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International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 07 | July 2019 www.irjet.net p-ISSN: 2395-0072

Review on Design of Residential IoT based Smart Energy Meters

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Abstract - *The electricity consumption in household is increasing rapidly through time due to many issues. Since customers are not aware of their electricity consumption data and tariff in real-time electricity is wasted. Which lead them to pay high amount of money and due to the high tariffs of electricity some consumers are forced to do electricity theft. Due to this the application of smart electric meters is very important to track and record the real-time electricity consumption of a household. Application of internet of things (IOT) will make the collection, transmission and analysis of electric consumption data between users and utility's fast and easy process. This paper focuses on presenting the different features and technologies that are being used on current IoT based smart electricity meters and based on the current designs. We have proposed low cost and energy efficient smart energy meter design with wireless communication. Based on the new proposed system we have established wireless based smart metering system were users can easily their real time consumption.*

Keywords: Smart meter, energy efficiency, IOT, Residential energy

1. INTRODUCTION

Internet of Things (IoT) is a network of system where, typically, a massive number of objects, things, sensors and devices are connected through communications and information infrastructure to provide value-added services via intelligent data processing and management for different applications. The Internet of Things allows people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service[1].

The "Self-Monitoring Analysis and Reporting Technology" or simply called "SMART" is a technology integrated with different sensors and have the ability to be automated or self-managing. Smart technologies have the ability to be remotely accessed and controlled. Smart technologies are also designed with the ability to be aware of their environment analyze changes and learn from the changes happening around their environment.

Smart technologies are also self-healing devices when they have system failure it can either repair itself or report the failure that's the reason it's called smart [2].Currently we can say that IoT is almost applicable in every aspect of human lives. IoT is making our daily life easy and interconnected people can communicate and exchange data and information with people device with people and device with device. IoT is playing a wide range in smart cities, smart retail, smart transportation, smart health, smart grid, smart transportation and many more. Smart grids are a wide-ranging and advanced infrastructure consisting smart technologies with advanced communication and monitoring systems. Smart grid in the energy industry staring from production distribution and consumption of energy have changed the traditional electric delivery system.

In earlier times utility's distribution and communication was only unidirectional they generate and distribute electricity to customers and using the traditional energy meters consumption was recorded the monthly estimated bill was calculated by man power going door to door to each customers house which is time wasting coasty and inaccurate but in smart grids the communication between utilities and customers is bidirectional by the implementation of smart meters consumers electricity consumption is recorded in real time and with bill estimation data is sent to the utility wit out any need of human interface.

A smart power meter is a digital tool that records intake of electricity in real-time and communicates that data with the utility company for record and analysis. To the application for tracking and billing Smart meters provides bidirectional communication wirelessly between customers and utilities.

Utilities are one of the electrical departments, which set up these devices at each location like houses, industries, organizations to measure the electricity consumption. They use the smart meter data's to notify the bill for consumption and to analyze their customers consumption pattern and make smart decisions on saving electricity's[3].most IoT based smart electricity maters use different kinds of sensors to record the power consumption in real time and also use GSM technology to notify consumers electricity tariff. These smart meters use wireless technologies to store the recorded meter data on cloud servers. Besides the billing most use this consumption meter data from cloud servers are highly used to detect electric theft, to track unusual electric usage and for the detection of blackouts or power cut.

2. LITRATURE REVIEW ON SMART METER DESIGNS

In this era of smart technologies researchers have tried to transform traditional energy metering system in to smart automated metering system in order to achieve this a lot of different studies and designed have been done in order to develop energy efficient and low cost smart meters in [4] in this publication thee objective was to design low cost IoT based energy efficient meter which offers android app for

the consumers in order to monitor their power consumption and know their bills and the system has also a database and website for the energy suppliers so that they could monitor power usage this smart meter design has Minimized power consumption by 16% relatively than the existing systems.[5] in this paper IoT base smart meter the objective of the author's was To change the existing meters to smart maters by making modifications like the use of GSM module to send notifications on billing and energy usage. One can easily access the meter reading and cost through a web page and User can set threshold value and can also automatically control the meter by switching on and off. What makes this smart meter design different than the others is Users can set threshold value and can switch on and off their meters.

In a paper reviewed by Visalatchi & Kamal Sandeep in 2017 [6], a Microcontroller based detection and control of energy meters from power theft was proposed this system consists of digital energy meter, Arduino(microcontroller), GSM modem and SSR. After switching power on the Arduino and the GSM modem, turn on the SSR and connects the energy meter to load via SSR. This design has contributed a great technique of increasing power efficiency by allowing Suppliers to disconnect power of a particular consumer when there is theft. In the publishing [7] The author's paper mainly concerns on avoiding human interface with the current electricity billing system in household and planning to achieve high efficiency electric consumption load data transfer through internet .they have used Beagle bone black to monitor real time energy consumption and LDR to count the pulse of the energy meter. They have designed a webpage to show the consumption data through the intranet also what makes this design different than the others is users can also see the predicted amount of consumption and bill before they used it. To achieve this, Neural Network Time Series in MATLAB is used. Non-Linear Autoregressive (NAR) neural network have been used to predict the unit consumption time series this system is also low cost, and includes features easy real-time ease of settlement and error detection, elimination of human involvement, online payment and ease of monitoring the entire process from a far-off location. The implementation of neural networks in an energy meter system is completely a whole new innovation giving the user an idea of the future meter data readings of a device.

Also in [8] authors tried to Design a devices that have built-in capability to measure and report the energy use or receive control input over the network. In this paper they divided the design as electricity measurement circuit, controllers, and internet of things part. In the measurement circuit current is sensed based on the principle of hall effect. Arduino Uno receives the measured data from sensor and send calculated data to raspberry pi In the IoT part they used a plat form called Smart Living Make and ThingSpeak. This is open data platform to the internet of things. Send Realtime data to the cloud for storage. Analyze and visualize the data. This paper has contributed Real time data is stored on the cloud and users can see their consumption any time and visualize their data Users can also control the meter using mobile application. The journal published in 2018 [9] also shows the design of wireless based smart electric meter The objective of this design was to use the concept of wireless meter reading to get the monthly usage reading of our household and society. IR sensor was used to sense the power from the energy meter and transmit the data to the microcontroller and the raspberry pi and using the Wi-Fi module the data will be sent to the web database Using the data collected and stored on database cost per unit of power used is being calculated and appears on the web. This design has contributed the goal of reducing the manpower involved in power management. It also avoids data loss. It provides better power management for the utility as the values are directly sent from the meter and store in their data base.

Another 2 author's [10] proposed system with a prepaid energy meter, which can control the usage of electricity on consumer side to avoid wastage of power to minimize the electricity theft. The system operates in 2 modes prepaid and postpaid In prepaid mode when we insert smart card the meter displays the power consumed and bill if the bill exceeds 500 buzzer will turn on and when bill less than -200 the power will be disconnected On the postpaid mode power data is sent to base station If there is any difference between the total power sent and the feedback then it is identified as power theft case and then the local operator is alerted with an SMS. This system contributes a buzzer notification for the customers when they exceed certain amount of bill and helps the suppliers to cut off power when theft is occurring. In the present work wireless meter reading system is designed to continuously monitor the meter reading and to shut down the power supply remotely whenever the consumer fails to pay the bill, As the billing process is done automatically in the proposed system it mainly reduces the manpower.

Likewise based on the paper published in 2017 [11] researchers their main Objective was to create automation of the electric billing system using microcontroller and GSM module n this system When the energy consumption exceeds a particular value the heavy loads will automatically disconnected and alert the consumers.

The energy meter is interfaced with the Arduino microcontroller using optocoupler to convert the pulses to electrical signals acting as clock pulses for the microcontroller. In actual system 1unit =3200 pulses An LCD display is connected with microcontroller to show the consumed units and cost. At the end of each month the data containing the consumed units and cost is shared using internet shield web interfaced data are received and stored in a database at the premises of service provider. This paper suggests a method for effective energy management and power theft detection on distribution lines also. In the proposed system if there is any tapering between the distribution post and the actual customer, power theft detected message will be sent to utility office.

They have also proposed a new method for power theft detection on distribution line by using 2 energy meters at the distribution pole and consumer side one can analyze the difference between power distributed and consumed if there is difference the meter sends message to the suppliers What makes this system better than the other is that Intelligent energy meter is easy to install and beneficial for both energy provider and consumer plus its cost effective and energy efficient. Other author's [12] presented an Intelligent Energy Meter (IEM) which provides solution for maintaining power quality, provides superior metering and billing system also controls power theft. The IEM has mainly three functions power theft, power quality and unpaid bills. To detect power theft IEM has two facilities, one of them is SMS alert system. The SMS alert system will send alert SMS to control server when there is power theft after supply cut in addition to this, as there is daily data availability fetched from each IEM, so one can predict per day consumption of consumer.

In case if there is sudden drop in consumption for some period then one can check respected IEM for energy theft. The IEM provides solution to improve power quality and protects appliances from overvoltage and undervoltage with automatic circuit tripping feature. To work on billing system wireless billing and for action. This paper provides a solution to control of the electricity theft whenever the supply is cut from the server and even though consumer tries to connect load by connecting phase wire directly to the grid.

On other hand Server has the daily load consumption data through which we can predict the daily load flow graph. Through which we can analyze the daily need of power to the consumer and sudden drop in load will indicate the electric theft. The most important fact of this project is low cost of the components required for the development of IEM as well as the Server.

2.1 Challenges in existing systems

In this paper we have tried to see most of the IoT based smart energy meters designed by different authors. This system has contributed a lot in giving awareness of electric consumption for users. Also, most systems have achieved in reducing the man power involvement in the billing system since they are using GSM and web interfaces in notifying users their electricity consumption and bill. But still the current IoT based smart meters also have their own drawbacks.

- The above IoT smart meters are not stand alone they are usually interfaced on the traditional meters their power consumed is not measured directly which makes the system less accurate.
- Most of the smart meters designs in the above paper focuses only on showing the amount of energy consumed and calculate the bill they don't perform any energy efficiency works.
- Most smart meters are not working on electricity savings or increasing electricity efficiency only give awareness of the energy consumed.
- On most designs Users can't control their load demand
- There is a lot to be done on the security concern
- Energy data management issues
- Fault detection and theft detection methods are not accurate

3. PROPOSED WORK

Founded on recent works a single-phase low cost residential IoT based smart energy metering system that records real time energy consumption has been proposed the system consists the smart energy meter (sensing unit) and cloud webpage. The overall systems objective is to establish IOT (internet of things) based energy metering system.by designing a smart energy meter with Wi-Fi module that uploads the real time power consumption and calculated bill of a residence in a cloud server where customers can access and be aware of the real time consumption both on web and mobile.

3.1 Overall system architecture

Based on the standard IoT architecture the smart metering system was designed to show the communication between the utility and the residence through cloud.

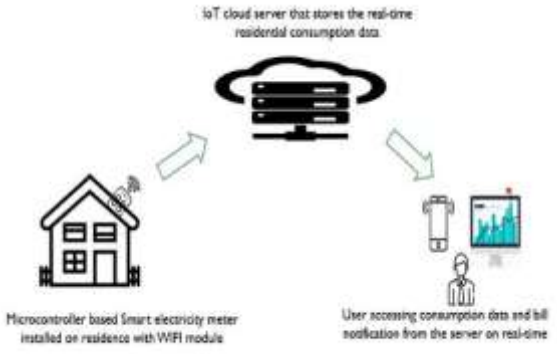

Fig -1: overall system architecture

3.2 Methodology

Based on IoT architecture the system will have 3 basic parts the energy meter, communication unit and data storage and visualization unit.in this part the design of energy meter integrated with Wi-Fi module will be discussed.

3.2.1 Energy Meter Design

The Single-phase energy meter designed in this project mainly consists a current sensor, voltage sensor, microcontroller and relay.

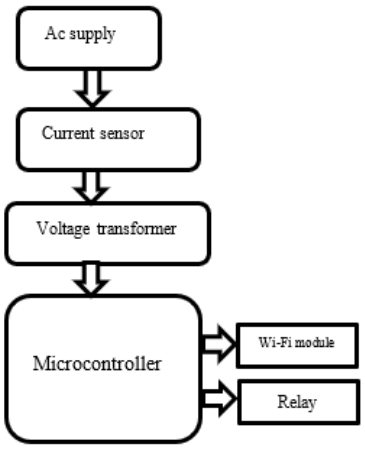

Fig -2: Smart energy meter design

- Main power supply: The utility company's supply 240V Ac (alternating current) which cannot be used directly.so we have to change it to DC (direct current) using a voltage transformer.
- Current sensor: For this project purpose the current sensor used is Generic Hall Current Sensor Module ACS712 20A Model. This sensor is chosen for this project purpose since its low cost and easily interface with microcontroller

Fig -3: ACS712 20A current sensor

Table -1: ACS712 20A current sensor specification

Model	ACS712
Measure	DC/AC
Current Range	30A
Sensitivity	66mV per Amp

Current measurement: Since the current coming from the main source is AC (alternating current) which forms a sine wave there for we have to calculate the RMS (root mean square) value.

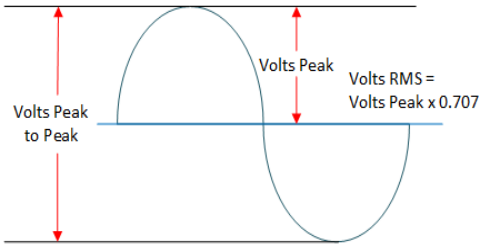

Fig -4: RMS calculation of current sensor

To calculate the RMS value first we have to measure the peak to peak voltage then divide it by 2 and get peak voltage. Then multiply the peak voltage by 0.707.

Vrms=Peak Voltage*0.707

In order to get the RMS current Irms value we should multiply the Vrms value by its sensitivity value. The sensitivity value for ACS12 30A module is 66MV/A.

Irms=Vrms*sensitivity

- Voltage Transformer: The current sensed from the ACS712 will be passed to the voltage sensor so as to be changed to direct current using the transformer in the voltage sensor ZMPT101B is Single Phase Voltage Sensor Voltage Transformer which can measure ac voltage up to 250V.

Fig -5: ZMPT101B voltage transformer

Table -2: ZMPT101B specification specifications

Model	ZMPT101B
Input	2MA
Operating Frequency	50HZ
Supply voltage	5V-50V
Turn ratio	1000:1000
linearity	0.1%

- Microcontroller**:** The Arduino UNO is an open-source microcontroller board based on the Microchip ATmega328P microcontroller and developed by Arduino.cc. the current sensor and voltage transformer will be interfaced to the analog inputs of Arduino

Fig -6: Arduino microcontroller

Table -3: Arduino r3 specification

Model	Uno R3
Clock Speed	16MHZ
Microcontroller	ATmega328
Analog input	6
Digital input/output	14
EEPROM	1KB

Calculating Power: Power is simply the product of voltage and current sensed. The unit of measurement of power is watt or KW

Power=voltage x current

Calculating Energy: Energy is the product of the power calculated by time in hours. The energy calculated is expressed in kilowatt hours (KWH)

Energy=power x time

Calculating Tariff: Energy is usually expressed in unit 1000 unit=1KW and there will be a Tarif per unit set by the utilities. There for to get the total bill we need to multiply both.

Tarif/hour=units consumed / hour x tariff in rupee

3.2.2 Communication unit design

In order to create wireless communication between the device and customers ESP8266 WIFI module is used since its low cost standalone wireless transceiver that can be used for end-point IoT developments. ESP8266WIFImodule uses TCP/UDP communication protocol in order to communicate the microcontrollers data with client or server. The power calculated by the Arduino including time stamp will be transmitted to cloud server using this Wi-Fi module.

Fig -7: ESP8266 WIFI module

Table -4: Wi-Fi module specifications

Model	NodeMCU
CPU	ESP8266
Memory	128kBytes
GPIO	10
Baud rate	115200
CPU frequency	80MHz

- Solid-State Relay (SSR): In this project relay is used for demand side load management a solid-state relay (SSR) is an electronic switching device that switches on or off. The microcontroller is set to a certain level of energy consumption whenever the user passes that limit the relay will turn off the energy meter.

3.2.3 Data storage and visualization

In this project the users Realtime energy consumption data needs to be stored on cloud server so that the user can easily access the consumption and Tarif data from anywhere plus the consumption history will be useful for further analysis purpose. Here we have used an open source IoT platform called ThingSpeak. That lets collect and store sensor data in the cloud and develop applications. ThingSpeak is an open-source Internet of Things (IoT) application and API to store and retrieve data from things using the HTTP protocol over the Internet or via a Local Area Network.

4. EXPERIMENTAL RESULTS

Based on the above proposed design we have set up the implementation as seen below.

4.1 Hardware prototype

This is the hardware set up of the smart meter were the current sensor and voltage transformer are connected with the microcontroller and interfaced with the WIFI module.

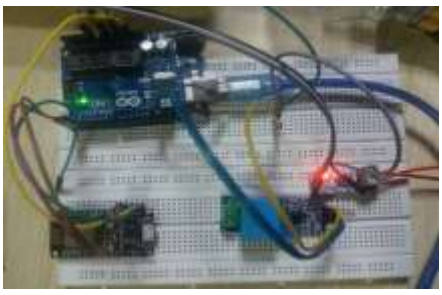

Fig -8 smart energy meter prototype

4.2 ThingSpeak webserver

First a channel is created in the ThingSpeak webserver with a channel id and API the channel access can be set to public or private. Each user can access their meter databased on their unique channel ID

Fig -9: ThingSpeak channel

In the below field's user can see the real time energy consumed in watt in different hours both in graphical form and in power meter gauge form.

Fig -10: Real time energy consumption

Hereon the total bill field users can see their real time tariff they are using per consumption.

Fig -11 tariff display

5. FUTURE WORK

After uploading and recording the load consumption of resident the data can be accessed and exported by the utility in JSON, XML, CSV format for further analysis.

- Residential based load/demand forecasting
- Customer behavior analysis (load profiling)
- Bad data (electric theft) detection
- Demand response program

6. CONCLUSION

In this review paper based on different designs of smart meter done so far, we have seen the design of single-phase energy meter for residential purpose. The energy meter consists of signal conditioning circuit, microcontroller and relay the meter senses data from main source and calculate bill in real time also the design consists a Wi-Fi module in order to store the data on cloud for further data analytics. This design allows users and utilities to control their load consumption and show customers peak hour usage and real time bill.

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