A Robust IoT Based Smart Energy Grid Monitoring System with Robotic Maintenance

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Abstract - *The presence of tiny dust particles, soil, or soot over the solar panels decreases the efficiency of the solar plates, which causes overburden on the power grids, due to the overburden there can be severe blackouts, therefore online surveillance of the power grids become cardinal for the fault detection and maintenance of the power grids [1]. This paper presents "A Robust IoT-Based Smart Energy Grid Monitoring System with Robotic Maintenance" to address the constraints in the cloud computing [2] paradigm in power networks—where many issues remain unresolved, such as completely achieving the requirements for significant bandwidth with low latency—this study presents an edge computing [3] system for IoT (Internet of Things) [4] based smart grids. The novel solution develops an innovative software and hardware design and primarily integrates edge computing into conventional cloud-based power networks. As a result, an enormous amount of data produced by the power grids will be examined, handled, and kept at the network's edge. The edge computing paradigm will let IoT-based smart grids connect and manage large terminals, process and analyze vast amounts of data in real time and encourage the digitalization of smart grids. Furthermore, the IoT-based smart girds, provide privacy protection techniques based on edge computing, data forecasting, and pre-processing schemes of hierarchical decision-making based on task grading (HDTG) [5]. An inbuilt robotic water motor in the suggested model cleans the photovoltaic panels. The numerical simulations provide validation of the proposed model's efficacy.*

Key Words: IoT, Smart Grids, Cayenne, Online Monitoring, Fritzing Software, ESP8266, Solar Panels, Robotic Control, Arduino Uno.

1. INTRODUCTION

Today we are facing a huge power problem. With the increase in gadgets, our requirements have increased. Solar energy is the most advanced sustainable power source in this system. Solar energy production is now the most practical and economical form of green energy [6]. We are trying to implement this concept in many sectors starting from small to large sectors like urban areas, Industries, and Individual houses. Researchers are going to convert transports to use this technology to reduce the world's major problems like pollution. Electric Vehicles have started entering in the market which will again put the loads on the electric power plants [7].

So to reduce the overburdening on power grids, the solar power plants and small solar units can helps in reducing the burden and also helps to get more clean energy. Concerning solar power systems, it is crucial to keep an eye on the power output of the photovoltaic panels in order to achieve maximum efficiency. That is the reason it is essential to implement a real-time surveillance system [8]. It may also be utilized for the surveillance of the power produced from individual panels in a big solar power plant, which assists in locating any dust accumulation. Additionally, it eliminates any fault situations from arising while the system is in use. When it comes to small solar units like the solar in communities, villages, and cell phone towers where these units are managed and maintained by individuals [9]. If the maintenance is not done regularly then the efficiency of panels goes down and there may be high power loss.

So to overcome these problems we have come up with the proposed novel model by which the whole thing can be monitored, get alerts on phone or mail, and even automated according to the customer calendar and needs of the system.

1.1 Benefits of Solar Energy

Do exorbitant electricity costs and unstable power supplies restrict your ability to use electricity as freely as you would like? Imagine being able to turn on your TV, air conditioning, heater, refrigerator, computer, food processor, and other appliances without any outages thanks to the sun's energy, all while offering you an incredible chance to reduce your monthly electricity bills. Solar energy investment is the way of the future! It minimizes your carbon impacts, your reliance on centralized power sources, and much more in addition to helping you save money on electricity bills [9]. Let's examine the main advantages of switching to solar electricity for residential use.

(I) Save lots of money

The ability to save money on monthly electricity expenses is the main benefit of using solar energy for residential purposes. Deploying rooftop solar panels can save up to 95% of your monthly electricity bills, according to a combined study by the power distribution company BSES Yamuna Power Limited (BYPL) and the legislative & research body Council on Energy, Environment and Water (CEEW) [10].

(II) Increase the property value

It may surprise you to learn that adopting solar panels can raise the value of your house by 3–4%. Installing a rooftop solar power system increases the value of your house and gives real estate professionals a compelling reason to promote it. According to US research, owners who sell their homes with solar power systems not only recover the initial expenditure of the installation but also gain a bonus that boosts their return on investment [11].

(III) Freedom from centralized grids

You immediately become less reliant on centralized private or governmental grids once you switch to solar power. In an environment where demand is rising and supply is erratic, being independent is ultimately the most prudent and sustainable course of action. A safe investment for the future is solar energy. Your solar energy system will become even more independent if you include a backup battery. Under such circumstances, you would be producing and storing your own electricity in case the main grid failed. In this way, anyone can achieve complete energy independence [12].

(IV) Contributing to a better environment

Electricity produced from fossil fuels may be handy, but the ecosystem suffers greatly from it. Installing solar energy systems contributes to an environmentally conscious investment in a clean, renewable energy source. Solar energy is entirely clean; it doesn't cause any greenhouse gas emissions or contamination of the air or water. Additionally, it emits no hazardous pollutants; solar panels do not release any carbon during the production of power. Further, it minimizes carbon footprints and the need for limited resources.

The United States is the largest user of renewable energy, although making up a small portion of all energy utilized. However, even with ten years of increased solar energy availability, solar energy still only contributes up to 2.3% of the entire energy consumed in the United States. With 11.5% of the clean energy consumed in the United States in 2019 coming from solar power, hydropower and wind are still the most prevalent sources of clean energy [13].

1.2 Challenges with IoT based Smart Grids

At present, there are only two kinds of solar technology available, photovoltaic and solar thermal that can harness the energy of the sun to generate electricity. Solar thermal collectors use energy from the sun to warm houses or water. Solar energy is used by photovoltaic devices to add to or substitute electricity from the power grids.

(1) Upcoming study initiatives must address numerous problems in order to meet technological goals for IoT applications in smart grids. IoT devices need to meet specific standards, like compatibility and credibility, to function in many locations that may include extreme conditions (such as worst weather, high voltages, exposure to electromagnetic waves, functioning in water, etc.) [14].

(2) It is important to employ or build appropriate energy harvesting strategies since many Internet of Things (IoT) gadgets and sensors run on batteries (such as different kinds of sensors used for the surveillance of transmission lines). IoT devices should implement the essential communication protocols because SG has many communication networks spread throughout different areas. This will ensure an adequate and reliable flow of data from smart meters to the central system.

Data fusion procedures should be implemented to compress and aggregate relevant data in order to have improved energy and bandwidth utilization as well as collecting data, since IoT gadgets in SG have finite resources and capabilities, like batteries, processing power, storage, or bandwidth [14].

(3) Two crucial factors that impact how well a smart grid performs are delay and packet loss. Congestion reduces system performance because it results in packet loss and delay. Furthermore, because IoT gadgets or gateways have to send back data, it increases the likelihood of future congestion and produces additional delay. Moreover, SG is unable to meet predefined demands, such as the maximum tolerated latency. As a result, it's essential to reduce latency, optimize network architecture by figuring out the ideal quantity of gateways and Internet of Things gadgets, and reduce the number of links to each gateway. The interoperability of these devices is essential for data exchange because the smart grid is made up of a wide variety of gateways and IoT gadgets with varying resources and requirements. With IP-based systems, interoperability can be achieved in part. IoT gadgets supporting various communication protocols and topologies are another way to solve this issue [15].

(4) Big data, which can use an excessive amount of electricity along with additional resources and cause congestion, is produced by sensors, smart meters, and other devices that monitor and gather information within the smart power grid. The smart power grid should be built in a way that allows for the effective processing and storing of the massive volume of data that has been gathered [16].

(5) There are numerous independent IoT device standards, but the smart power grid does not have a single, cohesive standard for IoT devices. IoT gadgets within smart power grids may experience problems with security, dependability, and compatibility as a result. Thus, it is important to coordinate standardization activities in smart power grids.

We utilize the Internet, which is vulnerable to cyber-attacks, to track and operate IoT gadgets in the smart grid. Hackers can alter measured data [17] by sensor and smart meter which can result in major monetary losses. Therefore, by taking into account the resource constraints of IoT gadgets and coming up with appropriate security solutions for these gadgets, we should establish safe communications for IoT gadgets in the SG. IoT gadgets, for instance, are limited in terms of computing and storage. As a result, we need to come up with or employ safety measures that are compatible with IoT devices. Certain details regarding the habits of customers (such as wake-up hours) may be gleaned from the statistics that smart meters measure, hence it is essential to ensure that consumers' consent is obtained before using this sensitive information. Additionally, appropriate methods for safety precautions such as data security, privacy, authentication, authorization, management of trust (between IoT gadgets owned by various individuals, such as consumers and utilities), and identity counterfeiting detection must be developed [18].

1.3 Contributions

The essential feature of this novel work is to provide the cheapest and most secure smart grid online monitoring system with an additional privacy protection technique by utilizing edge computing, data forecasting technique, and pre-processing technique of HDTG for the IoT-based smart power grids. Also, the suggested model has an inbuilt robotic water motor to clean the solar plates which will help in reducing the men's labor costs. The numerical simulations provide evidence of the efficacy of the suggested methodology.

The rest of the part of this search study is designed as, In Section 2, problem formulation; in Section 3, proposed architecture; Section 4, materials and methodology of proposed technique; Section 5, hardware prototype and results; Section 6 challenges and future scopes and thereafter in Section 7, concludes the analysis.

2. PROBLEM FORMULATION

When solar plants on a small scale or large scale are set up in various parts of India maintenance is required to get the maximum power from the system. Due to different pollution rates at different times, the dust affects these plates differently [19]. So we need to find a solution that can monitor the output and let us know when is the best time to clean the plates. Cleaning of the panels at the correct time is also required as during the daytime the solar panel may be hot and may get damaged too. This is our first problem.

Coming to the wear and tear of the solar plates or wiring in these places also reduces the output of the systems so there may be confusion when the output goes low it may be because of sand particles on the solar plate too. This type of error can be corrected by replacing the solar panels or rectifying the error in the electrical as per the fault. These faults should be cleared as soon as possible as they may damage other things also.

Monitoring the whole output over a long period to find the real power generated we need to have some real-time record. So this can be either done by keeping a record daily of what is the production each day or by a meter. But if we get any Mathematical digital tool like a graph so it will be easy to understand and can be predicted for more future investment in a profitable way.

Overall the above problem can be solved by the latest technology called the Internet of Things [20].

3. PROPOSED ARCHITECTURE

This paper propose an architecture, as illustrated in Fig.1, for the online surveillance of electric parameters with robotic maintenance of the power grids. It can monitor the current, voltage, and power. Since we are using IoT-based microcontrollers so can monitor these parameters from anywhere in the world via using Internet and daily records of electricity production can be saved by using web servers. The auto cleaning of the solar panels can be done by utilizing

Cayenne IoT-based programming [21], we can set the slot to clean the panels two times in a week or only on weekends as per the convenience of the customers. This proposed architecture provides safety, security, and cost reduction in electricity to the users.

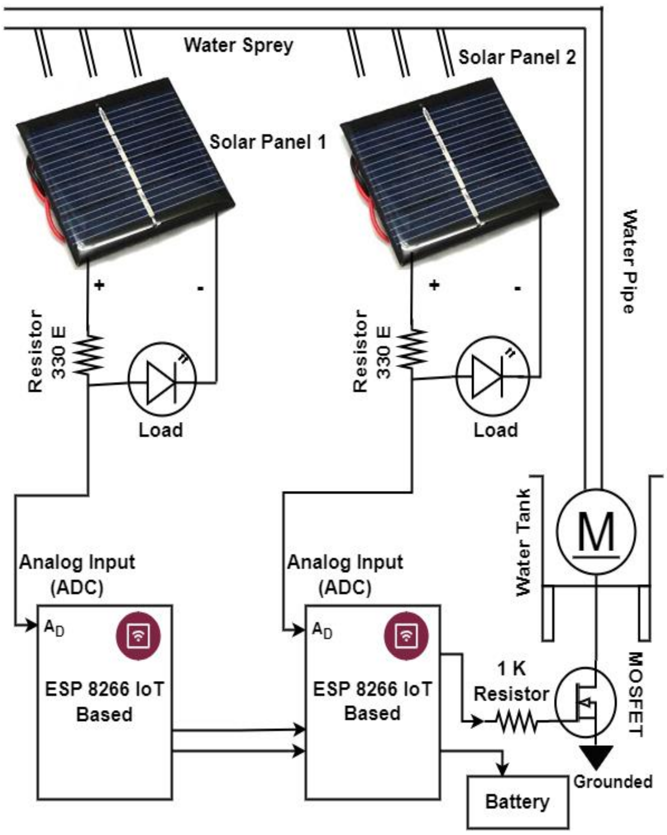

Fig -1: A Robust IoT Based Smart Energy Grid Monitoring System with Robotic Maintenance

It is presumed that there is dust or soot accumulated on the solar plates which reduces the efficiency of the solar plates [22] or there can be an electrical fault in the system which may damage the other equipment, and also as we know nowadays most of the things are working based on IoT so there is a chance of cyber-attack, cyber attackers may steal the data of customers, therefore, for the safety and security of the customers the proposed model can be implemented which deals with all the above-mentioned challenges as well as helps in the detection of faults, improving power grids efficiency, cheapest online surveillance and robotic maintenance.

4. MATERIALS AND METHODOLOGY OF THE PROPOSED MODEL

Now we are clear that we have to find a few things for our project that can cover all three of the problems as mentioned in section 2. We need to customize the whole project. So that the project will be simple and parts are also easily available for the project testing. Therefore we decided to go with the following tools and parts.

a) ESP 8266 NODE MCU
b) Arduino software for programming
c) Cayenne IoT platform
d) Mini solar panel
e) DC water pump for testing
f) LED's
g) Resistor
h) Battery
i) Wires
j) Switches
k) Pipes
l) Containers
m) Basic Electronics stuffs (glue gun, cutter, soldering Iron)

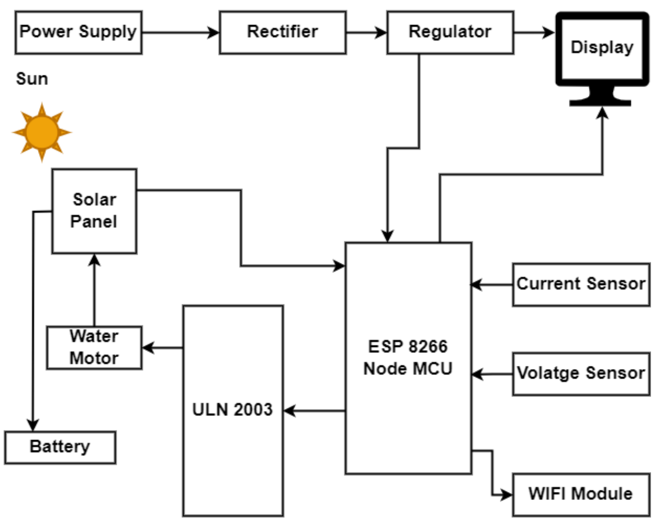

Fig -2: Block Diagram for the Proposed Model

Fig.2, represents the block diagram for the proposed model. The solar panel produces electrical energy by converting the sunlight into electrical power thereafter the electrical power is stored in the battery. The ESP 8266 MCU microcontroller [23] is used to control all system activities like solar panel current and voltage sensing, operating water motor, wireless fidelity (Wi-Fi) module, ULN 2003 [24], and display.

4.1 Introduction of IoT Platform

In the first stage create an account on the Cayenne website. Cayenne, the First Drag-and-Drop IoT Project Builder in the World, is released by "MyDevices" [21]. In this project, the Cayenne cloud is used. "MyDevices" introduces a free mobile app and web portal that enables users to construct IoT applications in just a couple of hours rather than months. A strong IoT platform called "MyDevices" was created to help corporations connect devices quickly, display information, apply intricate regulations, and communicate with their linked clients. The key features of Cayenne programming are mentioned below:

- A smartphone application that enables remote setup, monitoring, and control of sensors & gadgets.
- Pi may be easily set up within minutes and connected to the web, sensors, actuators, and accessories.
- Rules engine that initiates activities across multiple gadgets.
- Dashboard that can be customized using drag & drop components for displaying.
- Scheduling of lights, motors, and actuators.
- General-purpose input-output (GPIO) management can be adjusted by a dashboard or smartphone application.
- Instantaneous desktop or smartphone access from anywhere.

After signing in the Cayenne account. We have selected the ESP8266 board. For each device to connect with the cloud it requires a unique code.

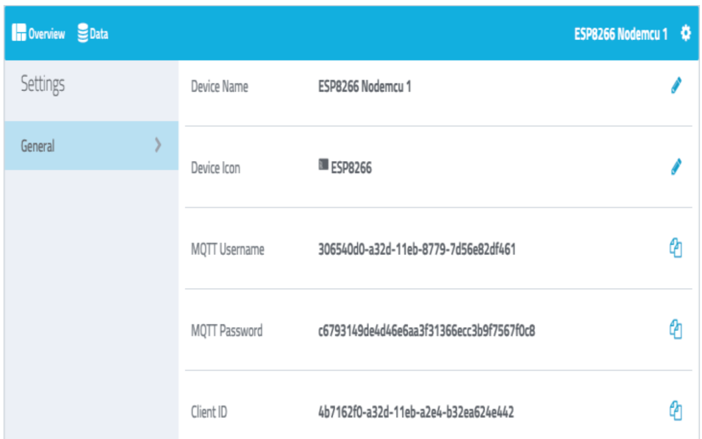

Fig -3: MQQT Credentials for the ESP8266 Node MCU 1

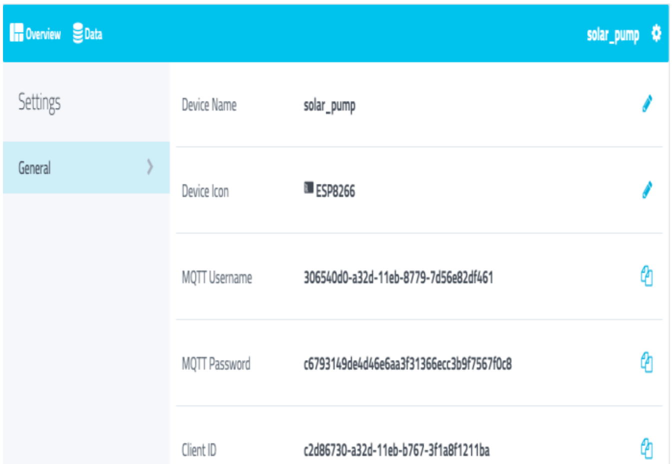

Fig -4: MQQT Credentials for the ESP8266 Node MCU 2 (Solar Pump)

Fig.3 and Fig.4, show the message queuing telemetry transport (MQTT) Username, password, and Client ID. These are needed to be placed in the Arduino code and then uploaded to Node MCU. When the Node MCU is connected to the internet the device is recognized. Since here we are using two Node MCU therefore it is needed to set the 2 MQTT credentials.

4.2 Circuit Design for The Proposed Model

The circuit is designed by utilizing the "Fritzing" software [25] as presented in Fig.5 and Fig.6.

With the ULN2003, Node MCU is selected as high voltage, high-current Darlington arrays. These arrays generally have 7 common emitters and open collector Darlington pairs. Capable of withstanding peak currents up to 600 mA, every channel has a 500 mA rating. To make the board layout simpler, the inputs are pinned adjacent to the outputs, and suppression diodes are incorporated enabling inductive load control. Which will drive the DC water pump as Node MCU cannot drive the motor. Set up the whole diagram according to the circuit as shown in Fig.6.

This is the main board that will be controlling the functions of cleaning the solar plate from time to time to give us better performance. Here we will program in the Cayenne IoT platform like event management and hence automation can also be done as per the requirement of the user. We can find the performance over a certain period by observing the graph of the recorded time.

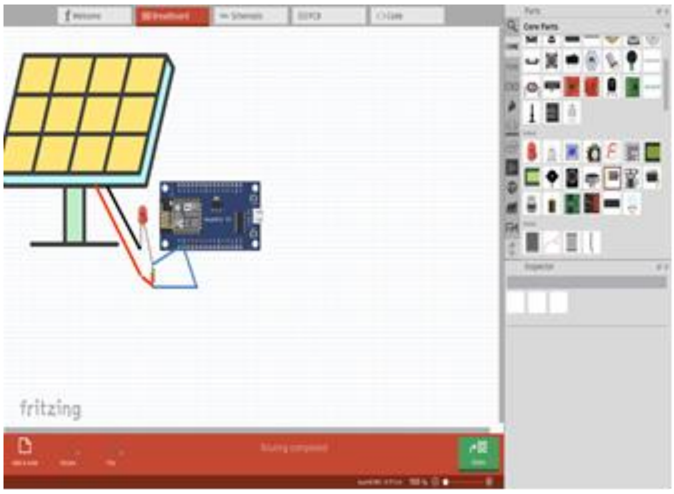

Fig -5: Circuit Design for the Solar Panel 1 IoT Setup.

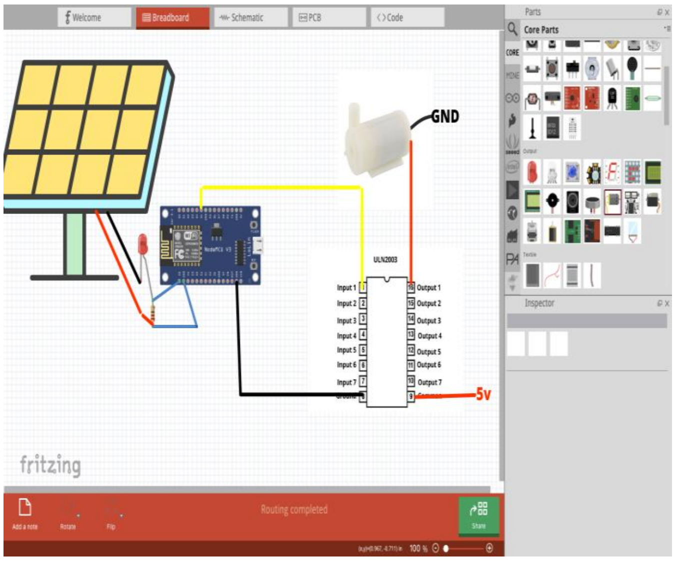

Fig -6: Circuit diagram for the Second Board with motor connection

4.3 Software required for programming the Board

The Cayenne Node MCU library contains sketch files for microcontrollers which send data to and from the Node MCU hardware and Cayenne cloud for implementing incoming and outgoing commands, actions, triggers, and alerts. The Cayenne bring your own technology-application programming interface (BYOT-API) [26] is used to connect your custom board with the Cayenne Cloud. After writing code to connect your board, you can transfer data from your system to the Cayenne dashboard & monitor it using widgets. You may receive instructions from Cayenne, allowing access from anywhere and automation of your system. The BYOT-API currently supports MQTT in a variety of languages.

Here we have used the library and then added the Wi-Fi and password. The formula to calculate the voltage generated and current in the solar panel circuit. CH340/CH341 driver needs to be installed.

Link for the download:
httloads/CH341SER_EXE.htmlp://www.wch.cn/down

4.4 Environment Setup

Search and install the Arduino IDE and then install the board package or ESP8266 by using the following steps.

(a) In the File -> Preferences add http://arduino.esp8266.com/stable/package_esp8266com_index.json to the Additional Boards Manager URLs field.

(b) Load ESP8266 platform from Tools -> Boards Manager. For ESP32, manually install the board package by the following the instructions here: https://github.com/espressif/arduinoesp32/blob/master/README.md#installation-instructions.

A. Download this library as a zip file.
B. Load the downloaded zip library from Sketch. -> Include Library -> Add .ZIP Library.
C. Use a USB to console connector to link the PC and ESP module.
D. Under the tool menu, choose the port and ESP module.

4.5 Building Examples

A. Click the provided example sketch from the selected File-> Examples -> Cayenne-MQTT-ESP.
B. Add your network details and the Cayenne authorization password you were given when you added your device to the provided sketch.
C. Put the sketch together and load it into your system. Bootload mode may need to be enabled in the system in order to load. The Adafruit HUZZAH ESP8266 module can be configured using the subsequent instructions:

    (a) Press down the GPIO0 key.
    (b) Press the Reset icon.
    (c) Put the GPIO0 button up.
    (d) When the device is prepared for uploading, the red LED appears to turn on.
    (e) Load your sketch.

D. Ensure that sample data from your device is being sent to the Cayenne dashboard.

4.6 Programming Node MCU ESP8266 with Arduino IDE

The Arduino IDE [27] makes it simple to program the Node MCU Development Board because of its user-friendly interface. Using the Arduino IDE to program a Node MCU will only take five to ten minutes. It requires the Node MCU board itself, the Arduino IDE, and a USB port.

Table -1: Node MCU Development Board Pin-out Configuration

Pin Category	Name	Description
Power	Micro-USB, 3.3V, GND, Vin	Micro-USB: Node MCU can be powered through the USB port 3.3V: Regulated 3.3V can be supplied to this pin to power the board GND: Ground pins Vin: External Power Supply
Control Pins	EN, RST	The pin and the button resets the microcontroller
Analog Pin	A0	Used to measure analog voltage in the range of 0-3.3V
GPIO Pins	GPIO1 to GPIO16	Node MCU has 16 general purpose input-output pins on its board
SPI Pins	SD1, CMD, SD0, CLK	Node MCU has four pins available for SPI communication.
UART Pins	TXD0, RXD0, TXD2, RXD2	Node MCU has two UART interfaces, UART0 (RXD0 & TXD0) and UART1 (RXD1 & TXD1). UART1 is used to upload the firmware/program.
I2C Pins	It should be found by user	Node MCU has I2C functionality support but due to the internal functionality of these pins, you have to find which pin is I2C.

Use the USB cord to link the board to the PC after installing the Arduino IDE on it. Launch the Arduino IDE now, select Tools → Boards → Node MCU 1.0 (ESP-12E Module) as the proper board, and Tools > Port as the ideal port. To initiate the Node MCU board and cause the integrated LED to flash, go to Files > Examples > Basics > Flash and load the example program. Click on the “upload” button located in the top bar once the sample program has been loaded into your IDE. The board’s integrated LED begins to blink after the upload is complete. The Configuration of the Node MCU Prototype PCB Pin-outs is represented in Table 1.

5. HARDWARE PROTOTYPE AND RESULTS

The hardware design of a "Robust IoT Based Smart Energy Grid Monitoring System with Robotic Maintenance" is shown in Fig - 7.

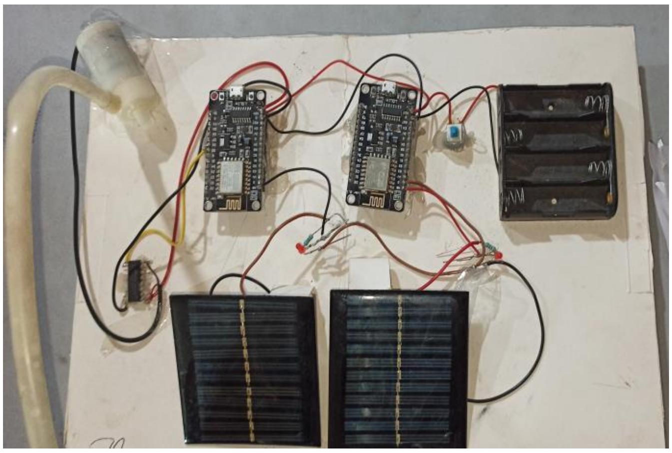

Fig -7: Robust IoT-Based Smart Energy Grid Monitoring System with Robotic Maintenance.

5.1. Monitoring the Power and Voltage Generated

When the proposed model is activated it shows the output of each of the solar panels in the Cayenne software. As represented in Fig – 8 (a) and Fig – 8(b).

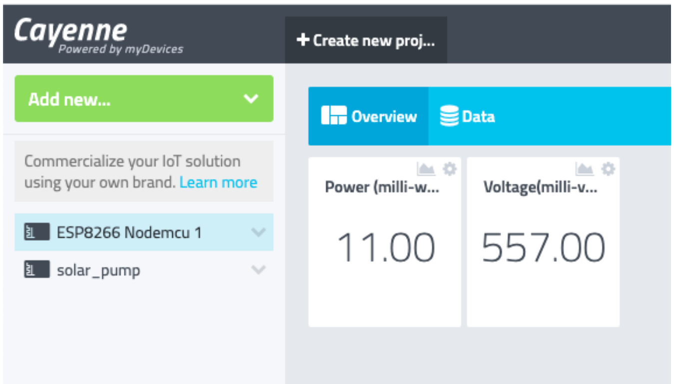

Fig -8(a): Power and Voltage Generated by Solar Panel 1.

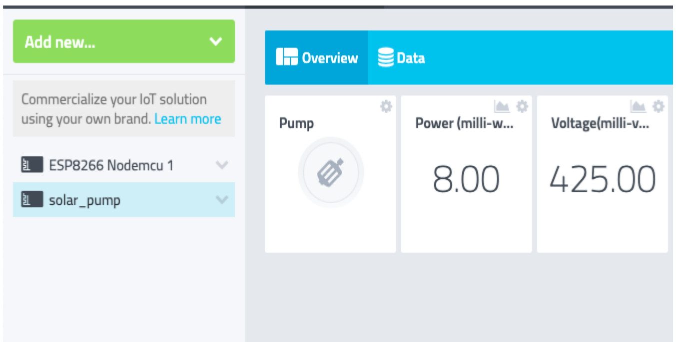

Fig -8(b): Power and Voltage Generated by Solar Panel 2.

Graphs of the power and voltage generated observation over a period of time in each solar plate is shown in Fig – 9 (a) and F – 9 (b).

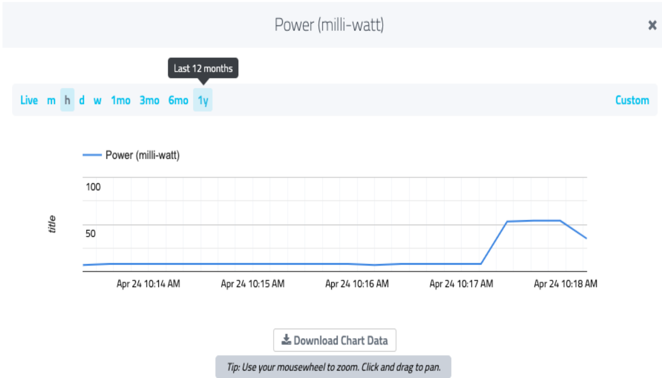

Fig -9 (a): Power Generated by the Solar Plates with Date and Time for the Record.

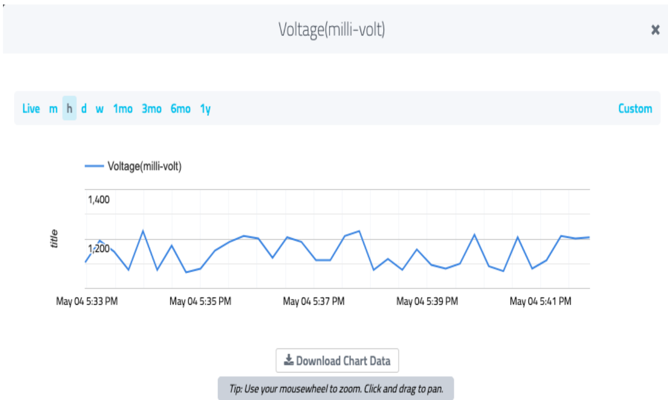

Fig -9 (b): Voltage Generated by the Solar Plates with Date and Time for the Record.

Actions should be taken based on obtained records. By observing the graph of the power generated it can be understood now the time is to clean the solar plates. So we can now turn on the water pump for the cleaning of solar plates by manually clicking on the pump icon as shown in Fig– 10 (a) and Fig– 10 (b).

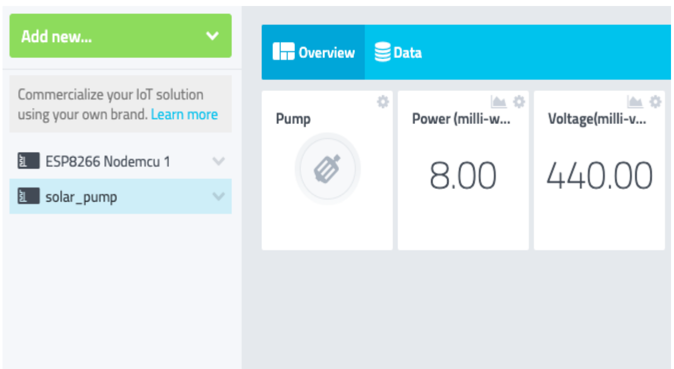

Fig -10 (a): Power and Voltage When Water Pump is off.

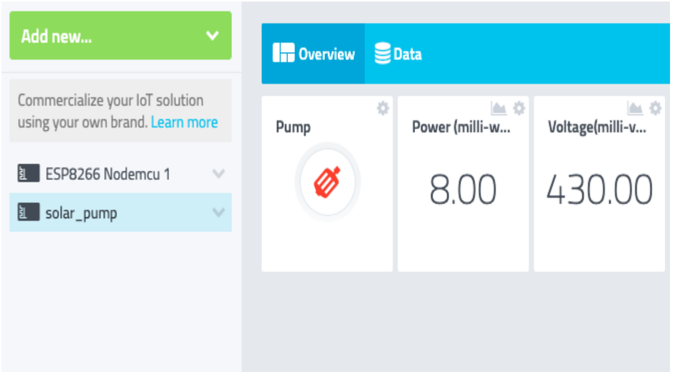

Fig -10 (b): Power and Voltage When Water Pump is ON.

5.2. Event Setup for Water Pump:

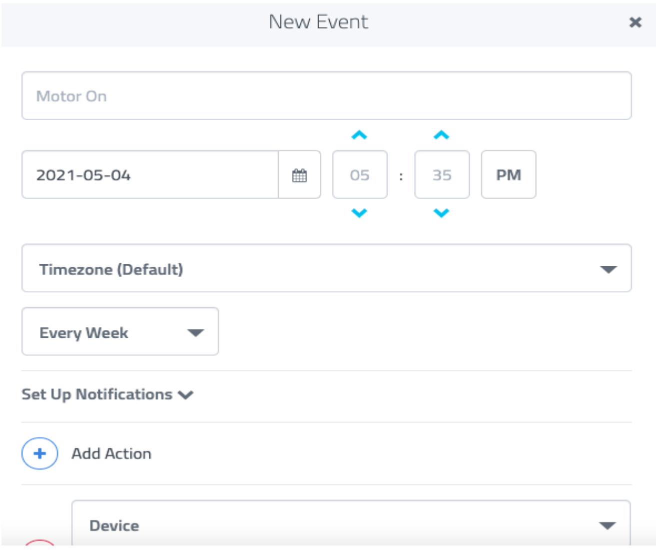

Fig -11 (a): Event Setup To Turn ON The Water Pump.

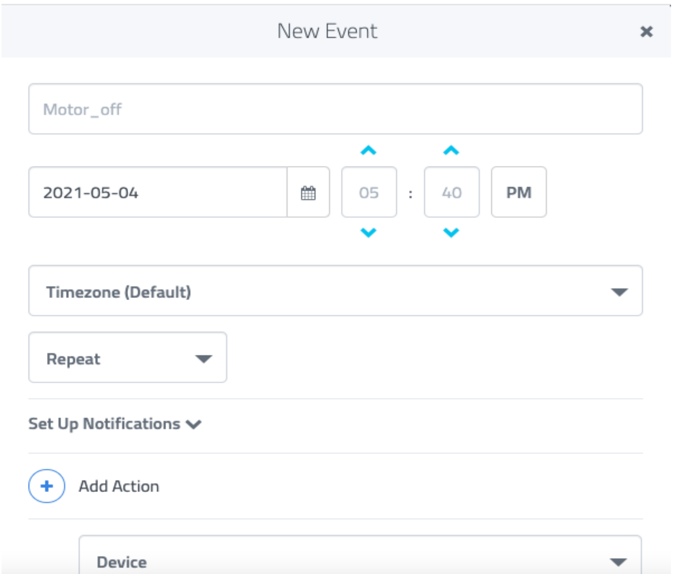

Fig -11 (b): Event Setup To Turn OFF The Water Pump.

If we want to make the water pump run in an event way like weekly twice or thrice and at a certain time for a certain minute then we can do it. As the season changes the dusting speed on the solar plate changes. Fig - 11 (a) and Fig - 11 (b) present how to setup the event to turn on/off the water pump.

To turn off the motor we can create another event else the motor will not off. So let's assume the solar plates will be washed in just 5 minutes and create another event to turn off the water pump. So this will clean the solar plates once in a week. This system will be turned ON at 5:35 PM and turned OFF at 5:40 PM on every Tuesday.

6. Future Research Directions

Many issues need to be addressed in the coming years in order to accomplish technological objectives applying IoT in SG:

(1) Big data, which can use an excessive amount of electricity along with additional resources and cause congestion, is produced by sensors, smart meters, and other devices that monitor and gather information within the smart power grid. The smart power grid should be built in a way that allows for the effective processing and storing of the massive volume of data that has been gathered.

(2) There are numerous independent IoT device standards, but the smart power grid does not have a single, cohesive standard for IoT devices. IoT gadgets within smart power grids may experience problems with security, dependability, and compatibility as a result. Thus, it is important to coordinate standardization activities in smart power grids.

(3) There is a need to come up with appropriate security solutions for these IoT-based smart grid gadgets, we should establish safe communications for IoT gadgets in the SG. IoT gadgets, for instance, are limited in terms of computing and storage. As a result, we need to come up with or employ safety measures that are compatible with IoT devices.

7. CONCLUSIONS

An important factor affecting the solar panel's effectiveness and efficacy is dust. Higher irradiation can marginally but not significantly mitigate the impacts of dust, and the reduction in peak power output can be boosted up to 30%. By utilizing the cleaning technique, power can be increased by up to 35%. The analysis indicates that the reason for the decrease in power is the accumulation of dust on the solar plates. Under actual use, microcontroller and actuator-based architecture ensure that PV panels operate at maximum efficiency under various kinds of dust circumstances. This proposed "A Robust IoT-Based Smart Energy Grid Monitoring System with Robotic Maintenance" project can be used in most of the solar plants. For example, in apartments, schools, parks, Industry, etc. Where the efficiency of the solar setup can be improved. Also, errors can be detected easily like faulty solar or wiring. After rectifying these types of the error we can easily maintain the power generated. This is a low-cost module that will consume very little power. We can get the data very accurately and hence the production of solar energy can be maximized.

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