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A Real-Time Invoice Based Smart Meter Design with Mobile Application

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Abstract
The energy consumption issue has become one of the significant problems that are given great attention by The governments, especially in the case of energy generation being less than required. It also has importance because of the rapid growth in the population and development and the dependence of millions of people on electric energy in their daily lives. In order to ensure the continuity of energy, it is necessary to regulate electricity consumption by providing the necessary real-time data to consumers. Currently, real-time data on energy consumption and information on the appropriate consumption time are not fully available for consumers. In addition, data is read manually at the end of each month to provide monthly invoices, a workforce is needed to complete this work, and errors occur due to human intervention. The proposed real-time invoice-based smart meter system is a measuring device to automatically read the data and provide the consumer with information on the energy consumed per hour, day, and month. The device helps the consumer choose the most suitable time for energy consumption and predicts the time when the amount of energy consumed exceeds the desired power.

Key Words
"Energy consumption, Real-time data, Smart meter"

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1. Introduction

Electricity is one of the most critical developments for humanity. However, global warming due to rapid growth and development is increasing day by day. As a result, the energy cycle has become an enormous problem with increasing greenhouse gas emissions. To this end, the scientific community has reduced its intervention to two approaches:

- Shifting electricity generation to renewable energy sources.
- Regulating electricity consumption.

While the greater emphasis is being given to the first solution, there is little awareness of the second alternative (Tonge et al., 2020). According to research, the units of electric power consumption used in enlightening buildings is around 40% in which the energy wastage is about 10-15%. This energy wastage is due to the irresponsibility of humans because they are unaware of how much energy has been wasted in a day (Mishra et al., 2020).

Demand Response (DR) utilizes electricity consumers' flexibility to regulate their electricity consumption and specific incentives. DR is also one of the techniques used to provide certain services, such as increasing the input of renewable energy in the grid, reducing peak demand, generation, transmission, and distribution costs. In DR programs, the aggregated energy demand is a crucial metric. An aggregator interacts with active consumers willing to minimize their electricity bill or maximize their utility to optimize this demand profile. In such a framework, energy can be seen as an asset demanded by consumers, with the cost of which depends on the total demand and the time of demand (Jacquot et al., 2018) and with the power consumption (Peak, Standard, and Off-Peak) varying according to the demand period. This will help regulate power consumption. In addition, consumers need to know their instantaneous consumption and grid power prices in this process.

Traditional electromechanical meters are still today widely used for residential consumers. Although it is a well-known technology, it has several limitations due to its constructive characteristics. In general, electromechanical meters are not very sensitive. The measurement process with these meters can be affected more than other types of meters by many technical factors such as waveform distortions or unbalanced load and operating temperature. In addition, this category of energy meter can only measure a cumulative active power component and consider unidirectional power flow. Another vital factor affected by this technology is the human factor. Still, the human factor is more sensitive to reading errors, typically caused by manual or human reading when measuring energy. Besides that, the operating cost is high because reading all electromechanical meters need a lot of workers. Such a process represents a high operational cost for the utilities, increasing energy tariffs (Garcia et al., 2017). For this purpose, both the network operator and consumers should benefit from electromechanical meters if they want to use the DR technique.

These days, we see an extensive development of public electric systems where energy flow becomes bidirectional due to increasing distributed generation plants. Electricity is shared among the several nodes of the power grid, named microgrids (Morello et al., 2017). In recent years, this development in the power system has necessitated the new concept of power measurement and control in the current concepts of smart grid and smart meters.

A smart grid system is a complex and high advanced technology that allows not just bidirectional power flow, but it also has several different features such as availability, effectiveness, accuracy, controllability, economically, flexibility, measurability, optimality, reliability, sustainability, and security (Çolak et al., 2020). Electromechanical meters are not suitable for microgrids, so smart meters should be used to take advantage of the DR technique. Smart meters are a vital development for smart grids.

Conventional electromechanical meters should be inspected separately by meter workers of energy provider companies. There are many solutions to traditional counter-related problems. On the other hand, smart meters using Internet of Things (IoT) technology have given consumers the ability to remotely monitor and regulate their energy consumption and get accurate automated meters. Smart meters can allow consumers to participate in the electric power sector on a large scale and economically, thereby increasing the end user's role in the energy transition (Alkawsi & Baahar, 2020).

Many researchers proposed different methods and algorithms to reduce power consumption using smart meters and data analysis:

A system was presented containing a smart home technology with a smart grid facility, interfaced with a cloud application to control or monitor the home appliances. Despite the authors taking into their account sent feedback to customers to warn them when the power consumption passes the pre-setting limit set by the customer (Bhilare & Mali, 2015). However, they did not tell the customer the best time to consume the power (peak off period).

A proposed algorithm has been developed in which the device will generate the unit rate and send it to the user's smartphone with the invoice at the end of each month (Joshi et al., 2016). Although the algorithm can optimize the bill according to its usage, the user does not know the optimum time for power consumption, and the reactive power consumption is not taken into account in the application.

A study is presented that plans the total cost, data center workloads, and EV charging demands of geographically distributed data centers and EVs in the smart grid in real-time, minimizing heterogeneous EV charging delays and peak power limits without violating them. (Yu et al., 2016). The study could be extended to include a residential energy storage system that would allow the consumer to charge the energy storage system during the off-peak period and use the stored energy or sell it during the peak demand period.

An algorithm approach has been proposed for home automation and metering systems to increase power consumption control and supervisory efficiency and reliability using Apriori Algorithm. An IoT embedded appliance and other electronic devices at home can be controlled reliably by a web portal designed and developed for this purpose. Consequently, the electricity consumption can be determined, and automated billing can also be generated with the help of the web portal (Kamal et al., 2017). Despite that, the system did not consider the effect of the storage system, which can be used to enhance the performance of the smartgrid.

An Atmega328P microcontroller-based device is used for detection and controlling the energy meter from power theft. When theft is detected, a particular consumer's service (line) will be remotely disconnected (Metering et al., 2017). However, the authors did not discuss the database used in the utility system and did not discuss the cost of GSM communications.

A methodology is implemented for monitoring the power quality parameters using an ethernet-based smart energy meter. Energy consumption data is sent to the server by the smart energy meter and stored there (Das et al., 2017). However, the price policy of power utility wasn't discussed.

A proposed smart energy meter has been presented that controls and calculates energy consumption using ESP 8266 12E. A read is uploaded to the "Thingspeak" cloud server. For this reason, energy analyzes made by the consumer become much more accessible and controllable. Thus, this smart meter has helped home automation using IoT and enabling wireless communication, which is a big step towards Digital Word (Barman et al., 2018). However, the pricing policy of the public service and how the electricity bills are calculated have not been discussed.

A prototype of an electric power smart meter designed for including in the AMI "Advanced Measurement Infrastructure" based on a wM-Bus 169 MHz has been presented. The radio module of the smart meter can work as a repeater, thus assisting network designers in the optimal siting of gateways in urban areas (Carratù et al., 2018). However, electricity bill generator and power consumption analysis for consumers is not discussed.

An end-to-end IoT solution used for an intelligent energy monitoring system to monitor and control devices were designed and implemented in real-time. The prototype of the smart sockets developed the firmware and set up a real-time platform to collect and store data for research purposes (Nguyen et al., 2019). However, data analysis and power measurement to generate invoices for consumers have not been studied.

Hardware is designed using a PIC16F877 microcontroller, current and voltage transformer, voltage regulator 7805, solar panel, solar charge controller, and inverter (Faisal et al., 2019). The hardware design is discussed only without considering the utility's database and invoice creation.

A proposed smart energy meter is studied. The consumer will be notified the amount of power consumed by the end of the day depending on a message sent by GSM such that the consumer can plan the consumption of power. In addition, the power consumed by the consumer will be notified to the distributor and consumer such that no manpower is necessary for meter reading (Prakash et al., 2019). But the system cannot depend on it if the price of the power is changed with daytime.

A Voltage Ampere Power Smart Meter (VAPSM) has been proposed, enabling efficient data collection in the billing process to network providers and sending messages using the GSM system (Malik et al., 2019). However, the utility's database was not discussed, how the bill was generated, and no attention was paid to hourly power consumption, which is very important for consumers and utility companies.

A proposed technology is presented that collects data from the meter and transfers this data to the central database for storing and analyzing the data and monitoring security-related issues. It also includes a module that enables optional unit installation by simply sending a demand SMS from the energy provider company (Sultan et al., 2019). However, the timing of sending messages to providers was not discussed, and no attention was paid to hourly consumption, which is crucial for customers and providers.

A ZigBee wireless technology-based data acquisition system was designed. Starting with hardware and software, the networking and data transmission of ZigBee have been introduced (Yongyong et al., 2020). However, pricing policy or how the database will generate invoices has not been discussed.

The design and fabrication of a smart meter sending power consumption information to a vendor by GSM are proposed. The system offers consumers to set consumption limits with SMS alerts and turn ON/OFF the electric energy supply. The utility also has access to the smart meter for power cut-off if bills are not paid (Kumar et al., 2020). However, how the database will generate bills was not discussed.

An FPGA-based smart energy meter is introduced. To ensure portability, the digital signal processing algorithms implemented on the FPGA device were entirely coded in hardware description languages. All equations are fully described to be applied to any digital signal-processing environment (Arenas et al., 2020). The paper focused on the signal processing side and did not deal with generating smart bills.

A smart meter depending on Power Line Carrier was introduced, as the transformer cannot transfer high-frequency signals without adding noise in the original signals and hence not useful for PLC. The proposed system was designed to collect the data of smart meters using PLC in low level, low voltage side, and send by the local server to venders using the internet (Rathee et al., 2020). However, the process of generating smart bills was not discussed.

The present paper discusses the development of an interface for real-time billing and helping the users avoid large energy consumptions and save energy. The real-time bill is generated by a proposed IoT system that has the following characteristics: (1) it uses low-cost sensors, arduino and arduino ethernet (2) it displays information about the consumption habits of the users; and (3) it activates alarms in case of abnormal or high consumption.

The main contributions of this study are described as follow:

- An interface design that provides a real-time invoice based on the three-time bands and the energy consumed gives the company the ability to make a price. These three-time bands are called “peak, standard and off-peak,”
- The forecast of energy consumption over a period using only one week of measurement.
- Detection of any fault in transformer, building, or house.

2. Material and Method

The block diagram of the proposed smart energy meter system and its hardware and software architecture is given in Figure 1. The hardware of the system consists of a smart meter, MySQL, and API. The smart meter measures the instantaneously consumed power, accumulates it for a specific time (Tminutes), and sends the information to the MySQL database over the internet. MySQL is used to store and analyze received information and generate electricity bills. The customer’s analyzed information and electricity valuable bill are sent to the customer’s smartphone via the Application Programming Interface (API). The details of the proposed system are explained as follows:

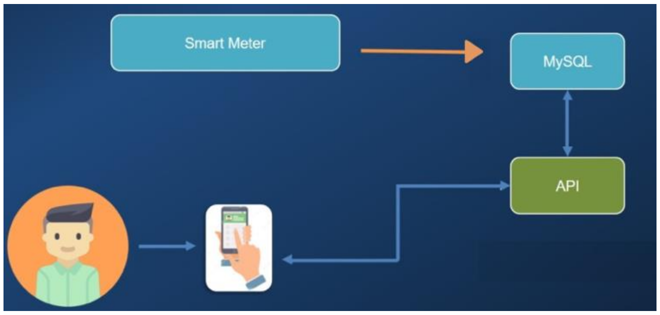

Figure 1. Proposed Smart Energy Meter Architecture.

2.1. Smart energy meter

The proposed energy meter is shown in Figure 2, and the prototype is shown in Figures 3 and 4, where two prototypes are made.

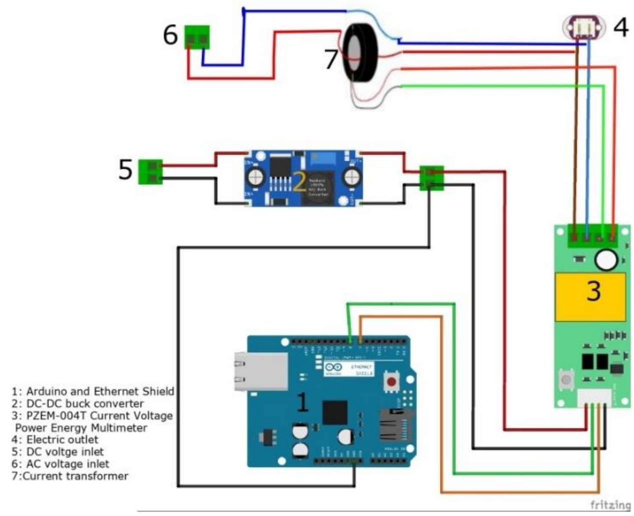

Figure 2. Smart Energy Meter Design.

Consumed power is measured using electrical sensors consisting of PZEM-004t modules to measure voltage, current, and sensed values to calculate power and energy. The modules yielded results that could be measured with digital codes with a three-digit resolution via a universal asynchronous receiver/transmitter (UART) interface. The measured results are voltage, current, power, and energy values in volts, amps, watts, and kilowatt-hours, respectively (Wasoontarajaroen et al., 2017). Instantaneous data is received by arduino and collected for a specified time and then sent to MySQL via ethernet shield. As the accumulated data increases, the size of the data retrieved in MySQL will decrease. The DC buck converter is used to step down the DC voltage to 5 volts; 5V will power the arduino and the PZEM-004t

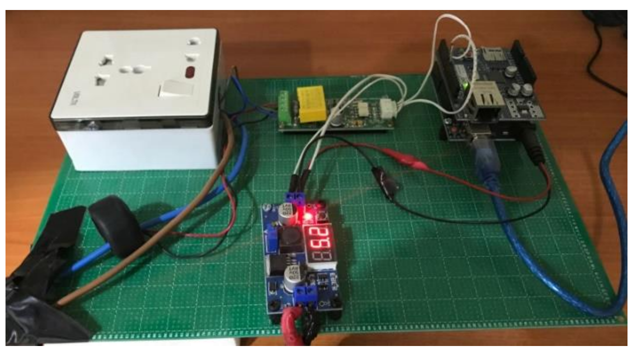

Figure 3. Smart Energy Meter Prototype I.

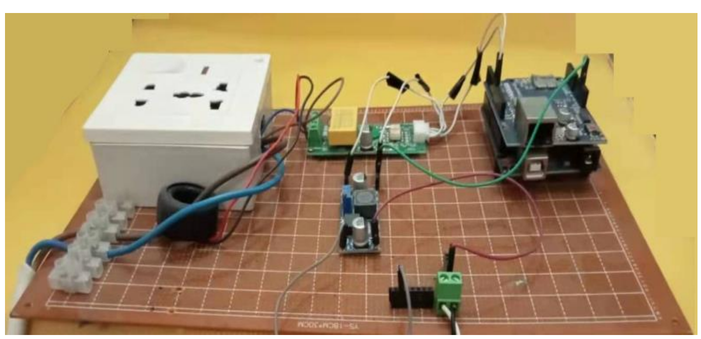

Figure 4. Smart Energy Meter Prototype II.

2.2. MySQL

MySQL is a relational database management system based on the Structured Query Language (SQL), the popular language for accessing and managing the records in the database. MySQL is open-source and free software under the GNU license. Oracle Company supports it.

The Arduino project can be connected directly to a MySQL server without using an intermediate computer or a web or cloud-based service. Having direct access to a database server means storing data from a smart meter and checking the values stored in tables on the server. The flowchart of how MySQL works are shown in Figure 5.

The received data is the device ID and the accumulated consumed power. This data is first recorded in the main table, then the power consumption calculated for Tmin according to the device ID is multiplied by the power price. The power consumed power and cost data stored in hours for one hour are then combined. This calculated hour data is collected with other previous hour data and stored in the daily table. Each day calculated is added up with the other consecutive days and stored in the per-device monthly table. The price depends on the time of consumption, and the day can be divided into three intervals: "peak, standard and off-peak." The normal price is in the standard period, the higher price is at the peak, and the lower price is in the low consumption period.

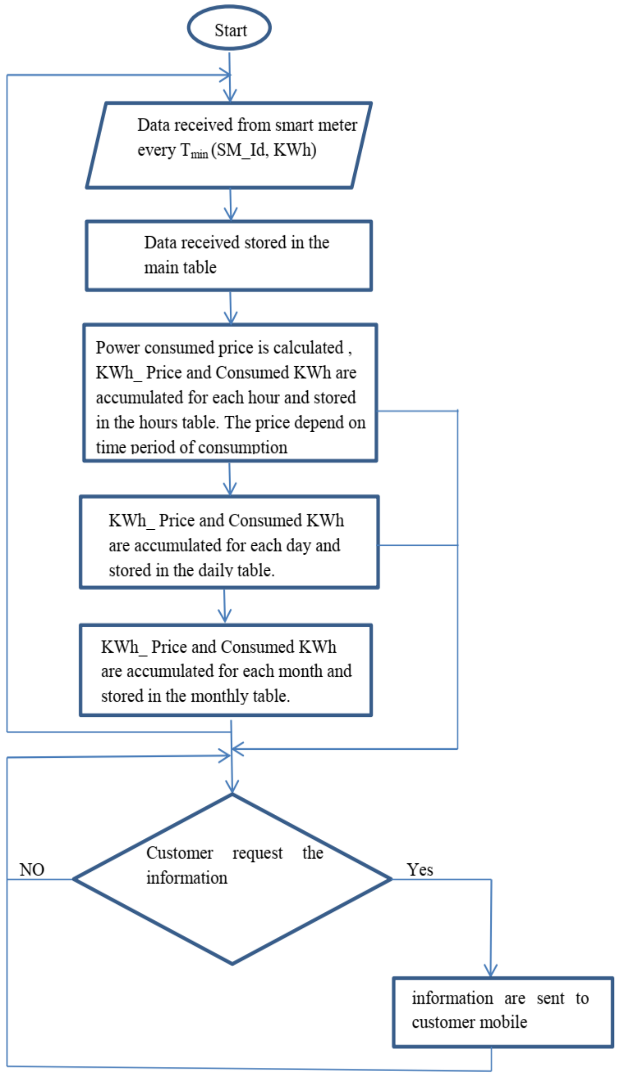

Figure 5. MySQL Flowchart.

2.3. API

Application programming interfaces (APIs) provide operational signatures for creating, reading, updating, and deleting data about business (or logical) entities. These are managed without revealing the software application that supports the transactions (Barros et al., 2020). APIs are essential to many modern software architectures as they provide high-level abstractions that simplify programming tasks, support the design and reuse of distributed and modular software applications (Meng et al., 2018). The API is created using a technology (Asp.net core5) that provides data to the users by connecting to the database (Mysql) and generates device data for each user, including idle usage, daily-monthly usage, and total usage invoices for each month. In Figure 6, the process diagram of the API is shown.

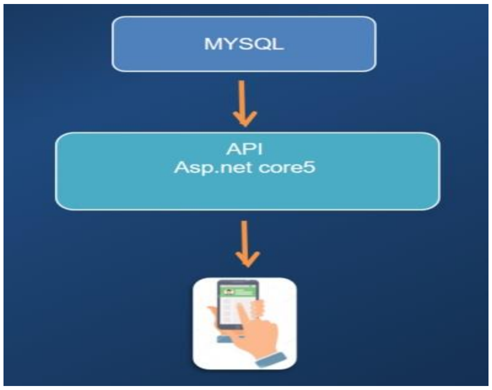

Figure 6. API.

2.4. Mobile application
Most commonly referred to as an application, a mobile application is a type of application software designed to run on a mobile device such as a smartphone or tablet computer. Mobile apps often provide users with services similar to those accessed on PCs. Applications are usually small, self-contained units of software with limited functionality. In this study, Ionic Framework was used to create the mobile application.

2.5. Ionic framework
Ionic framework is an open-source mobile toolset for building high-quality native and web application experiences across platforms. It moves faster with a single codebase that runs anywhere with JavaScript and the Web.

In this study, an API application based on Asp.net's core five technology was used. The API application receives the data from the MySQL database and sends it to the mobile application. ASP.NET identity is a membership system required for authentication and authorization of users and performing JSON Web Tokens (JWT) authentication to securely transfer requests between an application programming interface (API) and a mobile application. The electronic meter data is taken from the API server via the mobile application, and the quantity and price are displayed hourly, daily or monthly according to the user's request. In this way, the user can learn the current, daily, and monthly consumption amount.

3. Results and Discussion

3.1. Data in MySQL
Figure 7 shows the data sent from smart meters and stored in the MySQL database. The data consists of the device ID and power consumed. Besides, Mysql will store the data along with the received time. The price of consumed power will depend on the time of consumption. The price will be calculated for each hour, and thus the total hourly usage will be calculated according to the desired number of hours. In addition, hourly usages will be added to each other as kWh, daily usage, and monthly usage will be obtained as voltage, current, power, and price by adding daily usages to each other. As a result, the amount of power consumed per hour, day, month, and the price will be sent to the consumer's mobile phone.

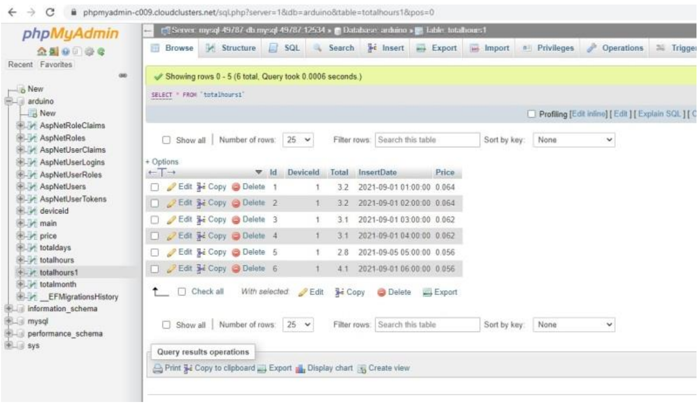

Figure 7. MySQL.

3.2. Data in mobile application
Figure 8 shows the login screen of the mobile application. This front page contains the user name and password of the customer.

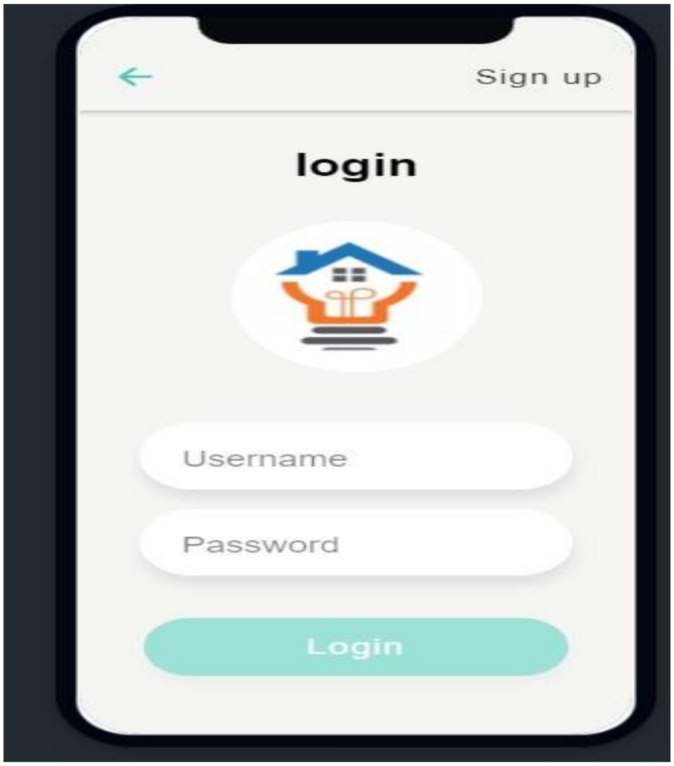

Figure 8. Mobile Application Front Page.

Consumers will see and evaluate the power consumed as kWh by their homes and the prices for each month, day, and hour as shown in Figures 9, 10, and 11, respectively.

Figure 9. Monthly Page of Mobile Application.

Figure 10. Daily Page of Mobile Application.

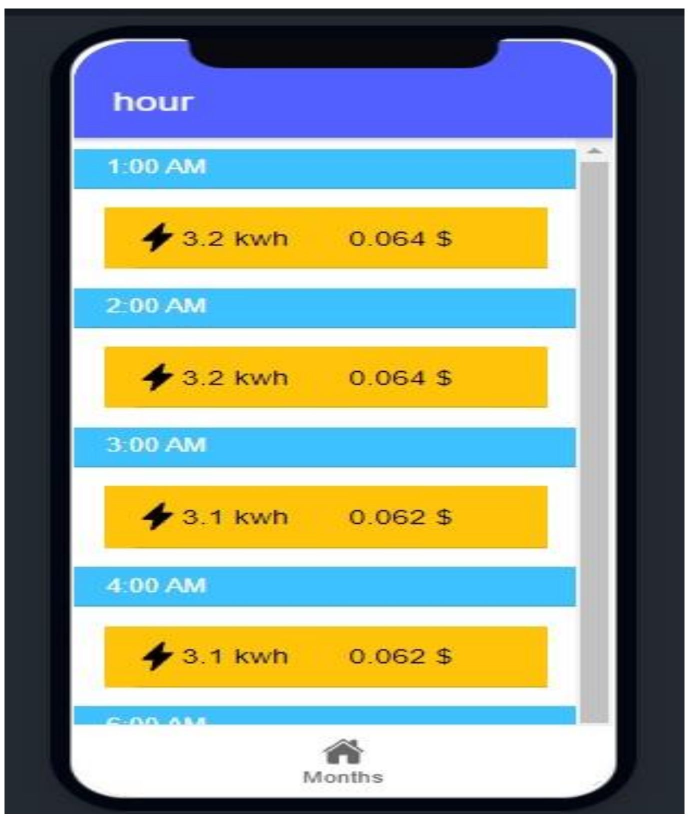

Figure 11. Hourly Page of Mobile Application.

4. Conclusions and Recommendations

In this research, a smart power meter monitors the customers' energy and sends the necessary information to the customer's mobile phone. Consumers' user names and passwords provide information security. The information was analyzed hourly, daily, and monthly by taking it to an interactive database with asp.net on the hardware. In addition, the amount corresponding to the amount of consumed electrical energy is automatically calculated by the device. This information seen from the mobile phone will enable consumers to precisely track their consumption and help them control their consumption, especially during peak demand periods when the price will be costly. In addition, instantaneous data will create sensitivity in the control of electricity consumption in consumers.

As a future study, further improvement of the reliability of the smart meter can be considered. It can be suggested that the device should be developed to store the consumption information produced when the device cannot send information to the database, especially in cases where the internet is cut off. Thus, the stored data can be restored to the database when internet access is restored. As another suggestion, data sheets explaining the importance of electricity saving can be added to the application. These devices can be recommended to the consumer through the system by calculating the amount of savings as new, more efficient devices are released.

References

Alkawsi, G. A., & Baashar, Y. (2020). An empirical study of the acceptance of IoT-based smart meter in Malaysia: The effect of electricity-saving knowledge and environmental awareness. IEEE Access, 8, 42794-42804.

Arenas, L. D. O., e Melo, G. D. A., & Canesin, C. A. (2020). A Methodology for Power Quantities Calculation Applied to an FPGA-Based Smart-Energy Meter. IEEE Transactions on Instrumentation and Measurement, 70, 1-11.

Barman, B. K., Yadav, S. N., Kumar, S., & Gope, S. (2018, June). IOT based smart energy meter for efficient energy utilization in smart grid. In 2018 2nd International Conference on Power, Energy and Environment: Towards Smart Technology (ICEPE) (pp. 1-5). IEEE.

Barros, A., Ouyang, C., & Wei, F. (2020). Static Analysis for Improved Modularity of Procedural Web Application Programming Interfaces. IEEE Access, 8, 128182-128199.

Bhilare, R., & Mali, S. (2015, December). IoT based smart home with real time E-metering using E-controller. In 2015 Annual IEEE India Conference (INDICON) (pp. 1-6). IEEE.

Carratù, M., Ferro, M., Pietrosanto, A., & Paciello, V. (2018, July). Smart power meter for the iot. In 2018 IEEE 16th International Conference on Industrial Informatics (INDIN) (pp. 514-519). IEEE.

Çolak, I., Bayındır, R., & Sağıroğlu, S. (2020, June). The Effects of the Smart Grid System on the National Grids. In 2020 8th International Conference on Smart Grid (icSmartGrid) (pp. 122-126). IEEE.

Das, H., & Saikia, L. C. (2017, October). Ethernet based smart energy meter for power quality monitoring and enhancement. In 2017 Recent Developments in Control, Automation & Power Engineering (RDCAPE) (pp. 187-191). IEEE.

Faisal, M., Karim, T. F., Pavel, A. R., Hossen, M. S., & Lipu, M. H. (2019, January). Development of smart energy meter for energy cost analysis of conventional grid and solar energy. In 2019 International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST) (pp. 91-95). IEEE.

Garcia, F. D., Marafão, F. P., de Souza, W. A., & da Silva, L. C. P. (2017, March). Power metering: History and future trends. In 2017 Ninth Annual IEEE Green Technologies Conference (GreenTech) (pp. 26-33). IEEE.

Jacquot, P., Beaude, O., Gaubert, S., & Oudjane, N. (2018). Analysis and implementation of an hourly billing mechanism for demand response management. IEEE Transactions on Smart Grid, 10(4), 4265-4278.

Joshi, D. S. A., Kolvekar, S., Raj, Y. R., & Singh, S. (2016). IoT based smart energy meter. Bonfring International Journal of Research in Communication Engineering, 6(Special Issue), 89-91.

Kamal, M. S., Parvin, S., Saleem, K., Al-Hamadi, H., & Gawanmeh, A. (2017, May). Efficient low cost supervisory system for Internet of Things enabled smart home. In 2017 IEEE International Conference on Communications Workshops (ICC Workshops) (pp. 864-869). IEEE.

Kumar, R., & Srivastava, S. K. (2020, February). Design a Model of Smart Metering System for Light Load Consumer. In 2020 International Conference on Electrical and Electronics Engineering (ICE3) (pp. 416-419). IEEE.

Malik, Q., Zia, A., Ahmad, R., Butt, M. A., & Javed, Z. A. (2019, November). Design and Operation of Smart Energy Meter for Effective Energy Utilization in Smart Cities. In 2019 IEEE Conference on Sustainable Utilization and Development in Engineering and Technologies (CSUDET) (pp. 219-223). IEEE.

Meng, M., Steinhardt, S., & Schubert, A. (2018). Application programming interface documentation: what do software developers want?. Journal of Technical Writing and Communication, 48(3), 295-330.

Metering, A. S., Visalatchi, S., & Sandeep, K. K. (2017, April). Smart energy metering and power theft control using arduino & GSM. In 2017 2nd international conference for convergence in technology (I2CT) (pp. 858-961). IEEE.

Mishra, R., Pandey, A., & Savariya, J. (2020, January). Application of Internet of Things: Last meter smart grid and smart energy efficient system. In 2020 First International Conference on Power, Control and Computing Technologies (ICPC2T) (pp. 32-37). IEEE.

Morello, R., De Capua, C., Fulco, G., & Mukhopadhyay, S. C. (2017). A smart power meter to monitor energy flow in smart grids: The role of advanced sensing and IoT in the electric grid of the future. IEEE Sensors Journal, 17(23), 7828-7837.

Nguyen, V. K., Zhang, W. E., Le, K., Mahmood, A., & Sheng, Q. Z. (2019, April). Demo abstract: An end-to-end real-time efficient system for smart energy monitoring. In IEEE INFOCOM 2019-IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS) (pp. 957-958). IEEE.

Prakash, K. J., Chethana, N. S., Tamkeen, F., Kala, C. S., & Kavya, N. R. (2019, July). Designing of Microcontroller based Energy Meter (Smart Energy Meter) for Energy Preserving. In 2019 International Conference on Communication and Electronics Systems (ICCES) (pp. 1252-1255). IEEE.

Rathee, S., Goyal, A., & Shukla, A. (2020, June). Designing Prepaid Smart Energy Meter and Deployment in a Network. In 2020 IEEE 4th Information Technology, Networking, Electronic and Automation Control Conference (ITNEC) (Vol. 1, pp. 1208-1211). IEEE.

Sultan, Z., Jiang, Y., Malik, A., & Ahmed, S. F. (2019, December). GSM based smart wireless controlled digital energy meter. In 2019 IEEE 6th International Conference on Engineering Technologies and Applied Sciences (ICETAS) (pp. 1-6). IEEE.

Tonge, K., Mane, V., Burad, S., Urkunde, V., & Aghav, K. (2020, July). Demand based Variable Electricity Tariff Meter. In 2020 International Conference on Communication and Signal Processing (ICCSP) (pp. 1452-1455). IEEE.

Wasoontarajaroen, S., Pawasan, K., & Chamnanphrai, V. (2017, October). Development of an IoT device for monitoring electrical energy consumption. In 2017 9th International Conference on Information Technology and Electrical Engineering (ICITEE) (pp. 1-4). IEEE.

Yongyong, Y., & Chenghao, H. (2020, August). Design of data acquisition system of electric meter based on ZigBee Wireless Technology. In 2020 IEEE International Conference on Advances in Electrical Engineering and Computer Applications (AEECA) (pp. 109-112). IEEE.

Yu, L., Jiang, T., & Zou, Y. (2016). Distributed online energy management for data centers and electric vehicles in smart grid. IEEE Internet of Things Journal, 3(6), 1373-1384.