Transactions on Energy Systems and Engineering Applications

Article

IOT Based Intelligent Energy Monitoring of Grid connected Hybrid systems and controlling of Loads using PLC

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Received: 07 March 2024; Accepted: 14 July 2024; Published: 11 September 2024

Abstract: Nowadays IOT becoming popularize in all the application especially in the power system network for data monitoring from the Hybrid power distribution system. Because of easy adaptability of IOT technology, it find its place in data monitoring for the remote system and data can also be logged in the cloud server for analysis of the system under surveillance. By having data enabled IOT system, which will make the complete system smarter in terms of monitoring and analysis of the performance of the power distribution network. In these research paper, concept IOT technology for data monitoring of grid connected Hybrid system consist of PV source for the typical educational institute was developed and implemented in the campus. Apart from the data monitoring, controlling of the critical loads connected to this hybrid system was developed using Programmable Logic Controller (PLC). The MyQtt based cloud server was used to store the data pushed from the IOT device and user interactive mobile Application was developed using MIT inventor to monitor the data in the mobile itself, the command from the Mobile app was given to the PLC to control the loads. The energy data from the Multi-function energy meter (MFM) is pushed to PLC through gateway of Raspberry Pi. In this paper, Raspberry PI was used as IOT device and ILC 131 ETH PLC was used to control the loads. Performance of IOT device along with PLC was monitored for 3 months and results obtained were satisfactory.

1. Introduction

IOT-based monitoring of system parameters is becoming a vital part most of microgrid systems consisting of renewable sources, this renewable sources parameters monitoring is very important to know about energy production by the sources. Based on data monitoring, the power system engineer can schedule the load and control the load demand in the power distribution network. Various methodologies were

How to cite this article: Thulasingam, Muthukumaran; P, Ajay D Vimal Raj.; Krishnamoorthy, Murugaperumal. IOT Based Intelligent Energy Monitoring of Grid connected Hybrid systems and controlling of Loads using PLC. *Transactions on Energy Systems and Engineering Applications*, 5(2): 641, 2024. DOI:10.32397/tesea.vol5.n2.641

adopted by the research engineer in monitoring the energy data from the load end as well as from the power generating sources. Low power long-range wireless area network (LPWAN) was adopted for monitoring the solar power sources in a decentralized microgrid system. In this scheme, PV parameters like voltage and current were monitored and the same was presented in open source IOT platform. IOT device Raspberry PI was used in the system to collect the data from LoRa devices and the same was transmitted to the cloud server and presented in Ubidots IOT platform [1]. The performance of PV plants in terms of electrical parameters and meteorological parameters was monitored using LoRa technology and Arduino boards. Electrical parameters on the DC side and AC side were collected by the voltage divider and Hall Effect sensor given as input to Arduino boards. Through serial peripheral interface (SPI) data was transmitted to a remote location through an RFM95W transceiver [2].

The various technology available for the transfer of data pertaining to PV plants used in residential applications is discussed. The data transmission of solar parameters by wireless wide area network (WWAN) takes advantage of the personal area network (PAN) and wide area network (WAN) in terms of data transmission rate and data traveling distance [3]. PV panel parameters such as DC Voltage, DC current, Temperature, and Irradiance were measured and data was transmitted to the remote location using LoRa technology tested and values were recorded at the receiver end. Measurement was carried out on a 250Wp PV module and electrical parameters of the panel were transmitted through LoRa devices [4]. The standalone PV system was designed to meet the energy demand of the lab in the educational institution, the energy monitoring system for the standalone system was designed and data of the PV system was monitored using an Open source IOT platform called Thing speak. Using the Wi-Fi technology PV plant parameters were pushed to the cloud server and the same was presented in the IOT platform [5]. The low-cost data monitoring using LoRa technology was discussed for low-income African countries. Hardware components required for implementing LoRa technology pertaining to data transmission over long distances at low power are also discussed [6].

The wireless-based data transfer of the PV plant was done using ZigBee Technology supported by the Arduino boards. Open source COSMO web publishing tool is used to monitor the PV plant parameters at the remote location [7]. The building management system (BMS) for the building was designed using the Raspberry PI and implemented the transmission of environmental sensors data using ZigBee technology. Raspberry PI used in the BMS act as a gateway that receives the data from the sensor and transmits the signals to the end user i.e. receiver which is enabled by the data connection through RJ 45 connector [8]. The energy monitoring of the manufacturing industry was developed using Raspberry PI and using the open source IOT tool Grafana is used for data representation of data collected from energy meters. The real-time value was monitored in an open-source tool and data logging was done on the local laptop or desktop computer [9]. Energy monitoring using IOT devices and controlling of load based on energy demand was done for residential home users. Arduino UNO was used to get the data of voltage and current of the load and the same was pushed to the cloud server using a GSM module connected to the Arduino board. Using HTTP protocol, data communication was established between the cloud server and remote monitoring station, thereby energy data is displayed on the web page. The author tested the prototype design by monitoring the energy displayed in the LCD and values displayed on the HTML web page. Controlling of load connected to an incoming power supply of the customer is also done by the author if the cost in the customer account is zero [10].

The energy monitoring of domestic appliances used in the residential sector was done using IOT devices and controlling of loads is done remotely by the customer. The customer will be having the real-time energy data of the appliances connected to the network and based on the values customer can take the call to On or off the load. The author used an Arduino Nano board was reading the data from the sensor which is used to measure the current and voltage of the load and the same was sent to the cloud server using ESP8266 Wi-Fi Module. The data from the cloud server is displayed on a customized web page designed using HTML script [11]. The review of different types of energy meters used for the measurement of energy in domestic customer places was done by the author. The importance of the usage of smart meters in the residential home was detailed by the author. Different technologies were available in energy monitoring and advancement available in energy metering of energy consumed in the domestic sector were explained by the author. The need for the smart metering system in terms of cost reduction in utility bills and accounting for all the energy loss in the utility lines is also accounted for in the meter there by utility companies [12].

The energy monitoring for the residential appliances is done using an Arduino IOT board and wireless data transfer to a remote monitoring station is done by Wi-Fi Module ESP8266. Energy consumption of the appliance is monitored using the Blynk app an open-source IOT platform [13]. Measurement of electrical parameters such as voltage and current which influences the power consumed by the load is measured using a voltage divider circuit and Hall Effect sensor and the same was given as analog input to the Raspberry PI device. The measured values are sent to the cloud server and the energy values are presented in the mobile application for the customer. The webpage is designed for utility companies to monitor the energy consumption of all residential consumers, thereby utility companies can see monitor the energy consumed by the individual customer connected to the power distribution network [14]. The energy management system in the small manufacturing industry is implemented using IOT devices and wireless transfer of energy data into the cloud server and remote monitoring of energy data is implemented using open source IOT platform application [15]. The design of the hardware circuit is done using the proteus tool for monitoring appliances used in the residential home. The controlling of the appliances is done based on sensor feedback received through the GSM module connected to the hardware circuit. The mobile application was developed to control the appliance if the threshold value of the feedback signal is reached [16].

The security assessment in the energy management network was analyzed using the fuzzy technique and the author proposed the model to evaluate the risk in terms of cyber-attacks in wireless data communication [17]. In modern power systems, the usage of smart meters is becoming popular in measuring the energy consumption of the loads connected to the power distribution network. Most of the companies started manufacturing the smart meter and it is getting deployed in the smart grid. The author described two communication protocol Radio frequency and power line carrier communication which is widely used in the smart meter. The usage of the smart meter in the smart grid environment brings advantages to power utility companies [18]. The author proposed a model for forecasting the energy demand of household energy demand using the regression technique. The regression model was developed by the author based on energy data collected from the smart meter and trained model to predict the future energy demand of the customer [19]. The author developed the algorithm for the effective management of energy demand ensuring the balance between generation and load demand. The proposed algorithm was simulated with real-time values taken from the smart meter and the algorithm was performing better in managing the energy demand and ensuring that there is no complete shedding of entire community loads [20]. The forecasting of the energy demand using Hadoop and R was proposed by the author who developed the model. The model developed by the author will predict the energy demand and it is trained based on the actual data taken from the smart meter. The model trained based on the RMSE (Root mean square error) and AIC (Akaike information criterion) gives future energy demand [21].

The author developed an algorithm to group the customer having similar load profiles and this cluster would greatly help the distribution companies to plan the energy supply to the clustered companies [22]. A smart meter system is deployed to monitor energy consumption in urban areas. In rural areas and remote places where there is no existence of network connection to get the energy data, in these cases, the author suggested collecting data through unmanned aerial vehicles and retrieving the data through LoRa technology [23]. The smart grid requires proper surveillance of the complete system since the smart grid is having many interconnected devices and monitoring of these devices is necessary to have a highly reliable operation of loads connected to the power system network. The author explored different techniques for data monitoring of smart devices used in the smart grid environment [24]. The need for big data tools for analyzing the data gathered from the smart meter is discussed in the paper. Possible security attacks in the smart grid environment and IOT devices used in data gathering from sensors were detailed and discussed in the paper [25]. Earlier researcher worked on LoRa devices in combination with IOT devices for data transmission of energy meters parameters of quite shorter device having the limited data bandwidth for transmission. If we need to push the data to longer distance in terms of several kilometer's it is not possible using LoRa devices, these difficulties can be overcome by using the internet enabled IOT devices. In this research paper, we are going using IOT devices connected to internet for transferring the energy parameters data to longer distance and as well as to push to data in to cloud server. Using the customized mobile app, data is viewed in the mobile at anywhere in this world, apart from data monitoring even controlling of load is implemented through PLC based on set value of the power (kW) in the mobile app. Using mobile app, continuous monitoring of energy value in real time is done in this paper.

The main objectives of this research work are,

1. To Design and Develop the Hardware circuit to interface the multifunction meter (MFM), Raspberry PI and PLC.
2. To establish the wireless Wi-Fi internet connection to Raspberry PI module through Wi-Fi router.
3. To enable the internet connection to PLC through LAN cable from Raspberry PI module.
4. To create the cloud server account in MyQtt webserver to read the data from the IOT devices used in the project.
5. To design the Mobile Application to monitor the energy parameters pushed from MFM to the cloud server in the mobile.
6. To develop the PLC logic program to push the data to the cloud server as well as to control the load based on the maximum demand set in the mobile app in terms of kW.

This research paper is organized and presented as Section 2 covers the Design Methodology, Section 3 deals with Architecture of Project, Section 4 covers the Description of IOT devices, Section 5 deals with the implementation of hardware design, Section 6 deals with PLC program of the project, Section 7 shows the analysis of the results and Section 8 outlines the conclusion of the project.

2. Design methodology

In this research paper we took multifunction energy meter (MFM) EM316C of Selec make for energy monitoring, which is placed at LT side of the power distribution network. The distribution network of system under study is feeded with LT supply from local DISCOM at voltage level of 0.433kV, with maximum power of 55kW. The Distribution network under study consist of lighting loads, computers load, Welding machine , CNC machine, domestic loads like fans, air conditioner system, etc. and it is feeded with grid supply and as well as from the PV plant. Necessary equipment's for measuring current and voltage was placed in the electrical network and it is connected to multifunction meter (MFM). MFM displays the energy consumed by the loads which includes active energy (kWh), apparent energy (kVah) and reactive energy (kVarh). This meter would displays the instantaneous power (Real, Reactive and apparent) draws by the load. Meter which is used in this work supports data transfer to the external environment through the Modbus protocol. Data from the MFM is pushed to PLC for data processing through Raspberry PI, which is acting as gateway. Internet was established to PLC through Raspberry Pi, where Raspberry Pi receives the internet connection through it is Wi-Fi antenna present in it. PLC (ILC 131 ETH) of phoenix make which is used in this project is IOT one, which is having the capability to push the data to the cloud server. The cloud server used in this research work is MyQtt cloud Server which receives the data from the PLC and it interact with Mobile APP , where it send the data and receives the command from mobile app. Command received from the mobile app is retransmitted to PLC for necessary control action to controls the loads. There is continuous interaction between the PLC, Raspberry Pi and fire base cloud server for data monitoring and controlling of the loads connected to the distribution network.

3. Architecture of the proposed smart IoT system

The hardware circuit is designed as per the standard design and sequence of steps followed in the data capturing from the field devices and pushing data in to cloud server is done as per the flow chart shown in the Figure 1. The data from the cloud server is sent to the mobile app as well as there is continuous data exchange between MFM (Energy meter), PLC and Cloud server. The data connection to field devices such as PLC is enabled through Raspberry PI module, which is having in built the Wi-Fi antenna. Both Raspberry and PLC is having the RJ 45 port, through this port, Raspberry PI module establish the internet connectivity to PLC through physical LAN cable connected from Raspberry PI to PLC. Data from the energy meter is read by the Raspberry and same is transmitted to PLC as well as to the cloud server. From the cloud server, data is pushed to the customized mobile Application, using the mobile app, monitoring of energy parameters and control of the loads can be done anywhere in this world. Real time monitoring of energy performance of the system and controlling of loads is done through PLC.

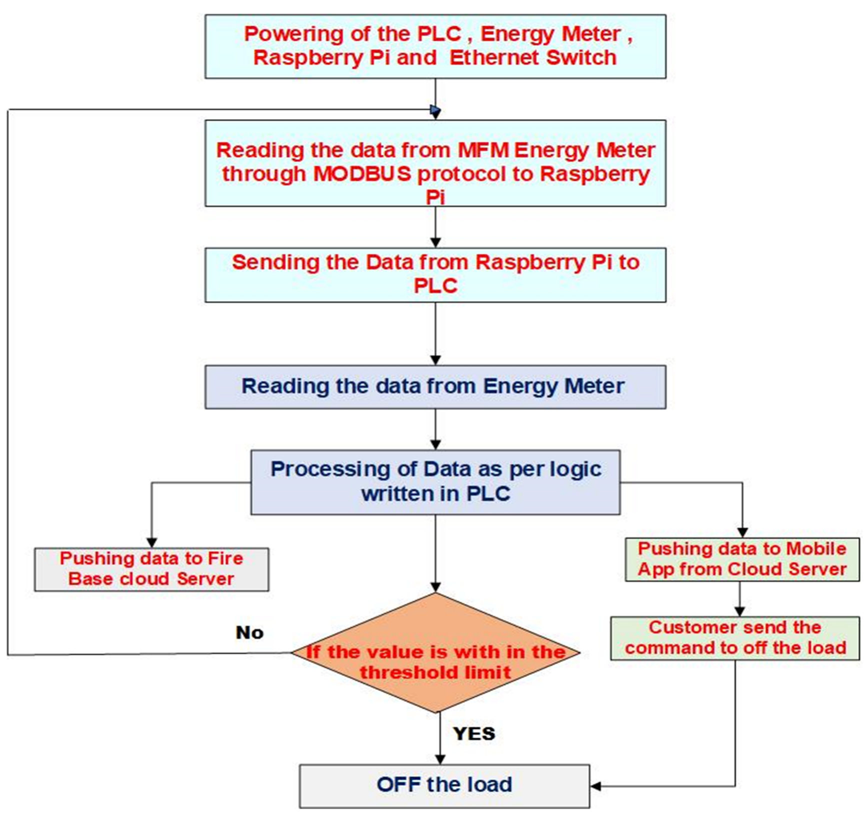


Figure 1. Flow chart of Energy Monitoring.

4. Description of IOT Devices

In this paper PLC, MFM (Energy Meter) and Raspberry PI is used for building hardware circuit in order to monitor and control the energy performance of the loads.

4.1. PLC (ILC 131 ETH)

This PLC supports Modbus/TCP and PROFINET Ethernet-based protocols and its memory can be expandable up to 2 GB. It also supports networking protocols such as HTTP, FTP, SNTP, SNMP, SMTP, SQL, MySQL, etc [1]. The Number of I/O supported by this PLC is 4096 and it is having the processor of Altera Nios II 64 MHz's. The Programing of PLC is done by ladder logic (LL), statement list (STL) and Functional block diagram (FBD), the physical structure of the PLC is shown in the Figure 2.

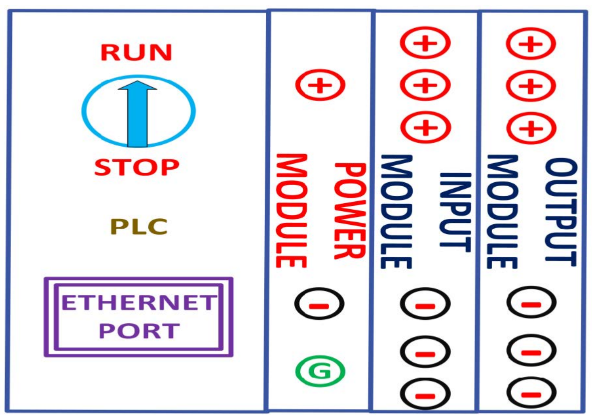


Figure 2. Phoenix PLC.

The PLC supports webserver through RJ 45 bus system. Number of interface available for data connection is one and it is done through RJ 45 Jack connection system. The data transmission system speed supported by this PLC is 10/100Mbps.

4.2. MFM

Multifunction meter (MFM) used in this hardware setup is MFM 383 A [26], this energy meter supports the electrical connection of three phase three wire system, three phase four wire system, two phase three wire system and single phase two wire system. This supports the data communication protocol of RS485 and MODBUS RTU. The current transformer (CT) can be configured in this energy meter is ranging from 5 amps to 10 Kilo Amps and it can be programmed.

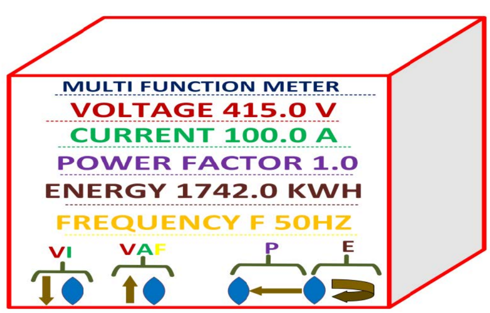


Figure 3. Energy Meter MFM 383.

Line voltage (LL) can be configured ranging from 100 V to 500V and it can be programmed. The accuracy of the meter is $\pm$ 0.5% for voltage and current, 0.01% for PF, 1% for Power, Class 1 for Active, reactive and apparent energy, the physical structure of the MFM 383 A is shown in the Figure 3 The connection diagram of energy meter MFM 383 C is shown in the Figure 4.

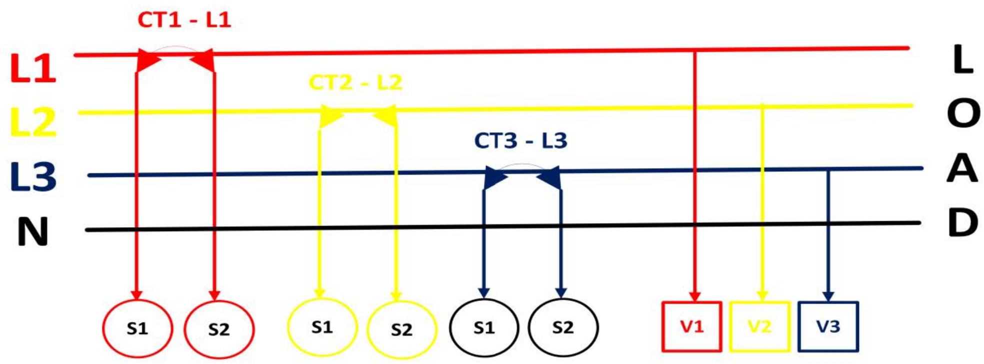


Figure 4. MFM 383 A Energy Meter.

4.3. Rashberry Pi

In our hardware configuration we used Raspberry Pi4. The Raspberry Pi4 is a highly popular single-board computer that offers several advantages over other boards. One key factor is its affordability, providing a cost-effective option for a wide range of users. Additionally, the Raspberry Pi4 benefits from a large and active community, ensuring extensive support and resources for beginners and experienced users alike.

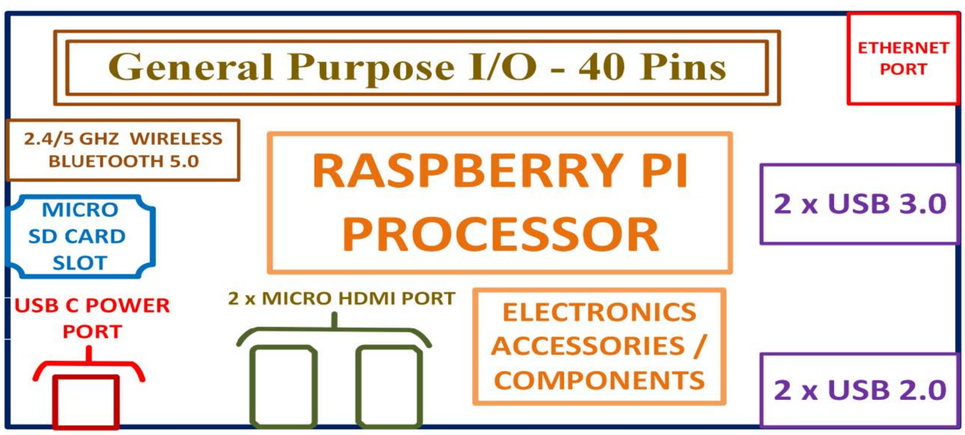


Figure 5. MFM 383 A Energy Meter.

The availability of a vast ecosystem of accessories and add-ons further enhances its capabilities, offering options for customization and expansion. Lastly, the Raspberry Pi Foundation focus on education makes the Raspberry Pi4 an excellent tool for learning programming, electronics, and STEM concepts. Keeping all this points in mind in our hardware configuration we used Raspberry Pi4 to get data from multifunction meter (MFM) through Modbus protocol. The data collected from multifunction meter is given to PLC through Profinet protocol and gathered data is processed and control action was taken based on the logic build in the PLC to control the loads. The physical structure of Raspberry Pi4 is shown in the Figure 5.

5. Design and development of IoT based monitoring and control system

In this research paper we developed the Hardware setup consist of Multifunction Energy Meter (MFM), IOT Enabled PLC, Raspberry Pi and relay. We developed customized mobile app for data monitoring and controlling of loads from the mobile.

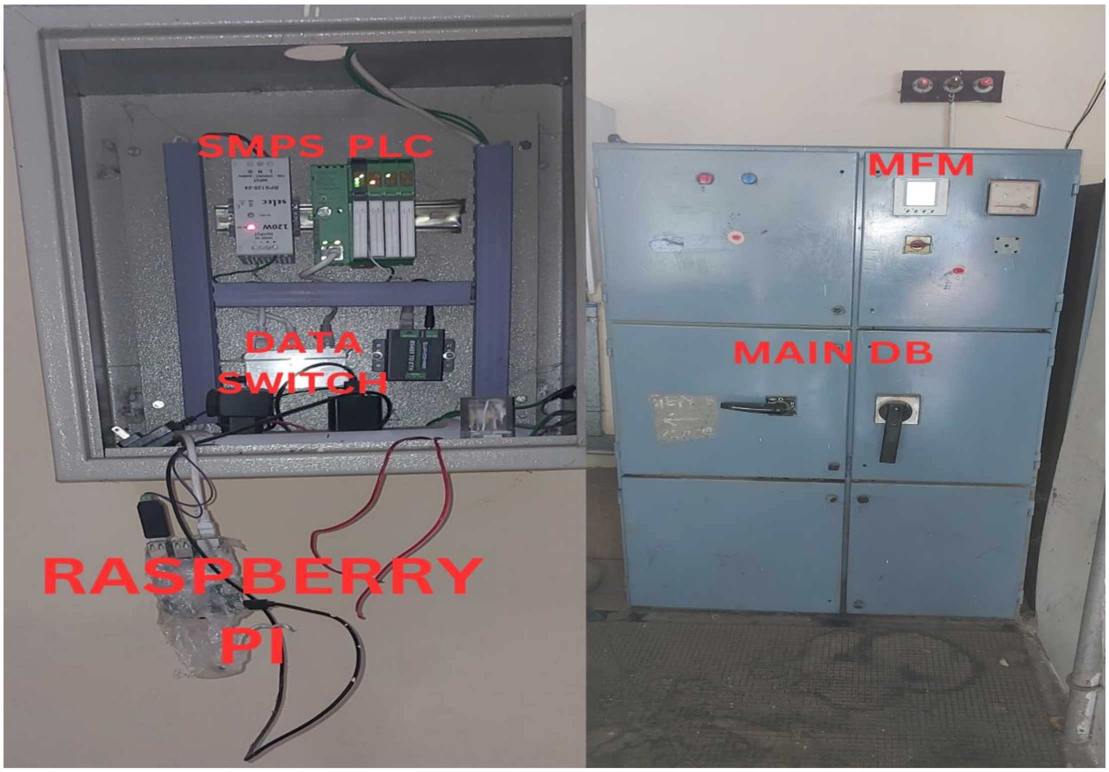


Figure 6. IOT based Hardware Setup.

Figure 6 depicts the IOT based energy monitoring system, this setup was implemented in the power distribution network operating at 0.415kV which consist of grid supply as well as renewable energy. Energy data from the MFM meter is fed to PLC through Raspberry PI gateway, data communication between energy meter and Raspberry PI is done through RS 485 protocol. The Raspberry PI board has inbuilt Wi-Fi antenna by this data connection is enabled and data connection is shared with PLC through Ethernet switch. PLC used in this hardware setup is having the Ethernet Port by which LAN cable is connected from switch to PLC, thereby data connection is enabled in the PLC. Energy data from the PLC is sent to cloud server and from the server is data is sent to mobile app, there is bidirectional data communication between the cloud server and mobile app. In this paper MYQTT web server was used to send and receive the data from IOT devices and customized mobile app was developed to read and write the data from the MyQtt server.

6. PLC Program

PLC program was developed and energy parameters from the MFM meter is read by the PLC through MQTT protocol. Program which was developed for reading the parameters is given in the Figure 7.

7. Validation of IoT-PLC based system monitoring and control

Hardware setup as shown in Figure 8 was connected to existing the power distribution network and energy data was successfully monitored in the mobile app. The controlling of loads is done through PLC

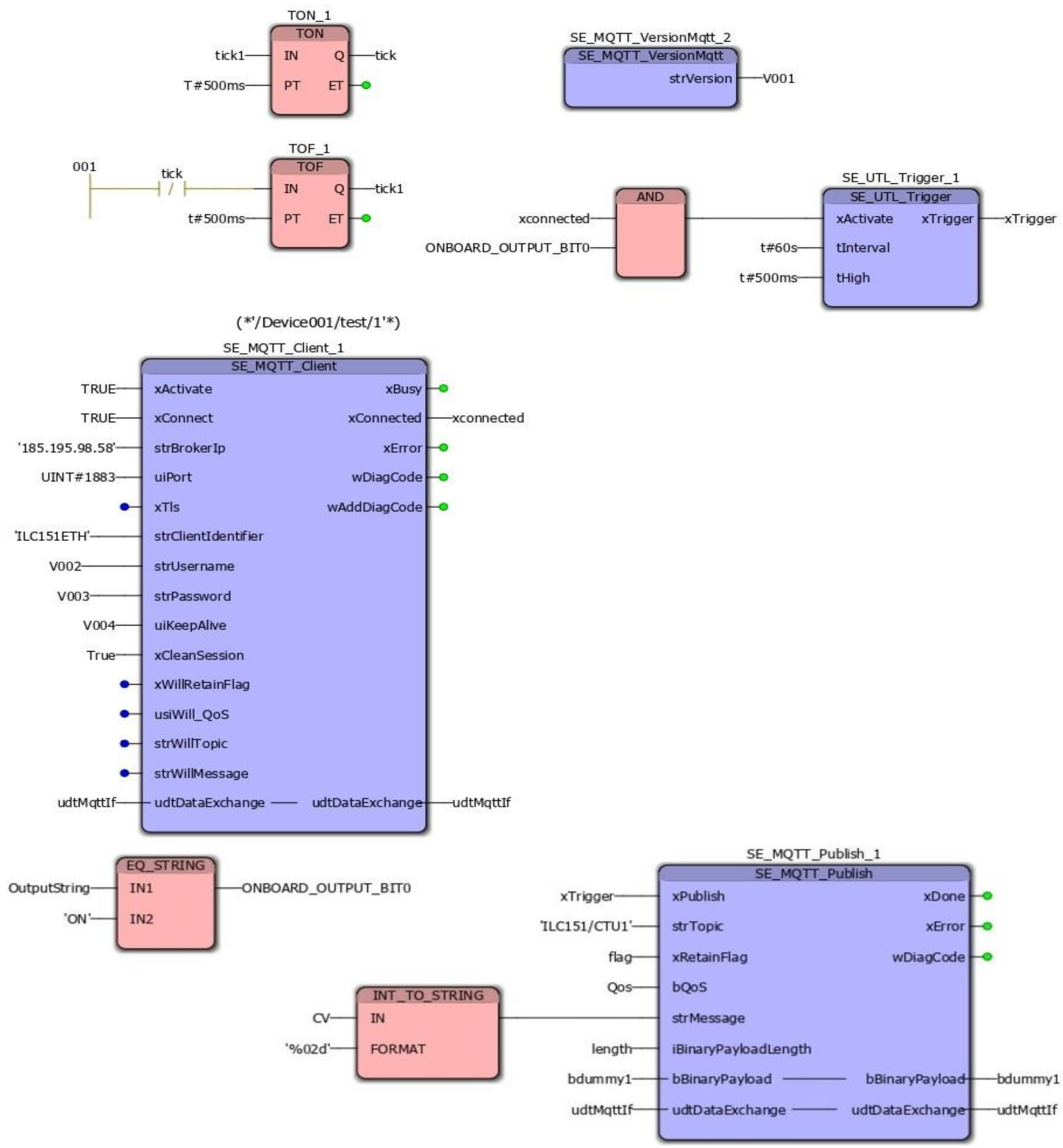


Figure 7. PLC pin enables related to the proposed work.

for the set value in terms of kW is done through mobile app. In this paper we controlled the one load through PLC, output from the PLC is connected to the relay, through relay load is switched ON and OFF. Load connected to PLC will OFF, if the instantaneous actual value of the power is greater than or equal to the set value of the power. Load connected to PLC will be in ON, If the instantaneous actual value of the power is lesser than set value of the power. Data monitoring of energy data from energy meter was monitored for past 3 months and hardware setup was working fine without any major technical issue. Even controlling of load based on set values of power is working fine, we witness that PLC giving the signal to relay to on and off based on the set values given from the mobile app.

Figure 8 depicts energy data which is sent from IOT devices to cloud server. We can see the how many data was sent from IOT devices to cloud server on hourly basis, daily basis as well as monthly basis. In this

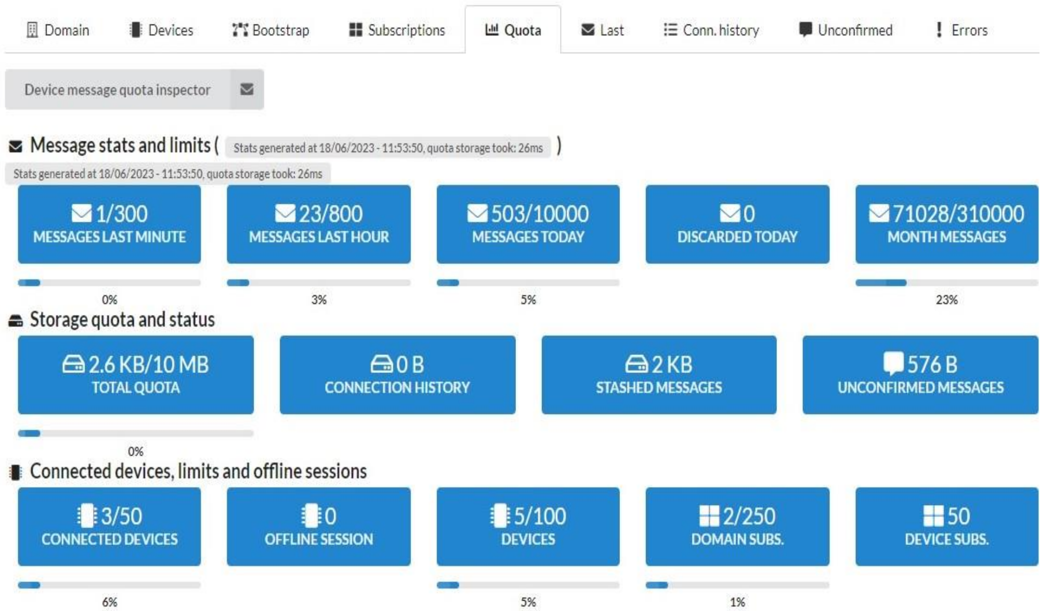


Figure 8. Cloud Server data monitoring.

paper we took open subscription scheme there by number sent from the IOT device is limited to 310000 per month similarly number of data per hour is limited to 300.

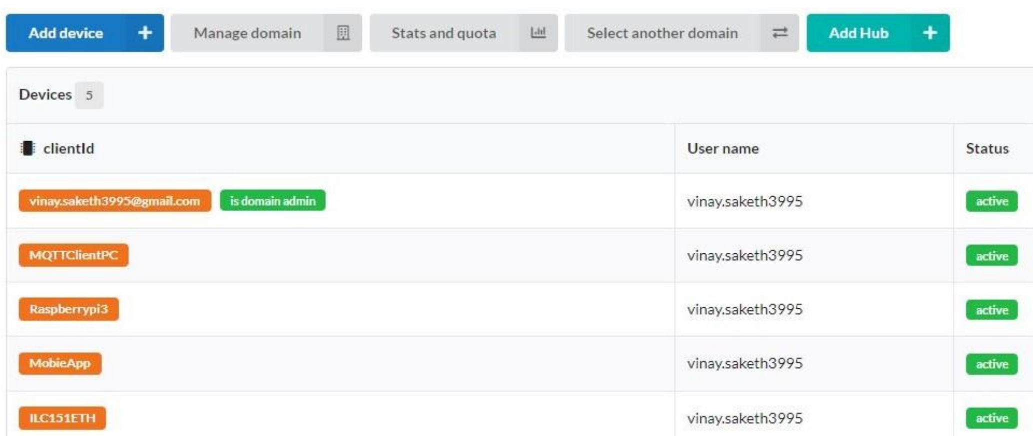
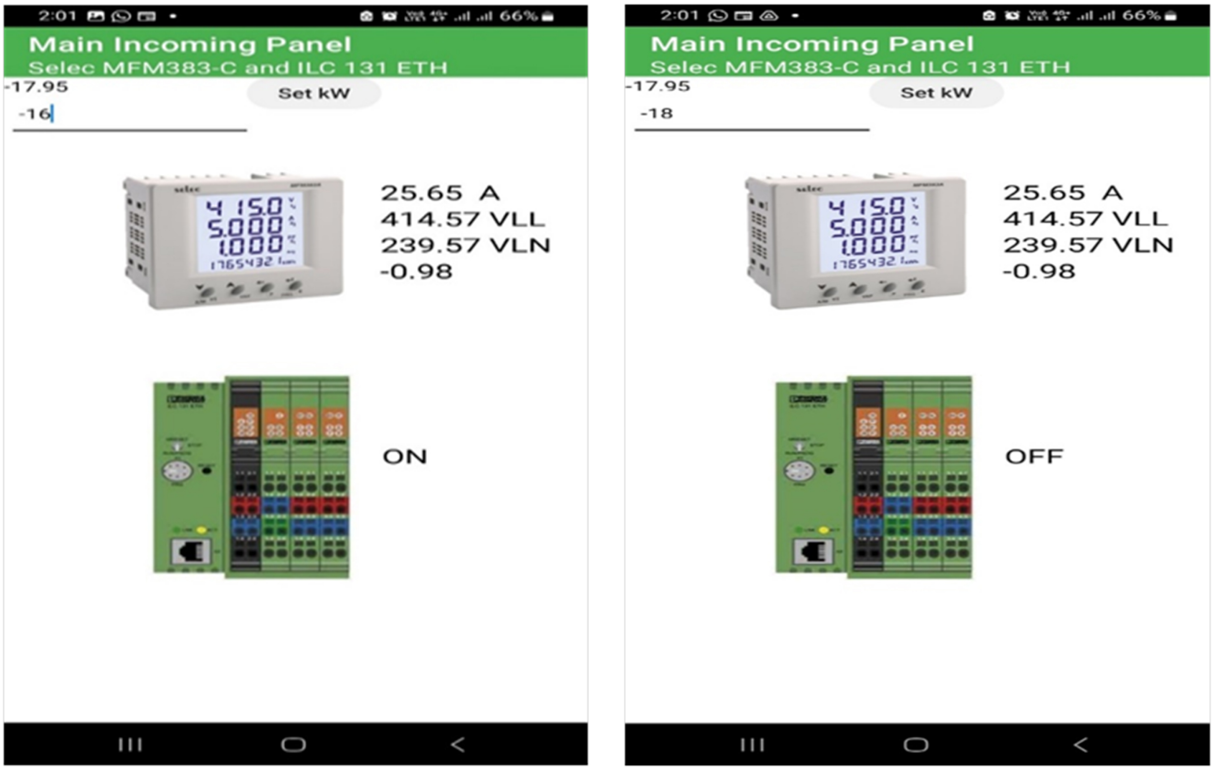


Figure 9. IOT in MyQtt Server.

The storage capacity of data is restricted to size of 10 MB and number of IOT devices connected to single user / project is restricted to 50 Nos. If number of data exceeding the allotted quota then this server won't receive as well as send any data from the IOT devices, in this case user can reset the data count in the web page of MyQtt server in his login page, after resetting the data count again MyQtt server would start receiving the data from the IOT devices and it can send the data to mobile app.in this project we took number of IOT devices is 3 Nos and status of IOT devices can also be viewed in the MyQtt server page of the user and user login page of the MyQtt server displaying the status of the IOT devices is shown in the Figure 9. It is depicts the IOT devices used in the project for data monitoring and controlling of loads using the PLC. Based on maximum demand given in the mobile app, PLC will give the control signal to On /Off the loads through the relay connected in the output port of the PLC.



(a) (b)

Figure 10. (a) Load is in ON (High), (b) Load is in OFF (Low).

The Figure 10(a) depicts that controlling of the load using PLC, in this fig set value of the paper is-16 kW whereas instantaneous value of the paper is -17.95 kW since instantaneous value of the power is less that set value, PLC giving the ON command due to this load connected to the PLC would be in ON condition. In another scenario, the instantaneous value of the power is -17.95 kW whereas set value of the power is -18kW as shown in Figure 10(b) due to this load connected PLC would be in OFF condition since the instantaneous value of the power is greater that set value.The mobile app was developed using MIT APP inventor applications, energy data from multifunction meter is viewed in the mobile app. In the mobile app we can monitor the instantaneous value of the power which includes real power, reactive power and apparent power for all the three phases individually. In the mobile app we can monitor, load current for all three phases individually, power factor (PF) of all three phases individually, line voltage and phase voltage of each phases. The energy data from energy meter is moved to the mobile app from Raspberry PI to cloud server and from cloud server data is pushed to the mobile app. The energy data tagging in the mobile app is shown in the Figure 11.

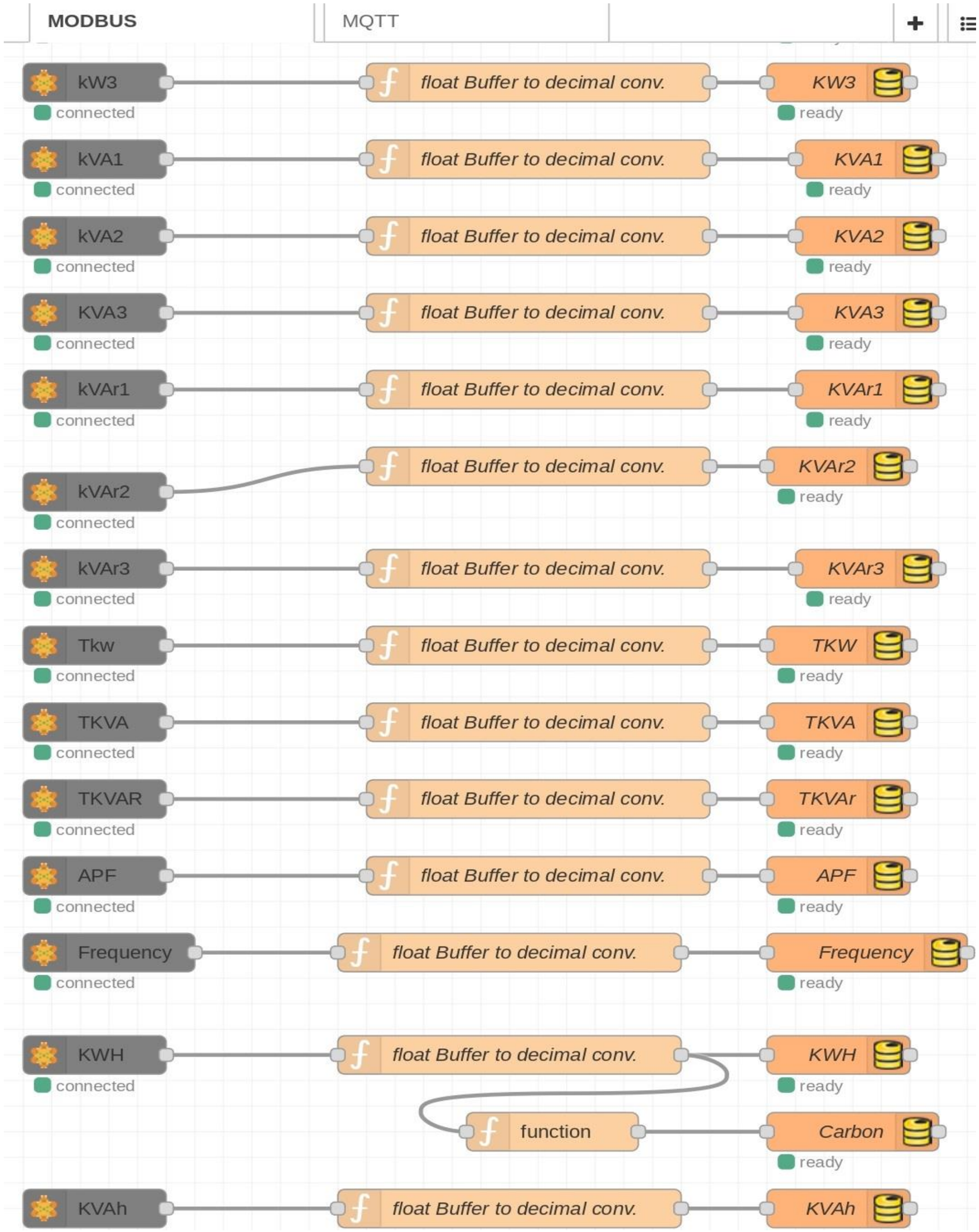


Figure 11. Tagging of Energy data in the Mobile App.

Figure 12 depicts the energy data of the energy meter which is connected in power distribution network in the mobile App. Fig shows energy data of individual phases in mobile App.

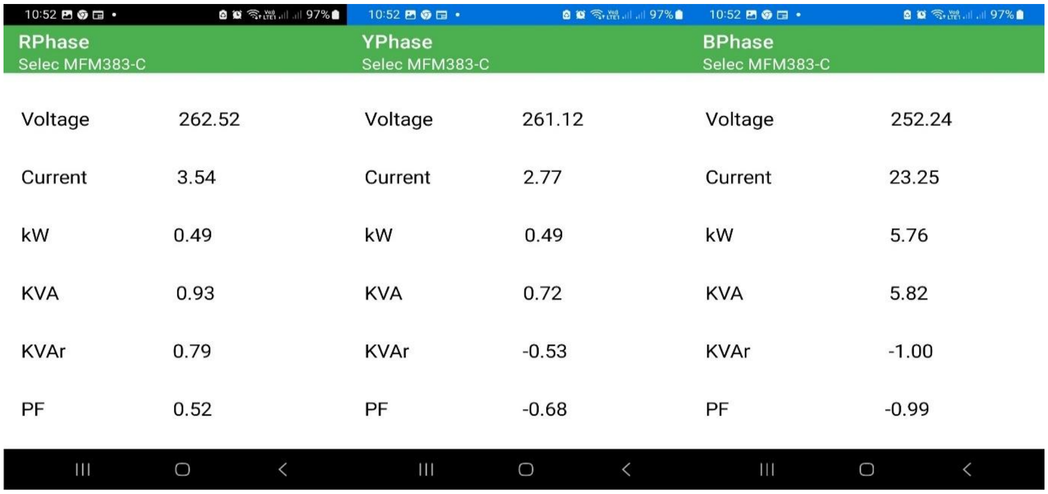


Figure 12. Energy Data of Energy meter in Mobile App.

The total energy value of the building under study was captured separately and CO2 emission in Kg per kWh was tagged in the mobile App and same was shown in the Figure 13.

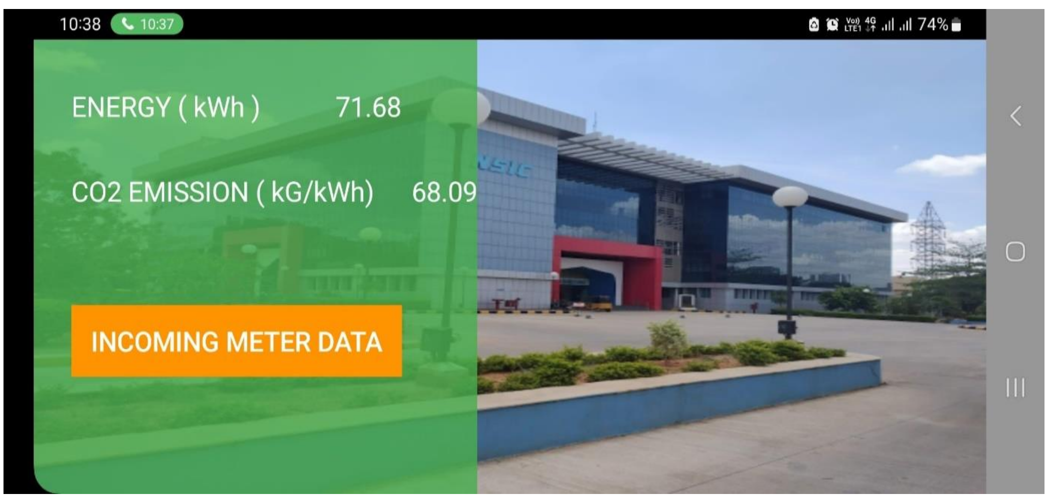


Figure 13. Total Energy and CO2 emission in Mobile App.

8. Conclusions

In this study real time monitoring of energy data of typical power distribution system pertaining to Educational institute located in Hyderabad was monitored using IOT devices. The monitoring of Energy data using Mobile App was done and controlling of critical loads is done based on the power demand value set in the mobile app and it is implemented through PLC. In this project remote monitoring of energy data of the campus was done through Multifunction meter, Raspberry PI and Mobile App. Controlling of loads connected to the PLC was implemented successfully. Functionally of complete hardware setup was verified and tested in real time power distribution network. In this paper we done data monitoring of campus and controlling of single load was done successfully, based on the need we can increase the number of loads connected to the PLC. This hardware setup is having high reliable and all the data was monitored continuously using Mobile App and loss of data in this setup is zero. In past 3 months, performance of the system is good and we have not noticed any loss of data connection among the device connected in the network. This concept can be further explored for implementing the data monitoring and controlling of loads in the manufacturing industries since all the manufacturing industries is having the PLC and Multifunction meter through this hardware components, low cost of data monitoring and controlling of loads can be achieved.

Acknowledgments

The authors are highly thankful to Faculty members of Puducherry Technological University for their support extended towards this project

Funding: This research received no external funding.

Author contributions: First Author made a detailed literature survey pertaining to this research work and contributed in physical implementation of complete IOT system i.e Section 5 and 6. Second Author mentored the first author in writing the research article and he contributed in reviewing and editing the paper. Third Author contributed in interpreting the results took from the hardware setup and given his input in writing the conclusion.

Disclosure statement: All the information collected and presented in this research paper is correct and no influence has been done in getting the data from the third party and all the data presented in this paper is duly collected and measured by the authors. Authors had no conflict of interest in submitting this research paper to the journal.

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