# IoT-based smart net energy meter with advanced billing feature for residential buildings including solar PV system

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**Article Info**

***Article history:***

Received Jun 21, 2023
Revised Dec 4, 2023
Accepted Dec 17, 2023

***Keywords:***

Advanced metering infrastructure
Grid
Internet of things
Microcontroller
Net-meter
Solar PV

**ABSTRACT**

Electricity consumption is rising across all industries. Residential electricity use dominates the sector. Solar photovoltaic (PV) systems on residential roofs are increasing quickly, notably in Dhaka, Bangladesh. PV power generation is high at peak sun irradiance. Due to light loads, residential structures use less electricity. PV system surplus electricity may be transmitted to the national grid. Residential customers may sell power to the government, lowering their electricity expense. Traditional energy meters make it difficult to calculate PV system consumption by load and grid injection. This is possible with net metering. Thus, this study presents an internet of things (IoT)-based smart net energy meter for home users to provide surplus solar PV power and consume grid electricity when needed. With the government's new power tariff rate, the net bill will be calculated automatically. A dedicated mobile application is used to monitor all the activities. The billing statement will be generated automatically, and the payment of that bill will be payable using a redirect link with the same mobile application. The suggested smart net energy meter will inform SMS/mobile app users of gas, smoke, and tempering. The suggested meter's performance and efficacy were evaluated using software simulation and hardware analysis.



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## 1. INTRODUCTION

An internet of things (IoT)-based smart net energy meter is a device that measures the amount of energy being consumed by a household or building and sends the data to a remote server for monitoring and analysis. It utilizes IoT technology to transmit energy consumption data in real time over the internet, allowing for improved monitoring and control of energy usage. This device can be programmed to set usage limits, provide alerts for excessive usage, and integrate with smart home systems for more efficient energy management [1].

For socio-economic progress and improvement of people's standard of living, the government brought electricity to all the country's citizens under Plan 2021. To provide universal electrical facilities, ensure energy security and achieve sustainable development goals (SDG-7) announced by the United Nations, the Bangladesh government is taking steps to generate environment-friendly electricity from renewable energy in addition to conventional fossil fuels. Among the main renewable energy sources (solar energy, hydropower, biogas, biomass, geothermal energy, wave energy, and tidal energy), solar energy is the most promising resource in Bangladesh [1]–[3]. But setting up large-scale solar power plants is difficult because more than three acres of non-agricultural land are required for each megawatt solar power plant project. As an alternative, initiatives have been taken to increase electricity generation through renewable energy by installing solar systems on the unused roofs of various facilities connected to the electrical distribution network, such as houses and industrial plants. The Bangladesh government for this purpose, created the net metering guidelines 2018 (revised in 2019) [4]–[7].

The net energy meter has background research with robust technical architecture from many years but can only measure cumulative energy use [8]. An IoT platform is required for process monitoring. An IoT-based smart net energy meter provides energy use for daily monitoring and payment in one-period intervals or fewer [9]. Researchers claimed that a photovoltaic (PV) panel could ensure more available energy that is extracted from solar irradiance. According to data from the last few years, the PV industry has changed dramatically. Such as, the PV power capacity of 520 GW could reach up to 1.4 TW by 2024. Not in Bangladesh, globally PV panel have become more popular and usable to extract power from nature as a renewable power medium [10]–[13]. Some research also concluded that most of each renewable energy study had apprised the critical role of PV panels in this renewable sector [14]. Not only in $CO_2$-free supply of power but also in generating energy fluently. So, developing a system like a net-meter using a PV panel can provide more accurate electrical industry monitoring.

The advanced metering infrastructure (AMI) system, which permits bi-directional communication between an intelligent energy meter and a monitoring system, has been used [15]. An energy meter using global system for mobile communications (GSM) has also been implemented to use a dedicated mobile subscriber identity module (SIM). This type of meter always faces issues like lacking a real-time monitoring system. It sends a short message to show the consumption, generation and exported amount of electricity as well [16]–[19]. In addition, to know about the billing and other parameters, consumers were also massaging to learn about their uses [20], [21]. Automation is essential in case of any invention. Major limitations in the energy management system are accurate metering, energy theft, and effective tariff and invoicing implementation [22], [23]. These applications are possible with smart meters. Energy computation using smart meters is suggested for automated data collecting and notification through messaging. Hence, a survey of recent literature reveals that most research works focused on developing the net metering system. In contrast, few researchers are considering developing to perform in real-time operation mode and can collaborate with IoT [24]–[26].

Based on the above discussions, this article developed a smart net energy meter for residential users to allow bidirectional power flow. The following are the salient features of this study: i) A real-time monitoring system with a proper IoT platform has been implemented to operate the net-meter more accurately. An easy-to-use meter with a proper, uniquely organized display with the meter has developed that contains almost all-important information that makes a clear sense for the consumer about all the parameters at a time; ii) A dedicated mobile application has already developed for monitoring the grid voltage, inverted PV voltage (DC-AC), exported energy from the PV to the grid, and consumed energy from the grid; iii) The automated detail billing system for both the user and distribution company has developed; and iv) Additional features like flame, gas, smoke, and theft detection have also featured in the proposed net energy meter, which are the prominent features of this study.

## 2. METHODOLOGY AND SYSTEM ARCHITECTURE

Figure 1 illustrates the proposed smart net energy meter scheme. The proposed architecture comprises IoT, PV panel linked through a battery and inverter, and a grid system. The controller converts the battery's direct current (12 V DC) to alternating current (220 V AC). Two-way metering concept accumulates the PV system and the grid linked simultaneously. A residence load is connected to the grid as a load from the net energy meter. Users and distributors will have an online platform through the IoT cloud and a Wi-Fi module. Consumers can see their most up-to-date electricity bills and pay directly to the distributor from the mobile banking system by using the app with a redirect link. The data will be stored on the “Thing Speak” server that is part of the “MIT App Inventor” platform.

The flowchart in Figure 2 describes the initialization of the working principle of the proposed smart net energy meter. Initially, the operation starts with the microcontroller that controls all the parameters through different sensors connection and visualizes the entire results in the display. After establishing a proper connection of Wi-Fi between the microcontrollers (ESP8266 & Arduino Mega 2560 V2), the defined process runs for activating the system. If the main system does not respond, it will run the loop again.

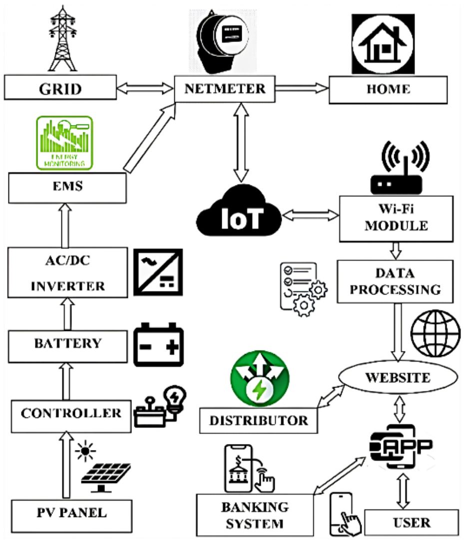



Figure 1. Block diagram of IoT-based smart net energy meter

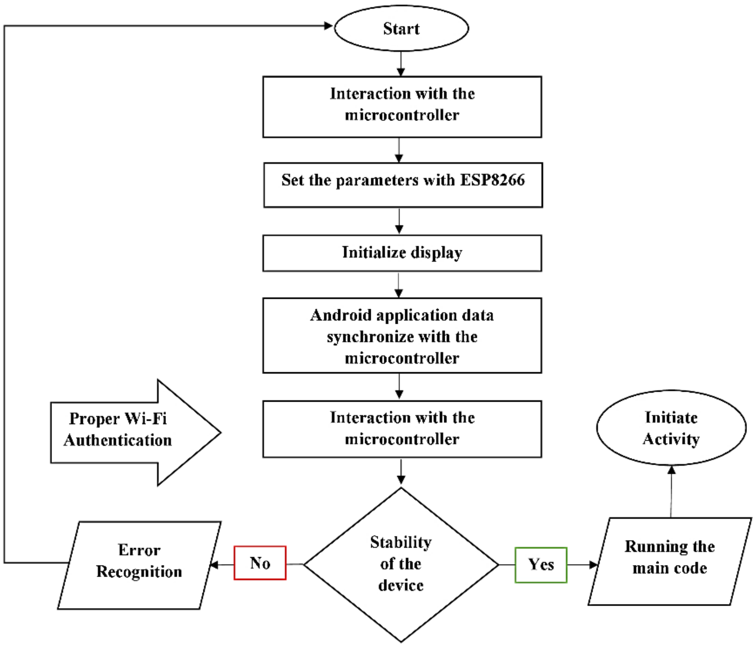



Figure 2. Initialization of components and IoT

The monthly bill calculation with the tariff rate is depicted in Figure 3. The tariff rate has taken from the Dhaka Electric Supply Company (DESCO) Ltd., Bangladesh. After starting, the whole calculation uses all the tariff rates divided into six individual slabs. Unit from 1-75 kWh, the cost per unit is 4.19 BDT; for 76-200 kWh unit, the per unit cost will be 5.72 BDT and entirely depending on the uses of the consumer.

In the flowchart, some short abbreviations such as A1, B1, and AB1 are used to define the billing calculation individually and monthly. If a user's consumption is under 300-400 kWh units, then the calculation will be done under this condition with the specified unit price. At the end, these terms will be summed up with a demand charge (30 tk/kW) per month and VAT (5%) to complete the billing.

Figure 4 shows the relay switching conditions of the proposed smart net energy meter, considering PV as the 1st priority and the grid as the 2nd priority. If there is no supply from the PV panel, the connection will be switched from the PV line to the grid line, and it is continuously measuring inverted PV voltage. If PV voltage is detected, the connection will be switched to the PV line from the grid line again. After detecting PV voltage, the PV line will connect to the load and continuously measure user's consumption and generation by PV panel. If energy generation is greater than energy consumption, then the PV line will be switched to the user's load as well as the grid for exporting. The remaining states will check and apply if this condition is false.

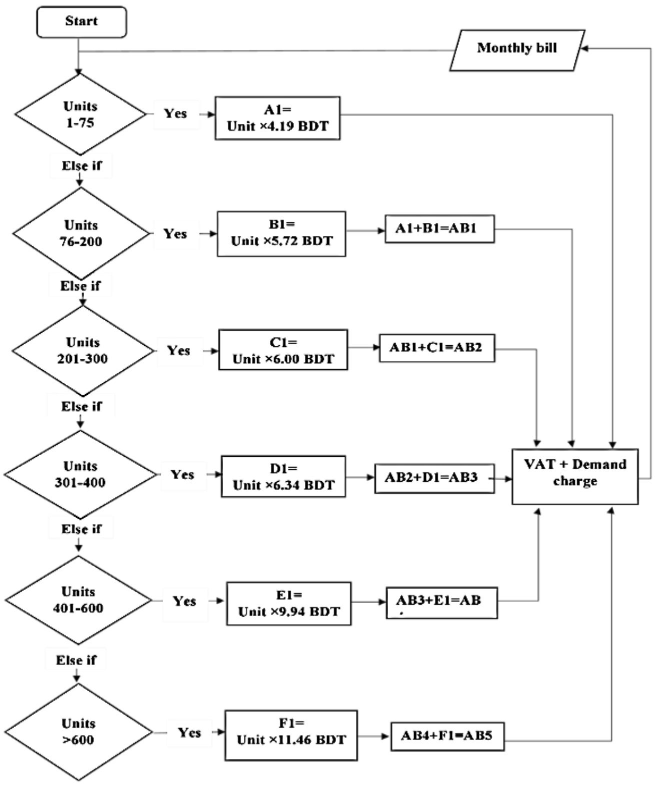



Figure 3. Tariff rate & billing flow diagram for the proposed meter

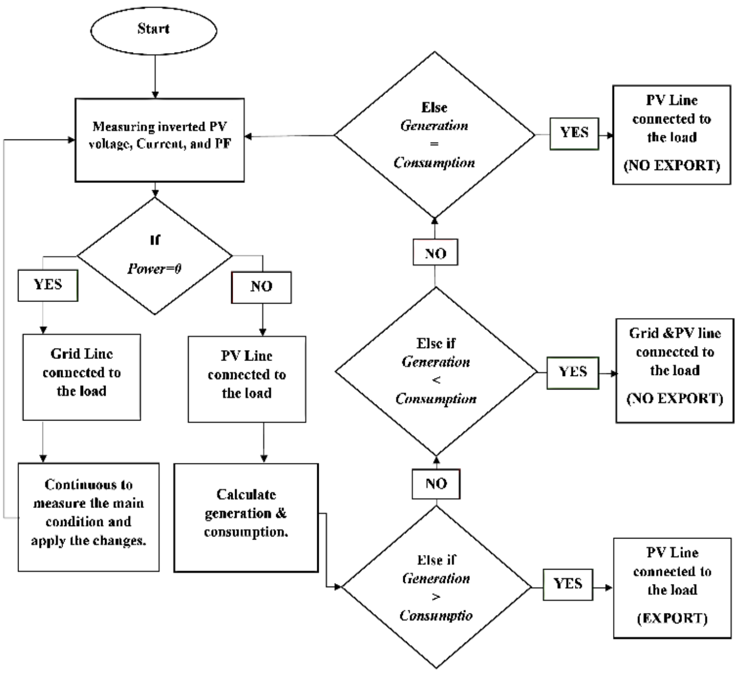



Figure 4. Flow chart for switching conditions from solar to grid and grid to residential load

## 3. SOFTWARE SIMULATION

The schematics that has been done using "Proteus 8 Professional" to simulate the project in Figure 5(a) (see Appendix) contain a 2.8-inch thin film transistor (TFT) display for visualizing the data, and Arduino Mega for processing and calculating all the sensors value. Three voltage sensors & three current sensors are connected to the analog pin of the Arduino Mega 2560 V2. The ESP8266 module is connected to the Arduino Mega 2560 V2 with a serial communication pin; it collects data from Arduino Mega 2560 V2 and then sends it to the cloud server. Microcontrollers can collect, visualize, and analyze live data streams in the cloud with "Thing Speak", an IoT analytics platform. It feed device data to "Thing Speak" for real-time viewing and warnings. "Thing Speak" IoT clients can update and receive channel feed updates using the MQTT broker. MQTT is a TCP/IP or WebSocket publish/subscribe protocol.

Three relays are used for switching between solar and grid consumption in real-time. For maintaining time and date, the real time clock (RTC) module is used along with the whole net meter scheme. A vibration sensor is used for notifying the meter tempering alert, the flame sensor is used for flame detection, and smoke and gas sensors are employed for detecting smoke and gas. Four bulbs are used as a load, and another shows the exported energy, as shown in Figure 5 (see Appendix), with proper alignment. Buzzer and LED are used for the alarm. For further measurements, an inverter circuit inverts the DC voltage from the PV to the AC voltage. All the values can be observed simultaneously, as presented in the simulation Figure 5(b) (see Appendix). In a specific time, the grid is not connected to the meter, so no values are showing in the grid section. But as the solar is connected, the display shows the solar data in real-time. Here consider 1 (high-low condition) as the threshold value for any sensor. The simulation shows that the flame has been detected because, in the code, it's declared if the value reaches up to or above 1, it will activate and show in the display.

## 4. HARDWARE SETUP OF THE METER

The hardware prototype of the proposed smart net energy meter is presented in Figure 6. As a primary microcontroller, an Arduino Mega 2560 V2 has used. In this hardware setup, many sensors are used to detect abnormalities. Relay does the switching in the smart net energy meter; when it senses the solar power is almost at its end, it will automatically switch the whole generation of electricity to the grid and vice versa. A solar power generation system has also been constructed, and the bulbs are considered as load. The topmost bulb represents the exported part, which means whenever any amount of electricity is exported, it will light up and indicate the presence of the exported unit. The remaining bulbs indicate the grid consumed load and solar consumed load in general use without exporting. Solar is user's first priority, which is "Solar consumed (solar C.)". If solar generation power is larger than user's consumption will supply extra amount of power to grid, which denoted as (S. to G.). Solar power typically generates DC voltage. To use and supply to the grid, a DC-AC inverter has employed. "Grid Consumption (grid C.)" means how much energy user consumed from the grid.

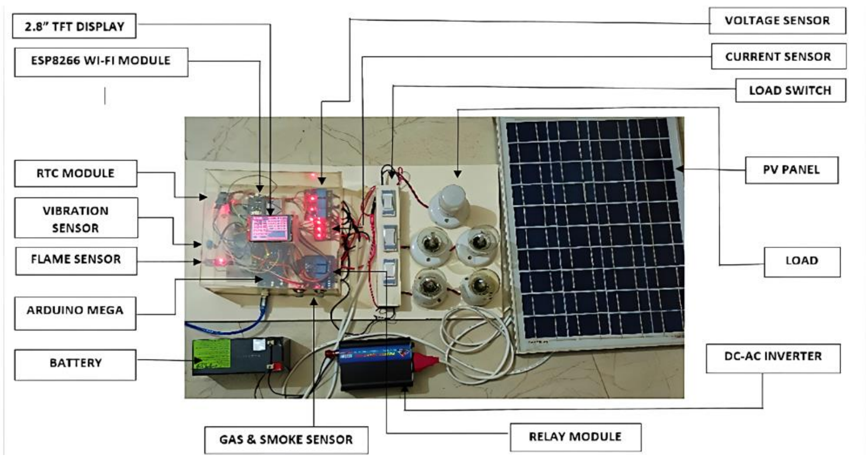



Figure 6. Hardware prototype of the proposed smart net energy meter

Figure 7(a) demonstrates all the internal parts of the proposed meter. It clearly indicates the Arduino Mega 2560 V2, voltage and current sensors, NodeMCU (ESP8266), gas, flame, smoke and vibration sensors, relay, and RTC. The initial scenario of all parameters of the net-energy meter is summarized in Figure 7(b) with the TFT display showing time using RTC module that enables the main device to retain time even in the absence of a network time protocol (NTP) server during a power outage because RTC can work offline. However, once the device reconnects to the internet, it will synchronize once more with the NTP server. NTP enabled RTC module for precise timekeeping. We utilize the NodeMCU to establish a connection to the NTP server and synchronize the time using the RTC module. Separately a few sections have been distributed for consumed units, exported units, and voltage current value from the grid and solar. A notice box is also there to notify the consumers of any trouble the meter faces, such as security alerts sensing by the sensors used in the hardware part. As presented in the diagram, the display shows all the necessary information regarding solar PV, grid, electricity consumption amount, electricity export amount and the net bill. Finally, the notice box will show the smoke, gas, flame, and theft detection. This section specified the grid voltage in Figure 7(c) presents the consumptions of the grid with a voltage of 211.76 V, and current of 838.67 mA and the power factor of 0.97 on the other hand, the solar side shows every value of 0 because there is no solar system connected and this meter will work without solar system. Figure 7(d) displays the total amount of solar energy used and the amount of energy sent to the grid. A negative net section value results from energy exports exceeding energy consumption. If the net meter detects any kind of anomaly, it will immediately notify the appropriate authorities and broadcast the fact. In addition, a buzzer and LED will notify concurrently.

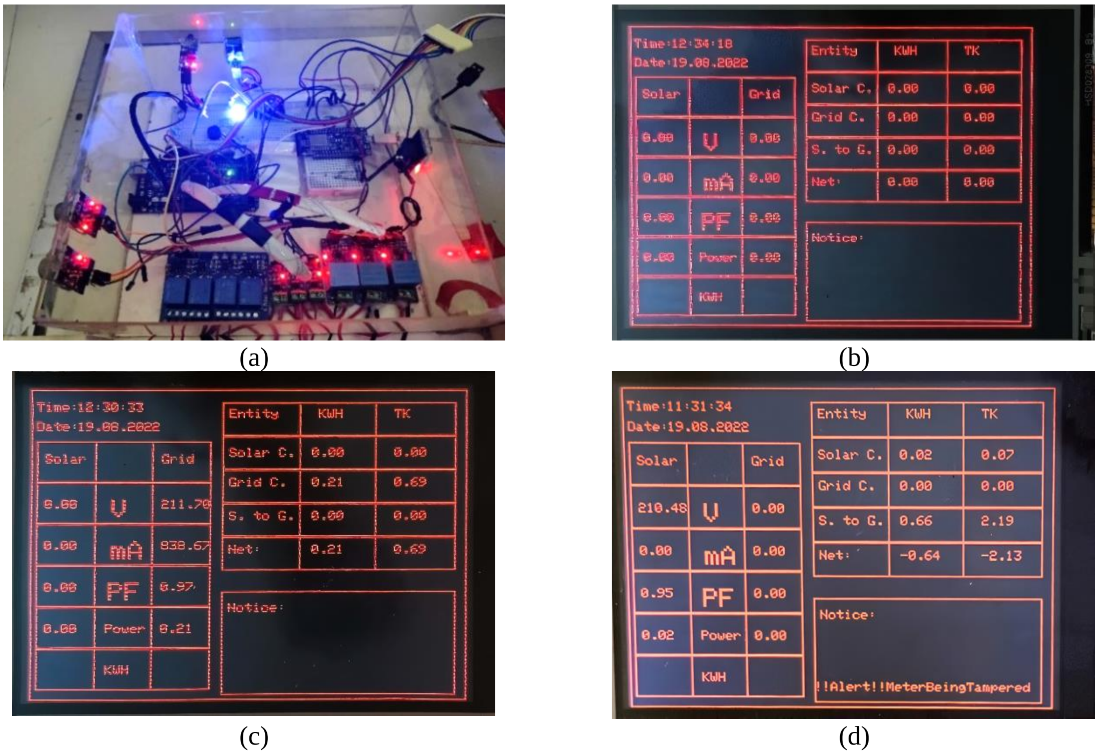


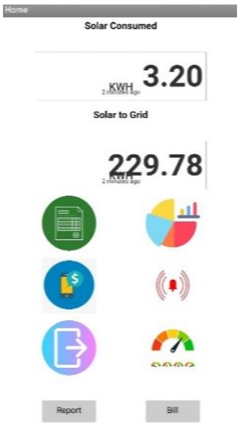

Figure 7. Hardware setup and results: (a) top view of the proposed meter, (b) display of the hardware setup, (c) solar and grid parameters, and (d) consumed, exported quantities, and notice section

## 5. MOBILE APP INFRASTRUCTURE WITH FEATURES

The app's home page is presented in Figure 8(a). That shows the solar energy and exporting energy to the grid. In the below part, it shows the user's different interfaces such as the billing part by the green circle from where consumers can download their bill as a pdf or excel file, different types of graphs are shown in the other part. A payment system that is represented via the finance logo and the security alarm system has also been integrated here. Lastly, some voltage and current gauges have also featured as essential application part. The power statement and bill from the application in Figure 8(b) elaborate all the values that are available at the same time. In the upper part, solar and grid units are shown separately. The green text shows solar voltage and grid voltage, and the red text only shows the solar current because there is no load on the grid side. Similarly, consumed units are shown in blue text. These data are changing with respect to time. Exported amount of energy is also shown in the same statement. The provided part of grid is blank as no energy is provided from grid to grid. It can only be done from solar to grid. The below part shows all billing calculations according to the current tariff rate, which the government provides. The alert message works as a security feature. Such as gas, flame, smoke or if the meter is being tempered. Same as notifying users for recharging. This system is working via the application. In case of any emergencies, if any of the sensors active, SMS will automatically come, as Figure 8(c) shows. It will help the consumers to be safe and secure.

Users can deal with the most up-to-date payment method offerings around the mobile banking system through bKash, Nagod, Debit cards that is organized in Figure 9(a). When users try to make a payment, it will get into a new page as a redirect and show a model of making payment. This system is also known as a digital wallet. Figure 9(b) notified the alert notes in the user's app in case of a specified hazard. Where the sensors are actively operated.

The inverted solar PV voltage from DC to AC is presented in Figure 10(a) over a specific period. At a certain time when the voltage was beyond 200 then after a while, it drops and becomes zero at a moment. Figure 10(b) presents the exported power to the grid from the solar PV panel. Different values are obtained from this curve that indicates the different amounts of power extracted at different times.

(a)
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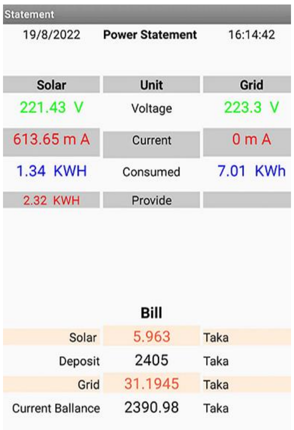


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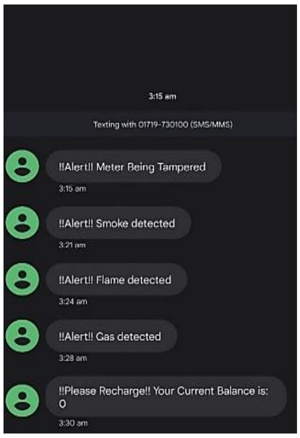
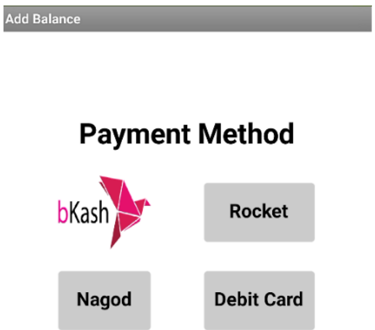



Figure 8. Software activity monitoring via mobile application: (a) dashboard of the mobile app, (b) power statement and net billing, and (c) safety SMS on consumer's mobile phone

(a)
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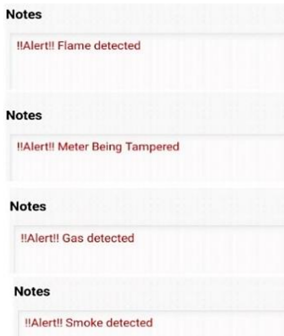
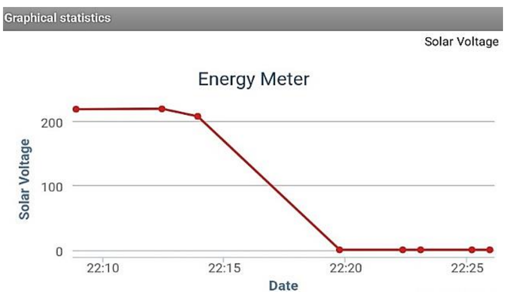



Figure 9. Key features of the mobile application: (a) payment and (b) security notifications

(a)
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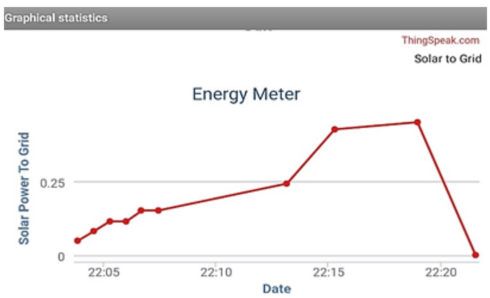



Figure 10. Graphical data from the mobile application: (a) inverted solar voltage from DC to AC and (b) exported power from solar to grid

## 6. RESULTS AND DISCUSSION

As the globe transitions to renewable energy, IoT-based smart net energy meters with data analysis, smart grid optimization, and renewable energy integration have a bright future. Other infrastructures like wireless communications will incorporate 6G and 6GE to improve system efficiency and security. Consumer empowerment will be another revolution when consumers become providers and save money by feeding the national grid.

This work aimed to create a meter that displays all power use parameters on one platform. Figures 8-10 depict the app's features, results, and various graphs. We succeeded using the unique presentation and specialized mobile app. This study is more specialized and distinct than any previous research since anybody can monitor the meter using the touch screen meter display, making power bill payments easier. It gives most of the essential information so the user may understand all parameters at once. That will make the meter easy to use and provide real-time display information in seconds that make the research distinct and precise. Previous study has shown that the “Blynk App” stores and monitors data. Blynk App isn't always efficient, like the meter app. That make this research more efficient and unique then previous research. Figures 6 and 7 indicate that the hardware implementation has been completed successfully. The most essential component was integrating renewable energy with the national system to reduce demand on the grid and lower power rates by allowing consumers to utilize their rooftop using PV panels to produce additional electricity. Due to sensor calibration, voltage and current measurements may contain some errors. The application was developed using an open-source website. The hardware and application have some communication lag.

Wi-Fi can function at a slower rate than local area network (LAN) connections. Wi-Fi occasionally experiences network dropouts. Development of LAN interface integration may be the focus of future research. If the meter provides both options, the user may select either one based on their capacity. If the app was developed by a professional, it would be more functional and aesthetically pleasing, with minimal lag time. It can be solved using a professional premium platform, but for this work the usual version is used thus these issues arrived. The size of the meter could be an issue because the world is getting digital and electrical components are being embedded and compact. In case of this whole work, the components that have been used is mentioned in Table 1 with each of their prices as per the latest market price, that will help to make understand about the economical aspect and the key elements of this kind of research.

Table 1. The cost analysis and design specifications for the proposed meter

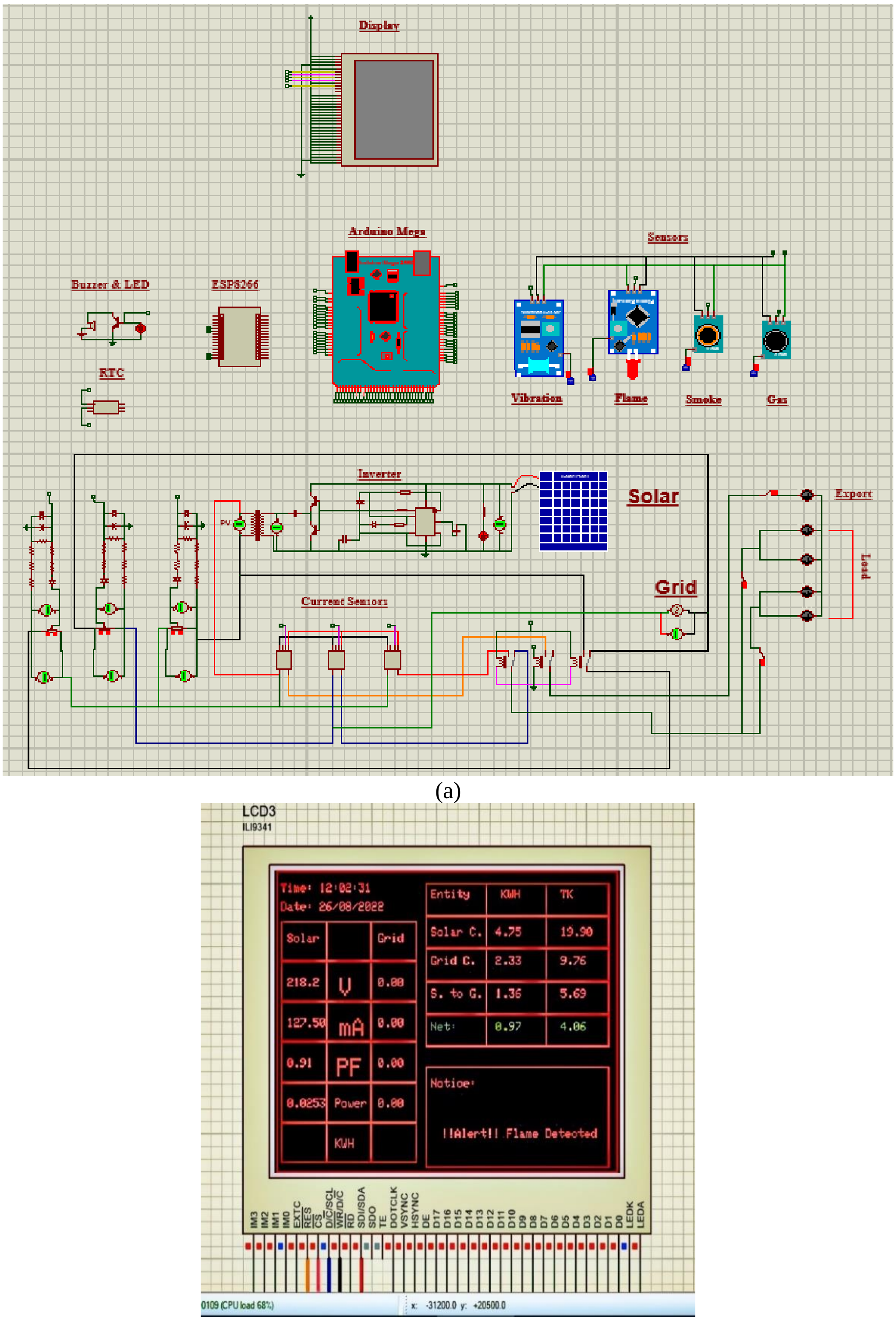
| Equipment | Quantity | Amount (USD) | Ratings | Equipment | Quantity | Amount (USD) | Ratings |
|---|---|---|---|---|---|---|---|
| Arduino Mega 2560 V2 | 1 | 24.49 | 7 V, 40 mA | Bread board | 1 | 1.17 | N/A |
| AC current sensor | 3 | 3.52 | 4.5-5.5 V, 20 A | Holder, plug | 5,3 | 2.84 | N/A |
| AC voltage sensor | 3 | 8.12 | 250 V, 2 mA | PV panel | 1 | 69.50 | 20 W, 12.1 V, 1.65 A |
| Flame sensor | 1 | 0.5 | 2-6 V, 760-1100 nm | UPS battery | 1 | 17.60 | 12.1V, 7.5 AH |
| Smoke sensor | 1 | 0.5 | 4.99-5.1 V | Switch | 4 | 1.17 | 100-220 V |
| Gas sensor | 1 | 0.5 | 4.99-5.1 V | LED | 2 | 6.85 | 5 W |
| Vibration sensor | 1 | 0.83 | 3.3-5 V | Bulb | 3 | 1.47 | 20 W |
| Relay module | 5 | 3.52 | 5 V, 10 A | Android APP | 1 | 85 | N/A |
| RTC module | 1 | 3.13 | 2.2-5.5 V | Connecting wire | 5 m | 1.22 | N/A |
| ESP8266 | 1 | 4.69 | 3.3-5 V | Inverter | 1 | 7.04 | 500 W<br>Input:12 V(DC)<br>Output: 200-220 V (AC) |
| Buzzer module, LED (green) | 1 | 0.39 | 3 V | Miscellaneous | | 12.5 | N/A |
| Jumper cable | 3 | 3.42 | N/A | Total cost | | Total: $259.97 | |

## 7. CONCLUSION

This paper proposed a smart net energy meter that can reduce electricity losses and perform better in energy monitoring systems than any other meter currently used in Bangladesh. Extracting power from renewable sources like PV panels will break down the conventional way of extracting power. Microcontrollers like Arduino Mega and NodeMCU with IoT make it more reliable and easier for consumers.

Using the dedicated application and the dedicated cloud server of the MIT App Inventor platform helps the consumers to monitor their uses and the amount of electricity they have provided to the grid in a real-time basis. All the advanced components have been used in the hardware part, and simulation was also done to verify the results. All the results from hardware and simulation were matched to verify the overall performance of the smart net energy meter. Energy characteristics curve, billing, and payment facilities have made a unique and easy concept that can make revolutions in the power industries compared to any other existing energy meter.

## APPENDIX




(a)

(b)

Figure 5. Simulation model of the proposed system: (a) schematic diagram and (b) simulated results

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