *2016 International Conference on Informatics and Computing (ICIC)*, Mataram, Indonesia, 2016, pp. 394–399, doi: 10.1109/IAC.2016.7905751.
- [6] K. Sayed and H. A. Gabbar, "SCADA and smart energy grid control automation," in *Smart Energy Grid Engineering*, Elsevier, 2017, pp. 481–514, doi: 10.1016/B978-0-12-805343-0.00018-8.
- [7] H. M. Fahmy, H. I. Helmy, F. E. Ali, N. E. Motei, and M. S. Fathy, "Industrial applications of sensors," in *Handbook of Nanosensors*, G. A. M. Ali, K. F. Chong, and A. S. H. Makhlof, Eds., Cham: Springer Nature Switzerland, 2024, pp. 1–34, doi: 10.1007/978-3-031-16338-8_55-1.
- [8] L. Chen, X. Xu, and C. Wang, "Research on anti-electricity stealing method based on state estimation," in *2011 IEEE Power Engineering and Automation Conference*, Wuhan, China, Sep. 2011, pp. 413–416, doi: 10.1109/PEAM.2011.6134972.
- [9] S. Kumar V., J. Prasad, and R. Samikannu, "Overview, issues and prevention of energy theft in smart grids and virtual power plants in Indian context," *Energy Policy*, vol. 110, pp. 365–374, Nov. 2017, doi: 10.1016/j.enpol.2017.08.032.

- [10] S. Kumar V., J. Prasad, and R. Samikannu, "Overview, issues and prevention of energy theft in smart grids and virtual power plants in Indian context," *Energy Policy*, vol. 110, pp. 365–374, Nov. 2017, doi: 10.1016/j.enpol.2017.08.032.
- [11] P. Leninpugalhanthi, R. Janani, S. Nidheesh, R. V. Mamtha, I. Keerthana, and R. S. Kumar, "Power theft identification system using IoT," in *2019 5th International Conference on Advanced Computing & Communication Systems (ICACCS)*, Coimbatore, India, Mar. 2019, pp. 825–830, doi: 10.1109/ICACCS.2019.8728361.
- [12] N. Mohammad, A. Barua, and M. A. Arafat, "A smart prepaid energy metering system to control electricity theft," in *2013 International Conference on Power, Energy and Control (ICPEC)*, Sri Rangalatchum Dindigul, India, Feb. 2013, pp. 562–565, doi: 10.1109/ICPEC.2013.6527721.