Journal of
Data Acquisition and Processing
ISSN: 1004-9037
https://sjcjycl.cn/
DOI: 10.5281/zenodo.7546533

AUTOMATED RESIDENTIAL ELECTRICAL ENERGY MONITORING USING IOT

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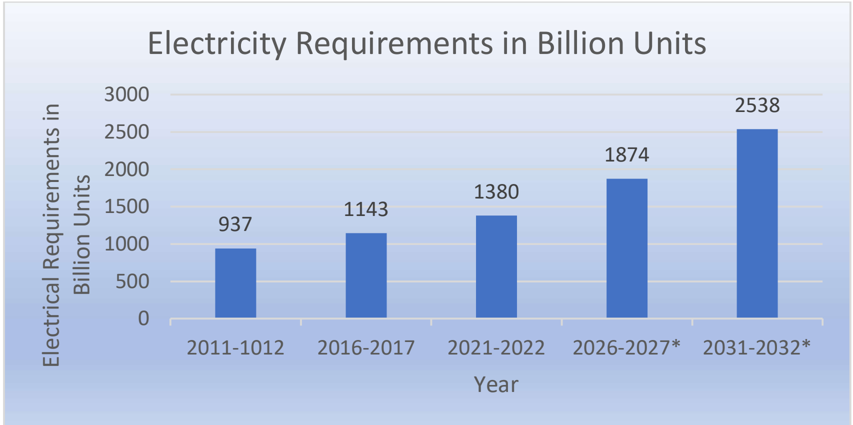
Abstract
Internet of Things (loT) is a network of devices that are connected to the internet. It facilitates communication between devices and the cloud. IoT has its applications in several areas, including medical, healthcare, smart home control, and environmental surveillance. IoT has brought in tremendous improvement in the ubiquitous computing sector. IoT-based energy management programs may allow a significant contribution to energy conservation. Therefore, this paper proposes Residential Energy Monitoring System (REMS). REMS is a state-of-the-art Cloud based Energy Monitoring system for residences of all sizes. With energy costs spiraling upwards every year, Users are under pressure more than ever to control their energy costs. In order to control cost, energy use must be monitored and End-users need to continuously understand their daily usage. This system alerts the users if they cross their usage limits based on billing slabs on monthly usage. On the other hand, the proposed system also helps Electricity board to capture meter reading of residences automatically with the help of a proposed interface device called eSense. Implementation of the proposed system involves the interfacing of electronic meter reader with the cloud using Internet of Things. It helps the end users in reducing electricity cost and at the same time helps to reduce the manpower in electricity board.
Keywords: IoT, Energy Monitoring system, Electrical energy, Electricity Board

Introduction
The International Energy Agency (IEA) has projected that the power consumption in residential and industrial segments is expected to grow at an annual rate of 6.5% between 2022 -2024. During pandemic, power consumption in India reduced by more than 2% during 2020. However, there was 10% increase in power consumption in the following year [10]. India's electricity demand is expected to increase 1.8 times between 2021-22 and 2031-32 by CEA (Central Electricity Authority). Figure 1 shows the electricity requirements in Billion units. The projected values are shown for 2026-2027 & 2031-2032 [12].



Note *2026-2027 & 2031-2032 are projected values by CEA

Figure 1: Electricity Requirements in Billion Units

As the demand for electrical energy is increasing year by year, automated energy monitoring and management is very much essential that can help consumers understand the energy usage at unit level and at the same time helps them to cut down electricity cost and to bring in the optimum utilization of electrical energy at residence.

Currently, the Electric meter installed in every residence helps the electricity board to charge the consumers based on the amount of energy they have consumed. Current flow through various devices in residences are measured by the electric meter. These electric meters can be analogue, digital or smart meter. In the case of analogue meter, a person from electricity board visits residence on a monthly basis to record the meter reading. With the help of the smart meters, this information is transmitted through internet. The electric meter measures the power consumed in kilowatts hours and the same is recorded.

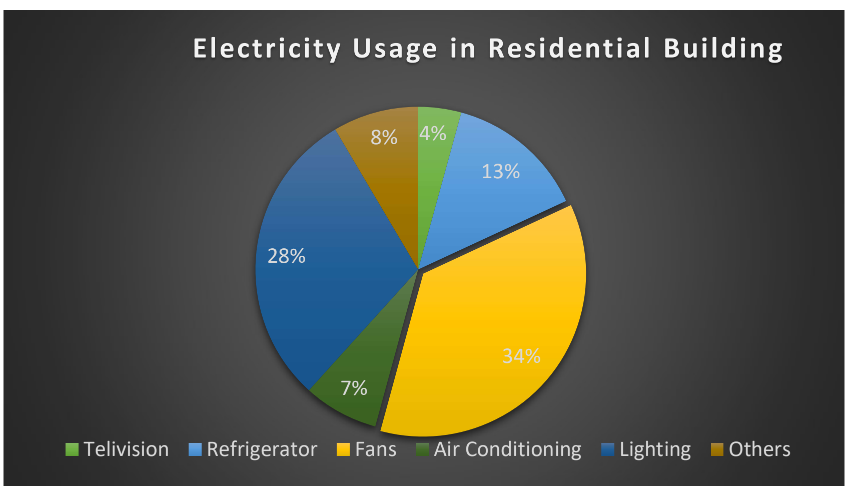


Figure 2: Electricity Usage in Residential Building

From the above figure 2, it is evident that a vast majority of home appliances consume large amount of power and energy. People have the tendency to keep lights, fans and other electrical appliances switched on unknowingly when they are not needed, resulting in wastage of electrical energy and at the same time, it can shorten the life span of the devices. It has been observed that old appliances consume lot of energy than the newer ones [11]. The research work proposed in this paper helps to constantly monitor the

consumption of energy and alerts the user when it reaches a threshold value. So that the user can take necessary action to reduce the energy and lower the consumption cost.
The objective of this research work is three-fold. Firstly, the proposed work will help to achieve optimal electrical consumption by the consumers. Secondly, electrical meter reading is automated thereby reducing man power. Finally, the proposed device helps consumers to get reduced electricity bill.

Literature Review

N. Darshan et al., [1] describes energy meter using internet of things with the PIC18F46k22 Microcontroller implementation. The proposed system does not require human interaction in electricity meter processing and maintenance. The centralized server will record the energy consumption and payment process. The system is able to identify payment fault and automatically disconnect the power supply. It is also capable to detect meter tampering through PLC modem which display the report in the provider end window. The components used in the circuit consists of PIC18F46k22 Microcontroller, MAX232, LCD display, theft detection element, Triac switch circuit, DB18B20 temperature sensor, PIR sensor, PLC modem, and ESP8266 Wi-Fi module. The energy meter data is sent to the web page using Wi-Fi unit that accomplishes the IoT operation.

Patel et al., 2015[2] presented the review on energy meters in India stating that the electromechanical meters are being replaced by advanced and accurate electronic and digital meters. The study focused on the massive of loss of revenue caused by electricity theft, erroneous meter reading and billing, and the disruptive behaviour of consumers to make bill payment in the scheduled time. The smart meters are introduced that make use of internet technology and smart devices to ease the meter monitoring operation. The study concludes that the most appropriate technology for smart meter communication applications is the Zig-bee technology.

Hlaing et al., 2017[3] proposed a Wi-Fi based smart meter to implement a very low cost wireless sensor network protocol that automatically read the unit and transmit to users to view the current energy meter reading through web application. The system enables users to reduce the power consumption and thereby reduce the cost of payment. It makes use of ESP8266 Wi-Fi module embedded in the energy meter and the TCP/IP protocol is used to communicate the meter data to the web application. It is feasible to implement due to the efficiency and feasibility in implementation. The model can be enhanced in terms of tamper detections and outage notifications

S. Imran et al., 2017[4] implemented a microcontroller enabled digital meter in which the microcontroller is connected to the blinking LED signal. The blinking LED signal is used to convey the electric reading by using the LED flashes. The 3200 blinks of the LED is counted as single unit reading. An interrupted is generated by the LDR sensor and send to the microcontroller to update the readings in the LCD display. The reading is transmitted to a dedicated webpage using Ethernet shield module through level shifter IC and RS 232 link. The system operates the microcontroller and other components using 5V DC generated using 7805 voltage regulator which transformers the 12V AC supplied by the 230/12V stepdown transformer.

Prasad et al., 2017[5] proposed the electricity meter that measures the power consumed and uploads it to the cloud server via ESP 8266 a wi-fi module. It's a wireless digital meter which transfers the power consumption data, cost details to the website from the cloud server. It requires less human intervention. However, the system is statics to produce only the consumption data and do not control the utilization of the energy.

Indra et al., 2018 [6] proposed a smart energy meter that helps to monitors the power consumption via short message services in mobile phone. The Arduino UNO, main controller serves as the linkage between digital meter and Global System for Mobile communication module. This module connects the energy meter to the registered consumer mobile phone . Real Time Clock (RTC) DS1307 was used to get the real time to count and store the usage into the EEPROM. The proposed system is capable of checking the current usage and resetting the limits. The system requires enhancement to control the energy consumption from the data repository.

Mahmud et al., 2019[7] proposed a website controlled electrical appliance monitor system that manages the home appliances and other electronic devices. The hardware consists of a microcontroller (Arduino Pro Mini), Wi-Fi module (ESP8266 Wi-Fi chip), relays and an LCD. The system also supervises the metering system. The system helps the power supplier to observes the anomalies in power distribution and also to take the readings online. It supports payment of the electricity bill online. However, it's web-based application, that requires wifi enabled all the time. This results in loss of data if at any time there is failure in the connectivity to the internet.

Mir, Shaista Hassan, et al., 2019[8] proposed a Arduino and GSM based energy meter for meter reading, billing and to control tampering. The data is sent via GSM wireless protocol which use the network coverage of the SIM. The data is accessible in several peripherals like website, and Apps. The system is claimed to use low-cost equipment to increasing the affordability. However, improve the reliability to gain higher degree of satisfaction and safety, this scheme requires more modification. Also, the complications are due to the network issues in the SIM used for the GSM module.

Abate, F., et al., 2019[9] designed a smart meter at low-cost with high level of accuracy in measurements adapting to the inconsistency in the grid. On the proposed smart meter two algorithms: the Goertzel Algorithm and the zero-crossing Algorithm are implemented , for the evaluation of the period, with a low computational impact are considered. The set of tests conducted on this low-cost smart power meter highlighted the good performance. The temperature dependence of the measuring module has been considered and minimized. Still the system requires improvement of quality metrics for the evaluation of the smart power meter.

Proposed Methodology

REMS consists of metering devices and an interface box called eSense. If the end user has metering devices installed, the metering devices can be interfaced to eSense via LoRaWAN. An Internet connection is required so that eSense can collect the energy data, do the required processing and transfer the data to the Cloud Server through the Internet. This solution is totally cloud based so that any standard internet connected web browser or mobile can be used anywhere at any time. REMS uses a distributed systems approach to collect data from remote meters using wired Internet, wireless Internet and IoT technologies.

Web Services based interface can be made available to provide easy integration of data to third party applications. Application software can be customized to meet client specific requirements. The database can be maintained in a server in a cloud (AWS/ AZURE). The system can interface to Energy meters and other intelligent devices. A complete SMS interface / Mobile app interface can be made available for accessing the Energy and Resources data using normal cell phones. Resource consumption data can also be input to the system using SMS interface.

To make the system highly scalable and economical, this solution uses low-cost device called eSense. Each eSense can handle data collection from one or more metering devices. eSense serves as the basic building block and the system can be easily expanded by adding multiple devices at the desired locations. This feature enables EB to collect the electrical data from residences.

eSense has a central Server which can manage data collected from different locations. eSense server application framework supports data collection from hundreds or even thousands of eSense devices that are scattered at multiple geographical locations. The data can be made available to a centralized web-based monitoring for the entire system. This system can be made to support Databases like Oracle, DB2, SQL Server, MySQL etc. This will facilitate advanced integration with other Enterprise Applications if needed.

eSense will have a SIM Card so that it will connect to the cell phone through wireless network and transfer the data to the eSense server. It is quite possible the wireless coverage could be spotty at times. eSense server constantly checks if eSense at all locations are communicating with the server regularly. If internet service gets interrupted, eSense starts logging the Energy usage data in the SD card. As soon as the connectivity gets restored, data stored in the SD card will be immediately uploaded to the eSense server

Algorithm:

Procedure to generate alarm on slab change

1. *change in reading -> activate (sensor)*
2. *i=1;j=1; threshold[1..i..n]; slab[1..j..n]*
3. *While(activate(sensor))*
4. *if (current value==0) # resume of power*
   reset(current value) from database
5. *current value++*
6. *if (current value ==threshold[i])*
   Activate (display color change)
   Generate (SMS)
   Generate (web report)
   i++

7. *if (current value == slab[j])*
   de-activate (display color change)
   j++
8. *End loop*

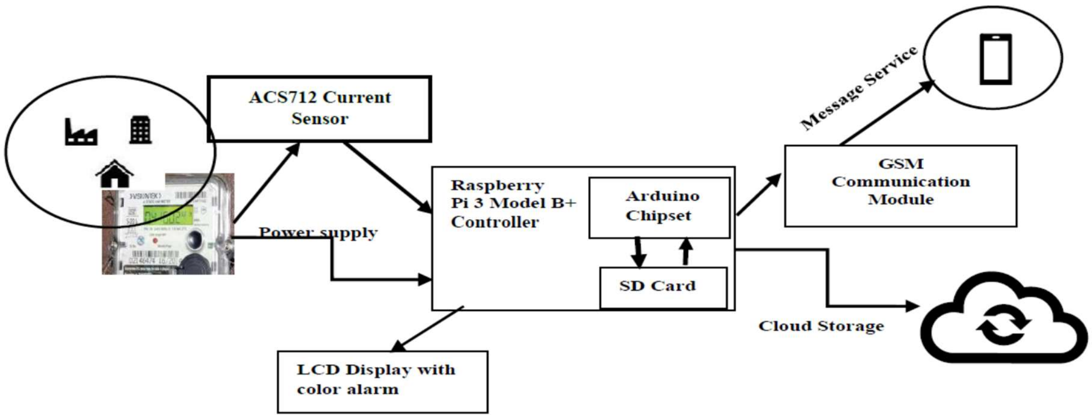


Figure 3: REMS Architecture Diagram

REMS monitors the readings of the digital meter to alert the users on the utility slabs to cutoff the excess expenses. It raises an alert to inform the occurrence of the slab change in mere near period. The operative model is depicted in the Figure 1.

REMS is plugged in the digital meter to monitor the reading produced on the consumption of the electricity. The inputs are transmitted to the controller, that will send the data for further exploration. The controller is connected to a display with alarm, storage unit (SD card). The communication between the controller and the storage unit is bi-directional. The controller transfers the energy consumption data to the SD card which is further streamed to the cloud storage using internet communication. The threshold bounds are stored in the controller to generate alarm physically and through messages on requirement. The auto reset process implemented in the controller is activated by the cloud calendar to restart the process after the billing date (different from payment date). The display alarm generation is also stored in the cloud for user verification process. The alarm is turned off once the consumption value crosses the threshold bound. The data generated by REMS is useful to the Electricity board to generate automatic billing and payments.

Results and Discussion

The primary objective of REMS (IoT-based model) is to provide residents with a comprehensive tool for monitoring their electricity consumption, fostering awareness, and promoting responsible energy use. By leveraging this technology, users will receive timely alerts through a user-friendly mobile app when their electricity usage approaches or surpasses predefined threshold values. In this research work, EB data collected from residences of all sizes to know the electrical consumption and the charges that they are paying to Electricity board. A pilot study is undertaken to know the effectiveness of using the proposed eSense. The study showed the significant reduction in the usage of electricity charges as the proposed model alerts the users when the electricity goes beyond the threshold value. Users of eSense are becoming cautious in their electricity usage and aim to reduce the electrical consumption thereby leading to lower electricity charges.

Sample EB data collected before implementing eSense

Status	KWH	KVAH	Recorded Demand	Power Factor	Units	CC Charges
NORMAL	11516.66	12439.02	5	0.927	1736.55	14652.05
NORMAL	9780.11	10567.23	5.702	0.933	2239.45	20183.95
NORMAL	7540.66	8167.07	5.432	0.917	1843.64	15830.04
NORMAL	5697.02	6156.9	4.616	0.925	1793.58	15279.38
NORMAL	3903.44	4218.22	3.806	0.923	1122.43	7896.73
NORMAL	2781.01	3002.57	3.604	0.929	1152.08	8222.88
NORMAL	1628.93	1762.47	4.006	0.92	1326.93	9503.03
NORMAL	302	325	4.63	0.94	2005	11663
NORMAL	53980	61830	4.87	0.95	2150	12620

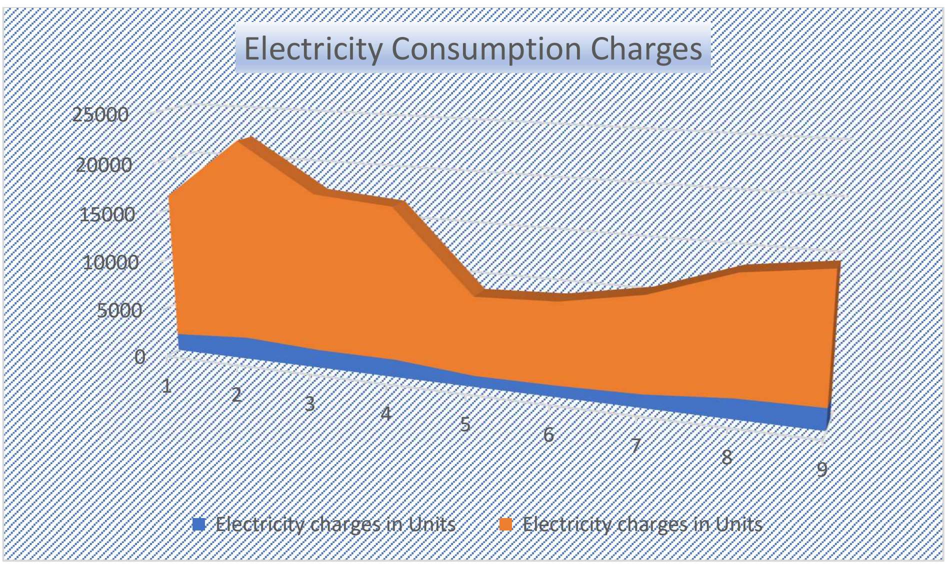


Figure 4: Electricity Consumption Charges before Implementing eSense

In machine learning methodologies, regression model is proposed to predict the dependency of parameters in a system. In this proposed system, linear regression is applied to predict the relation between the energy consumption in units and the cost remitted for the utility(*CC Charges)* to depict the advantage of using REMS to reduce the cost of energy consumption. Let the variables

$U_x \rightarrow energy\ consumed[units]$

$C_x \rightarrow cost\ remitted\ [CC\ Charges]$

The correlation function *r(*U_x ,C_x*)* of the two variables describes the existence of the positive relationship between the variables. And regression analysis predicts the dependency in terms of numeric values. The data is preprocessed to clean the NAN and missing values. The depend variable C_x is predicted using,

$$C = a + bU \rightarrow (1)$$

Where X &Y are independent variable &independent variable,

$$b = \frac{n\sum U_x C_x - \sum U_x \sum C_x}{n\sum U_x{}^2 - (\sum U_x)^2} \quad \rightarrow (2)$$

b is the slope

$$a = \frac{n\sum C_x \sum U_x{}^2 - -\sum U_x \sum U_x C_x}{n\sum (U_x)^2 - (\sum (U_x)^2} \quad \rightarrow (3)$$

a is the x intercept

The prediction is implemented in python to indicate the reduced charges after using the eSense. The procedure is as follows:

Load the Data

```
data = pd.read_csv('ebdata.csv')
```

Split the data into training set and testing set

```
X_train, X_test, y_train, y_test = train_test_split(data[['X']], data['y'], test_size=0.2, random_state=36)
```

Create a Linear Regression model

```
model = LinearRegression()
```

Fit the model & make Predicions

```
model = LinearRegression()model.fit(X_train, y_train)
predictions = model.predict(X_test)
se = mean_squared_error(y_test, predictions)
print("Mean Squared Error:", mse)
```

The performance analysis of eSense shows that the energy consumption is reduced, to result in the reduction of CC charges. Due to the slab monitoring mechanism in the eSense the prediction benefits the consumers.

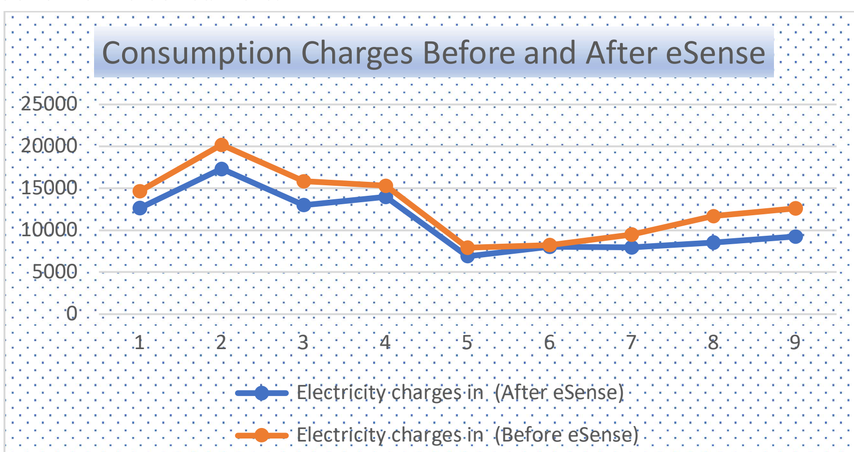


Figure 5: Comparison of Electricity consumption before and after implementing eSense

Key Features of the proposed Model

1. Real-Time Monitoring

The system continuously tracks and monitors electricity usage in real time, providing users with instant access to their consumption patterns.

2. Threshold Alerts:

Users will receive proactive alerts through the mobile app when their electricity usage reaches or exceeds predetermined threshold values. This feature empowers users to manage their energy consumption effectively.

3. User-Friendly App:

The accompanying mobile application is designed to be intuitive and user-friendly, offering a clear visualization of electricity usage trends and alert notifications.

4. Energy Conservation:

By being informed about their electricity consumption in real time, users can make informed decisions to reduce energy usage, leading to lower electricity bills and contributing to environmental conservation.

Benefits of the proposed Model

Residents can actively manage their energy consumption, resulting in potential cost savings on electricity bills by avoiding unnecessary usage. Providing users with the ability to monitor and control their electricity usage enhances their sense of responsibility and empowers them to actively participate in energy conservation efforts. The proposed model also has strong environmental impact by encouraging energy conservation among residents, and this contributes to a reduced carbon footprint and supports sustainability initiatives.

Conclusion and Future Work

The proposed research work focuses on monitoring the consumption of electrical energy at residences and alerting the end users before it reaches the threshold value. Data captured through eSense in every residence will be gathered by the electricity board for electricity billing purpose. Thus, the need to visiting each and every household for capturing electricity usage is reduced. Implementation of the proposed work includes the interfacing of electronic meter reader with the cloud using Internet of Things. It helps the end users in reducing electricity cost and at the same time helps to reduce the manpower in electricity board., these two situations will have economic impact at national level.

The significance of REMS is that it helps residents to control the consumption of electricity usage. It creates an opportunity for the consumers to monitor the performance of household appliances and practice energy saving at their residence. In our future work, the main challenge will be designing and implementing an efficient technique that can monitor power consumption in residential buildings and sending the gathered data to the Electricity board automatically.

References

1. N. Darshan Iyer and Dr. K. A. Radhakrishna Rao, "IoT Based Electricity Energy Meter Reading, Theft Detection and Disconnection using PLC modem and Power optimization*", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol. 4, No. 7, pp. 6482-6491, July 2015.

2. M. Patel Umang and M. Modi Mitul, "A Review on Smart Meter System", International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, Vol. 3, No. 12, December 2015.

3. Win Hlaing, Somchai Thepphaeng, Varunyou Nontaboot, Natthanan Tangsunantham, Tanayoot Sangsuwan and Chaiyod Pira, "Implementation of Wi-Fi-Based Single Phase Smart. Meter for Internet of Things (IoT)", 5th International Electrical Engineering Congress, Pattaya, Thailand, pp. 8-10, March 2017.

4. S. Imran and Dr. K. Prahlada, "IOT Based Electricity Energy Meter Reading Through Internet", International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES), Vol.3, No. 11, November-2017.

5. Giri Prasad, Akesh, BalaPravin, Gokila Devi and Gowri Devi, "IOT Based Energy Meter", International Journal of Recent Trends in Engineering & Research (IJRTER) Conference on Electronics, Information and Communication Systems, 2017.

6. Win Adiyansyah Indra, Fatimah Bt Morad, Norfadzlia Binti Mohd Yusof and Siti Asma Che Aziz, "GSM-Based Smart Energy Meter with Arduino Uno", International Journal of Applied Engineering Research, Vol. 13, No. 6, pp. 3948-3953, 2018.

7. Mahmud, Sadi, Safayet Ahmed, and Kawshik Shikder. "A smart home automation and metering system using internet of things (IoT)." 2019 International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST). IEEE, 2019.

8. Mir, Shaista Hassan, et al. "Review on smart electric metering system based on GSM/IOT." Asian Journal of Electrical Sciences 8.1 (2019): 1-6.

9. Abate, F., et al. "A low cost smart power meter for IoT." Measurement 136 (2019): 59-66.

10. Business Line, January 18, 2022 - Updated 07:31 pm IST | New Delhi, January 18

11. Hindawi Wireless Communications and Mobile Computing Volume 2021, Article ID 6544649, 16 pages https://doi.org/10.1155/2021/6544649, Wiley Publications

12. PRS Legislative research, Vital Stats, Electricity Sector – September 2022