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# Revolutionizing Home Automation: A Smart Energy Metering System Infused with IoT Technology and Data Analytics

***Abstract: -*** Electromechanical meters are still used to monitor electrical consumption and bill it. In countries like the Philippines, we can see electric utility representatives reading our electric meters outside our homes to determine the amount of electricity the users have consumed and how much they're supposed to pay.

This paper presents the development of a Smart Energy Meter with integrated home automation features based on IoT technology and data analytics as a solution to make improvements regarding the aforementioned. It is a device that measures and records the amount of electric consumption as well as electric parameters such as voltage and current levels, frequency, and power factor following an IoT-based approach and provides apt suggestions based on recorded data that gives insights regarding the user's consumption. It records changes in electric parameters in almost real-time and sends the information to the cloud wirelessly in short intervals using IoT protocols capable of managing and providing information to the user. This paper presents a clear goal of delivering information about the consumer's electricity consumption and other information to the consumer via web and/or smartphone application for a better understanding of consumption behaviour leading to an efficient use of energy, control of loads or appliances, and a better financial organization.

***Keywords:*** Smart Energy Meter, Internet of Things (IoT), Home Automation, Energy Monitoring System, Smart Energy, Smart Grid, Data Analytics.

## Introduction

With the intention of simplifying our lives, technology has become increasingly intelligent. It has made possible for us to automate many business processes so that we may now take advantage of them from the comfort of our homes. These developments are intended to improve environmental conditions, public safety, and health. As an example, technological advancements have made it possible for homeowners to control, manage, and monitor their homes using cell phones. These are referred to as automated homes.

Home automation is the use of local networking or remote control to run domestic appliances and other tasks, reducing electricity waste and encouraging energy efficiency for a cleaner planet (Gunge & Yalage, 2016). It is essential that customers utilize energy responsibly given the ongoing expansion in population and electricity consumption, as well as worries about the environmental effects of electricity generation. Energy users must monitor their daily electric usage and understand the requirements in order to better manage their finances and increase the effectiveness of their energy use.

A smart energy meter is a gadget that calculates how much electricity is consumed by homes, businesses, and other structures (Alter vista, 2017). It uses an IoT-based approach to capture data such as electric energy usage, voltage and current levels, and power factor. Traditional electromechanical meters are still frequently used in the Philippines today. Although it accomplishes its goal, it isn't as precise or user-friendly as its electronic version. Electric utility workers read our electric meters outside of our homes once a month to figure out how much energy we've used and how much we owe in bills. Unless the consumers are knowledgeable enough to read the analog electric meter and compute their monthly consumption, they actually don't get a solid real-time feel of their energy consumption and the amount they're going to spend with this method. Not to mention the ongoing issue of energy theft in our nation (Czechowski & Kosek, 2016), when members of the lower class use jumper wires to connect illegally to a consumer's electrical system, causing losses that we must pay for on our electricity bills as a system loss penalty. On the other side, smart energy meters reduce the tiresome chore of making actual visits to the site, encourage active engagement, and give consumers more control over how much energy they use. Through smartphone applications and other digital channels, smart meters provide the consumer with the data they collect to help them better understand their usage patterns. The information from smart energy meters is sent in brief bursts throughout the day to the cloud and internal memory, where it is available for users to access and examine via online or mobile applications. Smart energy meters record energy changes virtually in real-time. The gathering of data is made feasible by a middleware that can manage and deliver the information to the user over the internet. The data is wirelessly delivered using IoT protocols. Since

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this is one of the more practical methods for gaining access to information, web and mobile applications for smart energy meters are being created. Customers can check their current electric usage and current billing information on their smartphones.
Then, the smart meter will work in conjunction with a data analytics program that will combine the collected data and do an analysis on it. The data analytics will then inform the homeowner with recommendations on how to save electricity based on their individual use and preferences after providing a snapshot of data regarding the electrical consumption over a specified time period. The data analytics provides callouts based on the consumption habits of the homeowner, enabling it to offer personally-tailored recommendations that allow the homeowner to optimize their electricity consumption.

## Methodology

In this study, IoT Home Automated and Technology-Based Smart Energy Metering System was developed. The device will monitor the changes in near real-time of electric energy consumption, voltage and current levels, frequency, and power factor with incorporated data analytics that will analyse inputted data from the smart meter and provide suggestions to the user on how to optimize their energy consumption. The mentioned data will then be uploaded/saved to a cloud database for the users to access and view via web and/or smartphone application. In line with that, a user interface (UI) was also developed for the users to view the status of their energy consumption and the automation of the appliances.
This development study employed the prototyping technique to prove the workability of the design and the principles behind the system design. Prototyping is a technique that proves the effectiveness of the design, the computations made and the concepts applied, by making an actual working system.

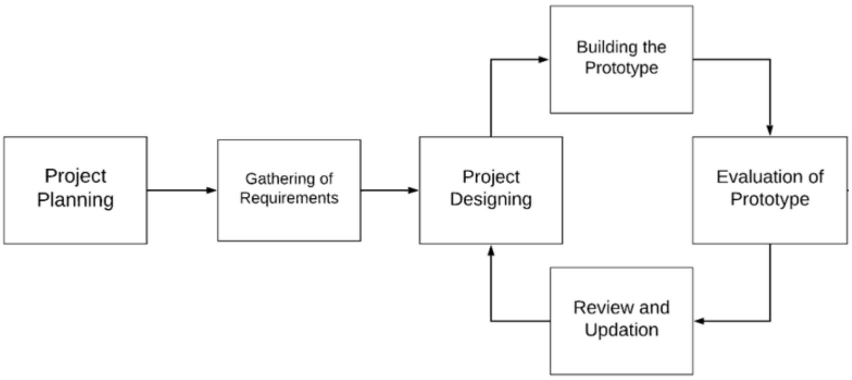


**Figure 1.** Prototyping Model

The first stage of the process in developing the IoT Home Automated and Technology-Based Smart Energy Metering System involves the identification of the existing needs, problems and formulating the objectives. After the needs, problems and objectives were clearly identified, the researcher come up with the design of the model which primarily helped them to visualize the final output. This stage is known as the project designing phase of prototyping, at this point, the researcher did the layout of the design of the model and made a sketch where each component of the model would be placed. Also, in this phase the researcher created a circuit diagram design (see figure 2) to describe and show how each component would be interfaced in the circuit board and to other parts of the prototype.

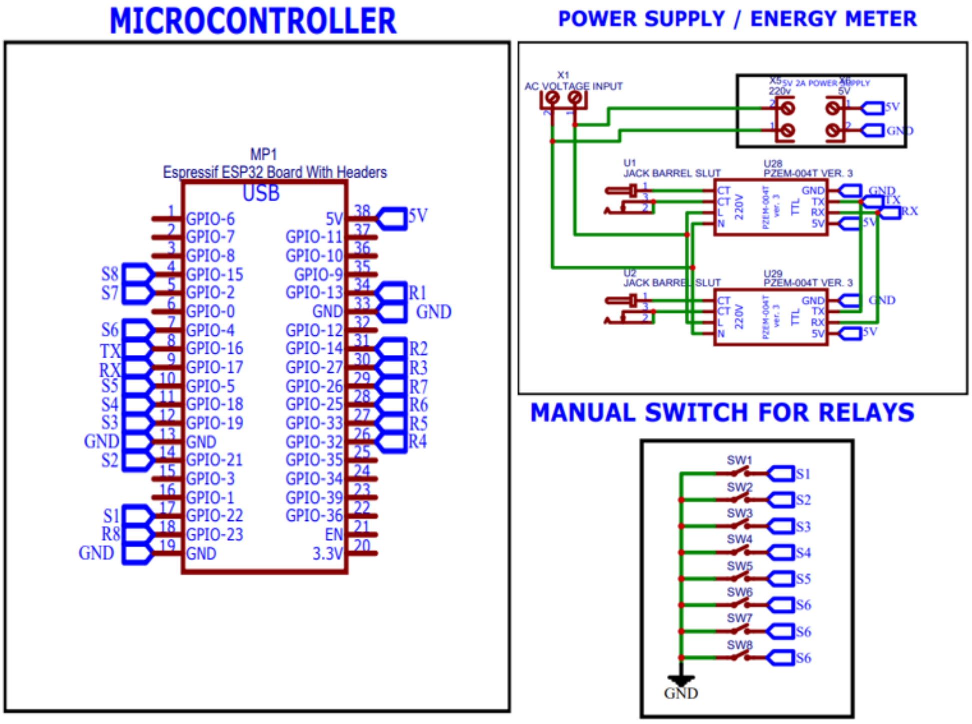


**Figure 2.** Schematic Circuit Diagram

As shown in figure 2, the components of the IoT Home Automated and Technology-Based Smart Energy Metering System were interfaced and connected properly. uses the ESP32 microcontroller along with other important components. The researcher then began assembling the prototype on a piece of breadboard to test the device’s hardware and software functionality. PZEM-004T Voltage and Current Multimeter Module is an electricity monitoring module with a split-core current transformer. This module is mainly used for measuring AC voltage, current, frequency, active power, power factor, and active energy. It can also store data when powered off, and store the accumulated energy data before power off. It can be widely used with power distribution boxes, distribution cabinets, voltage regulators, teaching aids and small household distribution boxes.

Software development of the device was also included in building the prototype. In the process of building the program that will run on ESP-32, the researcher considered using several libraries used to run the program. After completing the requirements analysis stage needed to run the software of the prototype, the software was designed while keeping the requirements in mind to ensure that the device will operate smoothly. Then the software was developed while taking into consideration on how this will affect the overall system once the software is integrated to the hardware. After the development of the software, the program was tested by simulating the operation. The testing phase includes the debugging of the program in order to ensure that the system will be compatible with the software being developed. The program is then deployed alongside the prototype to determine the compatibility of the software design used with the overall system. After testing and deployment, the performance is reviewed in order to determine if there are recurring issues or components that need to be upgraded. The process flowchart that guided the entire process involved within the device is presented in figure 3.

Figure 3 shows the flow chart for the smart energy meter system of the prototype. The process starts at ESP-32 development board, initializing and getting the corresponding sensor values to floating point and once that the floating point is configured; it will go into the server. Once the server is accessible, the system will prepare an SQL statement, which stores and retrieves database statements according to each clause. From the database, the values and settings from the sensor was inserted and displayed in the user-interface. Simultaneously, the system will also keep track of the energy consumed and re-initialize the settings to set the consumption limit. Once the consumption limit has been reached, the system will prepare an update statement, which will go back to the database, and if not, the system will take the last consumption and display it as current consumption.

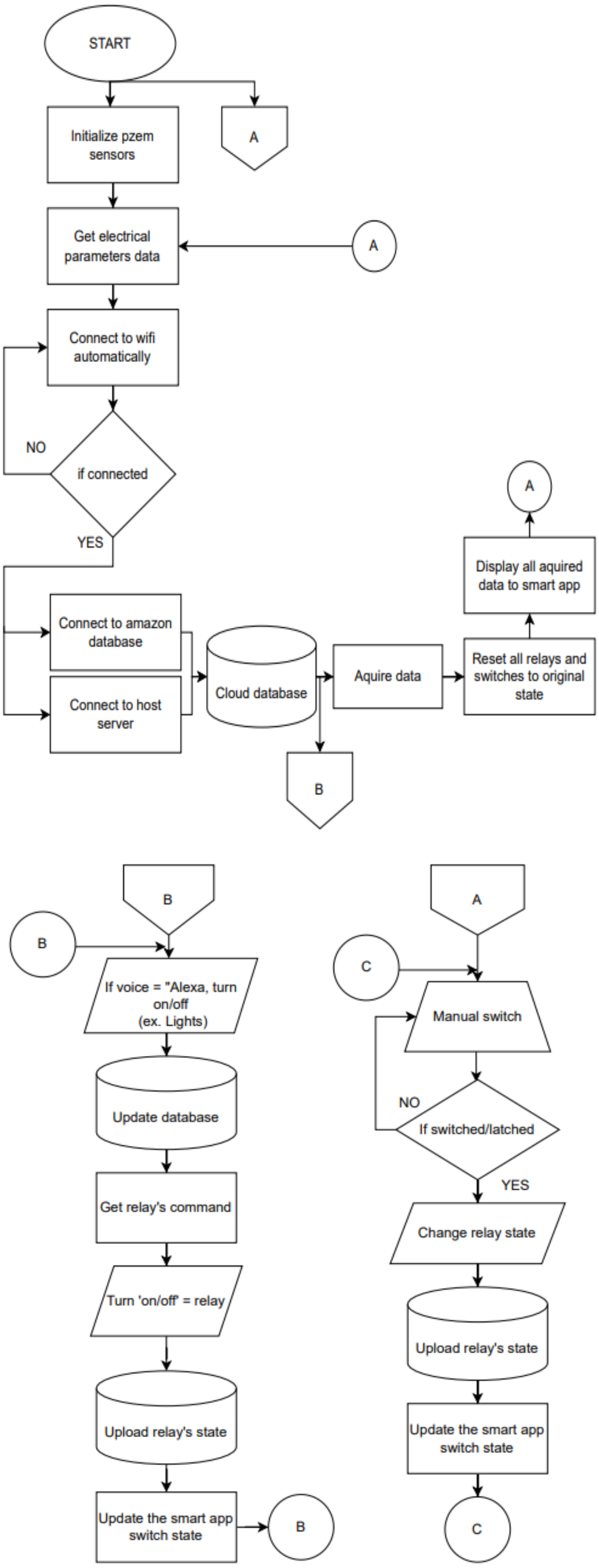


**Figure 3.** The Process Flowchart

Testing such as verifying whether the whole system works as intended, ensuring that software components or functions operate together, validating that each software unit performs as expected. The device passed as it works properly as intended based on the testing and Data Accuracy testing conducted.

Functionality testing done on how the software performs under different workloads such as running the application while multiple different appliances with different loads are running simultaneously. The device passed as it works properly as intended.

After undergoing a series of testing, the results were reviewed to determine if the prototype was functioning as intended. Once completed, the agile model phases start over in order for the software development to continuously improve with an updated version.

## Results and Discussions

### *IoT Home Automated and Technology-Based Smart Energy Metering System with Data Analytics*

The developed IoT Home Automated and Technology-Based Smart Energy Metering System with Data Analytics is shown in the figure 4. The prototype is mainly composed of relays, switches, the PZEM-004T, and the ESP-32 Microcontroller. The PZEM-004T is interfaced with the microcontroller. Once switched on, it will gather information from the appliances connected to the device. The collected data will then be sent to the mobile application. After the mobile application receives the data, it will then be processed and analysed by the software and be presented in the Graphic User Interface (GUI) in order to make it easier for the user to have access to their consumption.

**Figure 4.** IoT Home Automated and Technology-Based Smart Energy Metering System with Data Analytics

### *Assessment of the IoT Home Automated and Technology-Based Smart Energy Metering System with Data Analytics*

The functionality test used to check the relays, PZEM-004T, ESP-32 Microcontroller, switches, and mobile application revealed that these components are functional. Table 1 shows the result of the functionality test performed to the different components of the device.

The results showed that all the components of the IoT Home Automated and Technology-Based Smart Energy Metering System with Data Analytics gained a positive remark, thus the manual switch, PZEM-004T, ESP-32 Microcontroller, relay module, and LED found in the device were all functional.

Specifically, by pressing the switch on, the device automatically turned on, and when the evaluator pressed the off button, the device automatically turned off. In the actual test, the device successfully displays near real-time energy consumption of a simulated home. The Mobile application also allowed for the users to remotely control which appliances were on or off at a given time.

**Table 1.** Summary of the Functionality Test to the Components of the Smart Energy Meter

| Components and Modules | No. of Functional Requirements | Test Case | Remarks |
|---|---|---|---|
| Switch | 1 | 10 | Passed |
| PZEM-004T | 1 | 10 | Passed |
| ESP-32 Microcontroller | 4 | 10 | Passed |
| 8 Channel Relay Module 5v | 1 | 10 | Passed |
| LED | 8 | 10 | Passed |
| Mobile Application | 1 | 10 | Passed |

Furthermore, the actual test shows that the device successfully provides accurate reports on the energy consumption of a homeowner. The reports are then analysed by the device and provides the user with suggestions and brings to attention the deviancy from past consumption behaviours by providing notifications of this in the mobile application. The device also allows the homeowner to set limits to their consumption and exceeding the set threshold calls out the user and provides tips on how to save on consumption
Since the device is a microcontroller based, it allows the Smart Energy Meter to execute sequence of instructions and process that will enable to monitor, analyse, and remotely control appliances. The ESP-32 microcontroller used in the device was able to perform the expected task.

***Usefulness of the IoT Home Automated and Technology-Based Smart Energy Metering System with Data Analytics***
Results show that the developed IoT Home Automated and Technology-Based Smart Energy Metering System with Data Analytics is useful and convenient for homeowners

**Table 3.** Results of the Accuracy Testing of the IoT Home Automated and Technology-Based Smart Energy Metering System with Data Analytics

| ACCURACY TESTING | | | | | | |
|---|---|---|---|---|---|---|
| **Testing** | **VOLTAGE** | | **CURRENT** | | **POWER** | |
| **Test No (5-minute intervals)** | **SEM** | **OMNI Power Meter** | **SEM** | **OMNI Power Meter** | **SEM** | **OMNI Power Meter** |
| 1 | 224.9V | 224.8V | 0.48A | 0.46A | 105.1W | 104W |
| 2 | 225.2V | 225.2V | 0.48A | 0.46A | 105.1W | 103.9W |
| 3 | 225V | 225.8V | 0.48A | 0.46A | 105.3W | 104W |
| 4 | 226.1V | 226.4V | 0.48A | 0.46A | 105.7W | 104.4W |
| 5 | 226.5V | 226.3V | 0.48A | 0.46A | 104.5W | 104.2W |
| 6 | 225.7V | 225.9V | 0.48A | 0.46A | 104.6W | 104.8W |
| 7 | 226.4V | 226.8V | 0.48A | 0.46A | 104.8W | 104.6W |
| 8 | 226V | 226.7V | 0.48A | 0.46A | 105.2W | 103.9W |
| 9 | 225.1V | 225.2V | 0.47A | 0.45A | 104.5W | 103.6W |
| 10 | 225.6V | 226.7V | 0.48A | 0.46A | 105.4W | 104.8W |
| 11 | 226.8V | 226.9V | 0.48A | 0.46A | 106.1W | 104.7W |
| 12 | 226.3V | 226.8V | 0.48A | 0.46A | 105.3W | 104.8W |
| 13 | 226.2V | 226.4V | 0.48A | 0.45A | 105W | 104.2W |
| 14 | 226.5V | 226.7V | 0.48A | 0.46A | 105.9W | 103.7W |
| 15 | 224.9V | 225.2V | 0.47A | 0.46A | 104.1W | 104.8W |
| 16 | 225.3V | 225.7V | 0.48A | 0.46A | 104.1W | 104.1W |
| 17 | 225.6V | 225.6V | 0.48A | 0.46A | 104.4W | 104.7W |
| 18 | 225.7V | 226V | 0.48A | 0.46A | 105.1W | 104.7W |
| 19 | 226V | 226.4V | 0.48A | 0.46A | 104.8W | 104.9W |
| 20 | 224.8V | 226V | 0.48A | 0.46A | 104.1W | 104.7W |
| 21 | 226.7V | 226.4V | 0.48A | 0.46A | 105.4W | 104.6W |
| 22 | 226.8V | 227.2V | 0.48A | 0.46A | 105.3W | 104.2W |
| 23 | 226.1V | 226.3V | 0.48A | 0.46A | 105.9W | 104.3W |
| 24 | 227.2V | 228.3V | 0.48A | 0.46A | 105.3W | 105.5W |
| 25 | 225.2V | 226.1V | 0.48A | 0.46A | 104.8W | 104.3W |
| 26 | 225.7V | 226.3V | 0.48A | 0.46A | 105.3W | 104.3W |
| 27 | 226.4V | 227.6V | 0.48A | 0.46A | 104.7W | 105.8W |
| 28 | 226.7V | 227.6V | 0.48A | 0.46A | 105.4W | 105.8W |
| 29 | 225V | 226.7V | 0.48A | 0.46A | 105.4W | 105.4W |
| 30 | 226.5V | 227.8V | 0.48A | 0.46A | 104.9W | 105.5W |
| **Mean** | **225.90V** | **226.39V** | **0.48A** | **0.46A** | **105.05W** | **104.57W** |

**Table 3** shows the result of the accuracy testing done to determine the Smart Energy Meter's ability to provide consistent results over an extended period of time. An OMNI smart meter was used as a test variable to show the reliability of the Smart Energy Meter's results.

**Table 4** Results of the Functionality Testing of the Mobile Application's setting usage limit feature

| Test Scenario | Mobile Application Setting Usage Limit Functionality | |
|---|---|---|
| Test Cases | Utilizing the Main Console to Set Energy Usage Limit | |
| **Test Step** | **Expected Result** | **Actual Result** |
| The user utilizes the "Set Energy Usage Limit" feature to set a limit for energy usage | Pop-up with Message displaying: ***"Success! Limit has been saved!"*** | Pop-up with Message displaying: ***"Success! Limit has been saved!"*** |
| Remarks | PASSED | |
| Post Condition | All the components work properly | |

**Table 5** Results of the Functionality Testing of the Mobile Application's usage limit feature

| Test Scenario | Mobile Application Exceeding Energy Usage Limit Functionality | |
|---|---|---|
| Test Cases | Exceeding the Set Energy Usage Limit | |
| **Test Step** | **Expected Result** | **Actual Result** |
| The user exceeds the Energy Usage Limit that was set | Pop-up with Message displaying: ***"LIMIT USAGE! Room#1 has reached its limit usage for this month"*** | Pop-up with Message displaying: ***"LIMIT USAGE! Room#1 has reached its limit usage for this month"*** |
| Remarks | PASSED | |
| Post Condition | All the components work properly | |

**Table 6** Results of the Functionality Testing of the Mobile Application's suggestions and callouts feature

| Test Scenario | Insight - Suggestions and Call-outs | |
|---|---|---|
| Test Cases | Mobile Application Insights: Suggestions and Call-outs Feature | |
| **Test Step** | **Expected Result** | **Actual Result** |
| The user's energy consumption is higher compared to consumption from previous week/month | Pop-up with Message displaying: "***Please lessen the usage of Room2. Your energy usage this week is higher compared to last week"*** | Pop-up with Message displaying: "***Please lessen the usage of Room2. Your energy usage this week is higher compared to last week"*** |
| Remarks | PASSED | |
| Post Condition | All the components work properly | |

**Table 7** Results of the Functionality Testing of the Mobile Application's bill calculator feature

| Test Scenario | Insight - Potential Bill for Current Month | |
|---|---|---|
| Test Cases | Mobile Application Insights: Electricity Bill Estimate Feature | |
| **Test Step** | **Expected Result** | **Actual Result** |
| The user sets the electricity rate for the month | Mobile Application calculates electricity bill estimate based on inputted rate and current consumption then displays estimated cost for consumption per day, week, and month | Mobile Application calculates electricity bill estimate based on inputted rate and current consumption then displays estimated cost for consumption per day, week, and month |
| Remarks | PASSED | |
| Post Condition | All the components work properly | |

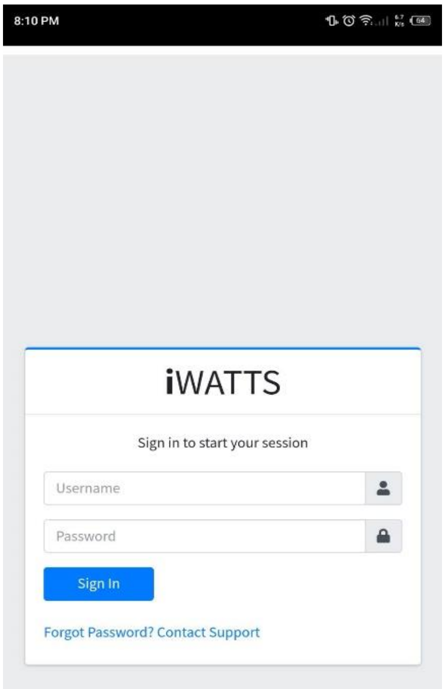


**Figure 4.5**: Mobile Application Log in screen

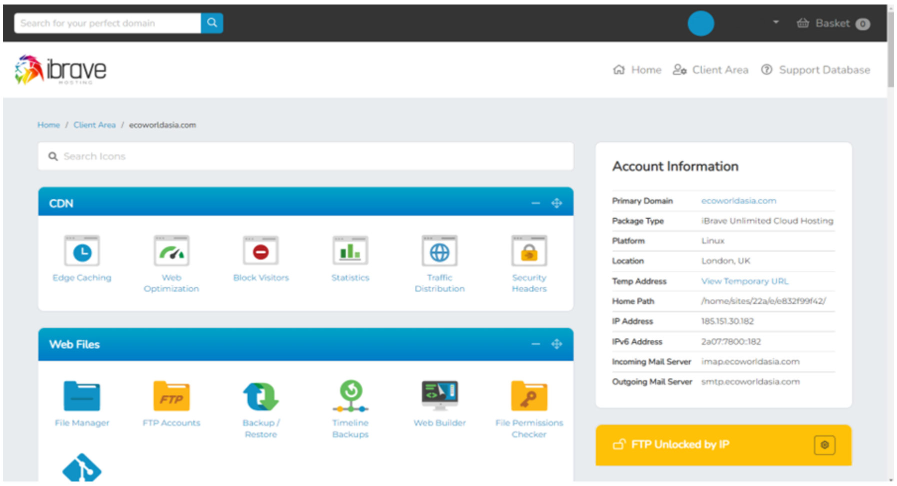


**Figure 4.6**: Local Host Database Interface

The above results display the ability of the IoT Home Automated and Technology-Based Smart Energy Metering System with Data Analytics to provide a homeowner with accurate and near real-time report on their energy consumption allowing for a homeowner to get a better understanding of how to save on their energy consumption. On top of being able to monitor their consumption, homeowner's will be able to remotely control their appliances as well with the help of the mobile application. It allows the user to switch certain appliances on or off by using the switches on the mobile application for their convenience.

## Conclusion and Recommendations

The study concludes that the IoT Home Automation Technology-Based Smart Energy Metering System with Data Analytics is a prototype that was designed and tested to measure electrical parameters such as voltage, current, power, and energy consumed by an establishment. The system includes a smart energy meter that provides almost 99% accuracy, a monitoring system that utilizes a cloud database to store measured values and displays it on a user-interface (UI), and a comprehensive graph and reports to monitor electric bill in almost real-time. Additionally, the system has home automation features that allow users to remotely control appliances, manual switches, and a software application of the smart energy meter device. Results of the test and evaluation show that the smart energy meter is comparable to commercial energy meters available in the market with high level of functionality and accuracy. The recommendations for improving the IoT Home Automation Technology-Based Smart Energy Metering System with Data Analytics include supporting multiple rooms in an establishment and controlling more than eight appliances, improving and expanding the software to make the user-interface more user-friendly, comprehensive, and interactive, expanding the cloud database for commercialization to support more users, constantly improving and updating the software to mitigate known issues and cater to consumers' needs, and addressing delayed responses due to slow internet connection by identifying a strong internet service provider based on the location of the device.

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