IoT Based Smart Energy Management in Residential Applications

Md. Rakibul Hasan
Department of Electrical and Electronic Engineering
Khulna University of Engineering & Technology
Khulna, Bangladesh
rakibul.eeekuet@gmail.com

Eklas Hossain
Department of Electrical Engineering and Renewable Energy
Oregon Institute of Technology
Klamath Falls, USA
eklas.hossain@oit.edu

Hossain Mansur Resalat Faruque
Department of Electrical and Electronic Engineering
Khulna University of Engineering & Technology
Khulna, Bangladesh
resalat_f@yahoo.com

Tipu Sultan
Department of Electrical and Electronic Engineering
International Islamic University
Chittagong, Bangladesh
ssultanstipu@yahoo.com

***Abstract*—The lack of credibility of data acquired through traditional means from a conventional metering system has reduced the efficacy of the energy management system. For overcoming the drawbacks of the conventional metering system, this paper proposes a smart IoT based energy management system (EMS), which not only ensures transparency and credibility of data but also offers flexibility to the consumers by offering the facility of remotely controlling their home appliances. Electricity consumption and its corresponding cost is calculated automatically and then the data is sent to a server in a periodic manner. For carrying out the task, NodeMCU has been utilized, which has the combined functionality of both microcontroller and Wi-Fi modules. By means of its microcontroller function, constant readings of energy meter are collected and saved in NodeMCU; then the data is transferred to a remote server on the internet via Wi-Fi. Consumers can observe real-time data on the server to gain a clear idea of electricity usage, therefore, they can reduce or increase the consumption as per their budget. This proposed system also provides the functionality of controlling the home appliances remotely over the Internet. Furthermore, electricity suppliers can produce bills from the server data automatically, making it a feasible solution. This paper also proposes and analyzes individual sub-metering of home appliances of high rating to observe and control their energy consumption. A detailed cost analysis of the system has been performed for ensuring its cost-effectiveness. According to the analysis, the total cost associated with the system is BDT 1064, which is fairly economical compared with existing systems. The add-ons of this proposed system can be also integrated with the existing prepaid meters of the market, eradicating its major drawbacks by providing added functionality.**

Keywords— IoT, Smart meter, Energy management, Home automation, Residential tariff.

I. INTRODUCTION

Bangladesh being a developing country, the energy demand is increasing by leaps and bounds. In order to meet with this rising energy demand, there has been a prolific increase in the implementation of alternative energy sources for generating more electricity, however, this is proving to be insufficient due to system energy loss. Therefore, a smart energy management system (SEMS) is necessary to ensure proper electrical power management, which will reduce the system energy losses. Furthermore, the integration of the SEMS with the internet enables the consumers to observe their consumption of electricity and take action according to their budget by remotely controlling the electrical equipment. It also provides a feasible mean to the electric suppliers for producing bills with minimal error.

With the advancement of technology, the accessibility of the internet is increasing day by day. Apart from being used for communication and entertainment purposes, the internet also provides a bunch of scopes in power system management, development, control, etc. Internet of things (IoT) is a cutting-edge technology that interconnects the 'things' over the internet [1]. These ‘things’ incorporate everything we can perceive of connecting-goods, buildings, appliances, machines, vehicles, plants, animals, and even human beings. It is estimated that the number of objects connected to the internet will reach 50 billion by 2020 [2]. IoT is a bidirectional approach, where objects export data to a distant server and the users can control the objects through the server by software programs and it is mainly done over Wi-Fi networks. The traditional electric power network has many limitations, however, by integrating with IoT it can be transformed into an intelligent power network [3]. The application of IoT can effectively improve the accuracy of real-time monitoring and control of smart grid [4, 5]. The informatization of power grid system can be sped up by utilizing IoT and thus is beneficial for effective management of the power grid infrastructure [6]. It can also be used for precise and accurate estimation of energy consumption [7]. Recent studies show that IoT can also be integrated with smart energy meters and can increase their accuracy [8-10]. IoT based smart energy meter has been proposed in [11-13]. However, it does not have the functionality of remotely controlling the home appliances. An efficient billing system can also be developed using IoT [14, 15]. It also possesses great potentiality in its application in the control system of smart homes [16-18].

This paper proposes a SEMS based on IoT, which ensures the credibility of smart meter data as well as provides the facility for controlling home electrical appliances remotely. The energy usage data of the consumer is stored in NodeMCU, which is then transferred to a remote server on the internet using Wi-Fi. NodeMCU is an open-source

978-1-7281-3445-1/19/$31.00 ©2019 IEEE

development kit composed of microcontroller and ESP8266 Wi-Fi module, where microcontroller part does the necessary calculations and control and ESP8266 helps in communication over Wi-Fi. The corresponding cost of the consumed electricity is automatically updated, reducing the errors that occur in the conventional energy meter system. This proposed method also reduces the complexity of bill payment and the consumer can check his/her energy usage at any time. Furthermore, it gives consumers the ability to remotely control any home appliance. Hardware implementation of the system along with necessary software configuration has been carried out in this research. Additionally, a comparative cost analysis with the existing energy meters available in the market has also been shown in this paper.

The remaining part of the paper is organized as follows: in section II, the present condition of energy metering system in Bangladesh is represented. The tools and apparatus required for the proposed system and its working principle are discussed in section III. The problems that occur during the operation of the proposed smart energy meter and corresponding solutions are presented in section IV, which is followed by a cost analysis in section V. Finally, in section VI, the key features along with future scope are described as a conclusion.

II. Present Condition of Energy Metering System in Bangladesh

A common practice in Bangladesh is that a person from utility services goes to individual consumers to collect the energy meter data. The bill is prepared using those data and the bill paper, which contains all the information about the usage of electricity in that month, is sent to individual consumers for payment. Finally, consumers pay their bill according to the bill paper, which was sent to them by going to a particular station or a bank. Therefore, this process is very much hassling and requires a lot of time and steps, and since there is direct involvement of human in collecting the meter data, the credibility of this system is compromised.

There are system losses occurring in the power network due to technical and non-technical aspects [19, 20]. Technical reasons include losses in power generation equipment, transmission lines, distribution lines, etc.; whereas non-technical losses occur mainly due to customer level meter tampering. In order to reduce the losses occurring at the customer level, the prepaid meter has been introduced in some cities and the rest are on the way. Although the prepaid metering system offers more advantages than the conventional meter system, it also has some major drawbacks. The customers need to purchase a card to refill the account but purchasing the card is quite troublesome sometimes. The consumers also need to predict the monthly bill and recharge accordingly, which can create a situation of uncertainty. Furthermore, prepaid energy meters do not provide the consumer with the ability to control electrical appliances remotely.

III. IoT Based Smart Energy Meter

IoT-based smart energy meter solves the issues of prepaid energy metering by minimizing the complexities and mitigates the non-technical losses by ensuring the credibility of data. It also brings new important features, such as real-time viewing of consumption data and remote controlling of home appliances. A single phase static watt-hour meter is used to calculate the consumed energy and these data are extracted from the meter through a LED. Table 1 shows the specification of the watt meter used in this paper.

TABLE I. Specification of The Single Phase Static Watt Hour Meter

Supply System	Range
Voltage	0 to 240V (Phase to neutral)
Current	5A to 30 A
Frequency	50Hz ± 5%
Temperature	$-10°C\ to\ 50°C$

In order to perform IoT operation, a microcontroller along with Wi-Fi module is needed. The microcontroller sends the data to predefined internet server using Wi-Fi. NodeMCU is such a development board that provides combining the functionality of having both I/O ports like microcontroller and Wi-Fi module. This kit is based on the ESP8266 Wi-Fi module. It is programmed in an Arduino environment. Here, the microcontroller does all the calculations necessary, whereas ESP8266 provides the functionality of communication via Wi-Fi. The pin diagram of the NodeMCU is shown in Fig. 1.

Another required apparatus for the proposed system is the optocoupler, which provides isolation between relatively high voltage energy meter side and low voltage microcontroller circuit. The electrical signal from two isolated circuits is transferred using an optocoupler. Data from power circuit is fed to optocoupler and then microcontroller extracts the data from the optocoupler. The model used in this work is optocoupler – 4N25. Other components used for the proposed IoT-based smart energy meter are a 220V – 9V transformer to step down the supply voltage, IC 7805 to regulate dc voltage, diodes for rectification purpose, capacitors for smoothing the rectified dc, and some light emitting diodes (LED) to emulate the home appliances.

Fig. 2 shows the functional block diagram of the whole system. In the functional block diagram of a conventional meter, only the ac power supply, energy meter, and loads block exist. However, some additional blocks are needed to be added here to realize the IoT and energy management features. The energy consumption data is taken from the energy meter through the optocoupler. There is a LED in the energy meter named ‘Cal’, which blinks a certain fixed times per Kilo Watt

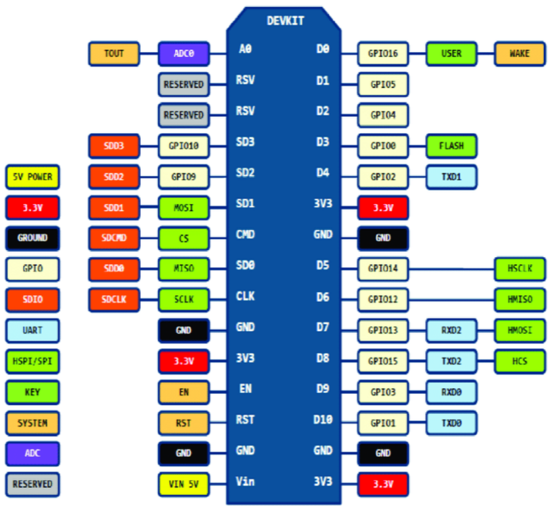

Fig. 1. Pin diagram of NodeMCU.

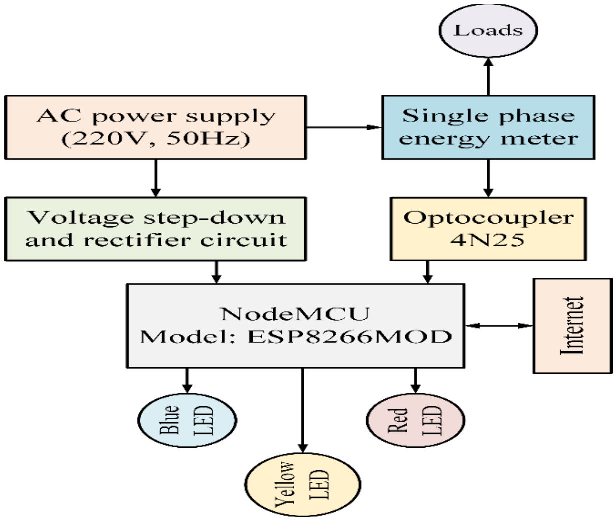

Fig. 2. Block diagram of the IoT based smart energy management.

Hour (kWh) for a particular energy meter. The meter used in this project has such a functionality, where the 'Cal' LED blinks 3200 times per kWh. This LED data is then fed to a microcontroller through the optocoupler. The number of blinking is observed by microcontroller programming and by using this data, the total electricity units consumed and associated cost are calculated.

The main feature of this system is to collect data over the internet. Therefore, the consumed unit of electricity and associated cost data need to be transmitted over the internet. This is done by writing the required Arduino code in the NodeMCU. In order to practically implement this system, NodeMCU needs internet connectivity and to store data on the internet, hence, a website domain is needed. However, in this prototype, the website is hosted locally and Wi-Fi hotspot connection is given to the NodeMCU to simulate the prototype. The Wi-Fi service set identifier (SSID) and password are written in the Arduino script. Therefore, NodeMCU gets connected to local Wi-Fi whenever Wi-Fi is available. The updated data are transmitted at a certain time interval.

The power supply of NodeMCU is taken from the main AC power supply. In order to use the 220V AC supply as 5V DC supply, voltage step down transformer and a rectifier circuit are used, which is shown in Fig. 3. In this circuitry, a step-down transformer is used to convert 220V AC to 9V AC. This 9V AC is then transformed into 9V DC by a full bridge rectifier circuit. The DC produced in the output of full bridge rectifier has a significant amount of ripples and in order to

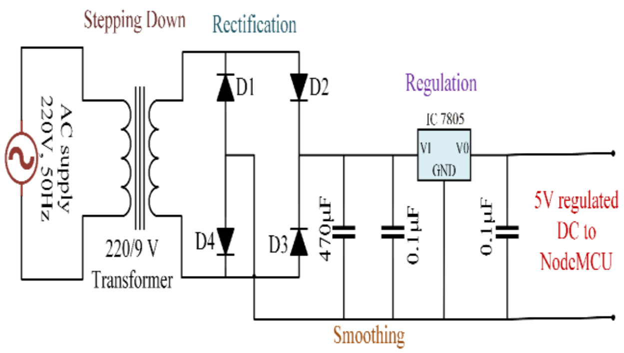

Fig. 3. Rectifier circuit to convert 220V AC to 5V DC.

reduce it, a smoothing capacitor is used in parallel. Finally, this 9V DC is transformed into 5V DC by using the 7805 regulator IC that is fed to the NodeMCU. The hardware implementation of the prototype is shown in Fig. 4.

Another important feature of this system is the control of home appliances over the Internet. A user of this proposed system can check the status of his home appliances and can take any action as he wants; that means he can turn on or off any home appliance remotely using the internet. In order to simulate this, three LED's are connected to NodeMCU and can be controlled over the Internet. The LEDs are connected to the general purpose input/output (GPIO) pins. Some predefined commands have been configured in the Arduino script to make the LED either on or off. When those commands are transmitted to the NodeMCU from the website, the LEDs will respond according to the specified commands and thus, they can be controlled easily. In real life application, this feature can be implemented by using a relay circuit. By controlling the relay, electrical appliances like fan, light etc. can be turned on or off as required.

When a user logs in to his account, he will see a webpage, which is shown in Fig. 5. This webpage has been developed using the basic HTML and bootstrap library which are open-source resources. Consumed unit of electricity and associated cost are shown on the webpage. The consumer can remotely

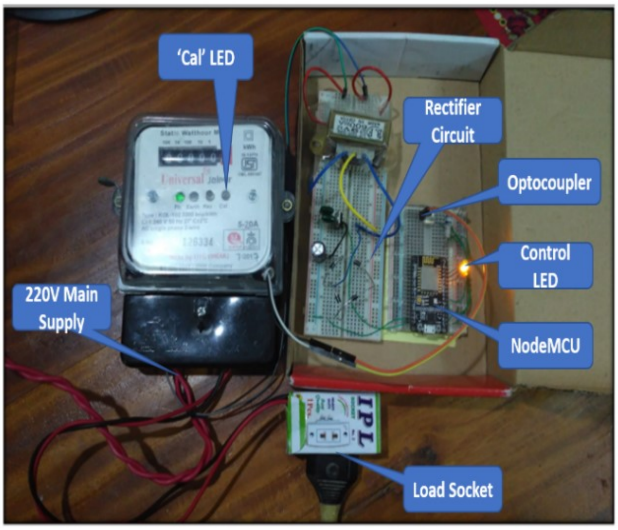

Fig. 4. Hardware implementation of the prototype of IoT based smart energy management system.

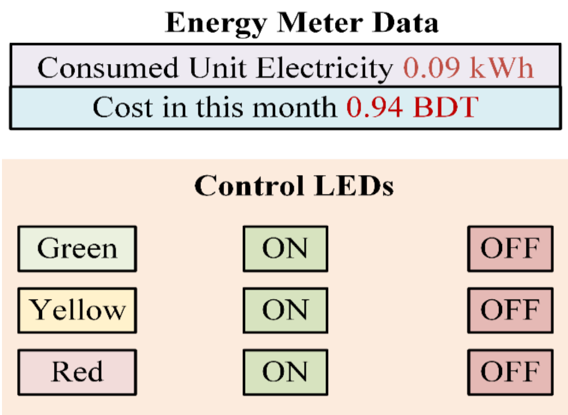

Fig. 5. Webpage showing the consumed electricity and their associated cost along with the feature of controlling the appliances remotely.

control any home appliance using this webpage. For this instance, in order to control the green, yellow, and red LEDs over the Internet, two buttons have been configured as ON or OFF for each LED and they can be turned on or off individually just by clicking on the corresponding buttons. A comparative analysis of the proposed system with existing works is tabulated in table II. The proposed system does not require any additional microcontroller as the NodeMCU has the dual functionality of microcontroller and a Wi-Fi module. Furthermore, the proposed system also has the feature of controlling home appliance remotely.

TABLE II. COMPARISON OF PROPOSED METHOD WITH EXISTING WORKS

Authors	**Microcontroller**	**Optocoupler**	**Functionality of controlling of home appliance remotely**
Abate *et al.* [11]	STM32F205RB	Not used	Not available
Sahani *et al.* [12]	ATMega328	MOC3071	Not available
Singh *et al.* [13]	ATMega328 and PIC16F877P	Not used	Not available
Proposed	Built-in microcontroller in NodeMCU	4N25	Available

The proposed system has been designed to determine the electricity consumption and calculate the corresponding cost for residential consumers only. Let us consider b is number of blinks of the 'Cal' LED in a month. As the 'Cal' LED blinks 3200 times per kWh, the total energy consumption (kWh) is

$$a = \frac{b}{3200} \quad (1)$$

If s and d are the service charge and demand charge per month in Bangladeshi Taka (BDT), respectively, then the associated cost of that month c can be calculated using the following equation

$$c = (a \times k) + s + d \quad (2)$$

Here, k is per unit price of energy in (BDT), whose value depends on a. According to Dhaka Power Distribution Company (DPDC), the value of k for different consumed unit (a) is shown in table III [21].

TABLE III. TARIFF RATE FOR RESIDENTIAL CONSUMERS

Consumed Unit (a)	**Per Unit Rate of Energy (k)**
0-75	3.80 BDT
76-200	5.14 BDT
201-300	5.36 BDT
301-400	5.63 BDT
401-600	8.70 BDT
601-above	9.98 BDT

The existing tariff rates in Bangladesh for different categories according to DPDC [21], is shown in Fig. 6. The variation of service charge s and demand charge according to DPDC [20] is presented in Figure 7.

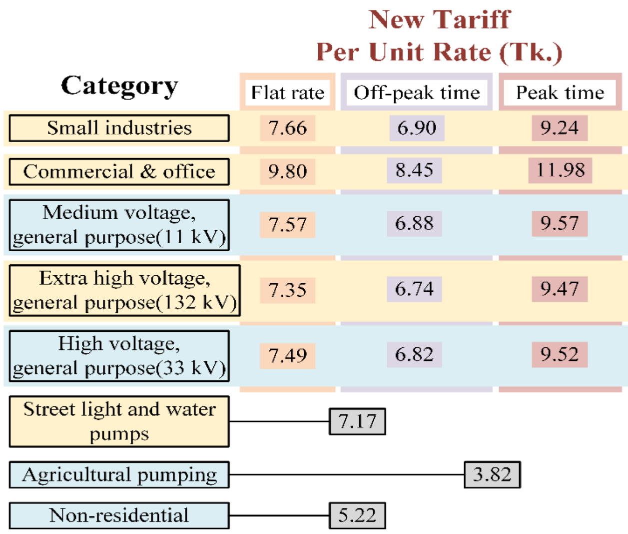

Fig. 6. Existing tariff rates in Bangladesh [21].

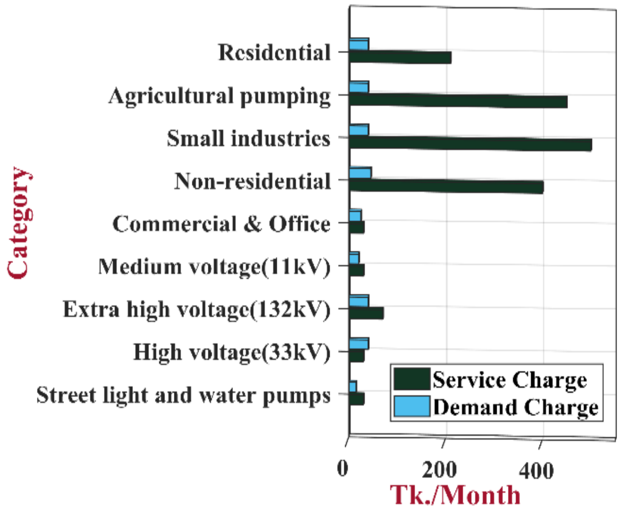

Fig. 7. Variation of demand charges and service charges in Bangladesh [21].

IV. PROBLEMS AND SOLUTION

NodeMCU needs power from the main supply to operate; thus when power interruptions occur, it will be turned off. However, there is no possibility of data loss as the data is stored periodically in the internal memory of the NodeMCU. Each time the NodeMCU starts, it extracts the most recently updated data from the memory. This system needs an Internet connection to send data to the web server and there might be the possibility of having no internet connection at a certain time. However, this problem is solved as NodeMCU sends the updated data whenever it regains internet connectivity. Data are always updated and stored in the internal memory of NodeMCU and is sent to the server whenever the internet is available. Therefore, there is no possibility of data loss. The exchange of data over the public domain such as the Internet is very much susceptible to unauthorized access [22]. Therefore, the system will be synchronized to a distant server and it can be programmed so that any undesirable attempt will inform the consumer as well as the electricity provider. In this way, the risk of data theft can be reduced to a minimum.

V. Cost Analysis

There are various types of energy meters available in the market, their price ranging from BDT 2000 to 10000. Different prepaid energy meters available in the market and their corresponding prices are shown in table IV.

TABLE IV. PRICE OF AVAILABLE PREPAID METERS IN MARKET

Product Title	Market Price
Liberty Prepaid Energy Meter	BDT 9880
Techno Prepaid Energy Meter Class 1.0	BDT 5070
Elmeasure Prepaid Energy Meter	BDT 5000
Meter by Yueqing Haixin Electronic Company	BDT 2540

Cost of different equipment required for the proposed system and the overall cost is shown in Table V. In our proposed design we used the Universal Energy Meter which is a conventional energy meter. Additional equipment such as, NodeMCU, optocoupler, and voltage step down circuitry are used as add-ons so that this conventional energy meter can function as IoT based smart energy meter. Furthermore, it has the facility to provide the consumers the ability to control their home appliance remotely. The aforementioned add-ons are also compatible with the existing prepaid meters available in the market. Therefore, the consumers are able to pay their bills without having to predict their monthly consumption of electricity with the added facility of remotely controlling their home appliance. From data presented in table III and IV, it can be said as the add-ons cost is very cheap, therefore, it is very much cost-effective integrate them with conventional or prepaid energy meters.

TABLE V. COSTING OF DIFFERENT EQUIPMENTS OF THE IOT BASED ENERGY MANGEMENT SYSTEM

Equipment		Market Price
Universal Energy Meter		BDT 430
Add-ons	NodeMCU V-3 Development Kit	BDT 500
	4N25 Photo Transistor Optocoupler	BDT 15
	Voltage Step Down Circuitry	BDT 120
Total		**BDT 1065**

VI. Conclusion

In this paper, integration of IoT with energy management system has been demonstrated to make a more effective and reliable system compared with the conventional energy management system. Instead of collecting data from door to door, the key feature of the proposed system offers a more accessible way of collecting data from a server through internet, which is automatically updated after a short time interval via Wi-Fi. The NodeMCU used in this system has the dual functionality of a microcontroller and a Wi-Fi module, which eliminates the need for an additional microcontroller. Furthermore, remote control of domestic appliances has also been made possible through this system. The total hardware implementation along with interfacing with the internet has been presented in detail. For ensuring the cost effectiveness, a detailed cost analysis has been conducted. The overall cost of the proposed IoT based smart energy management system is BDT 1065 and add-ons cost is BDT 635. Hence, the proposed system is cost effective and the add-ons can be also integrated with the existing prepaid meters, which can expunge its major drawbacks by providing added functionality. Therefore, the presented design in this paper, possesses high potentiality in its application in energy metering system of Bangladesh.

References

[1] S. N. Han, I. Khan, G. Myoung, N. Crespi, and R. H. Glitho, “Computer Standards & Interfaces Service composition for IP smart object using realtime Web protocols : Concept and research challenges,” *Comput. Stand. Interfaces,* vol. 43, pp. 79–90, 2016.

[2] M. Swan, “Sensor Mania! The Internet of Things, Wearable Computing, Objective Metrics, and the Quantified Self 2.0,” *J. Sens. Actuator Networks,* vol. 1, pp. 217–253, 2012.

[3] G. Bedi, G. K. Venayagamoorthy, R. Singh, R. R Brooks, and K. C. Wang, “Review of Internet of Things (IoT) in Electric Power and Energy Systems,” *IEEE Internet of Things Journal,* vol. 5, pp. 847-870, 2018.

[4] L. Li, H. Xiaoguang, C. Ke and H. Ketai, "The applications of WiFi-based Wireless Sensor Network in Internet of Things and Smart Grid," *6th IEEE Conference on Industrial Electronics and Applications*, pp. 789-793, 2011

[5] Miao Yun and Bu Yuxin, "Research on the architecture and key technology of Internet of Things (IoT) applied on smart grid," *International Conference on Advances in Energy Engineering*, pp. 69-72, 2010.

[6] Q. Ou, Y. Zhen, X. Li, Y. Zhang, and L. Zeng, "Application of internet of things in smart grid power transmission," *FTRA International Conference on Mobile, Ubiquitous, and Intelligent Computing,* pp. 96-100, 2012.

[7] F. Englert, P. Lieser, A. Alhamoud, D. Boehnstedt and R. Steinmetz, "Electricity-Metering in a Connected World: Virtual Sensors for Estimating the Electricity Consumption of IoT Appliances," *3rd International Conference on Future Internet of Things and Cloud*, pp. 317-324, 2015.

[8] D. Alahakoon, and X. Yu, “Smart Electricity Meter Data Intelligence for Future Energy Systems: A Survey,” *IEEE Transactions on Industrial Informatics,* vol. 12, pp. 425-436, 2016.

[9] P. D. Talwar, and S. B. Kulkarni, “IoT Based Energy Meter Reading” *International Journal of Recent Trends in Engineering & Research (IJRTER),* vol. 2, pp. 586-591, 2016.

[10] E. Hossain, J. Hossain and F. Un-Noor, "Utility Grid: Present Challenges and Their Potential Solutions," *IEEE Access,* vol. 6, pp. 60294-60317, 2018.

[11] F. Abate, M. Carratù, C. Liguori, M. Ferro, and V. Paciello, "Smart meter for the IoT," *IEEE International Instrumentation and Measurement Technology Conference (I2MTC),* pp. 1-6, 2018.

[12] B. Sahani, T. Ravi, A. Tamboli, and R. Pisal, “IoT Based Smart Energy Meter,” *International Research Journal of Engineering and Technology (IRJET),* vol. 4, pp. 96-102, 2017.

[13] A. Singh, and R. Gupta, “IoT based smart energy meter,” *International Journal of Advance Research and Development,* vol. 3, pp. 328-332, 2018.

[14] P. Mahajan, S. Tatia, and P. Jadhav, “Smart Meter: An IOT Based Smart Meter for Live Electricity Monitoring and Bill Payment,” *International Journal of Electrical, Electronics and Computer Systems (IJEECS),* vol. 5, pp. 49-51.

[15] N. N. Sasane, N. S. Sakat, K. N. Shital, V. R. Kaushik, and P. K. Pallav, “IOT based energy meter billing and monitoring system - A case study,” *International Research Journal of Advanced Engineering and Science*, vol. 2, pp. 64-68, 2017.

[16] S. Chen, C. Lai, Y. Huang, and Y. L. Jeng, "Intelligent home-appliance recognition over IoT cloud network," *9th International Wireless Communications and Mobile Computing Conference (IWCMC)*, pp. 639-643, 2013.

[17] W. T. Cho, Ying-Xun Lai1, C. F. Lai, and Y. M. Huang, "Appliance-Aware Activity Recognition Mechanism for IoT Energy Management System," *The Computer Journal,* vol. 56, pp. 1020-1033, 2013.

[18] M. Wang, G. Zhang, C. Zhang, J. Zhang and C. Li, "An IoT-based appliance control system for smart homes," *Fourth International Conference on Intelligent Control and Information Processing (ICICIP)*, pp. 744-747, 2013.

[19] F. I. Bappy, M. J. Islam, A. K. Podder, D. R. Dipta, H. M. R. Faruque, and, E. Hossain, "Comparison of Different Hybrid Renewable Energy Systems With Optimized PV Configuration to Realize the Effects of Multiple Schemes," *1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT),* in press.

[20] E. Hossain, I. Khan, F. Un-Noor, S. S. Sikander, and M. S. H. Sunny, "Application of Big Data and Machine Learning in Smart Grid, and Associated Security Concerns: A Review," *IEEE Access,* vol. 7, pp. 13960-13988, 2019.

[21] *Tariff Rate*. [online] Available at: https://dpdc.org.bd/article/view/52/Tariff%20Rates [Accessed Apr. 11, 2019].

[22] M. S. Rahman, M. S. Hossain, E. H. Rahat, D. R. Dipta, H. M. R. Faruque, and F. K. Fattah, "Efficient Hardware Implementation of 256-bit ECC Processor Over Prime Field," *International Conference on Electrical, Computer and Communication Engineering (ECCE),* pp. 1-6, 2019.