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Article

Electricity Theft Detection and Localization in Smart Grids for Industry 4.0

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Abstract: Industry 4.0 is considered as the fourth revolution in industrial sector that represents the digitization of production process in a smarter way. Industry 4.0 refers to the intelligent networking of machines, their processes, and infrastructure, as well as the use of information and computer technology to transform industry. The technologies like industrial internet of things (IIoT), big data analytics, cloud computing, augmented reality and cyber security are the main pillars of industry 4.0. Industry 4.0, in particular, is strongly reliant on the IIoT that refers to the application of internet of things (IoT) in industrial sector like smart grids (SG). IoT can be deployed in different sections of smart grids that include electricity generation, transmission, distribution and its utilization at customer side. However, the key obstacles that deployment faces are theft detection and localization in smart grids. Electricity theft causes huge losses to the electricity providers and in turn contributes in increasing the fiscal deficit of the government. Therefore, this paper provides an IoT based solution that implements a system which automatically checks for electricity theft in between the regional transformer and customer side. The system also sends the latitude and longitude coordinates of the place where the theft has been detected on to the thingspeak cloud platform. Further, the exact location of the theft has been displayed on the webpage using geolocation application programing interface (API) on Google maps. The proposed system can be easily integrated in the smart grid network structure and helps companies to increase their business.

Keywords: Smart grid; Industrial IoT; Industry 4.0; Electricity theft; ThingSpeak cloud

1 Introduction

Industry 4.0 is speeding up the use of data and software-driven digitalization in a variety of fields. The infrastructure for using big data, machine learning, and cloud computing software platforms is one of the many benefits of Industry 4.0 [1]. The continued automation of traditional manufacturing and industrial procedures with a variety of current sophisticated technologies is defined as Industry 4.0. Large-scale machine-to-machine communication (M2M) and the Internet of Things (IoT) are specifically coupled for improved automation processes, superior communication and self-monitoring, and the assembly of intelligent machines that can solve problems without the need for human intervention [2].

The Smart Grid is one of the most essential IoT applications. SG is a data communications network that is connected with the electricity grid to gather and analyze data from transmission lines, distribution substations, and consumers. By integrating modern digital equipment with the current electrical infrastructure, SG can provide predictive information to its suppliers and customers on how to effectively manage electricity [3]. In this method, the collector device sends usage readings through the internet to the operational center, and the power transmission business handles the payment process based on these readings. At the same time, the operation center uses a wireless network to collect user readings from neighborhood consumers' frequent updates. The primary goal is to eliminate energy loss and to offer reliable, cost-effective, and secure electrical supplies [4].

Electric power loss has become one of the most visible challenges affecting both traditional and smart grids today. According to statistics, transmission and distribution losses grew from 11% to 16% between 1980 and 2000. The amount of electricity lost varies per country. The United States, Russia, Brazil, and India each lost 6% to 18% of their total energy production. Technical loss (TL) and non-technical loss (NTL) are the two basic types of electricity loss (NTL). TL arises as a result of the joules effect on power lines and transformer loss during electricity transit [5]. The TL cannot be totally prevented; however it can be mitigated by implementing several system-wide modifications. Simply said, the NTL is the difference between a total loss and a TL [6]. Billing delays and anomalies, energy theft, defective energy meters, fraud, and unpaid bills are the main causes of NTL [7]. NTL is extremely expensive for both rich and emerging countries such as the United States, the United Kingdom, Brazil, Malaysia, and India [8,9]. As a result, preventing electricity energy theft is a big concern for many countries when attempting to improve their economic situation [10]. The only way to solve this problem is to detect and localize the theft in real time.

2 Literature Review

SG is the future of electricity supply. Smart grids are electricity networks enabling dual-way flow of electric power and of data hence, smart metering is a first step for implementing a SG. SG serves many purposes and also helps us to move from traditional electric grid to smart grid. This transition is often driven by certain factors, including the deregulation of the energy market, evolutions in metering, changes for the level of electricity production, decentralizing, changing regulations, the rising micro generation and micro grid, renewable energy all of these mandate us with more energy sources and new points where purpose for which electricity is required. The electrical grid is a network which delivers electricity from power plants to consumers. The grid is a thoroughly connected network with many components such as transmission lines, wiring and substations, transformers, distribution lines and more.

The classic grids don't have any storage capacity thus they are demand-driven having a hierarchical structure. For an electric network the voltage is generally, gradually lowered so as to make electricity useful for different consumers. In an electric grid the voltage level for transmission is much different than that is used for distribution i.e., the voltage is both stepped up and stepped down. In a smart grid the scenario is a bit different because the transmission of data and electricity is bi-directional. In this case, the consumers also generate electricity and send it onto the grid. This allows more and more new possibilities in making the existing system more efficient and feasible for both consumers and power producing companies at the same time.

Smart Grids are billion-dollar project and will be implemented nationwide or worldwide at a time so it is clearly analyzed that a little carelessness in its implementation can cause a loss of millions of dollars or equivalent. Therefore, a lot of studies are going on smart grids and theft detection or prevention system that can be implemented on these grids so that loopholes in our system can be filled effectively and efficiently. Traditional grids are not at all effective in dealing with theft. But theft detection and prevention systems are necessary as it is causing a huge fiscal deficit to government which in turn undermines the growth and development of national projects. IoT is among the most advanced emerging technologies which can be deployed in smart theft detection system and a lot of research is done and also going on its role in these systems.

Mucheli et al. [11] implemented a theft detection system which periodically sends data of current to the server where it is checked for theft. The basic problem in the system was that the proposed system requires modification in the basic structure of consumer meter and also there was no automatic theft detection system. They also do not propose any alarming system.

Gharavi et al. [12] presented a discussion of the future of the electric energy system, including the entire spectrum from power generation to substations to distribution and the consumer, as well as the feedback loops that are required to give the computational intelligence required to build the SG. More sophisticated methods for creating, distributing, transporting, and consuming power in a more sustainable manner were presented in the article. The drawback of the system was that it depended upon feedback loops whereas classic current electric system is based on a one-way flow of energy and information from the sources to the end users throughout the system.

Meenal et al. [13] developed an IoT based system for power monitoring and theft detection. The system utilizes Raspberry pi board and a GSM module for sending the real time values of voltage and current and messages to electricity board on detection of theft. However, there is no provision to detect the exact location of theft and system becomes costlier due to the use of these two devices.

Jeffin et al. [14] also developed an IoT enabled theft detection system which can detect the power theft due to meter bypass, meter tampering and direct line hooking. The system consists of NodeMcu as a central IoT board along with current sensor. The authors also presented a regression based model to detect the power theft. However, the system needs smart meters at consumer and transformer side and also needs a server to run the power theft detection algorithm. This system also not detects the real time location of the power theft.

Kumaran et al. [15] has also followed the same methodology for power theft detection as adopted by Meenal et al. The only difference is the IoT board utilized in the work is NodeMcu as compared to Raspberry pi. This makes system little bit cheaper.

Darteh et al. [16] designed the system which detects the power theft in between utility service box and energy meter. The utility service box is mounted at pole and equipped with Raspberry pi and current sensor. The real time values of current and voltages can be monitored on firebase cloud platform in real time.

It has be identified form the literature review that IoT is an important pillar of smart grid system as it enables to monitor and actuate hardware sensors anywhere in the system. The researchers have addressed the theft detection problem in different ways in the literature. However, some common shortcoming of the existing systems are that they require changes in the basic architecture of the electricity meters which tends to increase the complexity and cost of the system and none of the existing system is providing the exact location of the theft in real time.

In order to overcome these shortcomings, the proposed solution implements a prototype system using IoT for detection of electricity theft for SG. The system is utilizing two current transformer (CT) sensors with two microcontrollers one at regional transformer end and one at consumer end. Both CT sensors will continuously update the reading of the current consumed on the cloud and both the readings will be continuously matched. In case there is a mismatch detected between the two readings, it means that there is a theft in between so the location of the regional transformer where the theft is detected will be displayed as output. This process is fully automated but requires human interference only when theft is detected. It will reduce human effort and decrease the deficit on the companies producing electricity and also on the government too. The proposed system is also compensating the shortcomings of the existing systems presented in literature which did not propose any locating system for theft detection.

3 Proposed Architecture of the Electricity Theft Detection and Localization System

Fig. 1 shows our proposed system. The current sensor SCT-013-030 is placed in such a manner that detects the current both on the regional transformer and the consumer side. One of the UNO R3 Wi-Fi modules is used for sending the current reading of the consumer end to thingspeak from where the data is received by the other UNO R3 Wi-Fi module on the regional transformer end. Here, this microcontroller on the transformer end is already taking the current reading and it compares this reading with the reading received from thingspeak. If both the readings turn out to be same then no action is taken but if the readings come out to be different then it means that there is a theft in between which is drawing the surplus current of the transformer side. So, in case of theft the approximate location coordinates of the transformer end are fetched using geolocation API service. These coordinates are then sent to thingspeak where they are plot as "latitude" and "longitude". These coordinates are then sent to a webpage via thingspeak where they are displayed on the Google maps.

Integrated Arduino UNO and Wi-Fi R3 board-It is a customized version of the classic Arduino UNO R3 board. The microcontroller Atmel ATmega328 and Wi-Fi ESP8266 with 32 MB flash memory and universal serial bus-transistor transistor logic (USB-TTL) converter CH340G are fully integrated on one board. All the modules of the board work together as well as independent. On the board there are 8 dual inline package (DIP) switches for setting the mode of operation. The DIP switches can be configured to get the desired task and also the services of both ATmega328 board and ESP8266 can be availed simultaneously.

SCT-013-030 non-invasive alternating current (AC) current sensor-This SCT-013-000 is a current transformer that can be used to measure AC current up to 100 amps flowing through a wire. The CT sensor is clamped around the current carrying wire and can measure a load of roughly 30 Amps, and the amount of current passed though the wire can be calculated. It is useful for making an energy monitor or for making an over-load protecting device for an AC load. This sensor is clipped around the current carrying wire for which we wish to measure the current and it produces a very small AC voltage which is proportional to that current. The cable gives analog output through a 3.5 mm jack.

ThingSpeak cloud platform-ThingSpeak is an IoT analytics platform service that allows users to visualize, aggregate and analyse live data stream onto the cloud. This service is linked with MATLAB and allows only integer input onto the cloud. Users can send data to thingspeak from their devices and create instant visualization of the data and can also send alerts using other web services.

Google geolocation API-Google's Geolocation API returns the location coordinates based on information about Wi-Fi nodes and cell towers that a mobile client can detect. The communication is basically done over HTTP protocol using POST. The responses and requests both are formatted as JSON files and their content type is application/json. This service can be integrated with IoT also by the use of ESP8266.

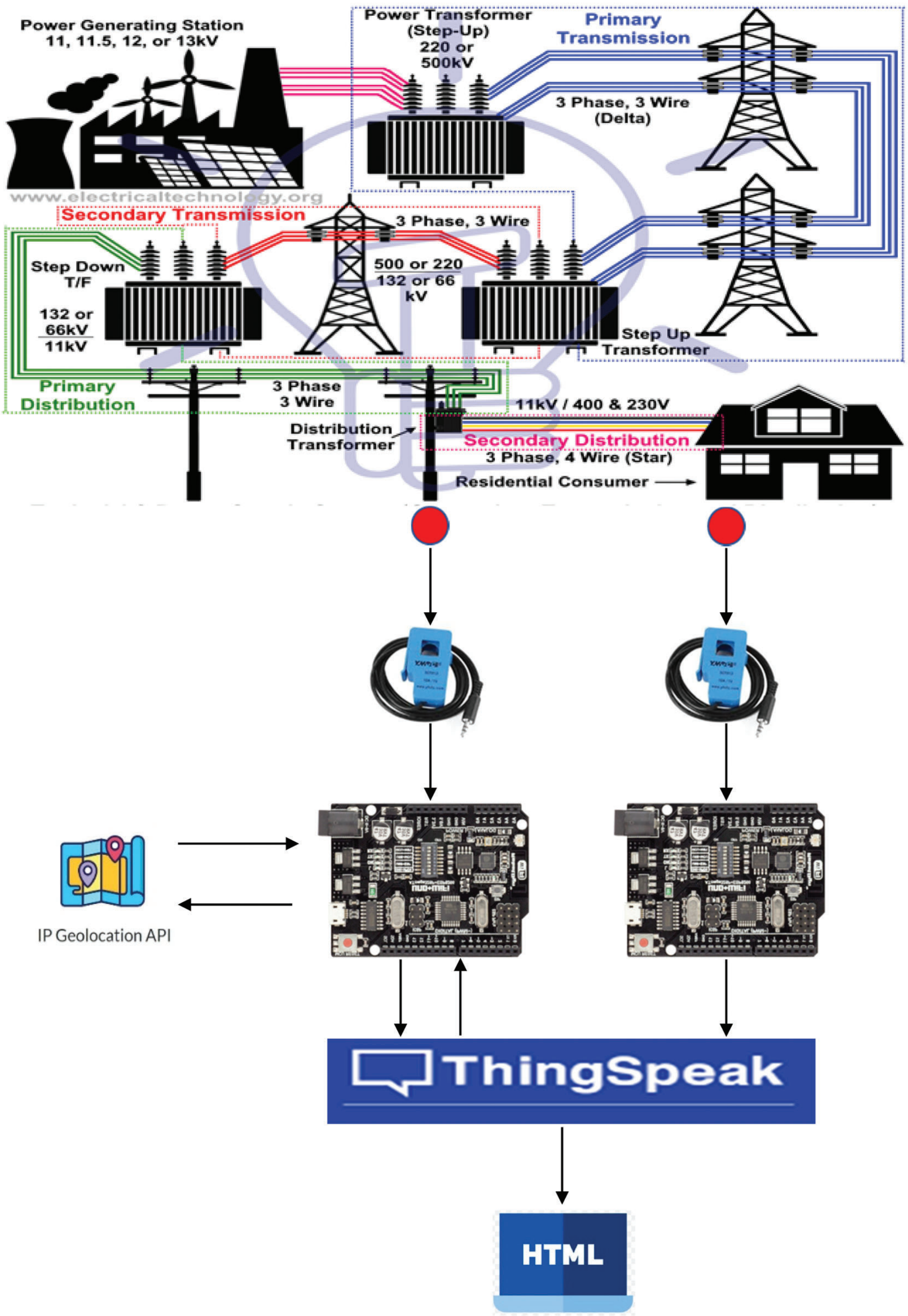


Figure 1: Proposed architecture of the electricity theft detection and localization system

HTML-HTML also known as hyper-text markup language is a language used to write code for designing the structure of a webpage. It consists of a series of elements which can be used to wrap different parts of the content of a webpage to appear in a specific manner. Also, the tags used to enclose the contents can act as a hyperlink to someplace else. Font of the content, color of the background/text, images and tables on the webpage all can be added and edited using HTML coding.

Arduino IDE-Arduino IDE stands for Arduino integrated development environment which is a cross-platform application. Its basic use is to write and upload a program to Arduino compatible boards. Arduino IDE application supports C and C++ using some special rules of code structuring. Arduino IDE also supplies software library which provides many common input and output procedures for programming various boards.

4 Working of the Proposed System

Fig. 2 shows the working of the complete system. The flow of the consumer side circuit and the transformer side circuit are shown separately. It can be seen that both the processes measured the current separately using their respective CT sensor. The current from the consumer end is sent to the transformer end via thingspeak. This current value is read by the Arduino UNO board at transformer end. Here, the theft is checked by matching the current of consumer end current and transformer end current. In case of any mismatch the location of the coordinates of the transformer side are tracked and displayed on the webpage.

5 Schematic Diagram of the Proposed System

Fig. 3 shows the schematic diagram of the circuitry that has been designed using EAGLE software. Both circuits are same except that one circuit is used at the consumer side and another is used at the supply side. The C.T. sensor output is connected to a burden resistance and the reading is sent to the A0 pin of the ARDUINO UNO R3 + Wi-Fi module. Further, an RC circuit is also used to filter the output and maintain the voltage while the sensor checks the current. This RC circuit is connected to the 5 V output pin and ground pin of the microcontroller. The complete demonstration setup of the proposed system is represented by Fig. 4.

6 Prototype Implementation of the Proposed System

Fig. 5 shows the internal working of the CT sensor circuit using Proteus design software and its interfacing with Arduino Uno board on breadboard for consumer and transformer side. Originally, the CT sensor has an aux output and the input can be checked using DTMF module. But since the CT sensor is an analog sensor and DTMF is a digital, so an ADC is required to convert the readings. However, instead of using ADC, a burden resistor is connected on the wires of the CT sensor to get analog output directly out of the CT sensor. The value for the burden resistance is calculated by the formula given in Eq. (1).

$$Burden\ Resistor\ (\Omega) = \frac{System\ Voltage/2.0}{I_{RMS}\ *\ 1.414/CT\ Turns} \tag{1}$$

Fig. 6 showing the real time theft detection and location coordinates on serial monitor. When the theft was turned off (means no hooking), it shows "no theft" whereas when the theft is turned on (means hooking) it shows "Theft!!! 28.5952445, 77.3333531" i.e., an alert message of theft followed by the real time location coordinates, where the theft has occurred.

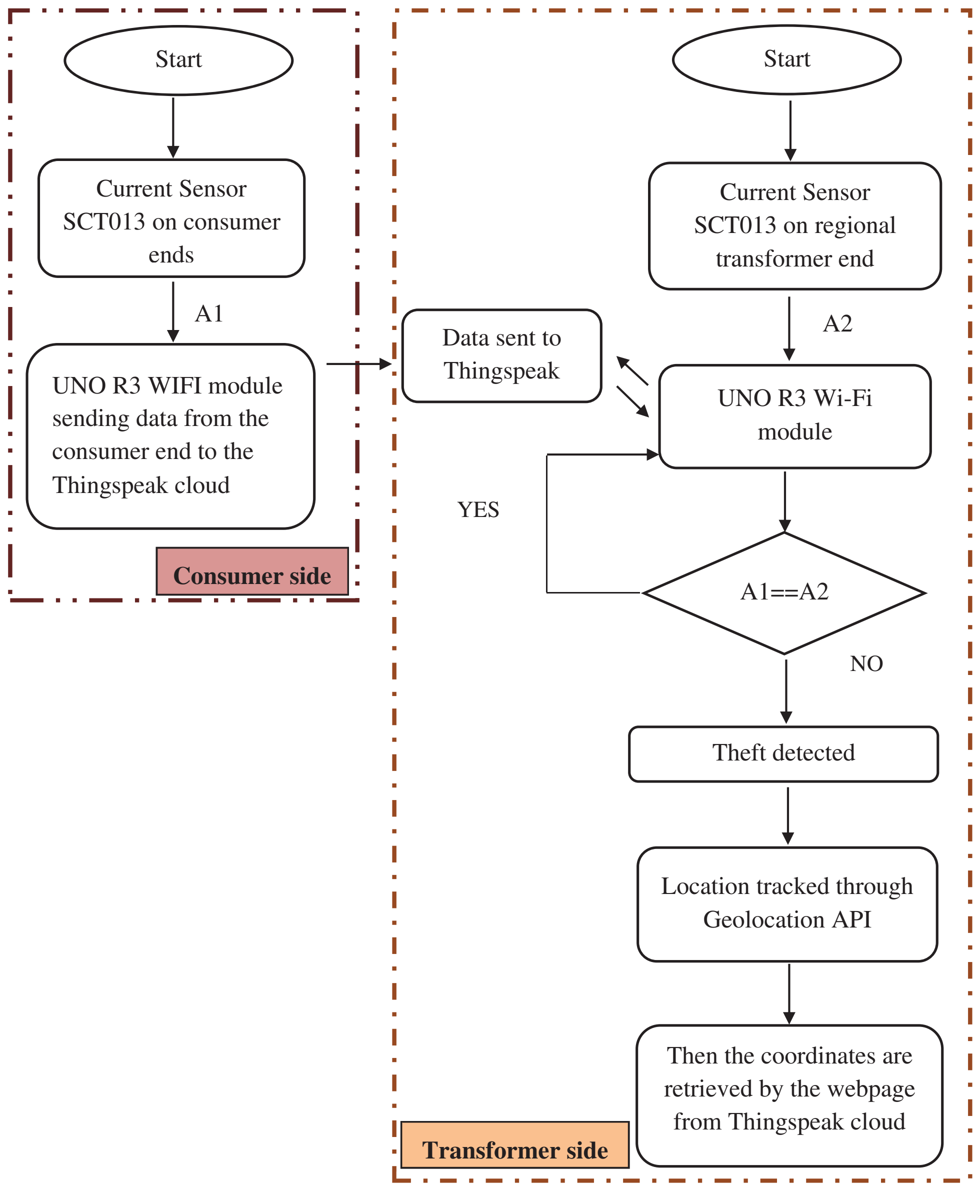


Figure 2: Flow diagram of the electricity theft detection and localization system

Fig. 7 shows the variation of current on the thingspeak graph, as you can see when the theft was on initially the current is coming out to be around (9 × 0.1) Amps but when the current is turned off the current is coming out to be (4.5 × 0.1) Amps.

Fig. 8 shows the webpage where the location of the theft is shown the maps and also the thingspeak graphs for the latitude and longitude of the location are displayed. The map shown is linked with Google geolocation services and it can be zoomed in to view the exact location.

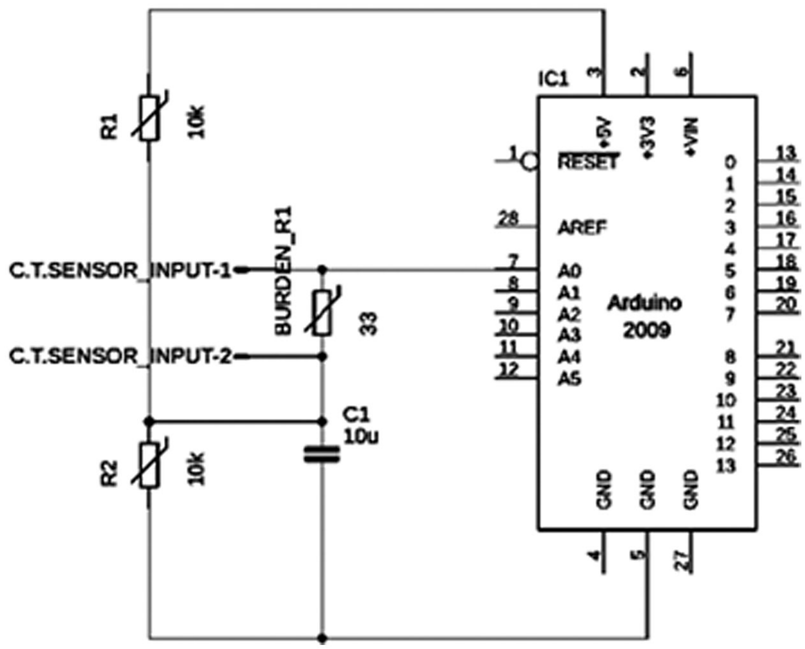


Figure 3: Schematic diagram of the proposed system at consumer side and transformer side

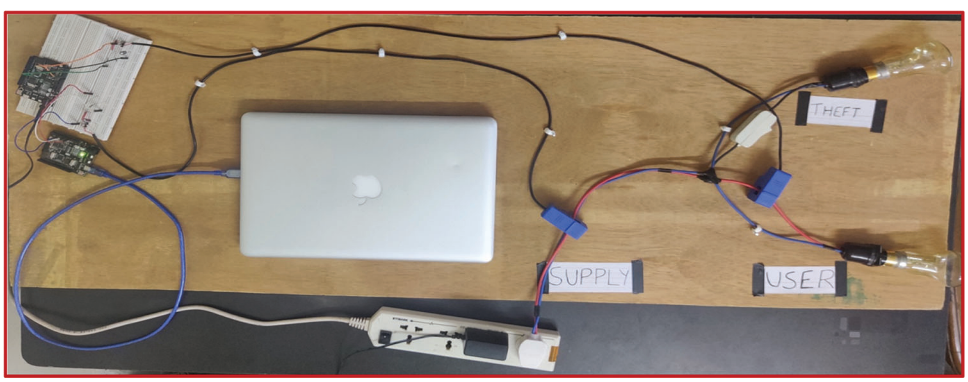
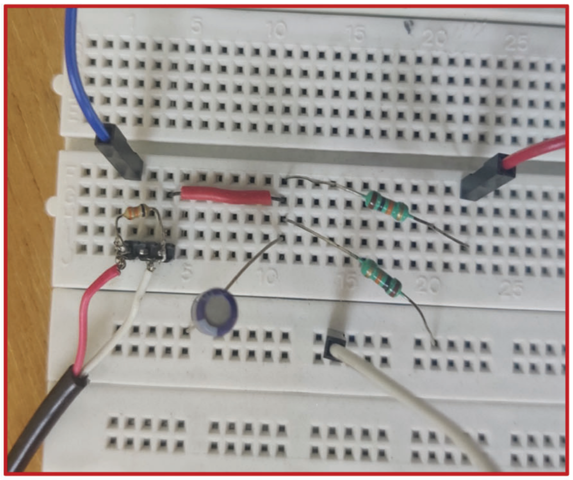
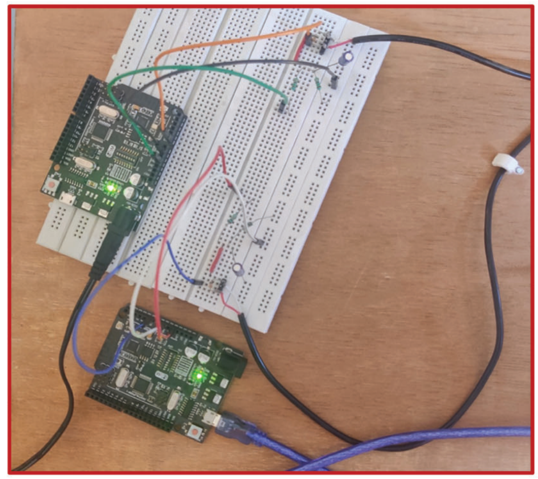


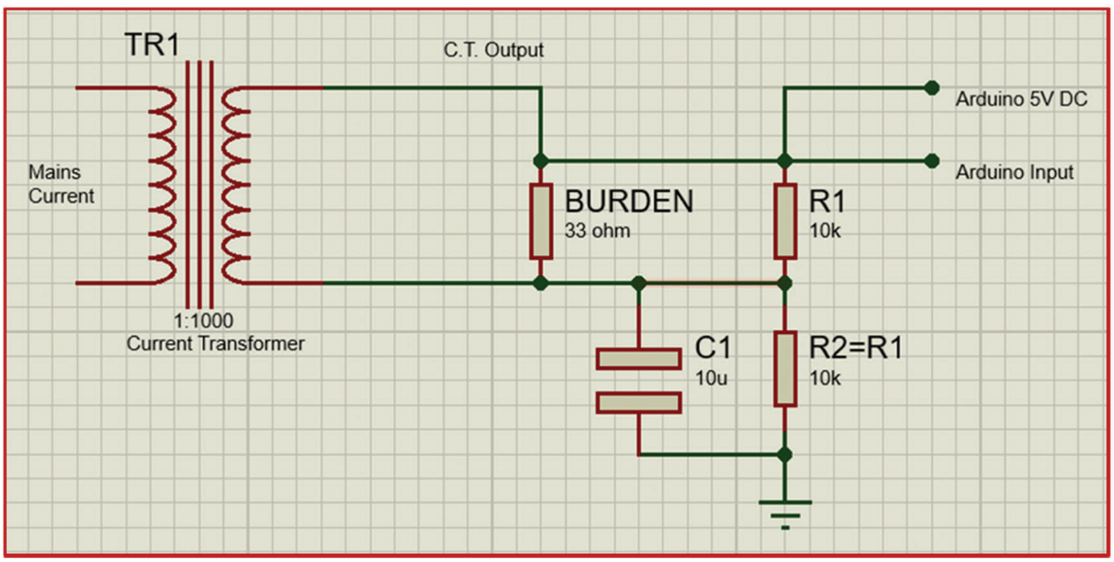
Figure 4: Complete demonstration setup of the proposed system



(a)



(b)



(c)

Figure 5: Prototype implementation of the CT sensor circuit at consumer side and transformer side (a) breadboard implementation of CT sensor circuit (b) connection between the CT sensor circuit and Uno R3 Wi-Fi board (c) schematic of the CT sensor circuit

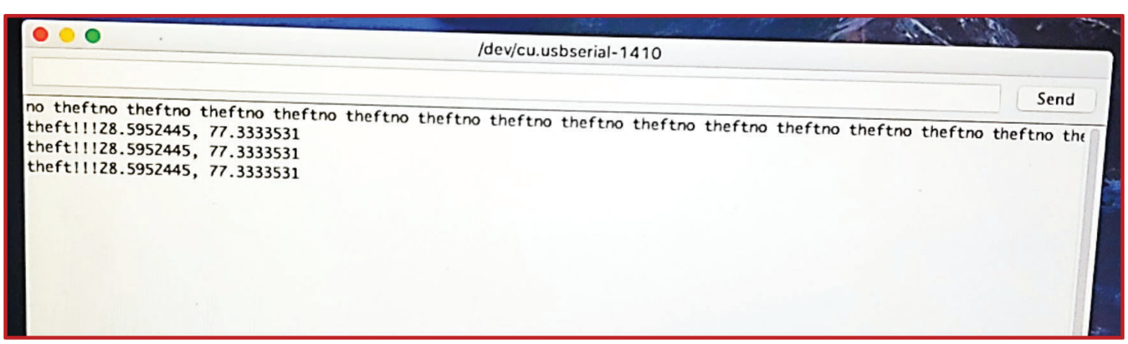


Figure 6: Real time theft detection and location coordinates on serial monitor

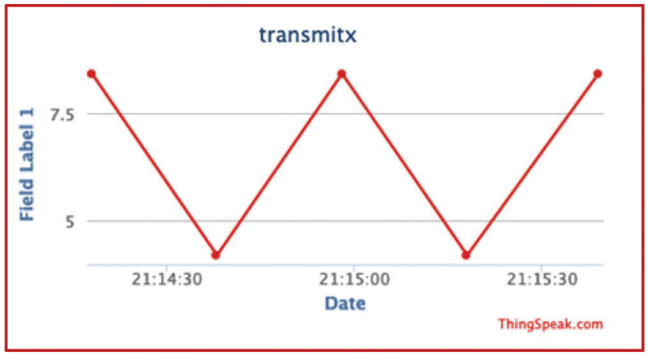


Figure 7: Variation of current on thingspeak cloud for theft detection

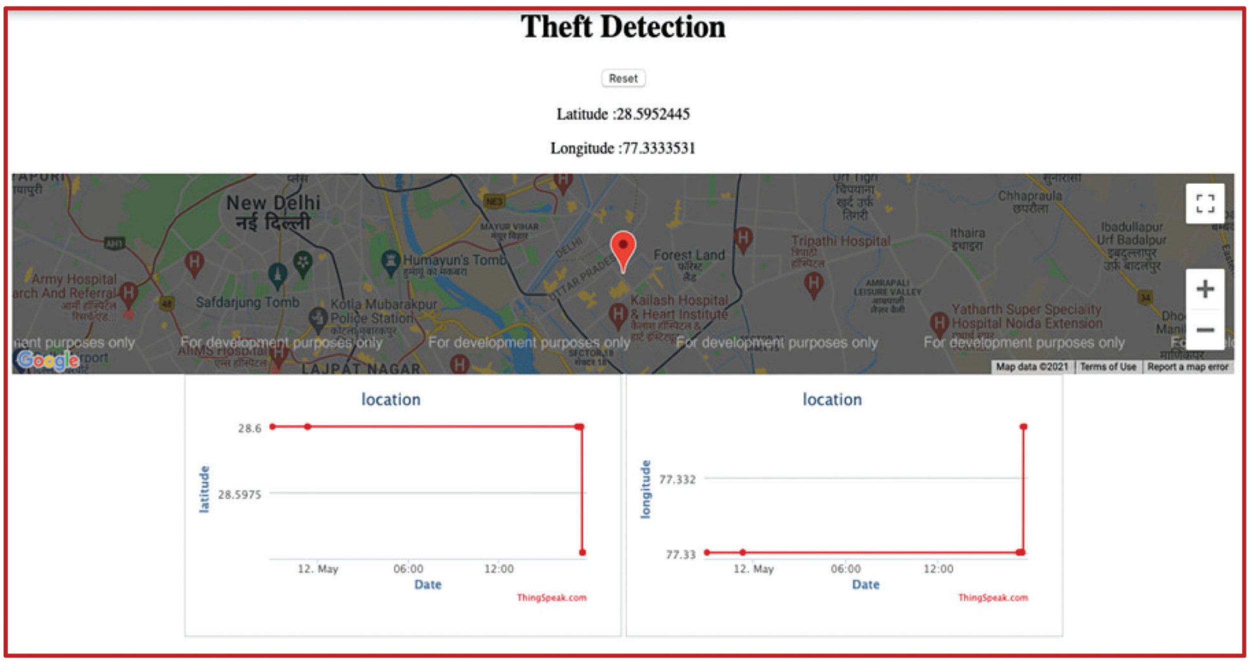


Figure 8: Webpage for theft detection and localization on google map via thingspeak cloud

7 Conclusions

The energy resources are the most important things for human survival and conserving them is very necessary. Therefore, this paper developed this prototype which can keep proper monitoring and help regulate proper distribution of electricity. As in both urban areas and rural areas people rely on electricity for many purposes. So, its improper distribution and theft can be dangerous for society. In that case, the proposed system can emerge as a long-term solution to control the increasing theft and improper distribution issues. The system will be more beneficial for densely populated areas. Decrement in theft thus, decrement in fiscal deficit of the government and electricity companies is our main goal. In the proposed system, the monitoring of current and then alert of theft is done automatically. Thus, it will serve as a perfect solution for this problem of electricity related issues. Further, the current and voltage data that has been sent to the cloud can be used for further analysis. Also, the cloud acts as an interface for user through which he or she can access the data about the electricity usage anywhere through the internet. The system also tells the approximate location coordinates of the theft. The system also displays the location of the theft on a webpage using these coordinates. Further, these coordinates can be directly sent to the concerned authorities by using services like push bullet cloud. The proposed prototype only facilitates in detecting current in a single-phase supply and more research, time and resources will be required to apply it on a three-phase supply grid. Also, supply's (i.e., transformer's) own losses are to be taken into consideration to reprogram the circuit which currently works only in ideal conditions.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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