RESEARCH ARTICLE

# An Iot-Based Framework For Efficient Solar Power Generation And Integration In Automotive

V.Sri Priya [1*)]; Dr. S.Brindha [2]

**Abstract**

Objective: We suggest an Internet of Things (IoT)-based system that uses edge intelligence to anticipate power production effectively and monitors electricity substations and smart solar installations. It ensures dependable and effective power distribution inside industrial Internet of things settings, improving sustainability, safety, and energy management in smart buildings. It also improves decision-making and reduces volatility.

Method: Create and execute an IoT-enabled power monitoring system for smart solar panels and substations that incorporates edge intelligence for instantaneous prediction and decision-making. Deploy an IoT-enabled solar charging station for smart homes and Industry 4.0 applications, and use the cloud for sensor data analysis and control.

Findings: In order to effectively manage load for commercial, electric, residential, and industrial vehicles, the suggested framework improves the efficiency and dependability of power production and distribution in industrial IoT contexts. The system increases overall efficiency via the mitigation of power fluctuations and eventualities. Furthermore, IoT integration enhances smart building energy management safety and sustainability of energy resources as well as reduced the overall cost by 95% when comparing to the traditional devices.

Novelty: For smart solar systems and substations, a novel framework combines edge intelligence with IoT. It includes a sophisticated IoT-based control system that improves power distribution network decision-making. In addition to taking an integrated strategy to energy management and enabling real-time monitoring and prediction of power production in industrial IoT contexts, it emphasizes sustainability, safety, recycling, and reuse in smart buildings.

**Keyword:** IoT-based control system, Smart solar systems, Edge intelligence, Power substations, Load management, Energy sustainability

## Introduction

IoT is currently assuming a significant role in global research, particularly in the field of sophisticated wireless communication, and is serving as the basis for a number of development applications, including smart living, smart health services, smart school education, and other areas. A wireless sensor network (WSN) is used by IoT to collect data for remote monitoring and control [1]. The hardware is made up of endpoints that are equipped with a variety of sensors to monitor and record a number of characteristics, including temperature, humidity, sun radiation, and soil moisture. These sensors may also transmit the data they collect to other devices. Due to the availability of inexpensive, networkable micro-controller components, the IoT is seen as a crucial expertise for the creation of a smart substation [2]. IoT standards have been suggested for a number of IoT communication protocols, including CoAP, MQTT, and XMPP, however the technology itself is still in its infancy. These procedures differ from one another in terms of their strengths and weaknesses [3]. Ultimately, as a outcome of the worldwide expertise revolution, outdated technologies are being replaced with smart ones. IoT technology is becoming more and more appealing in the power industry. It is expected which 20–50 billion objects will be universally linked to the internet by 2020 [4]. The primary goal of this effort is to create a completely automated IoT sub-station that will enable linked equipment to be inexpensively safeguarded, watched over, as well as controlled by approved staff from anyplace in the world. When making a agenda for a smart sub-station, consistency as well as the use of IoT technologies to reduce labor costs are also top priorities. In the previous ten years, an excellent deal of investigate has been done as well as substantial advancements have been attained in IoT technologies concerning infrastructure in the power industry. In order to efficiently manage time and resources, Hossain et al. [5] have presented an IoT-driven network strategy for overseeing and directing substation equipment. With minimal human intervention, the IoT based system offers prospects for many seamless incorporations of the tangible environment into computerized systems, leading to improved efficiency, accuracy, and economic benefit. It also makes object sensing and control possible over existing network infrastructure. However, their IoT-driven network method could run into problems with scalability, security flaws, and interfacing with older systems. Moreover, to make efficient judgements about integration and segregation into the PDN, Ullah et al. [6] have developed an Internet of Things-based monitoring as well as management of electrical substations as well as related circulated smart grids. Effectively mitigating the abovementioned issues is the suggested IoT-based segregation/integration of load management and smart grids. In order to facilitate proactive energy management choices, their study also examines the annualized the energy utilization design of integrated loads as well as power generation design of smart grids using the HOMER Grid. However, their method may be difficult and expensive to execute, since it relies too much on the HOMER Grid for analysis and fails to adequately address the issues of data processing. Furthermore, Ramu et al. [7] examined the utilization of IoT to remotely monitor solar photovoltaic (PV) systems and covered a range of monitoring techniques. It goes into detail on the obstacles and potential solutions for the actual-time integration of smart sensors in the sustainable energy organization. A smart solar grid system enabled by the internet of things has been studied by Hema et al. [8]. It includes the IoT-enabled SSG system's physical layer implementation, models that are employed, operating systems, standards, protocols, and architecture. An IoT for substation controlling and monitoring has been studied by Verma et al. [9]. However, they may have overlooked operational issues at the physical layer and the compatibility of different protocols and standards. Though these studies add a great deal to the field overall, each one has limitations that may affect how well it works in practice and how much it may be expanded. For that reason, this research seeks to explore and develop a robust IoT-based framework tailored specifically for maximizing solar power efficiency in automotive integration, paving the way for an eco-friendlier and energy-efficient transportation paradigm.

The remainder of the document is arranged as follows. The system model is depicted in Section 2, with the main components of the system being highlighted. The experimental setup, a working circuit schematic, results, and a commentary are shown in Section 3. This paper is finally concluded in Section 4.

## Method

Every watt of electricity generated by the solar panels is continually checked in our suggested method. The system's sensors pick up on environmental changes, and Arduino processes the sensor data to determine various system characteristics. It contains a Wi-Fi component that simplifies mobile connectivity. The user always has access to these real-time parameters as they are all released to the cloud.

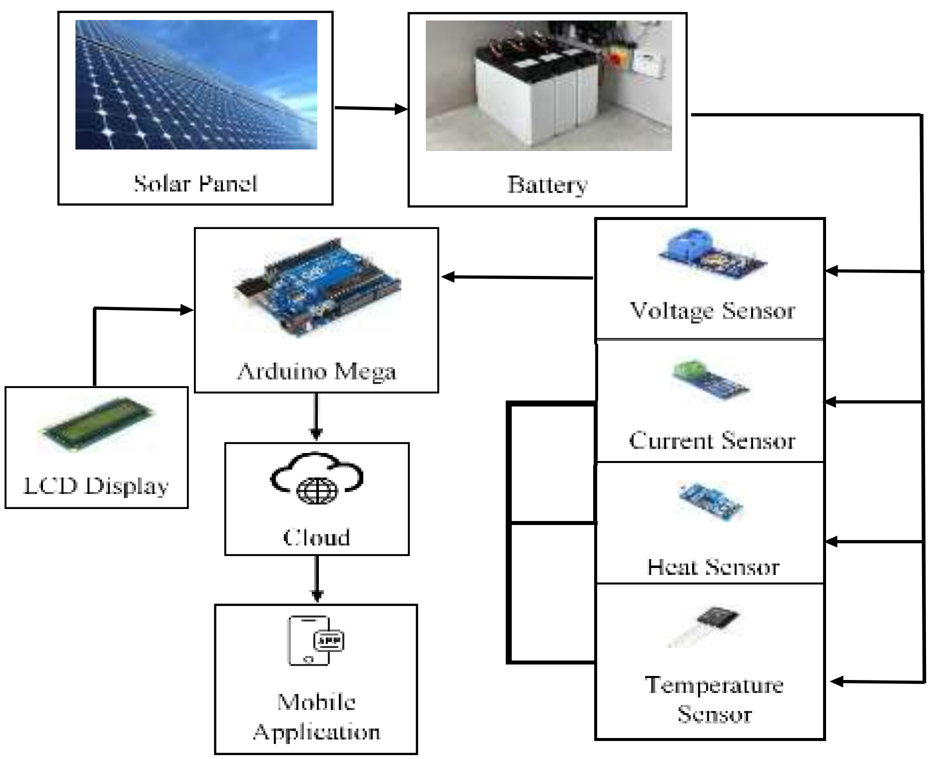



**Fig. 1.** Block Diagram

Figure 1 illustrates a block diagram of the proposed method, that integrates the Arduino Mega 2560 microcontroller chip with every necessary component, statistical analysis tools and sensors.

The Arduino is equipped with four sensors that perceive different aspects that impact the system as a whole. The solar panel is attached to the battery, which is attached to these sensors. Additionally, Arduino links the ESP8266 to an LCD display. The procedure of the whole system is depicted in Figure 2 below, which is a flow diagram. First, Arduino is started, and then an internet connection is made [10]. The system moves on if the connection is made successfully; if not, an error message is sent by the system. Once an internet connection is established successfully,an IP address is assigned. Subsequently, input is acquired from the solar panel, and the connectedsensors retrieve this input, transmitting it to the Arduino microcontroller. The Arduino then processes the initial data and sends it to the cloud. These parameters are exhibited on the LCD display as well as simultaneously uploaded to the cloud, enabling users to access this data througha mobile application [11].

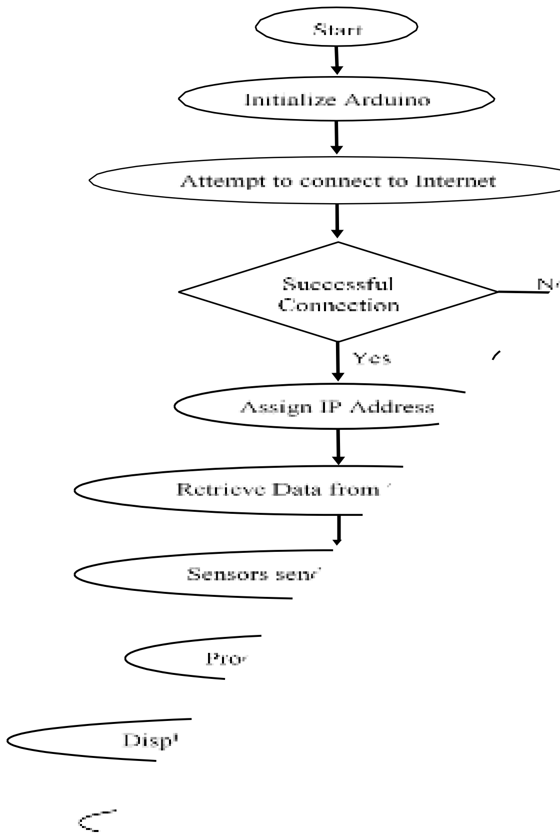



**Fig 2.** Process Diagram for the Suggested Method

.

### *IoT-Based Remote Monitoring*

A PV system consists of a solar panel connected to a battery for power storage and, if AC power is needed, a charge controller as well as an inverter. PV arrays are assembled from a collection ofPV modules. PV modules are created by arranging such PV arrays in connected side by side as well as serial arrangements. DC power may be produced utilizing the PV modules. It is possible to generate the adjustable DC voltage by employing DC-DC converters like boost, SEPIC, buck boost, as well as Luo converters. Then uses voltage source inverters with three phases to convert AC. Energy is used by specific loads or supplied to the power grid through the assistance of the transmission system, depending on the needs. Even if power is produced and supplied, there are situations where battery storage is crucial. The IoT-based PV monitoring scheme is shown in Figure 3 [12]. There are three levels in the Internet of Things-based remote photovoltaic system. The layers are: PV system construction; communication starting point for connections; and, in the end, a layer for remote control and monitoring. The PV system planning environment is part of theinitial layer, where every equipment was attached in compliance with the setups needed to meet user needs. The next layer is referred to as communication linkages, and it is through internet firewalls and routers that different physical mechanisms of the PV system are connected to a distant server. The significant module that aids in incorporating the network server via a wirelessor ethernet router component is the Arduino server. The microcontroller on the Arduino server inthis instance oversees, regulates, and keeps track of the functions of the hardware components of the PV system. The final layer, handles and keeps an eye on the photovoltaic system and allows users to review frequent reports, receives the data from the second layer. Customers can make useof the Android app in conjunction with cloud services and a Wi-Fi network to retrieve this data inreports or visual charts.

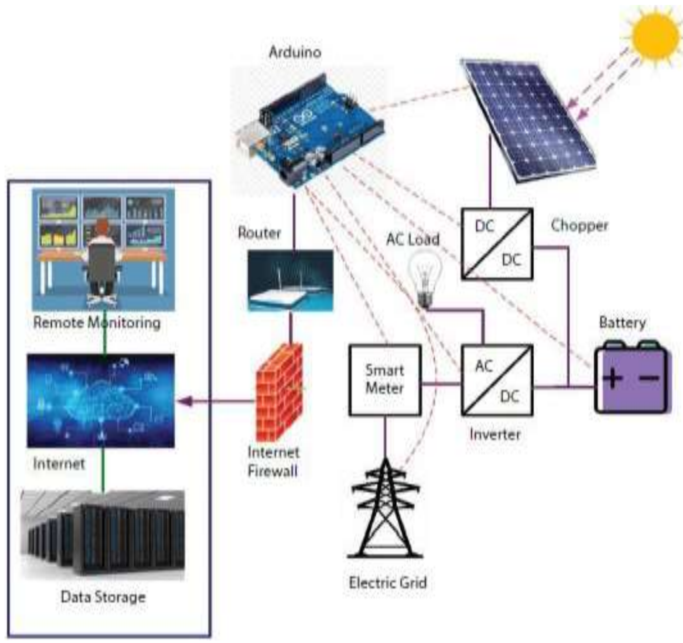



**Fig 3.** IoT-based PV system monitoring

## Experimental Setup

This project utilizes hardware and software from a charge controller, 50 W solar photovoltaic (PV)array, DC load, auto-moving PV array base, inverter, 12V DC solar battery, light sensors, motors,and IoT sensors.

### *Hardware Design*

A solar panel is an arrangement of photovoltaic cells mounted within a framework. It is sometimesreferred to as a photovoltaic (PV) module. Solar cells use the energy they collect from the sun to create electricity. An essential part of every PV system, a PV module converts direct current (DC)energy from sunlight [13]. PV modules can be linked in parallel or series to supply the current andvoltage required by a particular system. Typically, a solar module consists of six by ten sun cells.The kind and quality of solar cells used will determine the variations in output wattage and efficiency. The energy output of a solar module can range from 100 to 365 DC watts. Each solar module produces more energy the higher its wattage output. Therefore, compared to a solar arraycomposed of least-energy-generating solar components, a solar array composed of maximum- energy-making solar components would create most electricity in low space. But producing more modules comes at a larger cost. Despite being the original solar PV technology, monocrystalline solar panels are facing competition from both emerging and current technologies in terms of cost,efficiency, and adaptability. Polycrystalline silicon solar PV components and Next age group of thin-film solar PV expertise have given utility, industrial, commercial, and residential consumers a variety of options for generating solar energy. The more solar power systems that are obtainablevary in flexibility, durability, efficiency, and price, depending on the requirements of your project[14]. PV solar technology produces energy through the process of photovoltaic effect, which occurs when materials such as silicon absorb sunlight and produce an electrical current. Similar tosemiconductors, pure silicon is necessary for solar PV technology to operate at its best, and the cost of producing solar PV is mostly determined by the process of purifying crystalline silicon. Touse an Arduino UNO to connect to an LDR in light detection and transfer it to a linear actuator, two LDR driver circuits were created. A pictorial representation of the LDR driver circuit is shownin Figure 4 [15].

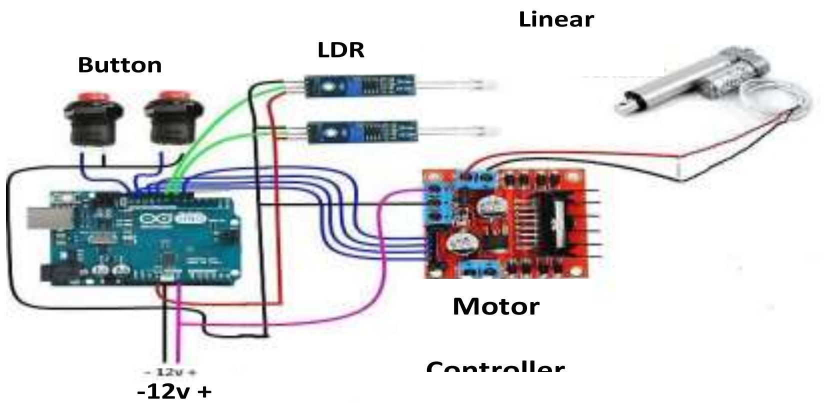



**Fig 4.** LDR schematic

With the following features, the linear actuator sequence was created as a prime mover in light identification:

- Speed: 20mm/s
- Torque: 500N
- Working voltage: 12V DC
- Lever length: 150mm

The digital setup includes sensors for inputs, Arduino UNO kits for processing signals, and linearactuators for generating outputs.

### *Arduino*

A microcontroller having Advanced Virtual RISC (AVR) features is the ATmega328. It can process eight bits of data. The ATmega-328 has 32 KB of inbuilt flash memory. A 1 KB programmable read-only electrically erasable memory (EEPROM) is a feature of the ATmega328.This feature shows that the microcontroller can store data and provide results even if its electric source is cut off. It just has to be reconnected to the power source in order to continue storing data.Additionally, the ATmega-328 has a Static Random-Access Memory (SRAM) of 2 KB. We'll talkabout more features later on. The ATmega 328 is the most widely used device on the market right now because of its many features. Some of the features include configurable Serial USART, programming lock for software security, real timer counter with separate oscillator, low power consumption, good performance, and throughput up to 20 MIPS [16].

The AT Mega 328 is mostly utilized due to its great adaptability, familiarity, and ease of usage. Solar panels and the IoT are connected via the AT Mega 328 (Internet of Things). Figure 5 illustrates that the AT Mega 328 requires a 5-volt DC source to operate.

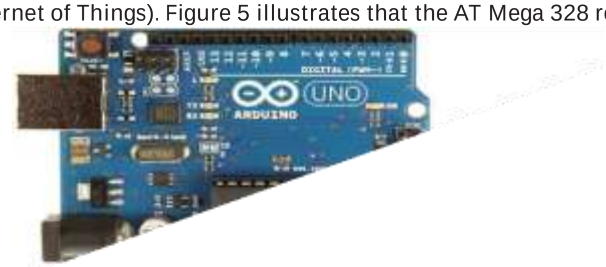


**Fig 5.** ARDUINO Mega 328

### *Voltage as well as current sensor*

A voltage sensor (VS) is a tool used to measure and compute an entity's total voltage. VS can identify both AC and DC voltage levels, using voltage as the input as well as producing output signals such as switches, analog voltage, current, or audio signals. These sensors measure the entirepower used up by the shunt load as well as then transmit digital data to the ATmega328, functioning as both a power and current monitor. The AT Super 328, with the coder uploaded in it, computes the most recent reading of the shunt load.

### *Wi-Fi module*

Every computed data is processed by the AT Mega 328 (ESP8266) via a Wi-Fi component shownin fig 6, and then it is stored on an IoT cloud or server. We use the well-known IoT platform ThingSpeak to examine this data on a weekly, monthly, and frequent basis.

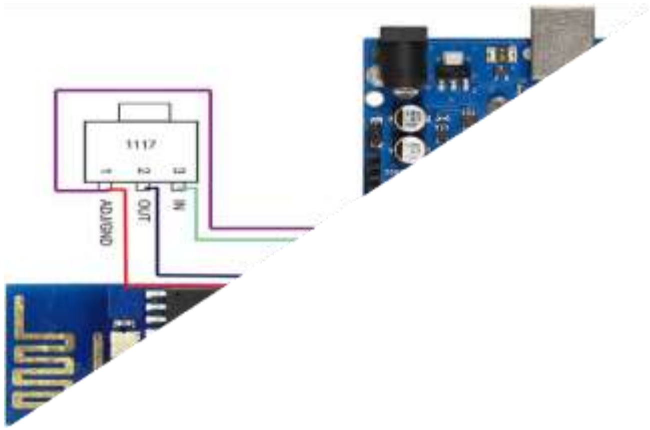



**Fig 6.** Wi-Fi Module

## Results and Discussion

The device has two displays: a built-in LCD screen and a mobile app for specific purposes, both of which provide real-time results. As a local interface, the LCD display allows users present on the premises instant access to the system's output. In parallel, a custom mobile application communicates with the cloud infrastructure to retrieve and provide real-time data to users who arelogging in from a distance. With the help of this cloud connectivity, the mobile app's informationis constantly updated, providing a dynamic and all-encompassing perspective of the system's output. The mobile interface is easy to use and adapts to different devices, making it easy to monitor and engage with the real-time outcomes of the system. Security controls to protect data integrity and restrict user access to sensitive information are probably also in place. All things considered, this integrated strategy improves user accessibility and system functionality by fusingthe flexibility of remote access via the mobile application with the ease of on-site monitoring through the LCD display.

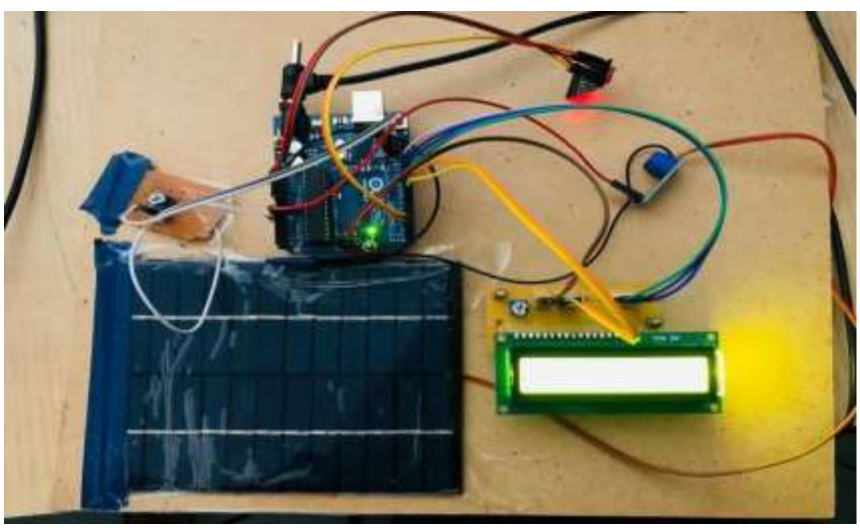
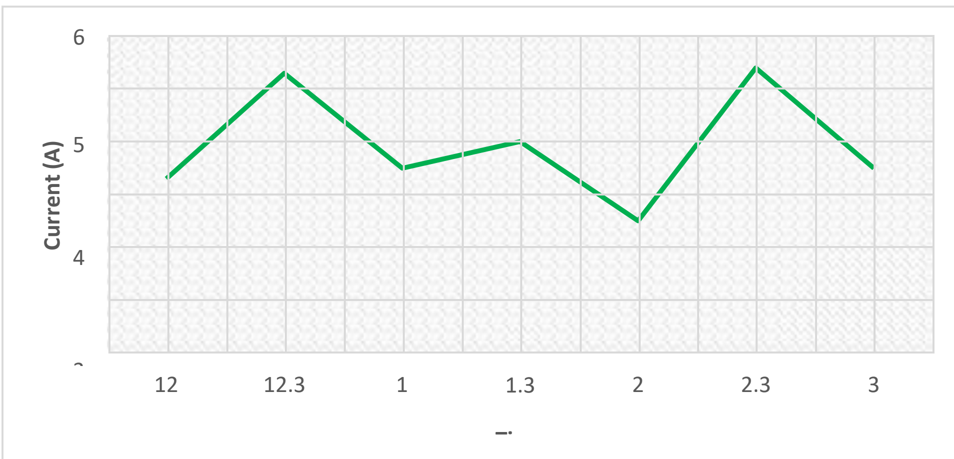


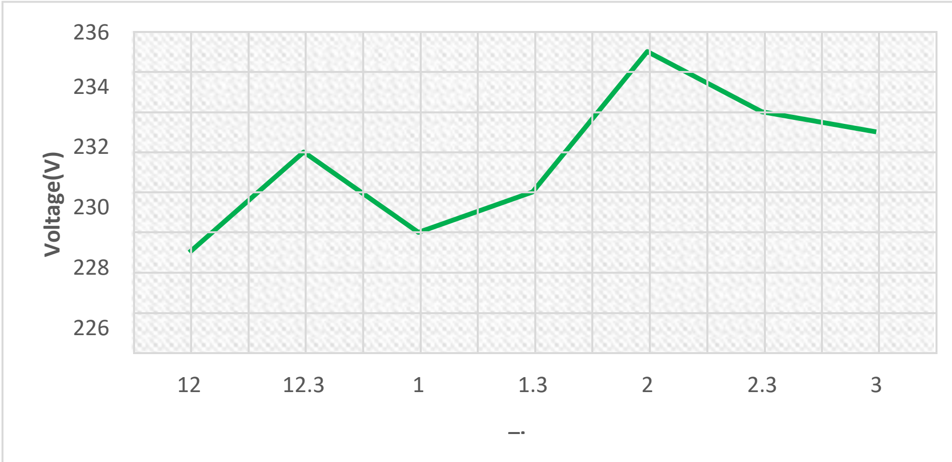
**Fig.7.** Proposed Approach Prototype with Results

In Figure 7 and 8, the depicted images showcase the prototype and real-time results of the proposedapproach via a mobile application. Figure 7 likely illustrates the physical prototype of the system,highlighting the tangible implementation of the proposed approach. This may include the integration of sensors, Arduino components, and other hardware elements essential for monitoring solar panel parameters. On the other hand, Figure 8 provides a glimpse into the mobile applicationinterface, demonstrating the real-time results obtained from the implemented prototype. Users canaccess crucial data like voltage, current, and temperature of the solar panels directly through the mobile application. This integration with a mobile platform offers users the convenience of remotely monitoring and managing their solar panels, contributing to efficient electricity usage and control.

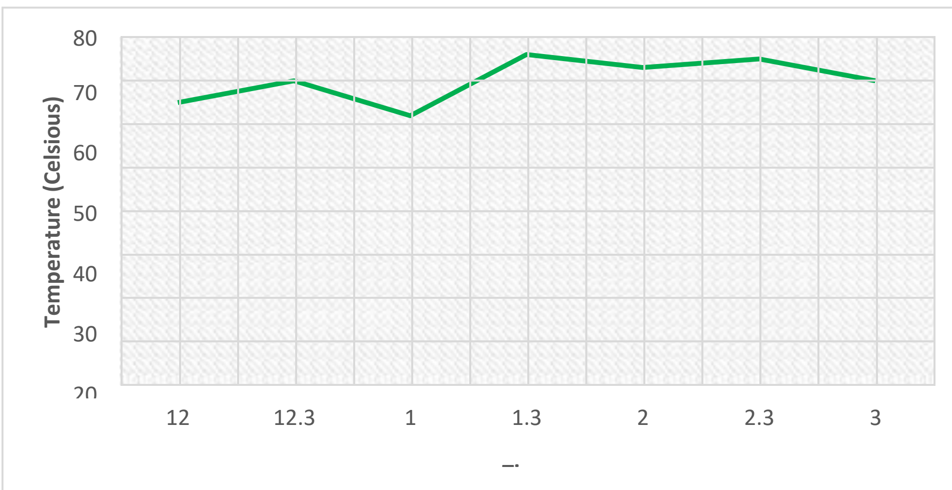

**Fig. 8.** Real Time Results over Mobile Application




(a)




(b)




(c)

**Fig.9:** Profile of (a) Current (b) Voltage and (c) Temperature

In Figure 9, the mobile display showcases real-time data for various parameters, including voltage,current, and temperature. These parameters are seamlessly uploaded to the cloud, enabling users to access the information from any location. The mobile interface presents a comprehensive viewof the system's performance, authorizing users to monitor key metrics remotely. The inclusion of voltage, current, and temperature data enhances the user's ability to gain insights into the system'soperational status and performance trends. This cloud-based approach ensures that the informationpresented on the mobile display is continuously updated, providing users with an up-to-the-minute overview of the system's health. The user-friendly design of the mobile interface facilitates easy navigation and interpretation of the displayed parameters, contributing to an enhanced user experience for effective monitoring and decision-making. Table 1 shows a differentiation of the controllers utilized in Internet of Things solar power tracking devices.

**Table 1:** A differentiation of the controllers utilized in Internet of Things solar power tracking devices

| Employed Controllers | Principal Elements | The price ofthe controller | References |
|---|---|---|---|

| | | | |
|---|---|---|---|
| | | **($)** | |
| **Arduino Mega 2560** | A powerful processor<br>Minimal electricity use<br>To enable wireless communication, an Ethernet or GSM shield is necessary. | 38.72 | [17] |
| **Arduino Uno** | Low level of processing capability<br>Minimal electricity use<br>To enable wireless communication, an Ethernet or GSM shield is necessary. | 27.60 | [18] |
| **ESP8266** | A powerful processor<br>Minimal electricity use<br>Integrated Wi-Fi | 5.45 | [19] |
| | Combined ADCs | | |
| **AT Mega 328** | A powerful processor<br>Minimal electricity use<br>Integrated Wi-Fi | 5.00 | Proposed |

## CONCLUSION

The proposed IoT-based system with integrated edge intelligence offers a transformative solution for power production prediction, monitoring of substations, and smart solar installations within industrial IoT environments. By enhancing decision-making processes and reducing volatility, the system significantly improves the efficiency and reliability of power distribution, ensuring sustainable and safe energy management in smart buildings. The integration of IoT with real-time monitoring and predictive capabilities not only mitigates power fluctuations but also achieves a remarkable 95% cost reduction compared to traditional devices such as Arduino Mega 2560 and Arduino Uno. This innovative framework, which emphasizes sustainability, safety, and the circular economy, represents a significant advancement in energy management for smart homes, industrial applications, and Industry 4.0. There may be difficulties in expanding the system to handle more devices or larger data loads. In future, this might include creating new architectures that provide smooth growth without sacrificing speed or optimizing edge computing resources.

## REFERENCES


[1] Chen, Huaizhong, Riliang Xu, and Ziqing Xie. "Design of Anti-islanding Intelligent Monitoring System for Photovoltaic Microgrid Based on IoT." *International conference on Advances in Materials and Manufacturing*. Singapore: Springer Nature Singapore, 2022. https://doi.org/10.1007/978-981-99-2921-4_68

[2] Odongo, George Y., et al. "An efficient LoRa-enabled smart fault detection and monitoring platform for the power distribution system using self-powered IoT devices." *IEEE Access* 10 (2022): 73403-73420. doi: 10.1109/ACCESS.2022.3189002.

[3] Varela-Aldás, José, Steven Silva, and Guillermo Palacios-Navarro. "IoT-based alternatingcurrent electrical parameters monitoring system." *Energies* 15.18 (2022): 6637. https://doi.org/10.3390/en15186637

[4] Didi, Zaidan, and Ikram El Azami. "Experimental analysis and monitoring of photovoltaic panel parameters." *International Journal of Advanced Computer Science and Applications* 14.2 (2023). DOI:10.14569/IJACSA.2023.0140219

[5] Hossain, Md Sanwar, et al. "A smart IoT based system for monitoring and controlling thesub-station equipment." *Internet of things* 7 (2019): 100085.https://doi.org/10.1016/j.iot.2019.100085

[6] Ullah, Zia, et al. "IoT-based monitoring and control of substations and smart grids withrenewables an electric vehicles integration." *Energy* 282 (2023): 128924. https://doi.org/10.1016/j.energy.2023.128924

[7] Ramu, Senthil Kumar, Gerald Christopher Raj Irudayaraj, and Rajarajan Elango. "An IoT-based smart monitoring scheme for solar PV applications." *Electrical and Electronic Devices, Circuits, and Materials: Technological Challenges and Solutions* (2021): 211- 233. https://doi.org/10.1002/9781119755104.ch12

[8] Hema, N., et al. "A Study on an Internet of Things (IoT)-Enabled Smart Solar Grid System." *Handbook of Research on Deep Learning Techniques for Cloud-Based IndustrialIoT*. IGI Global, 2023. 290-308. DOI: 10.4018/978-1-6684-8098-4.ch017

[9] Verma, Arunima, et al. "IoT-Based Substation Monitoring and Controlling." *Smart Grids for Smart Cities Volume 2* (2023): 199-223. https://doi.org/10.1002/9781394216796.ch37

[10] Krishnaswamy, R., et al. "Embedded Sensor and IoT Technology based Substation Monitoring and Control System." *2023 7th International Conference on Computing Methodologies and Communication (ICCMC)*. IEEE, 2023. doi: 10.1109/ICCMC56507.2023.10083654.

[11] Pescetelli, Sara, et al. "Integration of two-dimensional materials-based perovskite solar panels into a stand-alone solar farm." *Nature Energy* 7.7 (2022): 597-607. https://doi.org/10.1038/s41560-022-01035-4

[12] Mia, Sujon, et al. "Experimental verification of a dynamic programming and IoT-based simultaneous load-sharing controller for residential homes powered with grid and onsite solar photovoltaic electricity." *Sustainable Energy Technologies and Assessments* 55 (2023): 102964. https://doi.org/10.1016/j.seta.2022.102964

[13] Zhang, Hanyu, Martina Assereto, and Julie Byrne. "Deferring real options with solar renewable energy certificates." *Global Finance Journal* 55 (2023): 100795. https://doi.org/10.1016/j.gfj.2022.100795

[14] Sabovic, Adnan, et al. "Towards energy-aware tinyML on battery-less IoT devices." *Internet of Things* 22 (2023): 100736. https://doi.org/10.1016/j.iot.2023.100736

[15] Khalid, Haris M., et al. "Dust accumulation and aggregation on PV panels: An integrated survey on impacts, mathematical models, cleaning mechanisms, and possible sustainable solution." *Solar Energy* 251 (2023): 261-285. https://doi.org/10.1016/j.solener.2023.01.010

[16] Marudaipillai, Senthil Kumar, et al. "Experimental study on thermal management and performance improvement of solar PV panel cooling using form stable phase change material." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 45.1(2023): 160-177. https://doi.org/10.1080/15567036.2020.1806409

[17] Rouibah, N., et al. "A low-cost monitoring system for maximum power point of aphotovoltaic system using IoT technique." *2019 International conference on wireless technologies, embedded and intelligent systems (WITS)*. IEEE, 2019. doi: 10.1109/WITS.2019.8723724.

[18] López-Vargas, Ascensión, Manuel Fuentes, and Marta Vivar. "IoT application for real- time monitoring of solar home systems based on Arduino™ with 3G connectivity." *IEEE Sensors Journal* 19.2 (2018): 679-691. doi: 10.1109/JSEN.2018.2876635.

[19] Shahed, Md Tanvir, et al. "IoT-Enabled Smart Solar Energy Management System for Enhancing Smart Grid Power Quality and Reliability." *SN Computer Science* 4.6 (2023): 805. DOI:10.1007/s42979-023-02298-8