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Smart Energy Management and Scheduling using Internet of Things

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Abstract

Objectives: Increasing energy usage will affect the sustainability due to the presence of elevated level of greenhouse gases. The primary aim of energy management is to ensure optimum energy utilization, thereby minimizing energy costs and extenuating environmental effects. Real time energy monitoring and management assist consumers to overcome the burden of load shedding, energy surcharges and dependence on secondary energy sources like generators and inverters in residential buildings. **Methods:** A low cost, advanced embedded hardware with ethernet communication, i.e Arduino Mega 2560 and smartphone with cloud computing technologies are used to develop a prototype model. It will provide optimal solutions to the consumer for real time monitoring of energy for self regulation as well as to choose the energy provider for competitive energy price. A joint scheduling of electric supply and demand of consumer through Internet of Things (IoT) based smart energy management system on interruptible and shiftable load is proposed. **Findings:** The energy provider needs to regulate the energy usage during peak hours to manage massive energy demand of individual customer or on the whole. This also can be used to prevent the problem of overload on residential generator power supply system and subsequent damage to it. **Application/Improvement:** Low cost, scalable proposed system regulates the peak load by means of load sharing at lower production cost with maximum service utilization is achieved.

Keywords: Automated Energy Management, Energy management system, Energy Monitoring, Internet of Things

1. Introduction

The surge in energy demand, escalating energy price and shortfall between energy demand and supply express the importance of energy management. Real time monitoring, load regulation, load scheduling and load shifting will lead the consumer for optimized energy usage. Energy management system based on IoT facilitates such requirements at ease in a benefit driven manner. IoT acts as a communication link between things like energy meter and Internet for real time monitoring and responsive control on energy utilization. This will enhance the energy saving opportunities by various means of energy management. The data acquisition module and utility meters are connected to the Internet through a suitable gateway, to send data of interest to local web server or mobile applications. Thereby things become smart and adaptive for data exchange and control by the user. The collected energy data is stored and analysed locally and also in the cloud. Later this information need to be readily available to the user for visualization and decision making. This information benefits the consumers with energy consumption awareness, quality of power based on energy parameters. This will, directly and indirectly payback the economy, society and environment. Arduino based controller is an efficient tiny device to sense and process the real time data and also provides better response with system integration. Figure 1 gives an overview of Arduino Mega 2560 Node based prototype model. A consumer with sophisticated appliances use energy luxuriously and also rely on secondary energy source like inverters, generators at the time of load shedding. Inverters with lower energy efficiency while charging and discharging also place additional load on the energy provider. Meanwhile, low end consumer uses few appliances and lesser energy demand has to struggle without any alternate sources of power for

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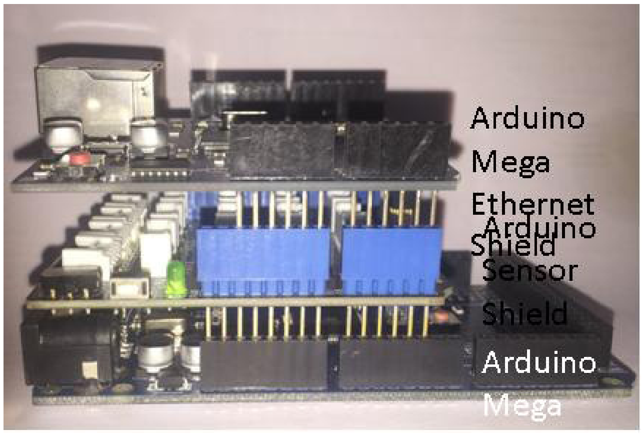

Figure 1. Arduino Mega 2560 node – prototype model.

hours. Thus during load shedding, low end consumer will be affected more than high end consumers. This prototype model provides the fairness in terms of a common load sharing strategy among all types of consumers for their basic necessity during peak hours. The difficulty of real time energy monitoring and dynamic schedule based energy regulation is minimized with IoT. This prototype work namely called as Real Time Energy Monitoring and Management System [RTEMMS], it supports the domestic users to plan preventive maintenance, reduce energy consumption and energy bill. It also proposes to provide demand oriented energy resource scheduling.

In[1] proposed Multi Agent System [MAS] to autonomously manage the energy beyond individual capability of a single agent. MAS enhanced the operational efficiency of energy management and consumer demand in autonomous energy management system. The agents are more responsive in task accomplishment. The growing demand for energy in different countries like India and China is emphazised[2]. Enforcement of energy management in real time case is for the benefit of the consumer considering the demand, change in energy price in real time and the time of energy use. Energy consumption during peak hours can be reduced with the focus on Heating Ventilation and Air Conditioning (HVAC)[3]. The access of physical data from remote locations and its transmission to the base station is made easy with Wireless Sensor Network (WSN)[4]. It also supports remote monitoring of energy meter data with high reliability. The role of WSN has further heightened with the evolution of the internet and advancement in the internet services to form an inseparable part of IoT[5]. However, it has its own restrictions in terms of extraction of information from the data, based on the application. At the same time, real time processing of the data and data security are the major concerns on integrating with IoT. With the advancements in the field of tiny controllers and devices, a vast range of hardware's are available for integration with IoT for real time network monitoring solutions[6]. With the help of IoT integrated controllers, RTEMMS can be realized at ease for monitoring and control. The current method of energy regulation by load shedding can be mitigated by load sharing with a proper demand supply based scheduling. An IP based[7] connectivity with WSN approach for IoT has been discussed where challenges and advantages of IPv4/IPv6 interconnectivity for the particular application has been analyzed.

Residential and commercial buildings consume one third of the global energy generation. The energy providers, as well as consumers have realized the importance of energy management during peak hours to avoid the burden of load shedding, energy surcharges and dependence on secondary energy sources like generators and inverters. Increasing energy usage will also affect the environment with the presence of elevated level of green house gas leading to climatic changes. The poor visibility of energy consumption data also obstructs the energy efficient management practices[8]. To overcome these difficulties, a prototype model using a low cost, advanced embedded hardware with Ethernet communication, i.e Arduino Mega 2560 and integration of smartphone with open source cloud computing technologies are used. The proposed model will enable real time energy monitoring and management in residential buildings with suitable load prediction[9] technique to get equipped with changing energy demand. It also gives provision for the administrator to choose the energy provider online for effective load distribution based on the demand.

2. Proposed Architecture

Embedded hardware is developed to establish real time monitoring of the energy data, load control and regulation based on the energy data. The peak hour demand is regulated by means of schedule with primary restrictions on HVAC systems whenever energy utilization crosses the limit. The system also looks for customers own self regulation during energy utilization restrictions by the shift of interruptable and shiftable load to off peak hours. The above objective is achieved with RTEMMS based on open source IoT infrastructure as illustrated in Figure 2. Low cost tiny microcontroller based advanced embedded system

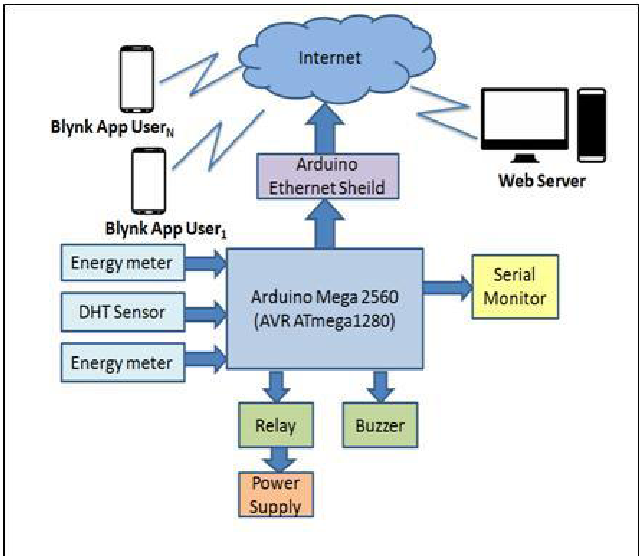

Figure 2. Layout of Working Module.

hardware with ethernet communication (i.e. Arduino Mega 2560) is used to collect and analyze the data from energy meters and temperature sensor. In this work a voltage regulator is chosen for simulated voltage rating for the energy consumption data. From the collected data, data of interest (energy data in Kilo Watt Hour (KWH) format) is sent to a local web server with the use of local network as well as an open source mobile application using internet via cloud based services. The data can be viewed in a KWH format in real time by logging into the local web server and also through smartphone application. The data received is analyzed by Arduino microcontroller for energy management decision making based on static or dynamic supply scheduling algorithm scheme with energy provider discretion. In static scheduling, during peak and off peak hours the energy supply is regulated at a constant rate. The scheduling cases are regulated with the time stamping for effective energy usage analysis with the support of Real Time Clock (RTC) integrated to the module. In dynamic scheduling, the energy supply allocation is based on the energy demand and energy available at central pool. Dynamic scheduling is much more efficient because of effective utilization of energy at the central pool which also ensures better profitability for the energy provider. The control action like actuating[10] the relay or siren is taken based on the results of the algorithm used in the indented module. The actuated relay will regulate the power supply initially by terminating supply to the HVAC system and later to interruptible and shiftable loads if the consumers still breach the energy limit even after systematic warnings. Figure 3 describes the entire process outline of the system. The consumer is given the choice to self regulate the energy usage within the designated energy limits based on their priorities. This can be easily done with the visualization of real time energy consumption data. Otherwise continue to use the supply by bypassing the termination at additional surcharges. The act of bypassing the regulations, the choice of energy provider, uninterrupted supply and its corresponding surcharges are handled by the admin in-charge. The led light indicates the outcome of trip based action. The Figure 4 describes the general hardware setup.

3. System Implementation and Results

Energy consumption is monitored in real time using IoT to bring about energy awareness to the consumer.

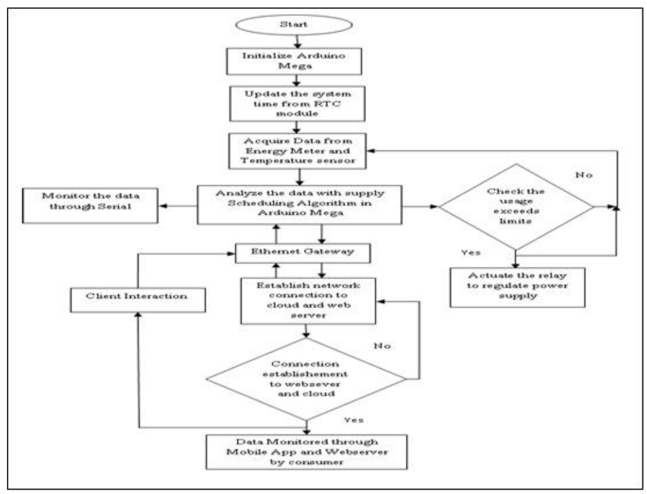

Figure 3. Flow Chart.

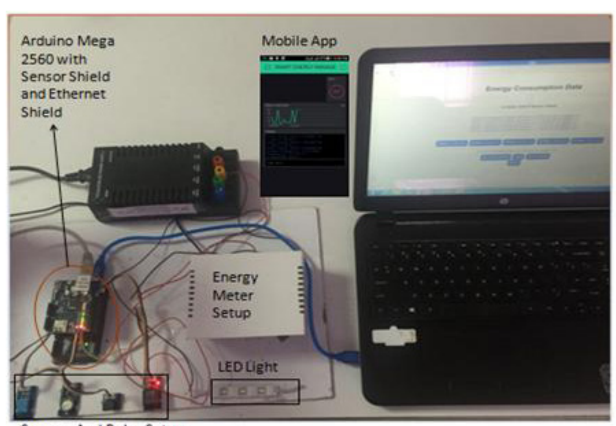

Figure 4. Proposed Hardware Prototype.

RTEMMS prototype model is implemented using an Arduino Mega 2560 microcontroller has provision for 16 analog pins and 54 digital pins. This enables interfacing of a number of energy meters and other sensors required with the board for providing off the shelf usage. In this prototype, the energy meter data either in digital or analog form is given as input to the controller. Likewise, energy data from five different consumers are considered in this work. Energy scheduling is incorporated for every customer to regulate interruptible and shiftable loads and also to manage the energy demand at peak hours. A static or dynamic scheduling algorithm scheme is being used depending on the energy provider discretion. The scheduling is proposed in three different time slots namely day, evening and night. The day time is from eight o'clock to 18 o'clock with a load limit of 12 KWHr. The evening time is between 18 o'clock to 23 o'clock with a load limit of 7 KWHr considering peak hour. The final time slot starts at 23 hours and extended till morning eight o'clock without usage limit. The peak hour period and usage limit need to be varied based on the customer class, local usage pattern and energy available for supply. The energy regulation is carried out only on the interruptible load like washing machine, microwave oven, refrigerator, decorative lightings and shiftable load namely the Heating Ventilation and Air Conditioning (HVAC) system. These are high power consuming devices and can be shifted to off peak hours without much disturbance to the consumer.

RTEMMS also enables consumers to self regulate the energy consumption. Moreover the consumer could easily identify the source of energy wastage and can make necessary maintenance. The real time energy data will be very useful to predict the energy demand from the consumer the next hour, next day, coming week using very efficient load prediction technology like fuzzy logic, neural network or artificial intelligence in future. The temperature data aggregated allows the consumer to get more energy allocation based on environmental conditions. Through supply scheduling model, energy demand can be efficiently managed through proper load sharing.

The energy data are sent to the web server via ethernet. The energy data are stored in the database server and can be retrieved by any authorized client. By using the web server, remote monitoring of energy data is done efficiently. The control action like bypassing trip and change of energy provider are also achieved through the web browser. An open source online monitoring and control application called blynk is used on android based mobile phones. This blink application provides cloud services for communication from the hardware to the smartphone and vice versa.

3.1 Experimental Results

The general hardware setup, i.e., the Arduino Mega 2560 interfaced with the sensors on the Arduino Shield and connected to Ethernet shield. Once the system is configured to Arduino, the application codes are developed in the Arduino IDE and tested. Initially, the output is monitored at the terminal. Further with the deployment of code, the energy data can be viewed at the web server and mobile application.

The Figure 5, Figure 6, Figure 7 shows the real time energy monitoring through web server for five flats in a residential building at normal, high consumption and regulated energy consumption. The lack of regulation system leads to unrestricted energy consumption, putting a huge burden to the energy provider especially during peak hours. The energy regulation is achieved through RTEMMS when energy consumption goes beyond the

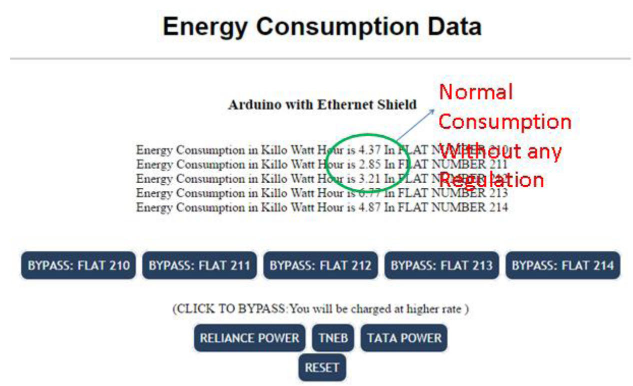

Figure 5. The real time energy monitoring through web server (case 1).

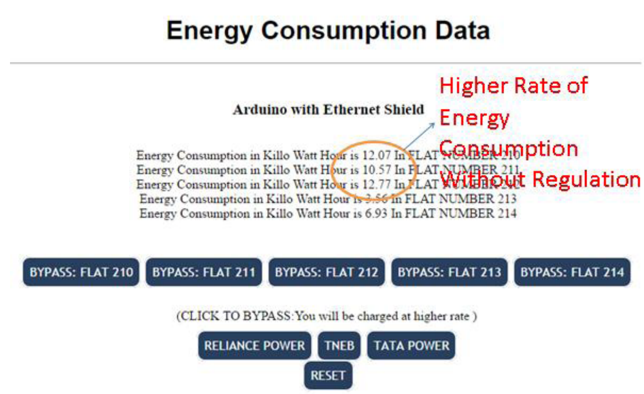

Figure 6. Real time energy monitoring through web server (case 2).

stipulated limit during peak hours. Figure 8 shows the graph for comparison of high consumption and regulated consumption for different residential users. The graph clearly explains the energy saving achieved with RTEMMS during peak hours through energy regulations. The saved energy is equal to energy produced to ensure energy for all the consumer for their basic energy requirements. Thereby the burden of load shedding is minimized. The user can choose trip bypass from the web browser. The provision to choose the energy provider also integrated to it.

Blynk mobile application is an open source entity that can be integrated with Arduino, Intel Galileo and Raspberry Pi based end devices. Through this application the processed data can be viewed in real time as well as to place control commands to the end device for action. The blynk mobile application is used to view the energy consumption in real time through a smartphone. Through the smartphone consumer can view the energy consumption as well as to give command to bypass trip once a trip warning occurs as shown in Figure 9. Decision based

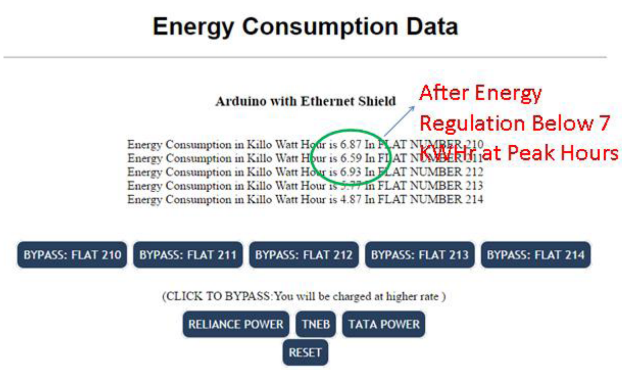

Figure 7. Real time energy monitoring through web server (case 3).

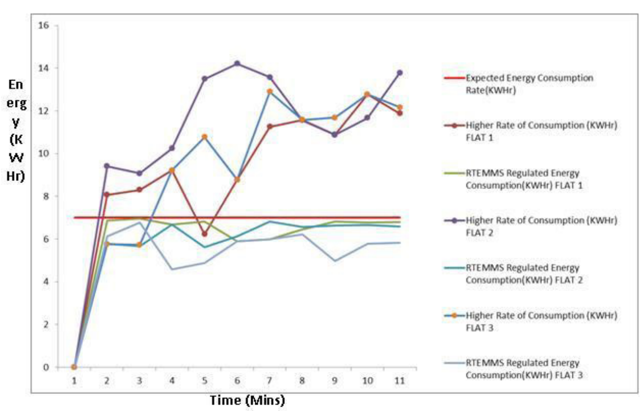

Figure 8. Unregulated Energy consumption Vs RTEMMS based regulated energy consumption.

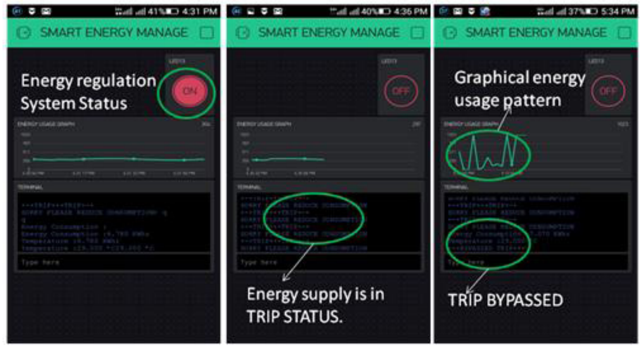

Figure 9. The real time energy monitoring through mobile application

control is achieved along with monitoring of energy data through the blink mobile application.

4. Conclusion and Future Scope of Work

The energy management system will get transformed to smart system with IoT by means of an advanced embedded device with Ethernet resource. The collected energy related data will facilitate high level of consumer awareness in real time for monitoring and control through web server as well as mobile application. The static and dynamic scheduling based energy management is implemented for optimum energy utilization during peak hours. The consumer is allowed to choose the energy provider for competitive pricing and energy allocation. The system can be enhanced in future by integrating non conventional sources like wind and solar power to be utilized during peak hour regulation to mitigate the effect of scheduled energy regulation and higher energy prices. The enhanced automated system will be switching from conventional source of energy to non conventional source when the consumer reaches the scheduled energy usage limit. Thus encouraging consumers with higher energy requirements to shift to non conventional energy sources. The proposed mechanism has been implemented with Arduino microcontroller and related peripherals, thereby user centric services associated with optimal energy management are achieved.

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