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Iot Based Smart Solar Pv Remote Monitoring System Using Grafana Platform

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Abstract

This research presents data from a smart solar PV remote monitoring system connected to the Internet of Things (IoT) and installed in a residential setting. The data demonstrates the system's success in demand-side management (DSM) and efficient energy utilization. In addition to monitoring energy generation and consumption, the system identifies demand peaks occurring around 0.5 kW, with values primarily below 2.0 kW. The system also notes peak energy generation at 0.05 kW. An examination of seasonal patterns reveals that consumption is higher during the summer months due to increased demand for cooling and greater generation resulting from longer daylight hours, while consumption is lower during the winter months. A time-based decision tree method is utilized by an IoT smart scheduler to shift peak loads, resulting in a reduction in conversion losses by seven percent. This optimization enhances the operation of deferrable appliances such as pumps and washing machines. Through a dashboard powered by Grafana, real-time data visualization and customized appliance operation are managed, improving user experience and reducing daily conversion losses by 5% and electricity bills by 12%. Grafana's intuitive user interface significantly enhances the system's usability, paving the way for further advancements in distributed solar management applications. Overall, the IoT smart solar PV remote monitoring system proves to be a technically and financially viable solution for managing residential energy, effectively optimizing energy use and reducing costs.

Keywords: Smart Solar PV Monitoring, Internet of Things (IoT), Demand Side Management (DSM), Energy Consumption Analysis, Residential Energy Management

INTRODUCTION

The Internet of Things (IoT) facilitates the integration of real-world objects with computer-based systems by enabling remote sensing and control through community infrastructure. In the context of IoT, data exchange between various devices is streamlined via a network. The term "Things" refers to the physical objects, while the twork serves as the backbone of the system. These two components are fundamental to the IoT.

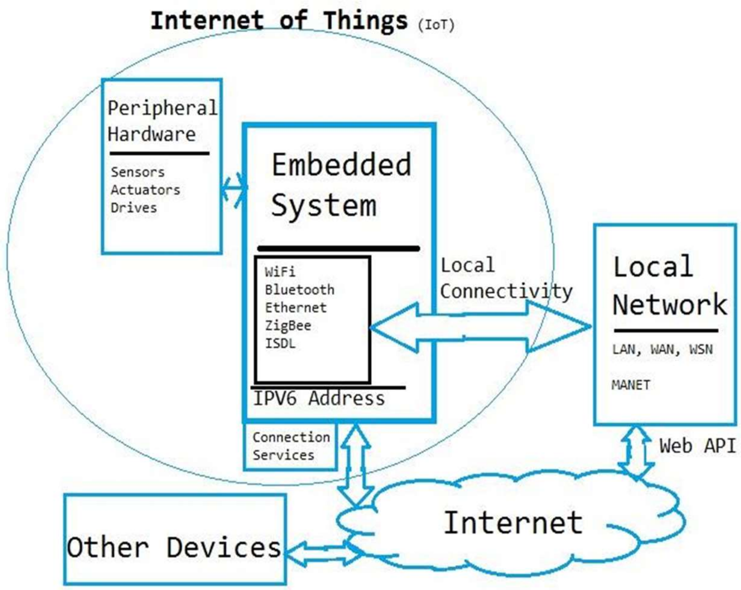


Figure 1: Internet of Things

The Internet of Things (IoT) can accomplish the greatest and ideal power yield, which is pivotal for solar power. By coordinating all actual gear with the web, the IoT resolves issues like failing boards, feeble associations, and low-yield boards that can decrease solar power productivity. Gadgets associated with the IoT can naturally screen and change the boards, alleviating these issues (Hugo T.C. Pedro et al. 2018).

A solar board system consolidating an AT mega microcontroller can screen exhibit proficiency, offering easy to understand improvement and tasks, further developed environmentally friendly power projecting, and progressions in power plant engineering, energy capacity, and electrical result customization. Late years have seen critical headways in the smart lattice and DC dissemination systems for private clients, driven by the boundless reception of solar boards, decreasing costs of DC items, and expanding electronic burdens. DC conveyance systems, controlled by solar PV energy and batteries, give a more normal point of interaction than other power sources. Interfacing homes with DC circulation systems and PV solar boards to the principal network guarantees continuous power supply. Enhanced integration of energy storage systems helps reduce conversion losses and optimize renewable energy use (Amit Kumar Rohit et al. 2017).

Energy consumption can be significantly influenced by factors such as geographical location, temperature, and weather patterns. Demand Side Management (DSM) financially incentivizes consumers to reduce energy usage during peak hours or shift consumption to off-peak times. Researchers have contributed substantially to DSM using various algorithms, as reviewed below. The IoT, aiming to connect all devices and sensors to a single network (internet), allows users to access and control data from anywhere. Automation with pre-defined logic reduces human intervention (N.A. Othman et al. 2010). The IoT's versatility has garnered attention across industries like security, smart cities, healthcare, consumer electronics, and home automation.

Monitoring solar PV systems is essential due to variations in sun irradiation, temperature, and weather. Opting for a wireless IoT-based system over a wired one prepares for a smart, automated, internet-connected future, avoiding wired system risks (Kangkana Hazarikaa and Pradyumna Kumar Choudhurya 2017).

The proposed system includes solar panels, a voltage transducer, a Hall Effect current sensor, an Arduino Uno microcontroller, a temperature sensor LM35, and a SIM900A GPRS module. Data is displayed, software is developed in MATLAB, and a website is created for data access. This setup detects environmental temperature, output voltage, and current. Users can compare data against databases and reference values, receiving notifications for anomalies. Information can be uploaded to an accessible online website.

1.1. Solar Power System Proposed: An IoT Virtual Environment

This examination presents a theoretical methodology using an Internet of Things (IoT) network for remote activity and monitoring of a solar system. Sensor readings are communicated by means of the portable radio network using a GPRS module to send information to a remote waiter. The IoT application for the Solar Power Plant is portrayed in Figure 1. At the foundation of the plan, the detecting layer incorporates different sensors, for example,

pyrometers for irradiance estimation, current and voltage meters, and microcontroller-based information handling units.
The schematic outline involves three particular levels. The microcontroller handles inception and information transmission to the server through the remote module. Layer 2, the network layer, is liable for continuous information assortment from the plant and incorporates a data set for information capacity. The application layer, following the network layer, uses the handled and put away information to fabricate modern web administrations. This layer is liable for making graphical UIs that upgrade the monitoring of the plant's tasks (Renata I. S. Pereira et al. 2017). By giving dynamic exhortation in light of authentic information, the control centre can essentially decrease the time required for managerial choices. The IoT-based remote monitoring system improves on the electronic monitoring of a solar power plant's general situation.
Design of solar monitoring system for remotely access to all energy parameters and records, we have to take into consideration the various points like component selection and specification, circuit diagram. In this chapter all equipment required for development of proposed work are discussed in briefed manner. Microcontroller selection and its specification, sensors for collecting the values of voltage and current for power calculations are discussed.

❖ **Component Specification**

In the component specification, we are discussing on various components which are used in this proposed work system design. LCD display specification and Wi-Fi module selection and specification along with cloud computing details are discussed. Finally, components of circuit diagram are simulated.

Atmega 328P

The Atmega 328 changed hardware design eight-bit architecture processor core.by capital punishment power instruction in an exceedingly single clock cycle, Atmega 328P achieves turnout approaching one unit per MHz permitting the system designer to optimize power consumption versus process speed.

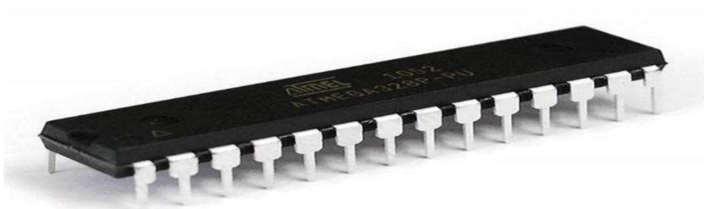


Figure 2: Atmega

The AVR core combines a reach instruction set with thirty-two general purpose operating register. All the thirty-two register are directly connected to the arithmetic logic unit (ALU), permitting a pair of freelance register to be accessed in one single instruction dead in one clock cycle.
Pin diagram of Atmega328p microcontroller is shown in following figure.

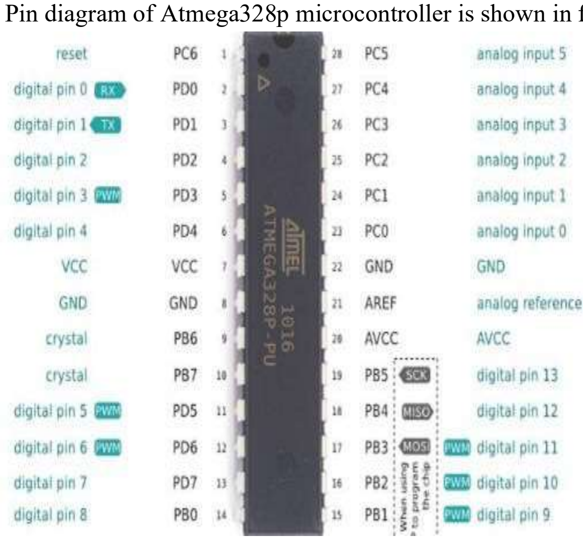


Figure 3: Pin diagram of Atmega328p microcontroller

This Atmega 328P microcontroller has various specifications as given below;

- 8-bit AVR architecture based mostly microcontroller.
- 32 K nonvolatile storage.
- 32 general purpose operating registers
- Three versatile counter/Timer with compare mode
- Internal and external interrupts
- A computer memory unit homeward-bound two wire serial interface.
- 10-bit ADC
- SPI port

1.2. Voltage Sensor

As INA219 is current and power sensing element which supplies the overall power consumed by shunt load and offers several readings in digital kind to Arduino with program loaded in it, calculates this and voltage reading of shunt load.

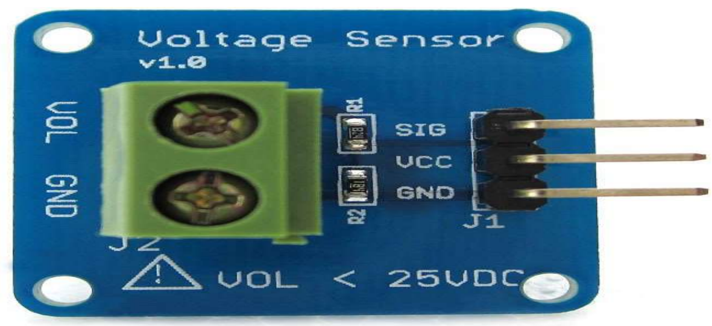


Figure 4: Voltage Sensor

Sensors square measure primarily a tool which might sense or establish and react to bound variety of electrical or some optical signal implementation of voltage and current detector has become a superb option to the standard current and voltage measure ways. A voltage detector will really verify, monitor the availability of voltage it can live the AC level or DC voltage level. The input to the voltage detector is that the voltage itself and therefore the output may be analog voltage signal, switches, sounding signal, analog current level, frequency, even frequency modulated output.

Current Sensor

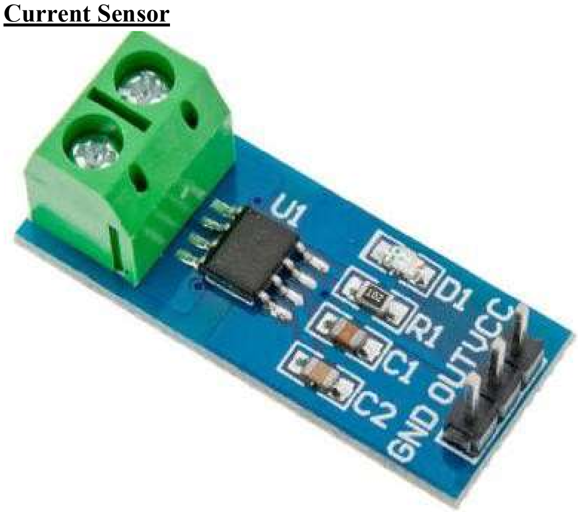


Figure 5: Current Sensor Circuit

A Current detector could be a device that detects electrical wire, and generate a symbol proportional thereto current. The generator signal may well be Analog voltage or current or a digital output. The generator signal will be then wont to show the measured current in associate meter, or will be keeping for more analysis in a very knowledge acquisition system, or will be used for the aim of management. A current detector could be a device that detects associated converts current to a simply measured output voltage that is proportional to this through the measured path. Once a current flow through a wire or in a very circuit, then dip happen. Additionally, a flux is generated encompassing this carrying conductor. Each of that development square measure created use of within the style of current detector. So, their square measure 2 sorts of current sensors: Direct and indirect. Direct sensing is predicated on ohms law. Indirect sensing is predicated on basis of faradays law. Direct sensing involves mensuration the dip related to this passing through passive electrical currents.

1.3. Liquid Crystal Display (LCD)

Figure 6: LCD Display

LCD is employed for displaying the merchandise name& total price. Once the product is place into cart when scanning, it'll show the value and name and if the second product is scanned, then second product price can get value-added and it'll be displayed on an alphanumeric display.

Specifications:

1. Resolution-Resolution of associate degree alphanumeric display is expressed by the quantity of columns and pixels i.e. (e.g. 1024*768).
2. Spital performance-For a laptop monitor or another show that's begin viewed from an in- depth distance, resolution is usually expressed in term of dot pitch or pel per in., that is in keeping with the printing trade.
3. Color Performance-There are multiple terms to explain totally different aspects of color performance of show.
4. Brightness and distinction magnitude relation- distinction magnitude relation is that the magnitude relation of brightness of full on pel magnitude relation to full off ratio. Brightness is typically declared as most lightweight output of the LED.

1.4. Wi-Fi Module

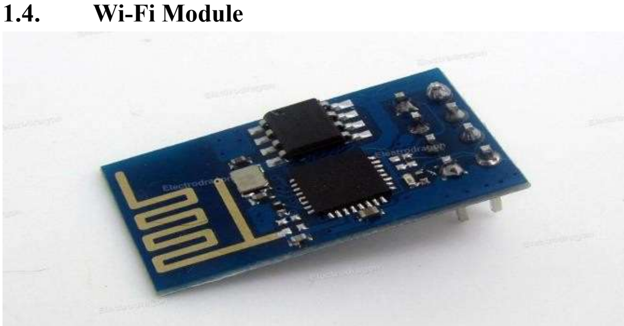


Figure 7: Wi-Fi Modules

ESP8266 is Wi-Fi enabled system on chip (SoC) module. The ESP8266 module could be a self-happy SOC with integrated TCP/IP protocol stack which will provide any microcontroller access to our American state FI network. The ESP8266 is capable of either hosting AN application or of loading all American state FI networking function from another application method. Every ESP8266 module comes pre-programmed with AN AT commands set computer code. The ESP8266 supports APSD for VOIP application and Bluetooth beingness interface, it contents a self-label RF permitting it to figure below all in operation condition, and need no external Rf half. there's AN nearly limitless fountain of data obtainable for the ESP8266, all of that has been provided by superb community support.

Features:

1. Integrated TCP/IP protocol stack.
2. American state FI direct (p2p).
3. 1MB non-volatile storage.
4. Power down discharge current

❖ **Solar Panel**

Figure 8: Solar panel

Solar power is population free and causes no inexperienced house gases to be emitted therefore once installation. It has reduced dependence on foreign oil and fussy fuel, virtually no maintenance as electrical device last over thirty year. Renewable power that's on the market a day of the year, even cloudy day, manufacture some power. It uses batteries to store additional power to be used at midnight. Some of the other advantages of solar pv panels are given below.

➢ Safer than ancient electrical phenomenon.

➢ Star is wont to heat power homes and buildings, even power cards

➢ Safer the normal electrical phenomenon.

➢ Come on investment in contrast to paying for utility bills

➢ Potency perpetually up therefore the same size star that's on the market these days can become a lot of economical tomorrow.

❖ **LDR Sensor**

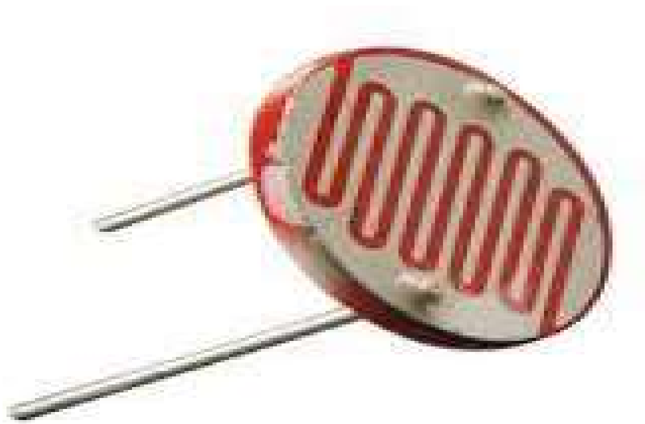


Figure 9: LDR Sensor

The resistance of LDR increases a Circuit Wizard computer code has been wont to show the variation of values of an ORP12, LDR. When a lightweight level of one thousand lx (bright light) is directed towards it, the resistance is 400R (ohms). An LDR (Light dependent Resistor) offers the resistance in response to close light-weight. The resistance of LDR will increase because the intensity of sunshine will increase the intensity of light increases.

❖ **Servo Motor**

Figure 10: Servo Motor

Tiny and light-weight with high output power, this little servo whirlybird, Quad copter or golem. Servo will rotate close to one hundred eighty degrees (90 in every direction), and works a bit like the quality sorts however smaller. We'll use any servo code, hardware or library to regulate these servos. It is smart for beginners UN agency need to create stuff move while not building a motor controller with feedback & gear box, particularly arms and hardware. Servo motor works on PWM (pulse breadth modulation) principle, which suggests its angle of rotation management by the length of the heartbeat, apply to its control pin. Essentially servo motor is formed of DC motor that is controlled by variable register and a few gears.

specification:

- Weight: 13.4 g
- Dimension: 22.5 x 12 x 35.5
- Stall torque: 1.8 kgf•cm (4.8V)
- Operating speed: 0.1 s/60 degree
- Operating voltage: 4.8 V
- Dead band width: 5 µs

❖ **Cloud**

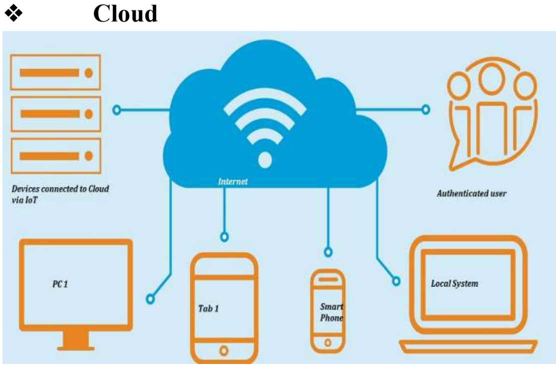


Figure 4.11: Cloud used for 1 MW Solar Power Plant

- The cloud services help the user to post their sensor data to the cloud and retrieve the data.
- The services will be available for the registered users.
- A utility is available for the registered users.
- The maximum number of posts per user is restricted 1000 per day. Posts received after the maximum limit is reached will be discarded.

1.5. Circuit Diagram Of Iot Based Solar Control System

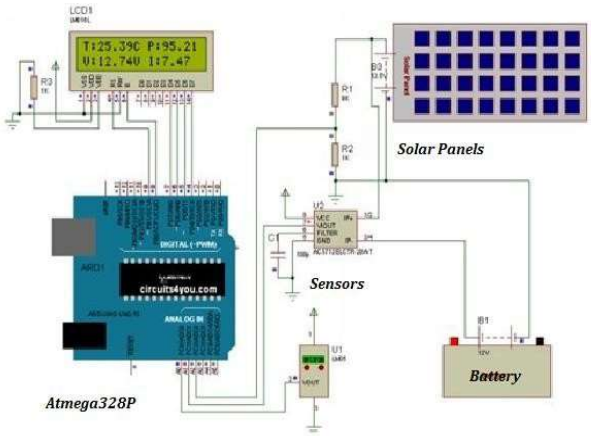


Figure 12: Circuit Diagram

In this circuit we have used two processors, one is AtMega328 (main processor) and ESP8266 (secondary processor). At mega 328 is an Atmel's 8bit microcontroller wile ESP8266 is a 32-bit built-in microcontroller and Wi Fi module, so the primary Atmega328 processor we used as only for sensor (voltage sensor and Current sensor) and display screen and for data processing purpose and secondary processor ESP8266. We have used for the data to the Cloud only and for triggering action. In this circuit solar panel take the energy from sun and convert that energy into electric energy. The output current and voltage sensor apply to the Microcontroller. Microcontrollers are used for processing purpose and data processing data applied to LDR and Wi-Fi Module. Wi-Fi module is used to connect our system to the internet via hotspot using the ESP8266 module which acts as silent which connects to any internets or Wi-Fi or access point or hotspot to send data to database. Cloud is used to storing the data and we use this data whenever we want that data. And display the data to the LCD

❖ **PCB Design**

After the circuit design, now we are moving for PCB design.

Power Supply

In this first session if PCB designs, we have built the separate section for power supply. In this PCB we have placed the all-rectification component, filtering component and voltage regulator. Also, we have built the cabinet for this PCB which covers the Voltage sensor and Current sensor value and gives the power to whole secondary main board.

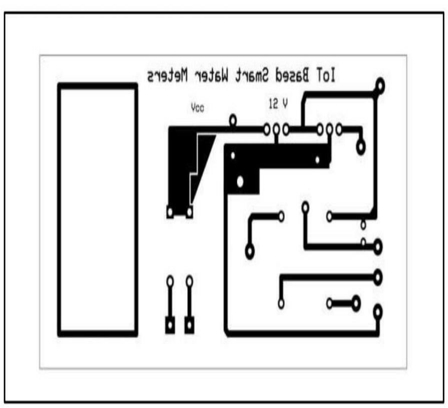


Figure 13: PCB layouts for Power Supply

Main Circuit Board

In this main circuit board, we have implemented the microcontroller, ESP8266 Wi-Fi module. This is main PCB layout in which all the components and sensors are work together in one PCB layout. The Wi-Fi module is on board microcontroller and Wi-Fi antenna so we have been implemented direct this module on the PCB with the help of male and female headers. We have used the single side copper clad PCB design. And all holes we have been drilled using the 1mm drill bit.

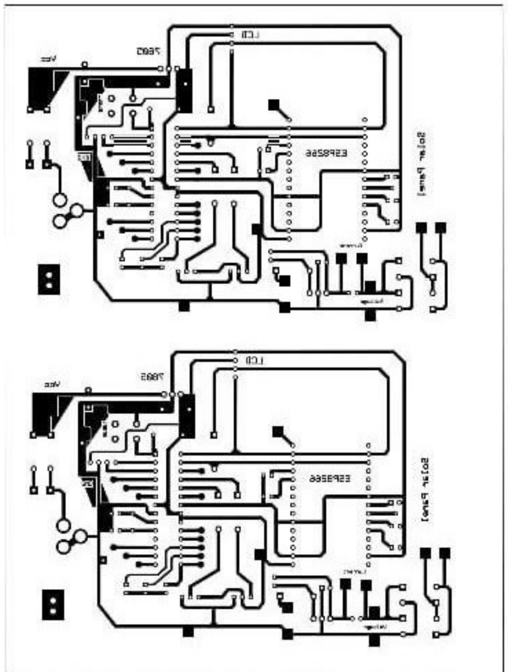


Figure 14: PCB layouts Main Board

❖ **Prototype Model**

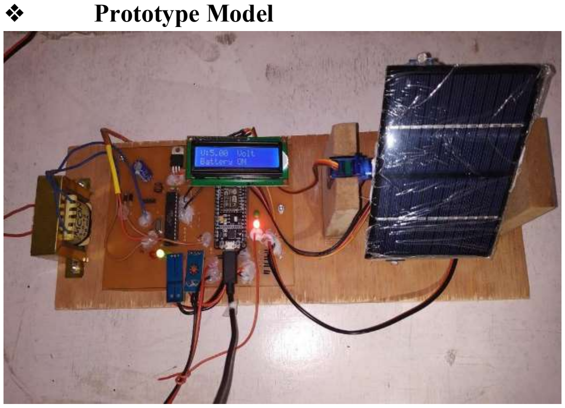


Figure 15: Prototype Model

Above figure describes the hardware of the system includes solar panel, microcontroller, WIFI Module, Voltage and current sensors as well as LDR sensors with LCD. A servomotor for the rotation of solar panels is also used in the system.

1. LITERATURE OF REVIEW

Liu et al. (2010) Harmony Search Algorithm (HSA), Enhanced Differential Evolution (EDE), and Harmony Search Differential Evolution (HSDE) are a portion of the planning algorithms that have been assessed. Their presentation was assessed as far as cost, top to average ratio, and holding up time decrease.

H. Suo, J. Wan, C. Zou, J. Liu (2012) The effective, reliable, and trouble-free functioning of a PV solar energy system relies heavily on data loggers and monitoring systems. Enabling correct operation and contributing to spotting system malfunctions before any severe breakdown, a data logger and monitoring system is essential. This primarily aims to provide pico solar home systems in rural areas of poor countries with an affordable, user-friendly, and dependable data logger and monitoring system. All of the monitoring parameters are saved on a micro-SD card and shown on a Blynk app using this data logger that is based on an ESP 32 microcontroller. In order to examine and validate the system's functionality, data may be downloaded straight from the website.

Just four sensors—humidity, temperature, voltage, and current—make up the prototype hardware for the data logger that was constructed. To provide effective monitoring and to alert maintenance staff of any problems with battery charging, a pre-existing Android app is used on mobile phones to show all metrics in real-time. We have

created the hardware implementation of the architecture for remote data collection of photovoltaic systems that are based on the Internet of Things in order to complete the work. All things considered; this prototype is cheap.
P. C. M. Carvalho (2018) It is recommended that a monitoring system be designed and developed in order to get information on the solar panels that are defective in order to facilitate prompt maintenance and repairs. A method for monitoring dispersed solar panels and automatically capturing data has allegedly been detailed in an effort to help with the current situation. A cheap wireless sensor network is the foundation of this system. This system can automatically choose the best resolutions for solar cell systems which have a maximum voltage of 146 volts and a current of 15.5 amperes. Their system comes with a price tag of twelve thousand rupees (P. C. M. Carvalho et al.2018).
M. D. Phung (2017). As shown in the article, a Lab-VIEW-based real-time interface system The performance and dynamic behaviour of photovoltaic systems are thoroughly evaluated in the 2017 paper by M. D. Phung and colleagues. They created programming that permits a few sensors to be connected to a solitary framework. The framework is equipped for both constant observing of all information sources and correlation of reenacted results to genuine information. A quick, secure, and dependable arrangement is given by this technique, which includes preparing the data set to investigate the exhibition of photovoltaic (PV) frameworks. It is achievable to study photovoltaic (PV) framework diagnostics utilizing a coordinated technique that joins solid demonstrating with information gathered progressively
K.Naga Venkatarao, K.Vijay Kumar (2017). To assist with the ongoing trouble of observing photovoltaic (PV) frameworks, particularly in remote or lacking regions, an open-source electronic stage information lumberjack in light of Arduino was made. With its 8 simple information sources and 18-piece goal, this information lumberjack can screen up to 8 sunlight based modules — all as per the norms laid out by the International Electrotechnical Commission (IEC). The information lumberjack's producers expressed that it very well may be modified to match the particular necessities of any task, regardless of the way that it costs something like 6,000 rupees (K.Naga Venkatarao and K.Vijay Kumar 2017).
Tejwani R et al. (2014) Utilizing internet-of-things (IoT)- based remote checking frameworks is one way to deal with bringing down working and support costs for independent photovoltaic (PV) establishments. The highlights, capacities, and reserve funds in working and upkeep expenses of the most well known Internet of Things (IoT) frameworks are analyzed in this review. By gathering framework disappointments and killing the most serious ones that would require actual site visits, we can ascertain the reserve funds in field trips utilizing three PV frameworks that can be checked from a distance. The discoveries are upheld by information gotten from four additional sun powered establishment firms with their central command in Nairobi, Kenya. In view of our exploration, it is feasible to remotely screen and fix most of framework issues. Spending on individual destinations might be sliced by $2040 to $3096 yearly with the assistance of Internet of Things (IoT) advancements. From 47 to 95 percent yearly reserve funds in working and support consumptions are conceivable contrasted with frameworks normally checked locally. This seeks prepare for the economical upkeep of sun oriented photovoltaic (PV) frameworks in off-matrix regions, guaranteeing the frameworks' lifetime and accommodation (Tejwani R et al. 2014).
Jongbae Kim et al. (2015) utilized Little operating system to construct a state of the art remote checking framework for overseeing and following sunlight based power creation. A snare of connected parts, including the host PC, ARM passages, and remote sensor organizations, considers remote checking and the board of the framework (Jongbae Kim et al. 2015).
B. Shrihariprasath and Vimalathithan Rathinasabapathy (2016) The worldwide cost of sustainable power hardware has fallen significantly because of innovative progressions that have facilitated the development of sun based photovoltaic frameworks. Sending refined development innovations turns out to be more smoothed out and basic with the utilization of the Internet of Things (IoT). It is the fundamental purpose of this research to prove that all solar photovoltaic arrays need to be monitored in order to ascertain their current status, since monitoring is critical for assessing performance and keeping panels in optimum working condition. The operation, monitoring, and maintenance of solar PV installations might be greatly enhanced with the use of technologies based on the Internet of Things. Everything you need for managing solar panels, doing preventive maintenance, analyzing plant history, and monitoring in real-time will be easily satisfied with this. Also, by automatically regulating the mechanism to collect the greatest amount of sunlight, this will assist in power production. In the event that the amount of light decreases, the solar panels will automatically turn so that they face the sun. This

will lead to an improvement in the efficiency of solar energy conversion (B. Shrihariprasath and V. Rathinasabapathy, 2016).

Soham Adhya et al. (2016) The use of solar energy, which is readily accessible everywhere in the globe, has the potential to reduce the reliance on energy imports. A sufficient amount of sunshine hits the globe in a period of ninety minutes to provide the energy requirements of the whole planet for an entire year. Many people have proposed technologies that harness renewable energy sources as a means to reduce human impact on the environment. Renewable energy sources must be used and closely monitored in light of the regularity of power disruptions. The biggest perk of implementing IoT into your solar energy system is the ability to keep tabs on all of your assets from one centralised dashboard. Connecting your devices to a cloud network will allow you to pinpoint the problem's origin and dispatch a technician to fix it before it affects the rest of your system. Without the Internet of Things, it would be hard to determine whether the problem is related to the network or the hardware. You may make your system more resilient to power outages and productivity disturbances by using the Internet of Things. In order to link your solar assets, you can manage even thousands of individual devices that are connected to our network if you install an all-in-one Internet of Things solution that connects the edge to the cloud (Soham Adhya et al. 2016).

Gad et al. (2016) have created a basic system that gathers data from sensors using a microcontroller to track solar system temperatures. In the event of a power outage or other corruption, the system may swiftly change the date, start and finish times of the experiment, sample rate, and other relevant parameters. Featuring its own storage systems like flash memory or SD card, the data collection system that has been shown can handle sixteen sensors at once. Its UI is a four-button LCD board. Thusly, it can store sensor information without an extra PC. With this design, the SD card will be naturally loaded up with information and another record will be created day to day. Any numerical instrument, for example, Succeed and MATLAB, can without much of a stretch oversee and break down information saved money on a SD card utilizing this setup. It is feasible to remotely screen the sensors over the internet utilizing this innovation.

A smart remote monitoring system in light of the Internet of Things was the point of a recent report by Shri Hari Prasath and partners. This gadget can screen the sun-based PV PCU and save information in a cloud data set through its natural web interface. The recommended method is versatile since it utilizes GPRS innovation to connect the PV Power Molding Unit to the distant server.

Soham and partners previously proposed the idea of utilizing an Internet of Things (IoT) organization to remotely control a nearby planet group by monitoring its ongoing status in 2017. The information gathered by the sensors is sent over the versatile radio organization. To send information to the far off server, a GPRS module is fundamental. There are three levels to an IoT application plan, with the sensor layer being the most minimal. An irradiance pyranometer, a meter for estimating current and voltage, and different sensors are housed in these layers. A way to deal with microcontroller-based sensor information handling is likewise a piece of the idea. Using a remote module, the microcontroller may start correspondence with the server and begin getting information from the server. Layer 2 is supposed to go about as the organization layer, responsible for gathering plant information progressively. There would likewise be a data set remembered for this layer for putting away reasons. The application layer, which comes after the organization layer, utilizes the handled and put away information. This layer is liable for building refined web administrations from the gathered, handled, and put away information. A superior method for watching out for how the plant is running is to utilize graphical UIs. Overseers could possibly altogether decrease dynamic time by utilizing the information driven ideas given by the connection point.

Renewable Energy Monitoring System (REMS) was presented by S. Adhya and D. Saha (2016) as an inventive, open-source, and financially savvy information assortment and transmission system that utilized multi-client cloud remote monitoring, Raspberry Pi, and the Internet of Things. This approach can possibly work on a disseminated plan for renewable power offices. The center parts of the REMS design are an Internet based Web Screen for continuous cloud monitoring, a San USB microcontroller, and an Embedded Linux System (ELS) on a Raspberry Pi (Rpi). This thought depends on distributed computing and the Internet of Things (S. Adhya, D. Saha, A. Das. 2016).

Along with partners, Saqib Kazmi1 in 2017 Meager burden moving utilizing a circulated method is presently open in demand-side management. The system's essential goal is to address the planning issue of savvy home apparatuses.

Chaojie Li et al. set up a novel, four-pronged DSM worldview (2016). A MLP-based forecast motor, circulated knowledge, demand-side energy management modules, and AMI are the parts that make up the system. At the point when 2020 rolls around, another DSM structure will have been laid out by Abdullah Nawaz and associates. Dissemination and the Alternating Direction Method of Multiplier (ADMM) comprise the premise of this system, which depends on a MPC convention.

A trustworthy and powerful correspondence foundation has been made in shrewd matrix by Milad Latifi and partners (2020). This system depends on mental radio innovation and the Game Algorithm (GA) from DSM. A coordinated system has been created by Kun Wang et al. (2018) to empower demand reaction in savvy lattices. By including renewable conveyed generators into this engineering, we can eliminate calculation time and correspondence costs. Utilizing a "individualized" evaluating procedure, Yang et al. (2013) presented another method for demand-side management (DSM). This strategy guarantees that each client gets a custom fitted energy cost plan that supports demand management for the most ideal treatment of their steadily changing energy demands.

Bruno Ando et al. (2015) A lot of people think that renewable energy sources are the way to go to meet our increasing energy needs because of how dependable and great they are. These days, solar photovoltaic energy is the most promising and eco-friendly option as it doesn't produce any carbon emissions. In order to generate power from solar energy, meticulous care during installation and maintenance is required. A solar energy monitoring system that relies on the Internet of Things is introduced in order to collect and analyze solar energy properties. The goal of this system is to predict how well the system will work such that electricity production remains constant. One of the most significant benefits of the system is that it can effectively establish the best performance for improved solar photovoltaic (PV) maintenance. The main goal of the photovoltaic (PV) monitoring system is to provide a solution that is both affordable and continually displays the performance and energy outputs from a distance. Both desktop computers and mobile phones are capable of accessing this feature. The suggested system is tested using a 125 watt solar module to monitor irradiance, temperature, string current, voltage, and string voltage. The CC3200 microcontroller, which is equipped with the most recent integrated ARM processor, is responsible for the development of this photovoltaic (PV) monitoring system. It maintains communication with the Blynk application and uploads the data to the cloud platform. A PV system's operational dependability may be maximized with the help of the wireless monitoring system, which also reduces the overall cost of the system (Bruno Ando et al. 2015).

Christian Floerkemeier et al. (2010) With the help of commonplace items, the Internet of Things aspires to bring the virtual world into the physical one. Through the Internet of Things (IoT), objects can be sensed or controlled remotely through preexisting network infrastructure. This opens up possibilities for the seamless integration of physical objects into computer-based systems, which in turn leads to reduced human intervention, increased efficiency, and economic benefit. Solar streetlights, smart villages, microgrids, and solar cities are just a few of the many uses for this technology. As During this time, the use of renewable energy sources increased at a pace never seen before. The online display of solar power utilisation is a renewable energy source that is mentioned in the suggested system. The flask framework is used to do this monitoring on a raspberry pi. Every day, the amount of renewable energy used is shown via Smart Monitoring. The user may analyse their energy use using this. Findings from the investigation into power issues and the use of renewable energy sources (Christian Floerkemeier et al. 2010).

Using a decentralized fuzzy-based controller, Barry Hayes and colleagues (2016) were able to successfully integrate and coordinate the charging of electric cars. Samy Faddel and colleagues (2018) used a precise research technique to perform a complete study on the likely effect of Low Voltage (LV) home Demand-Side Management (DSM) on costs and GHG emissions. It has been proposed by George Tsagarakis and colleagues (2017) to link a Home Energy Management System (HEMS) with a DSM software. Here, Deep Deterministic Policy Gradient is used.

In order to explore the use of demand side management to tackle the problem of voltage rise, Tan Li et al. (2019) released an autonomous energy consumption scheduling approach. Enxin Yao et al. (2015) created a new method for controlling EMS that is based on resident behavior patterns. Researchers Nadia Ahmed and colleagues have developed a hierarchical DSM model for the future (2017). Through its incorporation, this strategy makes use of renewable energy sources. Using the load shifting technique of demand side management, Dan Li et al. (2018) proposed a home energy management system. The goal of this system is to make the most efficient use of the energy that contemporary houses use.

Predictions about the power consumption ratings of residential structures across a whole region were made by Adia Khalid and colleagues (2018) using a support vector machine as the core optimization framework. Huiling Cai and colleagues (2019) detailed a strategy that combines rule-based methods with the capabilities of wireless sensors. To reduce electrical peak demand and electricity costs, Azim Keshtkar et al. (2016) proposed an intelligent energy management system based on the Multi-Objective Mixed Integer Linear Programming (MOMILP) paradigm.

Qinghai Ou et al. (2012) When solar photovoltaic power production is monitored using Internet of Things technology, the plant's performance, monitoring capabilities, and maintenance features may be significantly improved. Worldwide, the price of renewable energy technology is falling, which is encouraging massive solar photovoltaic installations. This is becoming possible as a result of technological advancements. This huge scale of solar photovoltaic deployment necessitates the implementation of advanced systems for the automation of plant monitoring remotely via the use of web-based interfaces. This is because the bulk of the plants at this size are situated in inaccessible regions, making it impossible to monitor them from a specific location. This article focuses on a novel, cost-effective method that is based on the Internet of Things for remotely monitoring a solar photovoltaic plant for performance evaluation. In addition to facilitating real-time monitoring, this will also facilitate preventive maintenance, defect identification, and historical plant analysis (Qinghai Ou et al. 2012)

Hamed Shakouri et al. (2017) have evaluated the effects of demand-side management techniques using a programme that maximises the return on investment and efficiency of hydro and wind power facilities. A stochastic programming approach based on multi-objective particle swarm optimisation was suggested by André Pina et al. (2012) to optimise the performance of a smart microgrid in the near term. The goal is to minimise operational expenses and emissions using renewable sources.

Rammohan, S et al. (2013) There has been a meteoric rise in the number of solar photovoltaic installations, thanks to technological advancements and falling equipment costs for renewable energy sources. Supplemental power sources are what most of these facilities are designed to do. Most of them are stationed in inhospitable areas, such as deserts or very close to rooftops. Thus, they need advanced systems that can remotely monitor these installations over wide area networks. An inexpensive integrated solar PV monitoring system based on the Internet of Things (IoT) will be described in this article. A GPRS module and an inexpensive microcontroller will be used by this system to upload the data measured at the manufacturing end to the internet. Anyplace on Earth can thereafter get to this data. We can use this for continuous data on the establishment, which will assist with upkeep and issue ID, and it will likewise record every one of the information at predetermined stretches (Rammohan, S et al. 2013).

2. ARCHITECTURE

3.1. IoT Framework

An execution of an Internet of Things (IoT) engineering has been made to screen and control all heaps in a direct current (DC)- fueled private structure. To achieve demand-side administration in this unique circumstance, an engineering comprising of five layers has been made. The three energy sources, the heaps appended to the house, and the sensors and information authorities are all essential for the design at the base level. As per Aissa Chouder et al. (2013), the subsequent layer is introducing demand reaction software and controlling gadgets. The Message Queuing Telemetry Transport (MQTT) convention is utilized in this review to address the Internet of Things convention on the third layer expressly. Demand-side administration programs fueled by simulated intelligence make up the fourth level. Finally, an intuitive dashboard that is connected to the cloud is an element of the application layer, which is the fifth layer. The proposed system's engineering design is portrayed outwardly in Figure 3.1.

3.2. Hardware Design

The CPU, power supply, voltage and current sensor module, and relaying system are among the hardware parts of the system. Below are thorough explanations of every element.

1. Microprocessor

The Raspberry Pi 4B+ model was selected for the main controller role in the suggested system due to its widespread availability, cost, precision, and dependability. It manages the residential complex's massive volumes of data with effectiveness. Additionally, the system has an ESP8266 MCU Wi-Fi module that creates a wireless interface between the energy sources and the load appliances. Microcontrollers may connect to a Wi-Fi network and create TCP/IP connections with ease thanks to the ESP8266, an affordable microchip that combines a microcontroller with a whole stack of Internet communication protocols (Bipin Krishna and Kaustav Sinha 2013). These Wi-Fi modules use hotspot capabilities to send the system's time series data to centrally connected Raspberry Pi 4B+ devices via cloud-based Message Queuing Telemetry Transport (MQTT). The Raspberry Pi Controller schedules appliances based on calculations and gives the user reports.

2. Power Supply

The CPU runs at 3.3 volts and needs a minimal amount of power. On the other hand, the transfers require a 5V DC power source. Contingent upon the specific necessities of the system, the quantity of hand-off units can be expanded or brought down on a case by case basis.

3. Voltage and Current Measurement

In the proposed Internet of Things (IoT) system, the PZEM-017 module capabilities as a voltage and current sensor, ready to gauge the two factors. It watches out for various power sources, for example, solar photovoltaic (PV) boards, batteries, and the fundamental framework. The voltage and current sensors on the module are associated in series and equal, separately. With this configuration, the system can recognize energy utilization from the principal matrix, assess battery condition, and gather information on energy generation from the solar PV system. The system can likewise look at the associated apparatuses' day to day load profiles.

4. Smart Metering

The proposed system can gather day to day information on the utilization of every device connected to a DC power supply in private designs. It provides detailed load consumption information for individual rooms, functioning akin to a smart meter. The system also accounts for energy losses in AC, DC, and mixed loads. Technical specifications of the system are detailed in Table 2.4. Additionally, a 1.5 kW solar power plant has been installed on the rooftop of the building, accompanied by a stock of twenty 12V 12Ah batteries.

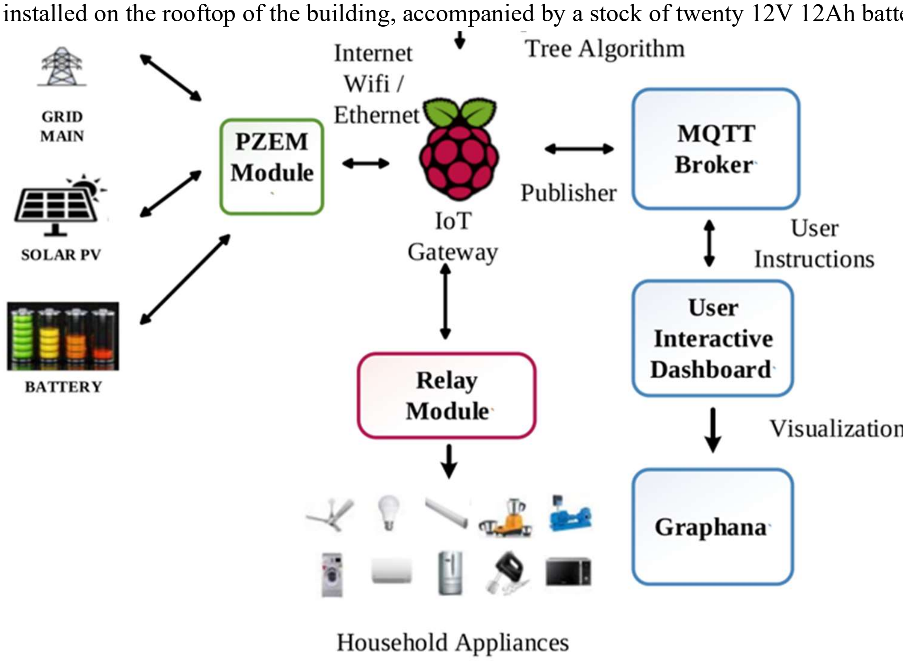


Figure 16: Proposed architecture

5. Relays and Relaying System

In the DC building, a microprocessor interfaces with all appliances via a network of relays strategically positioned within the relaying system. This setup enables remote control of appliance power states. Each relay operates with a 5V DC power source. The relay drivers are integral components of the demand-side management system, ensuring efficient operation. Moreover, they protect the system from potential overcurrent and voltage issues.

3.3. Software Design

In the process of putting the suggested system into action, the software is an extremely important component. The microprocessor will be able to read the voltage and current data from the sensors since the software has been meticulously crafted in such a way that it is correctly engraved (Haider-e-Karar et al. 2015). Calculating power and energy requires taking into account both the current and the voltage. It is necessary to comply with a protocol in order to send all of these data to the cloud server, which is situated in a distant location. Because of the many benefits that it offers, the wireless communication technology known as Wi-Fi has been selected for this research project. The MQTT protocol is selected since it is the one that is most suited for Internet of Things applications.

- **Wi-fi Communication**

In comparison to other Wi-Fi microchips that are currently on the market, the ESP8266 is offered at a price that is more affordable. Transmission Control Protocol/Internet Protocol, or TCP/IP for short, is the protocol that is used. Through the use of these Wi-Fi modules, all of the information that is gathered from the sources (voltage, current, and power) and load appliances is sent to the Raspberry Pi 4B+.

- **MQTT Protocol**

This Raspberry Pi 4B+ is used to do manipulations on the data. The sequential decision tree technique is used to determine the timetable for the individual appliances. Through the use of the MQTT protocol, this predicted load pattern is sent to the user-friendly dashboard.

- **Interactive Dashboard**

The user is presented with the consumption pattern, the current battery state, and the load shifting behavior via the usage of the Graphana dashboard. The user also has the ability to establish preferences depending on their own preferences. The data that was gathered may be examined on a daily, weekly, monthly, or annual basis simultaneously. Using this dashboard, the user is able to comprehend the amount of energy that is used (Rajalingam S and Malathi V 2016).

The PZEM 017 sensors are positioned in the line from the supply (grid, battery, and solar), and the data is sent to Raspberry Pi4B+ by means of the Wi-Fi module ESP8266. Individual relays are used to link each class of loads, and the ESP32MCU microcontroller, which is very inexpensive, is responsible for controlling the relays. Through the use of the Wi-Fi module, the status of each appliance, which may be either ON or OFF, is sent to the Raspberry Pi4B+. The deferrable loads are shifted according to the suggested DSM, The proposed DSM is implemented in Pi to shift the deferrable loads.

3.4. Types of Sources

Solar photovoltaic (PV) production, rechargeable batteries, and the main grid are the three sources of energy. Solar energy will not only be useful for providing dependable electricity, but it will also be kind to the environment. Battery is the mechanism that is applied for the storage of energy. Given the intermittent nature of solar energy, it is necessary to install a battery on the premises. A backup power source, the battery kicks in when the sun doesn't shine bright enough to power everything. The suggested system's energy management is informed by intelligent decisions that take the battery's state of charge, or SoC, into account. To keep the battery in good working condition for as long as possible, it's crucial to think about how often you charge and discharge it. When the energy that is generated by solar panels and batteries is not adequate, the main grid is used to provide the energy. In order to guarantee a constant supply of electricity to the residential building, the system that is being suggested is grid integrated. In order to achieve the goal of lowering the home user's monthly power cost, the suggested system is designed to perform continuous monitoring of the energy that is pulled from the main grid. (P. Papageorgas et al. 2013)

3.5. Types of load

As a general rule, the household appliances that are taken into consideration for this section of the study work are divided into three categories: AC loads (class 5 and class 6 loads), DC loads (class 2 and class 4 loads), and mixed loads (class 1 and class 3 loads). These categories are determined by the operational supply of the appliance. For further classification, the loads are separated into three categories: permanent loads, non-deferrable loads, and deferrable loads. Figure 3 illustrates the categorization of loads in a graphical format.

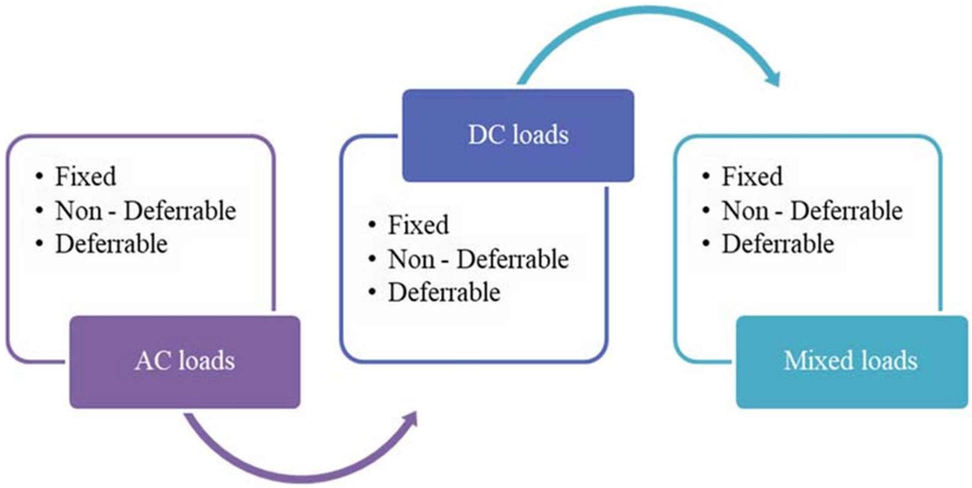


Figure 17: Types Of Loads

3. PROBLEM FORMULATION

The best way to minimise energy conversion loss and, by extension, peak load shifting, cost savings, and conversion loss at various phases, has been shown to be a temporal-based decision tree algorithm. The formulation of the issue will provide the scheduler with assistance in shifting the loads in accordance with the goals. (Awad, et al.2020).

3.1. Objective Function

In a traditional residential structure that is powered by solar photovoltaics and has an air conditioning supply, there are several conversion losses that result in a variety of conversion losses. Solar photovoltaic (PV) residential buildings that are powered by direct current (DC) have been favored as a means of loss reduction. By doing so, it is possible to prevent the losses that occur at a number of different junctures. As a result, the primary purpose of the system that has been presented is to plan the loads in such a way as to reduce the amount of conversion losses.

$$Min\ Loss_{tot}$$
$$Loss_{tot} = Loss_{MG} + Loss_{PV} + Loss_{Batt}$$

Subject to constraints,

$$DL_{st}^{n}(t) = 1, \{during\ \ 0, eleswhere\ P_g^s \geq D_{max}\ (t)$$
$$DL_{st}^{n}(t) \geq DL_{st\_user}^{n}(t)$$
$$DL_{et}^{n}(t) \leq\ DL_{et\_user}^{n}(t)$$

4. DECISION TREE ALGORITHM BASED ON TEMPORAL FACTORS

The sequential decision tree method is used to achieve the implementation of the DSM. The algorithm that has been developed works to adjust the loads in accordance with the state in which the DC house is operating.

4.1. Smart Scheduler

In accordance with the temporal-based decision tree method for the proposed demand side management, the scheduler is responsible for scheduling the deferrable loads, as detailed in the following list:

Step 1: Initiate the Internet of Things and begin gathering data.

Step 2: Determine the amount of energy produced by solar panels and the state of charge of the battery, as well as check the condition of the main grid.

Step 3: The daily load profile of the user should be determined.

Step 4: Find out what kind of load the deferrable load is composed of.

Step 5: Make sure that the source of supply and the mode of operation of the DC house are both checked properly.

Step 6: Establish the order of priority for the loads in accordance with the manner of operation of the DC house.

Step 7: If you want to transfer the deferrable loads in such a way that the conversion losses are small, you need to determine the optimal mode to use during the non-peak time period.

Step 8: The Graphana dashboard is where one may see the profile that has been planned.

Step 9: If all of the deferrable loads are moved to the optimal scenario and planned in such a way as to minimize the losses, then the end result is that.

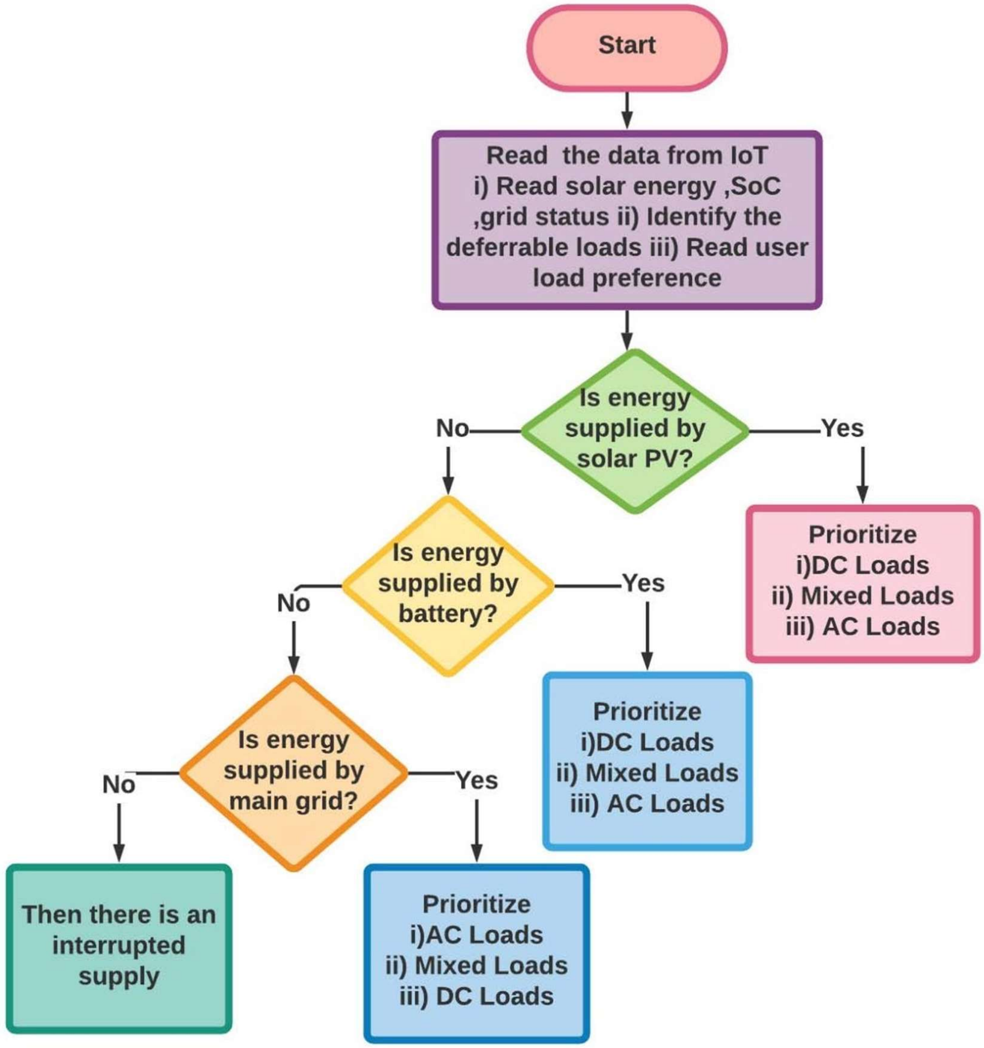


Figure 18: Flowchart for load prioritization

5. RESULTS AND DISCUSSION

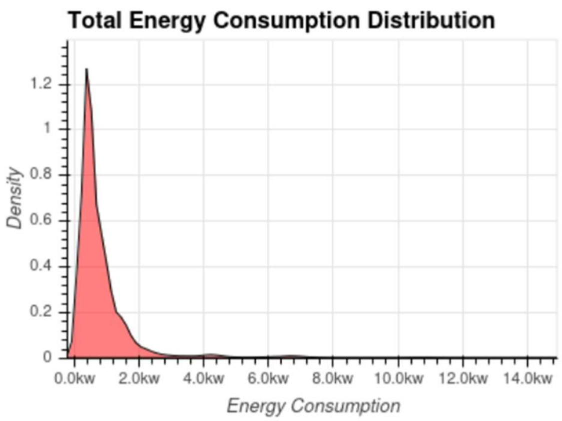
The following are some of the insights that were derived from the analysis of data on energy use and generation that was received via installing a smart monitoring system for solar data in a residential context using the Internet of Things.

5.1. Energy Consumption Distribution

the distribution of total energy consumption reveals a substantial density peak at roughly 0.5 kW. The majority of consumption values fall below 2.0 kW, indicating that the majority of consumption values are below that threshold. This suggests that the majority of energy consumption events are of a modest scale, which is typical for a residential building that makes efficient use of energy and has demand side management (DSM) measures in place that are successful.

5.2. Energy Generation Distribution

A significant peak can be seen in the distribution of total energy production, which is shown in the Figure 5. This peak is around 0.05 kW. The bulk of generation events are concentrated at the bottom end of the scale, which indicates that solar energy output is relatively low yet constant. This distribution shows that solar energy generation is generally low. The presence of this pattern indicates that smaller-scale solar power plants are being considered for household use.



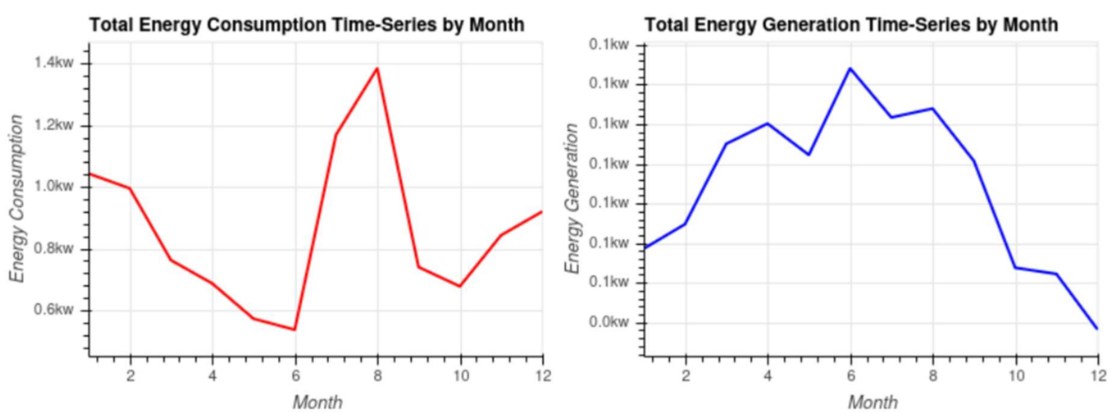
1.1. **Figure 19: Energy Generation Distribution**

5.3. Monthly Energy Consumption Time-Series

The monthly energy consumption time-series, as shown in Figure 6's left panel, clearly exhibits a seasonal tendency. From June through August, energy use may exceed 1.4 kW, which is the peak season. The dramatic increase in cooling needs could be to blame. In contrast, consumption is often lower in the spring (March–May) and fall (September–November) due to milder temperatures that decrease the need for heating and cooling.

5.4. Monthly Energy Generation Time-Series

Figure 6, right panel, shows that the monthly energy generation time-series also fluctuates with the seasons. Between June and August, the energy production peaks at around 0.1 kW, which is the peak summertime output. Because of the longer days and higher solar irradiation, this trend holds true throughout the summer. Reduced sun irradiation and shorter days define the winter months (November–January) as a time of reduced energy generation.



1.1. **Figure 20: Monthly Energy Generation Time-Series**

5.5. Summary

An significant amount of data on the patterns of energy usage and production in a residential building powered by solar energy has been collected using a smart monitoring system that is Internet of Things based. Both the consumption and generation statistics show that there is a substantial relationship to seasonal factors, with the former reflecting the predictable fluctuations in solar power availability and the latter showing no such pattern. The ability to optimize energy consumption and maximize solar energy utilization is made possible by this extensive monitoring, which also improves energy management.

5.6. Peak Load Shifting

Demand-side management is implemented via the Internet of Things-based smart scheduler through the use of a temporal-based decision tree algorithm. After determining that a new time slot will result in the lowest conversion loss for deferrable loads, the scheduler will use the temporal-based decision tree approach to reschedule them. In Figure 7, we can see the energy consumption trend of the one residential structure with a DC supply that was considered for all four scenarios. A average day's energy use looks like this. It is made abundantly evident that in scenario 4, when the suggested approach is put into action, the deferrable loads that are present during peak time are suitably relocated to other time slots where the energy conversion loss is minimized. As a result, the magnitude of the loads throughout the peak period is much lower. A resident's lifestyle, habits, the season, the weather, the day of the week (weekend, vacation), and other variables may all affect the energy demand curve. At each interval, the cheap Internet of Things framework decides how things will run.

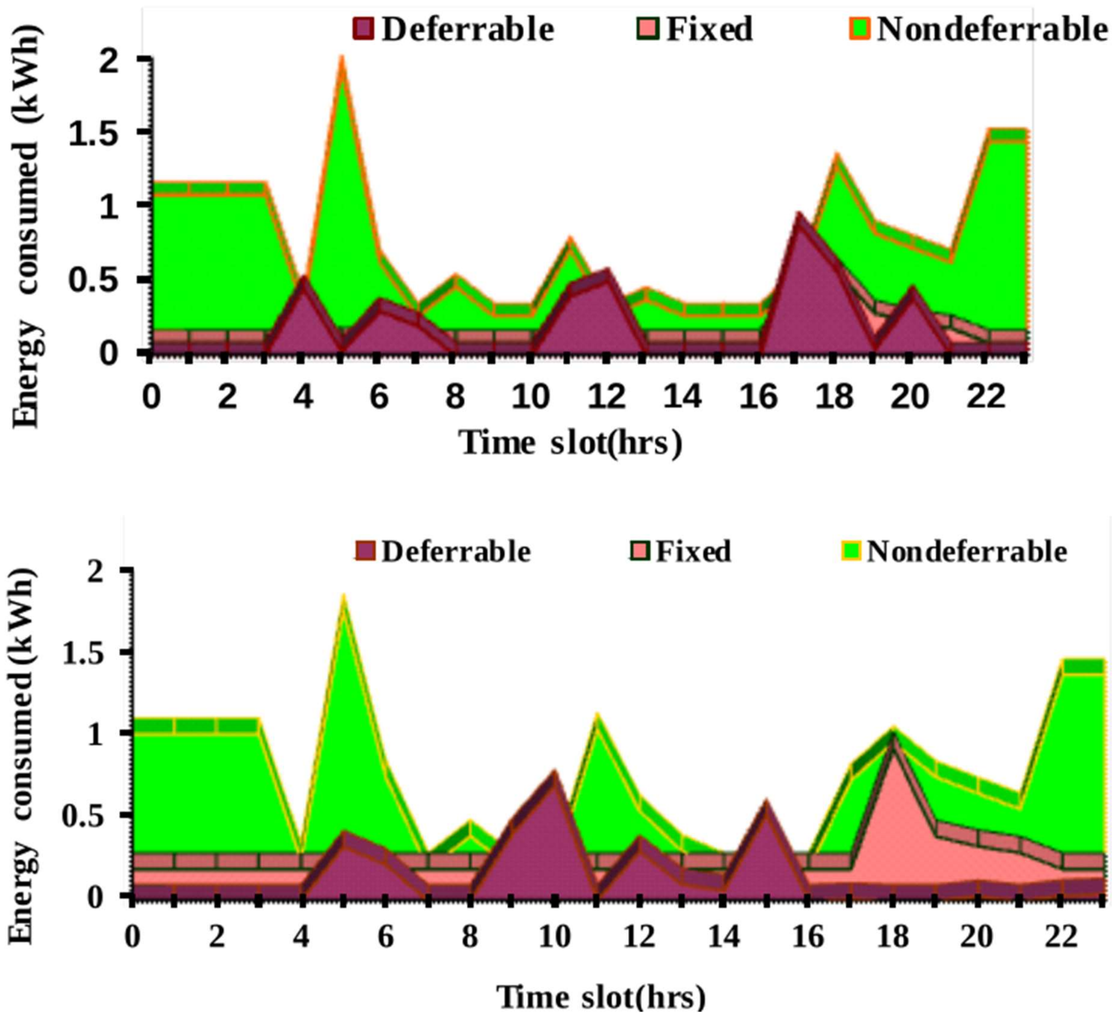


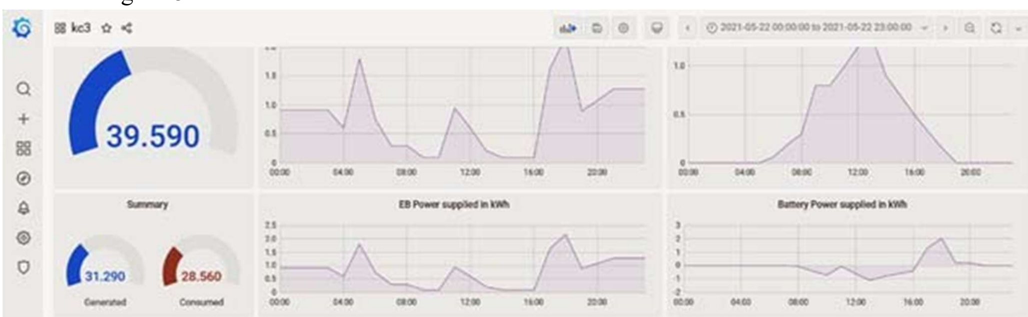
Figure 21: (a) Scenario 3 load curve of proposed IoT based residential building with DC supply (before DSM implementation) and (b) Scenario 4 load curve of proposed IoT based residential building with DC supply (after implementation of DSM)

The data shown in Figure 7. (b) shows that the peak demand is highest in the evening (time slot 18), when more loads are run. A smart scheduler that is based on the Internet of Things checks the deferrable load in that time slot. It has been discovered that the washing machine is being used at that particular time slot, and class 4 DC deferrable load is being used. Because of this, the scheduler determines the optimal state to transfer the load that was described before. As a consequence of this, it is possible to move it to other time slots that are not during peak hours when it is functioning in mode 1, in accordance with DSM's retrospective decision tree implementation. As a result of inadequate solar output, the load will be supplied by either the grid or the battery in the event that the washing machine is run during time slot 18. In such case, the losses would be substantial, and the cost will also be considerable. When the loads are transferred in the proper manner, the end result is that the losses are reduced by seven percent. In accordance with the methodology described in, the pump, which is a DC deferrable load of class 4, is also moved to non-peak time slots of state 1 during the nighttime hours.

The same thing happens with appliances like induction stoves, heaters, mixers, and blenders; they are relocated to non-peak time periods throughout the daytime so that they may operate at their most efficient levels possible. When mixed deferrable loads are operated in this mode, the losses are reduced by 3%, resulting in a loss reduction. The AC deferrable loads are moved to non-peak time slots of its optimal operating mode, which results in the conversion loss being reduced to a low level. The Energy Conversion Loss is further decreased by 5% on average across all of the time slots when the deferrable loads are switched to suitable modes in accordance with the technique that has been suggested.

5.7. Smart IoT Dashboard powered by Graphana

There is real-time data displayed on the screen regarding the following: residential building energy use; solar energy delivered to the load; energy purchased from the main grid; energy supplied by the battery; and energy required to charge the battery. In accordance with the requirements of the residential user, the information may be seen for a period of time ranging from one day to one year. (a) illustrates the Graphana dashboard picture that shows all of the information that was described previously associated with a residential structure that has an air conditioning supply. In (b), the dashboard picture of a residential structure that was equipped with DC supply is shown prior to the implementation of the suggested approach. The view of the dashboard is, (c) after the suggested approach was implemented in the PV-based residential building without the use of DSM. Following the implementation of the suggested approach (with DSM) in the same residential building, the dashboard picture is shown in Figure 8.



(a)

(b)

Figure 22: Graphana dashboards

5.8. Load Monitoring and Protection

All of the appliances' measurements have been calculated to find the conversion losses that happen under the various previously specified scenarios, proving that the DC-based distribution system in the home is efficient. A monitoring system that is based on the Internet of Things and is placed in a residential house is illustrated in Figure 9; it is responsible for capturing the voltage, current, and power consumption of each device in the home. The source that is providing the loads and the amount of energy that is being used by the appliances in the residential building that is operated with DC supply is shown in Figure 9 for a typical day.

Figure 23: Monitoring voltage, current and power in the proposed residential building with DC supply

6. CONCLUSION

The findings of the study that was given illustrate the tremendous benefits that may be obtained by using a low-cost In a DC-powered home, the Internet of Things allows for effective demand-side management (DSM). Reducing energy loss during conversion is made simpler with the use of a temporal-based decision tree method, which also facilitates optimal scheduling of deferrable loads. Successful scheduling of deferrable loads during peak time slots results in a 5% daily reduction in energy conversion losses. The strategy's effectiveness is shown by the real-time execution of the proposed system (Shirazi, A. et al. 2019).

Economic benefits of this DSM technique are also highlighted by the study; for example, compared to a similar home setup without DSM devices, users may expect to save 12% on electricity expenditures. The user experience is enhanced by the use of a Graphana-based interface, which allows users to customize their appliance operating options according to their unique needs (Thakur et al. 2019).

By doing this study, we have been successful in accomplishing the following objectives:

- A cheap framework based on the Internet of Things that effectively monitors and collects data from appliances.
- The best scheduling and moving of deferrable appliances during peak loads, in accordance with the operating mode of a residential building that is powered by a DC supply.
- A decrease in energy conversion losses that may be measured by five percent, in addition to a reduction in power prices by twelve percent.
- The implementation of a touch screen interface that is generated by Graphana and offers a user experience that is both pleasant and easy to understand

In general, the demand side management system that has been provided provides a solution that is both practical and cost-effective for the control of home energy, indicating both the technically and economically viable nature of the system. The findings of this research establish the framework for future breakthroughs in residential DSM, with possible applications extending to a variety of other energy management situations.

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