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Smart Electricity Meter Monitoring and Prediction using I-Socket

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Abstract*: As the world's population and energy needs continue to grow, the demand for power is ever-increasing. This has put a strain on natural resources and renewable sources of power, which are not yet developed enough to operate self-sufficiently. In this context, optimal power sharing and efficient energy consumption is essential. To this end, a smart electricity meter monitoring and prediction system has been developed using i-Socket, a hardware module that tracks the energy consumed by each device in a house and estimates the monthly electricity bill. This system notifies the user when the bill surpasses a set limit and sets the monitoring rate of a connected device to the socket based on the type of device, making it an energy efficient system. Current sensor used is the ACS712 sensor and the microcontroller is Arduino UNO. A Boost converter is used for the power supply and the software application is developed for monitoring electricity bills. This system takes input of present data of current and predicts the meter reading for the following months. However, the same can also be achieved by using a python server for holding an ML model that will be developed to predict future price of the bill based on the current usage of power. This is acts as an affordable alternative to that by using the iSocket.*

Keywords: ACS712 sensor, Arduino UNO, i-Socket, Boost converter, Current sensor, python server, ML model

I. INTRODUCTION

Over the years we have seen many smart meters and the implementation of smart electricity meter monitoring and prediction is a critical step in addressing the growing global demand for energy. Smart meters enable the real-time monitoring and prediction of electricity use, helping to reduce energy waste and improve efficiency. This is especially important as the world moves towards renewable energy sources, as it allows for the efficient use of available resources. Smart meters also provide utilities with insights into customer behaviour and preferences, which can be used to inform better pricing and marketing strategies. Finally, smart meters can help to identify problems or inefficiencies in the electrical grid, allowing for quick and effective corrective action.

Many of us our households don’t have a proper meter to monitor, as per our survey we have figured out that even though there is a meter in the houses, they are old and dusty and only one in every 10 households check their meters for the usage, and others just pay for the units that BESCOM employee asks for after generating the bill. The problem that arises here is we are wasting electricity so much by not keeping track of our usage. Currently there is nothing that provides the details of a particular current usage of an appliance in the home. There is no way a person can track the power usage in each appliance on his own, unless they calculate the electrical rating with the amount of time they are using per day. These are some of the problems that are faced by our people.

The objective of this project is to design a smart electricity meter monitoring and prediction system using I-Socket. The system will be used to monitor and predict the electricity usage of each household and provide an accurate and timely notification to the user when an issue arises. The system will be able to detect and inform the user of any increase in electricity usage as well as any sudden decrease in electricity usage. It also will be able to provide real-time monitoring of the electricity usage of each household and provide timely alerts when an issue is detected. Furthermore, the system will be able to predict the electricity usage of each household and provide the user with a timely prediction of the electricity usage for the next few days. This will help the user to budget their electricity usage to save money.

II. METHODOLOGY

2.1 System Architecture

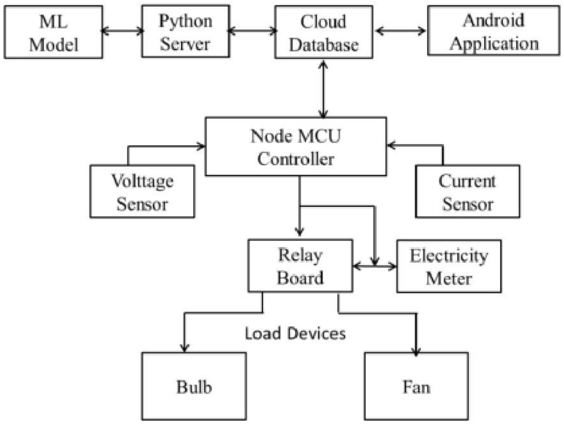

Fig.1 System Architecture

2.2 Principle of Operation

- The hardware components include a current sensor and a power source to supply electricity to the sensors and microcontrollers. A Wi-Fi module will be utilized to transmit the data for the observed measurements. Given the potential complexity that a wired connection could introduce into the system's layout, a wireless module is the preferred choice.
- The socket contains a hall effect current sensor that measures the electrical current. A microcontroller is programmed to convert the measured current into digital data. This digital data is then sent to a receiver located elsewhere in the house. Finally, the receiver uploads this current data to an online server.
- The collected data undergoes processing and is organized in a database. When the application is accessed either remotely or locally, it establishes a connection with the server to retrieve data from specific databases. It then performs necessary computations to generate an estimated electricity bill.
- The devices that can be plugged into this socket vary from low-power gadgets like mobile chargers to high-power appliances such as air conditioners.
- The hardware is engineered to allow the socket's installation at any point along the household electrical system. The sensors and controllers are safeguarded and insulated from potential dangers and moisture.

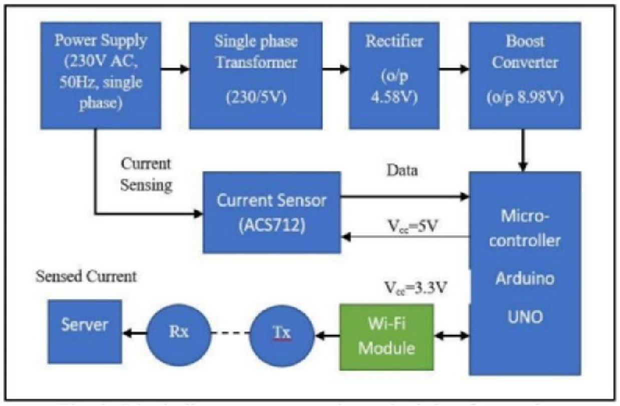

Fig. 2 Block Diagram of Principle of Operation

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III. SYSTEM REQUIREMENT SPECIFICATION

3.1 Hardware Requirements

- NodeMCU - NodeMCU is an open-source platform utilizing ESP8266 for connecting objects and facilitating data transfer via Wi-Fi. It incorporates essential microcontroller features like GPIO, PWM, and ADC.
- Voltage Sensor - A Voltage Sensor is utilized for monitoring voltage levels in objects, discerning between AC and DC voltage. It accepts voltage as input and generates switches, analog voltage signals, current signals, or audible alerts as output.
- Current Sensor - Current Sensor identifies and converts current into a measurable output voltage proportional to the current flow. Various sensors cater to specific current ranges and environmental conditions.
- Relay Boards - Relay boards are electronic boards containing relays and switches, with input and output terminals for controlling voltage distribution. They provide customizable control for numerous relay channels simultaneously, allowing real-time adjustments.
- Load Devices (Bulbs and Fan) - Load devices like bulbs and fans are typical electrical loads found in households, transforming electrical energy into light, heat, or motion. Any resistor or electric motor within a circuit fulfilling this function is categorized as a load.
- A computer or laptop with an internet connection and a web browser.
- A smartphone or other mobile device with an internet connection
- An iSocket smart electricity meter monitoring device.

3.2 Software Requirements

- Arduino IDE - The Arduino Integrated Development Environment (IDE), also known as Arduino Software, includes a code editor, message area, console, toolbar, and menus. It interfaces with Arduino hardware for program uploading and communication.
- Python 3.7 - Python 3.7 introduces new data handling classes, script compilation optimizations, improved garbage collection, and enhanced asynchronous I/O for faster performance. This latest version simplifies complex tasks and is now available for production use.
- Django - Django, a Python-based web framework for backend development, enables rapid creation of robust and secure web applications. It offers features like a powerful ORM, template language, and admin interface, emphasizing simplicity, efficiency, scalability, and extensibility for customization.
- Anaconda - Anaconda is a specialized distribution of Python and R geared towards scientific computing, data science, machine learning, and similar fields. It simplifies package management and deployment procedures to facilitate a range of data-focused applications.
- Android Studio - Android Studio, an IDE for Android app development, is created by Google and built on IntelliJ IDEA. It provides a comprehensive environment for building, testing, and debugging Android apps using Java, Kotlin, and the Android SDK. Additionally, it offers tools for performance profiling, testing, and debugging to enhance the development process.

IV. IMPLEMENTATION

4.1 Hardware Design

Circuit Diagram

The power circuit is designed to provide electricity to both the microcontroller and the Hall effect current sensor (ACS712 sensor). These components operate on DC power, with the microcontroller requiring a 9V DC supply and the Hall effect current sensor needing a 5V DC supply provided by the microcontroller. Consequently, power electronic devices were employed to supply power to these units. The 230V power source is distributed through wiring installed throughout the house to power various devices. A shunt wire is connected to a step-down transformer, which reduces the voltage from 230V AC to 5V AC. The transformation ratio is expressed as follows:

V1/V2 = N1/N2.

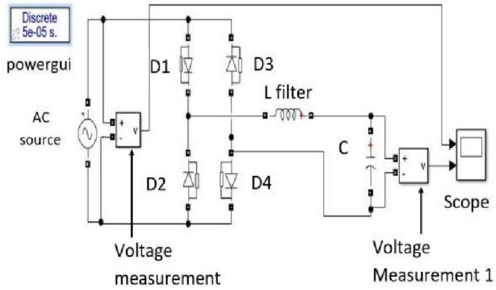


Fig.3 Simulation of Rectification Using MATLAB Simulink

The reduced 5V AC voltage is directed to a single-phase diode rectifier, depicted in Figure 6.2, resulting in an output voltage of 4.58 Volts, as indicated below for the rectifier:

V0in = 5V AC, V0out = 4.58V

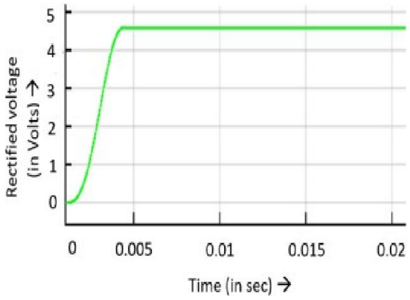


Fig.4 Plot of Rectifier Output Voltage Over Time

The 4.58V DC output voltage is directed as the input voltage (Vin) to the Boost converter, which amplifies it to generate a regulated output voltage (Vo) of 8.98V DC. Acting as a voltage regulator, the boost converter ensures a stable DC output. Additionally, the converter operates in continuous conduction mode (CCM). MATLAB Simulink is employed to simulate the functioning of the Boost converter. The boost converter is formulated using the following equations:

Maximum Duty Cycle (D):

$D = 1 - (Vin * \eta)/Vo$

Output current (Io):

$Io = (\text{Output power})/Vo$

Inductor ripple current (IL):

$IL = (0.2 \text{ to } 0.4) * Io * Vo/Vin$

Inductance (L):

$L = Vin * D/(fs * IL)$

(Where fs= switching frequency, specifically 20kHz)

Output Capacitance (Cout):

$Cout = (Io * D)/(fs * Vo(ESR))$

(Where Vo (ESR) represents the additional output voltage ripple due to the equivalent series resistance of the output capacitor)

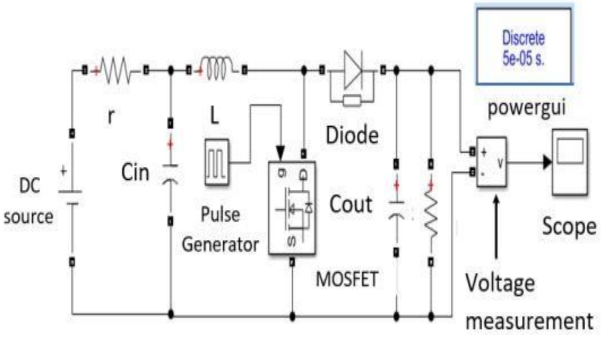


Fig.5 Simulating Boost Converter Simulation with MATLAB Simulink

Current Measurement utilizing Hall Effect Sensors

The Hall effect sensor is employed for detecting the input current of the system. This sensor is connected in series with the device's power supply where the sensing occurs. It operates using a 5V DC source (Vcc) and provides output pins for Vcc, ground, and analogue input. The analogue input is connected to the analogue pins of the microcontroller.

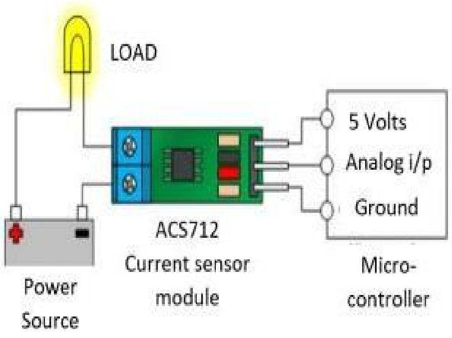


Fig.6 Schematic of Current Sensor Integrated with Microcontroller Unit

The microcontroller is energized through the Boost converter's output terminals. In the absence of an AC input, the sensor generates a DC bias voltage of 2.5V, indicating the absence of AC current flow within the system.

Data Transmission and Receiving System

The process of data transfer is facilitated through collaboration between an Arduino UNO microcontroller and a Wi-Fi module. The Wi-Fi module (ESP8266), operating at Vcc = 3.3V, is connected to the Arduino controller to enable data transmission and reception. The current data obtained from the current sensor is logged into the system, with the data being transmitted to cloud storage via the Wi-Fi module's transmitter unit. Positioned 10 meters away at the opposite end, the receiver promptly enters the data into the cloud database. This logging occurs every two minutes from the system's initiation, with the data logging rate adjusted to different time intervals based on the device connected to the system. This adjustment is communicated to the firebase cloud. Subsequently, the data is analyzed, and the projected electricity cost for the system is computed.

4.2 Software Design

Software Procedure

The software component is partitioned into two segments: the user interface and the backend application. A user interface for monitoring power bill progress is constructed using an Android application, while Django is employed to develop the backend. Android Studio, utilizing Java 8 Standard Edition and XML, is utilized for building user interfaces, while Python serves as the coding language for the backend. Data storage is facilitated through Firebase cloud, acting as a database for recording data, and sqlite is used as an application-level database to preserve specific user sessions. The Wi-Fi module captures current (in Amperes), which is then stored in the database alongside relevant socket information. Real-time data monitoring is possible via the Android application, where users input the total number of active sockets and the desired bill amount limit (in INR) for alert notifications. The backend organizes the sockets into groups based on their usage, such as grouping electric chargers separately from daily usage devices like refrigerators and microwaves. This enables the system to suggest improved strategies for utilizing different devices while considering the desired quantity. Throughout this procedure, the system also adapts to assist in providing efficient power consumption for the customer. Additionally, forecasting is employed to provide supplementary insights for predicting the power expenditure for the upcoming month.

Software User Interface Implementation

The software application is split into two components: user and admin. Regular users have access to the user module, while the admin module is dedicated to verifying the Know Your Customer (KYC) information of end users. Following are the steps to be followed:

1. To ensure that a single residence is not registered more than once, the user must register via our programme. Following registration, KYC papers must be presented, which must be authorised by the administrator before the user may use the application.
2. Upon approval, the user is required to input the quantity of electrical outlets in their residence. Subsequently, consumers will have the option to procure the physical device. Users are then instructed to synchronize hardware devices with our program using the provided code embedded within the hardware device.
3. The user is redirected to the main screen, which presents the current bill status. This includes the duration for which the bill is calculated, the total units consumed, and the cumulative payment made up to the present moment. Should a user switch from one device to another on a specific socket, the program issues a notification regarding the addition of the newly plugged-in device, determined by fluctuations in perceived current and power usage over time. Data is stored in a dedicated column within a real-time cloud database.
4. Users may add, update, or remove devices from the application at any moment. Through our application, they may monitor their energy bill, verify expected bills, and optimise their electrical bill spending.

Sequences of System Workflow

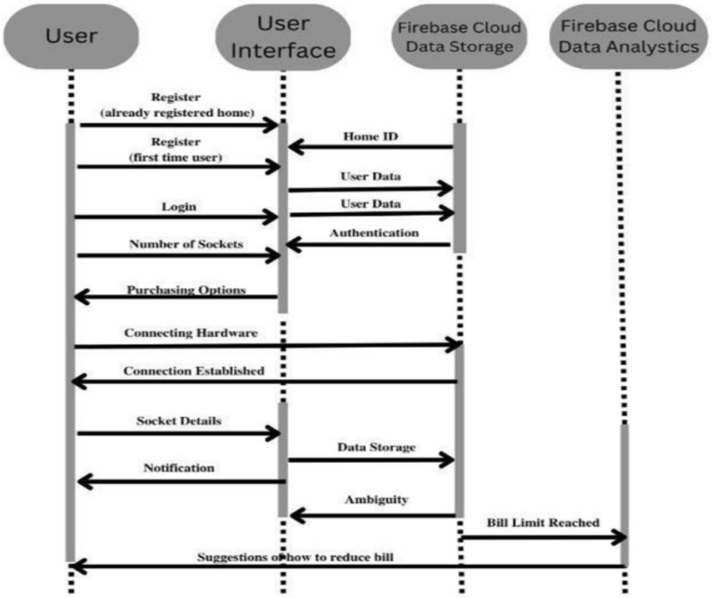
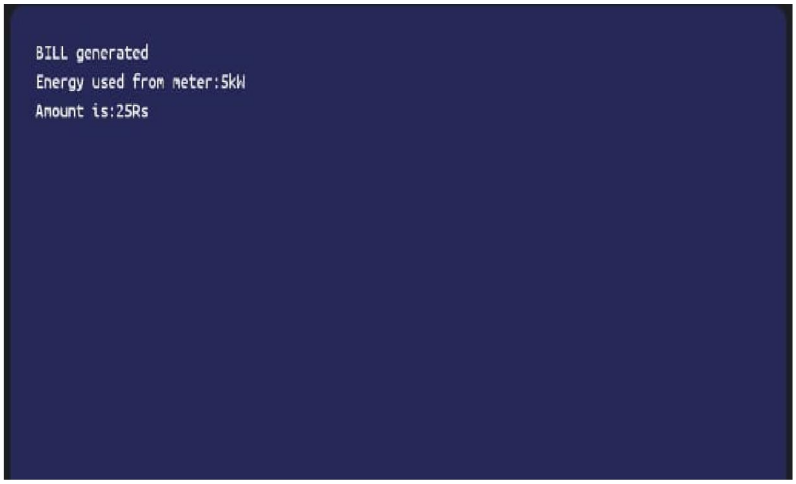
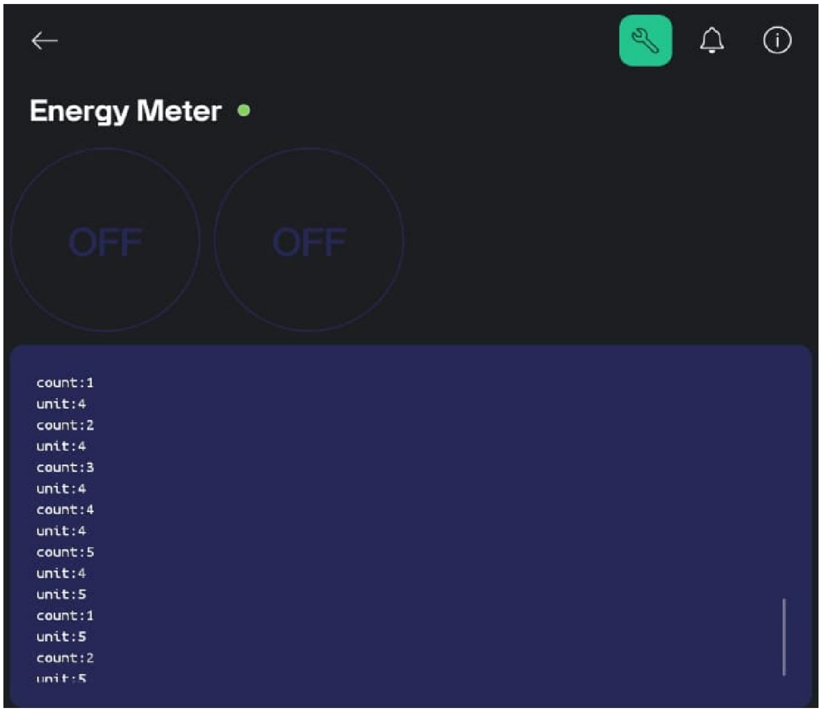


Fig 7:Sequences of System Workflow

V. RESULTS



```
BILL generated
Energy used from meter:5kW
Amount is:25Rs
```



```
count:1
unit:4
count:2
unit:4
count:3
unit:4
count:4
unit:4
count:5
unit:4
unit:5
count:1
unit:5
count:2
unit:5
```

Fig.8 and.9 Data from Monitoring Meter

The monitoring and prediction of smart electricity meters entail the utilization of sophisticated metering infrastructure for the continual collection and analysis of electricity consumption data. By monitoring energy usage in real-time, these systems offer comprehensive insights into consumption patterns, empowering consumers to streamline their energy usage and cut down expenses. Predictive algorithms, utilizing historical data and machine learning techniques, forecast future consumption, aiding utility companies in effectively managing supply and demand, thus averting outages and curbing energy wastage. Moreover, these systems facilitate the incorporation of renewable energy sources by predicting periods of high or low production, thereby enhancing the resilience and sustainability of the energy grid.

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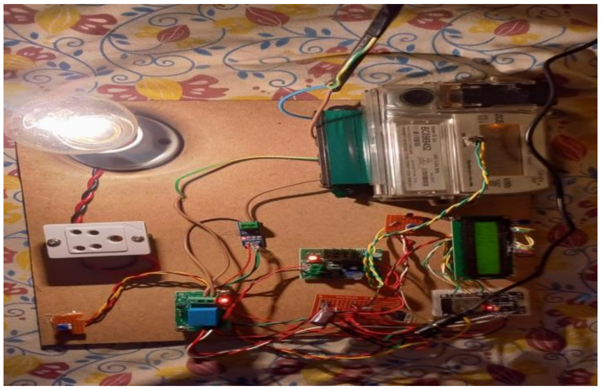

Fig 10: Hardware model

VI. CONCLUSION

The implementation of smart electricity meter monitoring and prediction marks a significant leap forward in energy management, offering substantial advantages to consumers, utility providers, and the broader energy landscape. Through the utilization of real-time data and advanced predictive algorithms, these systems facilitate precise monitoring of electricity usage and accurate forecasting of future consumption patterns. This real-time information empowers consumers to optimize energy usage, reduce expenses, and participate in demand-response initiatives, while utility companies can improve grid reliability, prevent disruptions, and efficiently manage supply and demand. Furthermore, the seamless integration of renewable energy sources enhances the resilience and sustainability of the energy grid.

Looking ahead, the potential for smart electricity meter monitoring and prediction is vast, with ongoing technological advancements promising even greater efficiency and effectiveness. Enhanced data analytics, AI integration, and IoT connectivity will refine predictive capabilities and allow for more detailed control over energy consumption. As smart grid infrastructure becomes more prevalent and regulatory support grows, the global deployment of smart meters, including in developing regions, will accelerate. These advancements will not only drive energy efficiency and sustainability but also foster consumer engagement and awareness, ultimately contributing to a more environmentally conscious and sustainable future.

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