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IoT Based Load Management Control and Theft Protection from DISCO's Side

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***Abstract*— Electricity serves as the primary power source that fuels our modern world. Without it, the functionality of everyday devices and appliances would cease. However, the relentless growth of populations, economies, and industries has led to an alarming disparity between energy demand and supply. Furthermore, power companies face a significant challenge in the form of electricity theft, resulting in substantial losses from the grid each year. To prevent electricity infrastructure from collapsing, utilities resort to load shedding, cutting off power to specific areas during shortages. To address this issue, the proposed study aims to develop a load management system that allows users to operate essential loads during shortfall hours, mitigating the impact of power cuts. Additionally, this study addressed electricity theft by introducing a theft control system by employing an automatic control unit that injects frequency-distorted voltage into low- voltage lines. As a result, the illegal consumers' loads will be malfunctioned upon detecting thefts and notifies utilities of theft occurrences, enabling them to penalize offenders. ensuring the utility's ability to act while the legal consumers will have the retention of power supply with normal frequency as due to the action of step-up cyclo-converter installed in smart metering infrastructure. The study implements a simplified design for a single-phase distribution system using the ESP8266 Wi-Fi module. This IoT-based solution sends consumer data to a web page accessible via an IP address, facilitating efficient monitoring and management of the system. Overall, the proposed study offers a load management solution and theft protection system to address the challenges posed by increasing energy demand and electricity theft.**

***Index Terms*— Load Management, IOT, Power Theft Protection.**

I. INTRODUCTION

PAKISTAN'S economic growth has been hindered by energy sector challenges, which play a crucial role in a country's development. Recent years have seen a significant rise in energy demand due to economic activities, population growth, and technological advancements. As a result, Pakistan's energy requirements are increasing, placing mounting pressure on energy resources and distribution networks [1]. Pakistan's energy sector is facing a crisis due to inadequate energy production to meet growing demand [2]. Factors such as debt recycling, financial conditions, and limited energy supplies contribute to this problem. The reliance on natural gas and oil as the primary energy sources, with over 80% dependency, exacerbates the issue. Insufficient production from hydroelectric and coal resources leads to energy shortages and inadequate electricity generation [3]. Power theft poses a significant challenge in Pakistan, leading to substantial financial losses in the power sector. Distribution companies (DISCOs) conduct regular inspections to detect illegal connections visually. However, tracking the methods used for theft is difficult due to the various techniques employed. Estimates suggest that power theft costs Pakistan billions to tens of billions of dollars annually [4]. This large-scale theft, coupled with energy shortages and default on payment of electricity bills, contributes to the ongoing crisis in the power sector. Resolving these issues is crucial for bringing about a visible change in the sector [5]. Zhang et al. [6] proposed an FPGA and DSP based system for electricity load management. Field Programable Gate arrays [7-10] and signal processing techniques [11-14] have also been utilized in different parallel programming systems [15, 16] for sensing [17, 18] and healthcare applications [19, 20]. In [21] their study, presented a system that utilizes IoT technology, specifically the implementation of a Wi-Fi module ESP01, to establish a connection between users and the utility. This system effectively restricts the load that an individual user can connect, resulting in a limitation of the overall connected load for a larger area. By enabling users to operate essential loads during load shedding, this approach successfully mitigates the potential discomfort caused by complete power cuts. In [22] a study conducted on an innovative approach was proposed to directly prevent electricity theft from the distribution line by maintaining a low frequency. The system adjusts the frequency of electricity to a range between 6Hz and 7Hz on the distribution side. At the consumer end, an authorized meter is utilized to convert the frequency back to the standard 50Hz.

In [23] the researchers argues that electrical shortages in Pakistan are the primary cause of the country's socioeconomic failure. He attributes these shortages to institutional and governance shortcomings and suggests the need for a better policy to resolve the energy crisis. The researchers in [24] used the ARIMA model to predict electricity consumption in Pakistan, considering seasonal temperature variations until 2020. Their findings indicate that as temperature rises, electricity consumption also increases, with the highest demand of 6785.6 GWh expected in July 2020. In [25] assessed Pakistan's current energy scenario, examining various aspects such as supplies, consumption, reserves, power generation, and demand-supply dynamics. They concluded that conventional resources are insufficient to meet the rising energy demands and advocated for the adoption of renewable energy solutions. Researcher proposed in [26] several strategies to address energy shortfalls, including analyzing the impact of energy imports on bridging the supply-demand gap. They also discussed planned projects like gas pipelines and LNG imports, emphasizing the need for infrastructure development based on renewable energy sources. In [27] the scientist provided a comprehensive overview of Pakistan's energy industry, covering its history, achievements, energy reserves, electricity generation/consumption, and renewable energy potential. They highlighted the reasons behind the energy crisis and explored potential solutions. The researchers in [28] conducted a study on the benchmarking and regulation of electricity distribution businesses in Pakistan. Using stochastic frontier analysis, they estimated the cost effectiveness and efficiency of government-owned power distribution corporations. Their findings revealed an average efficiency of 72.5 percent in this sector, highlighting the urgent need for action to reduce losses and improve service quality. The study in [29] employed Holt-Winter and Auto regressive Integrated Moving Average (ARIMA) models to predict power consumption by sector. They concluded that without adequate measures, the gap between electricity supply and demand will continue to widen. Their findings suggested that the residential sector would eventually have the highest demand. They proposed ideas to address the supply-demand gap permanently.

II. RESEARCH GAP

In the existing system, utilities resort to load shedding as a last resort measure to prevent the collapse of the electricity infrastructure during power shortages. However, this practice disrupts consumers' daily routines and causes inconvenience due to power outages in specific areas.

III. OUR CONTRIBUTION

- Implementation of a smart load management system
- Theft detection and prevention technique using IoT technology.
- Focuses on limiting connected load during shortfall hours.
- Allows operation of essential loads, reducing discomfort from power outages
- Real-time comparison method analyzes current at the low-voltage (LV) side of the distribution transformer.
- Detects power theft by comparing consumption of legally connected consumers.
- Injects frequency-distorted voltage into the line where theft is detected.
- IoT-based automatic control unit disconnects legal consumers.
- Display module at each consumer terminal provides real-time information on energy usage.

By introducing these measures, our proposed model aims to improve load management, prevent theft, and enhance consumer awareness of energy consumption in a more efficient and effective manner.

IV. METHODOLOGY

Proposed methodology for implementing an IoT-based remote access load management and theft protection system:

- Flowchart depicting the different stages of the proposed system for load management during power shortfall (see Figure 1).
- Incorporation of sensors to measure current, voltage, and power at consumer end and distribution transformer.
- Display of measured values on LCD module in each consumer module and on a graphical user interface (GUI) for the DISCO's side.
- Power threshold value set by the utility during deficit hours.
- Three warnings issued to consumers exceeding the threshold through a buzzer, indicator LED, and LCD display before electricity disconnection.
- Continuous updating of power status for each consumer on the DISCO's GUI.
- Utilization of differential protection principle for power theft detection.
- Disconnection of legal consumers and sending of frequency-distorted voltage to power thief in case of power theft.
- Manual control of the power theft detection process by DISCO employees.
- Combination of load management capabilities and theft protection measures in the IoT-based system.
- Real-time monitoring and control for improved power distribution efficiency and combating power theft.
- The block diagram in Figure 2 represents a simplified prototype of the proposed system.
- The prototype has been implemented on hardware.
- The system consists of three consumers and one distribution transformer.
- Current and voltage sensors are utilized at both the consumers' end and the distribution transformer's end.

- These sensors are responsible for obtaining real-time power usage data at the terminals.

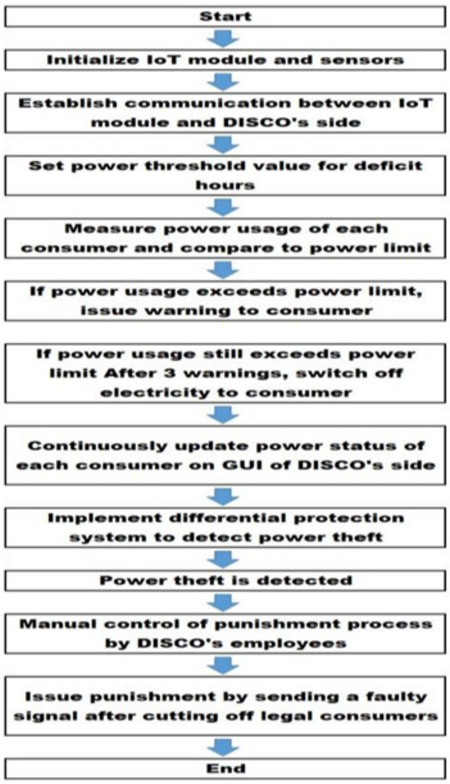

Figure 1. Flowchart of the proposed method.

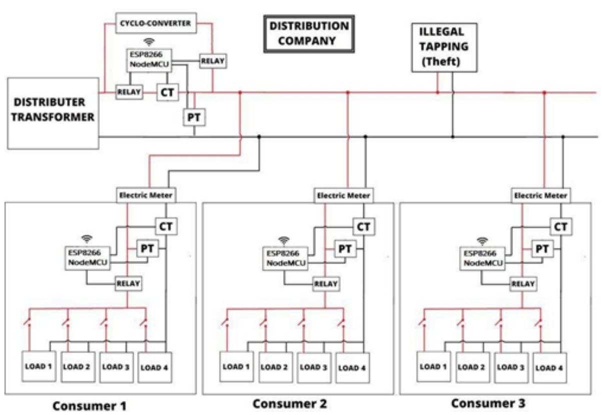

Figure 2. Block Diagram of proposed study

- Wireless communication with the utility is enabled using the ESP8266 NodeMCU.
- The system incorporates relays to control the power supply at the distribution transformer and consumer ends.
- The utility sets a predetermined threshold for power consumption during periods of power shortfall.
- Consumers exceeding this limit during peak hours will have their power supply disconnected.
- Power theft can be identified through differential power measurement.
- The utility can act against power thieves by disconnecting legal consumers and sending a frequency-distorted voltage to the thief.
- A Cycloconverter is used to send the frequency-distorted voltage, specifically targeting the distribution transformer where power theft is detected.
- The frequency-distorted voltage in main distribution line will also encounter with legal consumer but it will be rectified back via the step-up cycloconverter installed inside the smart meter.

$$E_{Transformer} = \sum_{i=1}^{N} E_{consumer(i)} \quad (1)$$

Where, $E_{Transformer}$ is unit delivered to the consumer from the transformer, $E_{consumer}$ is the units consumed by the consumer.

If

$$E_{Transformer} \neq \sum_{i=1}^{N} E_{consumer(i)} \quad (2)$$

Theft Occurrence Found.

Step down cycloconverter activate and ejects frequency-distorted voltage that is 10 Hz in the system. It will malfunction the load in terms of fluctuation and compel the illegal consumers to turn off their load.

While for legal consumers step up cycloconverter is activated installed inside their smart meter and restore the standard frequency.

Else if

$$E_{Transformer} = \sum_{i=1}^{N} E_{consumer(i)} \quad (3)$$

No Theft found and system will behave normally.

V. RESULTS AND DISCUSSION

A. Simulation

A Cycloconverter is a power electronic device that converts AC power at one frequency to AC power at another frequency. In our project, we have designed and simulated a Cycloconverter using Simulink. We have implemented the circuit schematic shown in Figure 2 and simulated the circuit with varying input voltage and frequency. The output frequency was analyzed and compared with the input waveform.

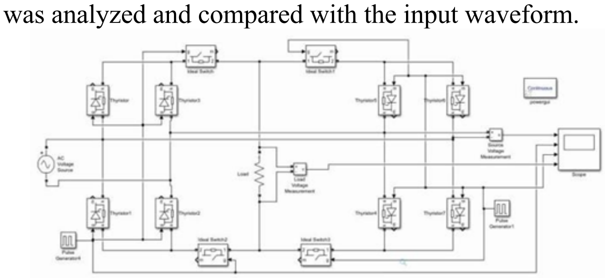
Figure 3. Simulink Model of Cycloconverter

The simulation results shown in Figure 3 show that the rectifiers are utilized to convert single-phase or three-phase alternating current (AC) into variable direct current (DC) voltage. Choppers, on the other hand, are employed to convert DC voltage into variable DC voltage with controllable magnitude. Inverters play a role in converting DC to single-phase or three-phase AC with variable magnitude and frequency. Similarly, cyclic converters are responsible for converting single-phase or three-phase AC to variable magnitude and frequency single-phase or three- phase AC. Within a cycloconverter, four thyristors are divided into two banks, with each bank consisting of two thyristors, one positive and one negative.

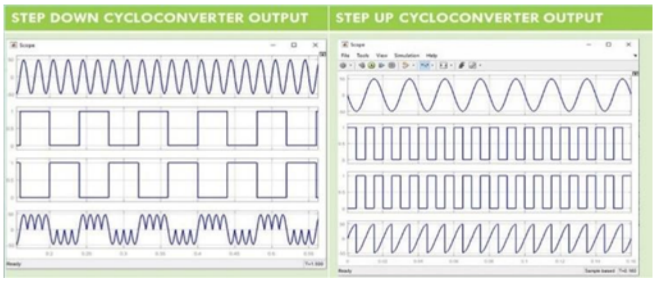

Figure 4. Cyclo Converter Simulation Results

Figure 4 depicts the waveform configuration, where the first waveform represents the input voltage. The fourth waveform represents the voltage across the load, while the second and third waveform correspond to the waveform generated by the PWM generators, which are utilized to trigger the four Thyristor bridges. It can be observed from figure 3 that cyclo converter step-up and step-down the frequency alternatively.

B. Hardware Developed

The hardware developed for this project shown in Figure 5 is a prototype of a simple distribution system that shows three consumers and one distribution transformer. At each consumer end, current and voltage sensors are installed to measure real-time power usage. Similarly, current and voltage sensors are installed at the distribution transformer end to measure the overall power usage of the distribution line. These sensors are connected to an ESP8266 module, which acts as an IoT module and helps in transmitting and receiving command and measurement data from the utility. ESP8266 module played a critical role in enabling the real- time monitoring and control of the distribution system. Its wireless connectivity allowed for seamless communication between the sensors and the utility, providing the necessary data for load management and theft protection.

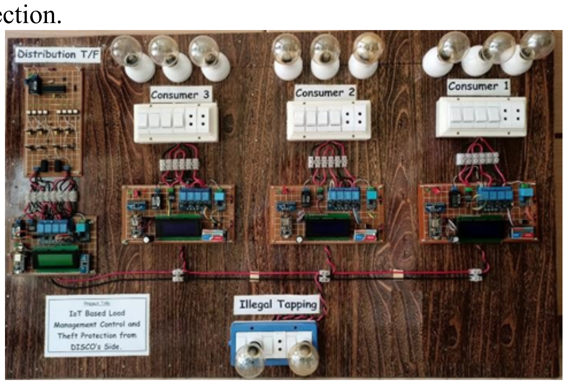

Figure 5. Hardware Design

The consumer's terminal is equipped with a mounted display that provides real-time information on power usage, as well as notifications regarding the maximum power allowed during shortfall hours. To capture the consumer's attention, each terminal is fitted with a small buzzer and LED indicators. During shortfall hours, a message such as "Allowed Power = *** Watts" will be displayed on the consumer's terminal, as depicted in Figure 06.

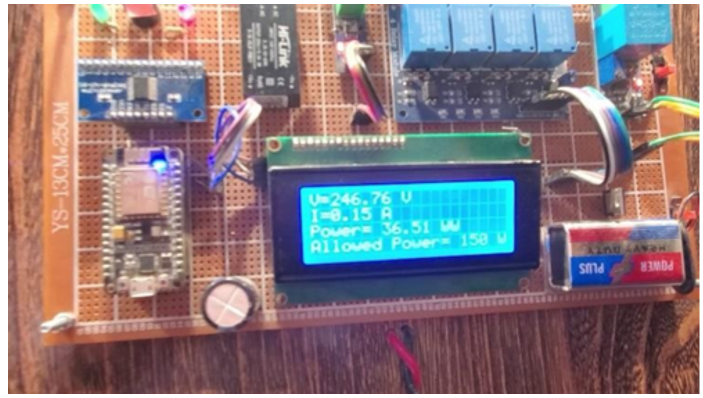

Figure 6. Allowed Power

The operator at the Distribution Company sets this limit (e.g., 150W in this case) through the GUI Terminal, based on the nature of the shortfall. If a consumer exceeds the allowed power, the display will issue three warnings at specific intervals, accompanied by a buzzer, prompting the consumer to reduce the load before power is cut off. Conversely, during normal hours without any shortfall, the consumer will see a message indicating "No Limit for Power," as shown in Figure 07.

Figure 7. Limit the Power

In Figure 08, the module used in conjunction with the distribution transformer is displayed. It includes an LCD display and LED indicator. The LCD display shows real-time power usage from the specific transformer, along with a brief message about the power status of the Cycloconverter, which is employed on the transformer side. In the event of power theft detected from a particular distribution transformer, an alarm is triggered on the GUI terminal at the Distribution Company. If the operator decides to penalize the power thief, they can take control through the same GUI to disconnect legal consumers from that specific transformer and activate the Cycloconverter, which injects a distorted signal into the line, causing damage to the thief's appliances. Once the legal consumers are disconnected, only appliances running through an illegal connection will remain connected to the line. At this point, the LCD display will indicate that the Cycloconverter is active.

Figure 8. Cycloconverter Activated

All the readings displayed on the consumer terminal and the distribution transformer modules are also accessible to operators at the Distribution Company through a Graphical

User Interface. IoT modules are employed in each consumer's terminal and each distribution transformer to transmit and receive information and instructions to and from the Distribution Company via the cloud.

C. Graphical User Interface

The development of the graphical user interface (GUI) for our project, as depicted in Figure 9, was accomplished using 'thingsboard,' an open-source IoT platform. This platform served as an effective tool for collecting, processing, visualizing, and managing data from the devices within our system. Our GUI comprises a variety of widgets that enable real-time monitoring of voltages, currents, and power consumption by consumers in the distribution system.

To exercise control over the power supply, we integrated power buttons into the GUI, allowing us to manage the power distribution to individual consumers or the entire distribution line. In order to maintain the system's load within acceptable limits, we included a widget that enables the setting of a maximum power limit during periods of power shortfall.

Furthermore, we incorporated a feature in the GUI to enhance theft protection measures. This feature initiates an automatic control unit capable of disconnecting power supply to all authorized consumers and activating the cycloconverter to introduce frequency-distorted voltage into the line. These measures work collectively to mitigate instances of power theft. Overall, the GUI we developed provides an intuitive and user-friendly interface for effectively monitoring and controlling the distribution system. It ensures efficient load management and contributes to the prevention of power theft.

Figure 9. Hardware Design

VI. CONCLUSION

The proposed IoT-based remote access load management and theft protection system gives a comprehensive solution to address the challenges faced by Pakistan's energy sector, including growing energy demands, inadequate energy production, power shortages, and widespread electricity theft. The proposed IoT-based load management system allows users to operate essential loads during shortfall hours, minimizing the impact of power cuts. The document also introduces a theft control system that employs an automatic control unit to detect and prevent theft by injecting frequency-distorted voltage into low-voltage lines. The proposed system uses sensors to measure current, voltage, and power at consumer and distribution transformer ends, enabling real-time monitoring and management. The study proposes a simplified design for a single-phase distribution system using the ESP8266 Wi-Fi module. The document includes simulation results and hardware designs of the proposed system, including an LCD display at each consumer terminal to provide real-time information on energy usage and notifications on maximum power allowed during shortfall hours. Overall, the proposed model aims to improve load management, prevent theft, and enhance consumer awareness of energy consumption in a more efficient and effective manner. Proposed system's potential expansion to three-phase distribution systems could significantly enhance its advantages.

- Integration with renewable energy sources such as solar and wind can help address Pakistan's energy crisis caused by a shortage of conventional resources.
- Incorporating machine learning algorithms for demand-side prediction and control can further enhance the proposed system's capabilities.

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