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Remote Cloud-Based Inverter Monitoring & Troubleshooting

COLLEGE OF
ELECTRICAL AND MECHANICAL ENGINEERING
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COLLEGE OF ELECTRICAL AND MECHANICAL ENGINEERING

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PROJECT REPORT

Remote Cloud-based Inverter Monitoring & Troubleshooting

Submitted to the Department of Electrical Engineering
in partial fulfillment of the requirements
for the degree of

Bachelor of Engineering
in
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2024

Submitted By:

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CERTIFICATE OF APPROVAL

It is to certify that the project **"Remote Cloud-Based Inverter Monitoring & Troubleshooting"** was done by NC Humayun Ahmad, PC Muhammad Wajeeh Ullah Kakar, NC Muhammad Saad Ali under the supervision of Dr. Mahrukh Liaqat.

This project is submitted to **Department of Electrical Engineering**, College of Electrical & Mechanical Engineering (Peshawar Road, Rawalpindi), National University of Sciences & Technology, Pakistan in partial fulfillment of requirements for the degree of Bachelor of Electrical Engineering.

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DECLARATION

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ABSTRACT

As nations progressively go to solar based energy as valuable option in contrast to conventional power sources, guaranteeing the proficient activity of solar power inverters becomes primitive. This project introduces the improvement in the traditional solar-inverter systems by introducing advance technological features including Maximum Power Point Tracking (MPPT), power prediction based on weather using machine learning model and inverter output parameters visualization on our custom mobile app with enhanced UI via cloud-based data management.

The project involves a design of kit to introduce smart features into traditional invertors by incorporating Maximum Power Point Tracking (MPPT) to enhance efficiency by optimizing the power output from solar panels under varying environmental conditions., propelling their abilities. Also, it integrates machine learning models that are trained on historical data of weather and power generated by solar panels. This model is used to get the anticipated power according to weather forecast. Thereby, improving the management and utilization of energy. To provide users with comprehensive control and insights, a mobile application is developed, offering real-time monitoring of energy production and forecasted power production. This app enables users to track performance, receive alerts, and make informed decisions to optimize their energy use.

SUSTAINABLE DEVELOPMENT GOALS

Goal 7: Enhances solar power efficiency with MPPT and machine learning, ensuring affordable and sustainable energy.

Goal 9: Integrating innovative technologies into solar inverters, promoting resilient and sustainable industrialization.

Goal 11: Offers real-time solar energy management through a mobile app, supporting sustainable urban living.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

Acronyms

ADC Analog to Digital Converter

MPPT Maximum Power Point Tracking

SEM Smart Energy Meter

IOT Internet of Things

DC Direct Current

AC Alternating Current

LCD Liquid Crystal Display

PWM Pulse Width Modulation

PV Photo-Voltaic

Wi-Fi Wireless Fidelity

VI Voltage-Current

MSE Mean Squared Error

MAE Mean Absolute Error

R2 R-Squared

SVR Support Vector Regression

GB Gradient Boosting

SVM Support Vector Machine

SVR Support Vector Regression

API Application Program Interface

ANN Artificial Neural Network

V_{mp} Maximum Solar Panel Voltage

I_{mp} Maximum Solar Paner Current

V_{batt} Output Voltage to the Battery

f_{sw} MPPT PWM Switching Frequency

$\%I_{ripple}$ Maximum Allowable Ripple Current

D Duty Cycle

Ipk Peak Inductor Current

UI User Interface

USB Universal Serial Bus

TTL Transistor-Transistor Logic

BCCU Back-Flow Current Control Unit

UART Universal Asynchronous Receiver-Transmitter

بسم الله الرحمن الرحيم

IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL.

CHAPTER 1: INTRODUCTION

1.1 Problem Statement for the Project:

The environmentally friendly power industry, explicitly in solar based power, has a significant importance: the costly idea of savvy inverters, especially those using Maximum Power Point Tracking (MPPT) innovation. These frameworks every now and again have excessive cost labels, frequently in a huge number of rupees per unit.

Fundamentally, they don't have prescient analysis and mistake analytic elements, which brings about clients being ignorant about potential issues and hampers their ability to improve execution. Also, solar based inverters are not programmable, and that implies that new gadgets should be bought for various purposes. Notwithstanding these hardships, monetarily accessible non-photovoltaic (PV) inverters give negligible or no remote checking or investigating abilities, not to mention prescient bits of knowledge empowered by AI calculations. This feature is the dire necessity for practicality and mechanically progressed arrangements in the solar based energy industry.

1.2 Objectives of the Project:

- Incorporate a Maximum Power Point Tracking (MPPT) unit into a traditional inverter to improve solar based energy and increase framework proficiency.

- Carry out Machine Learning models to examine authentic information and conjecture possible issues or shortcomings in the solar powered energy transformation process, empowering proactive investigating.

- Foster an easy-to-use versatile application to give ongoing checking of the Solar based inverter's presentation boundaries, like voltage, current, and power yield, engaging clients with experiences into framework activity.

- Use cloud innovation to empower remote checking of the solar based energy framework, permitting clients to get information and get alarms from anyplace with Mobile Application.

- Engage clients with complete experiences and command over their Solar based energy frameworks, empowering them to streamline energy age, utilization examples, and framework execution.

- Add to the headway of supportable energy arrangements by advancing the far-reaching reception of Solar based power frameworks through upgraded productivity, dependability, and ease of use.

1.3 Significance of the Study:

This work can possibly upset the field of Solar based energy and advantage people looking to improve the supportability of their energy use.

We are improving regular inverters by consolidating cutting edge innovation, for example, MPPT units and ML models, bringing about solar based power frameworks that are shrewder and more productive than previously.

Our review gives the potential chance to screen the ongoing presentation of your solar powered chargers through your smart phones and get alerts for any important updates, offering a feeling of strengthening. Besides, this isn't exclusively about comfort; it relates to cost reserve funds on upkeep expenses and limiting our natural effect through the advancement of clean energy usage. With the headway of sustainable power advances, we are upgrading existing frameworks, yet additionally affecting the usage of energy utilization later on. This present circumstance benefits clients, the earth, and the persistent advancement of economical innovations.

CHAPTER 2: LITERATURE REVIEW & BACKGROUND

2.1 Literature Review:

A Smart Energy Meter (SEM) is an electronic gadget that incorporates an energy meter chip, information association conventions, security highlights, and an information show interface for analyzing and showing electric energy used by the user [7]. SEM meters are recognized from customary energy meter by their capacity and ability to convey their information. An SEM might follow dynamic power utilization as well as other necessary data of the system for example, voltage and current phasors, responsive power etc. With the advancement of innovation and the utilization of IoT, smart digital meters & other smart systems should be created and integrated to achieve better efficiency, on spot parameters calculation and transmission to the mobile app & cloud and to also achieve user satisfaction. [4]. Such gadgets can be improved with capacities, for example, AI based control strategies [9, 10], visually appealing UI for the ease of user [11, 12], IoT abilities [1] and other extra capabilities [14]. This part presents the new advances in inverter improvement. Environmentally friendly power sources are presently being utilized to address energy requests because of expanded energy interest and contamination brought about by quickly exhausted petroleum derivatives [15]. Solar based energy, which utilizes PV (Photo-Voltaic) modules to produce power, is one of the most broadly utilized sustainable power sources. By charging batteries during the day and afterward using the stored energy in the battery, when the sun isn't sparkling, solar based energy can be utilized to create & store power. [4] introduced a brilliant inverter that speaks with the client in a two-manner way, telling the client of the inverter as well as the run season of the heaps that the client decides to work. Loads are likewise controlled electronically to minimize human intervention and digitalize the already existing technology.

A review distributed in [19] proposed an "IoT-based SEM" for effective energy utilization. It's pivotal for the electrical framework's improvement of a smart grid. Subsequently, the main focus is to analyze & control the power usage of the smart grid. One of the difficulties with the energy meter is the lack of full-duplex transmission therefore the concept of SEM was introduced. An SEM in view of the (Internet of Things) is presented as an answer for this issue. The system computes energy use by utilizing an ESP 8266 12E Wi-Fi module and sends the information to the cloud, where the consumer or client can inspect the results. A smart inverter which is linked to a Raspberry Pi for usage in home was proposed by [20]. The inverter can be controlled utilizing a cell phone; however, it must be connected to the (Wi-Fi). The system includes an Infrared (IR) sensor which displays the status of the appliances that are connect with this system. The status of ON and OFF can be controlled by the user and the state new state is updated in a data set stored in the cloud and showed on a pre-created website. Clients can likewise turn on and off the machines whenever the timing is ideal over the Internet based application as well. A very similar system is created by [21]. The fundamental contrast between these frameworks is that the latter utilizes LCD to display the parameters such as current, voltage and also power utilization and can be controlled utilizing a GSM module. The execution of the SEM can be coordinated into a power grid as examined by [22]. This requires stepping up or stepping down the power supplied to the power grid via the inverter in a way that if the grid voltage is 240V and the inverter supply is 300V, the inverter voltage is converted down to 230 V and vice versa. This is done through a PWM inverter. This kind of inverters can be controlled utilizing a micro inverter control phenomena which basically includes a voltage variable control, Low-Voltage Ride Through (LVRT) and system frequency response [23]. In terms of speech, mobile application control, and smart energy monitoring and allocation, the proposed technique in this study varies from the audited significant examinations. When contrasted with the examination in [20 - 22], the framework's technique for control is a web application and voice control by means of Bluetooth equipped for controlling the inverter somewhat through (Wi-Fi), which utilizes low energy thus avoiding the waste of energy and overall reducing carbon emissions. The innovation likewise assists with keeping away from energy robbery or abuse by limiting notices and managerial control to just the fitting clients.

2.2 Background of DC-AC Inverters:

A DC-AC inverter is a device which converts a stable & constant DC signal to an alternating AC signal, the Inverter makes use of precise switching of the signal to devise the positive and negative cycles of the sinusoidal wave.

2.2.1 Advantages of Sine Wave Inverters

1. Sine Wave

A sine wave or unadulterated or genuine sine wave Inverter gives waveform that you get from Hydroelectric power or from a generator. The significant benefit of a sine wave inverter is that the hardware which is all sold available is intended for a sine wave. This ensures that the hardware will attempt to its full particulars.

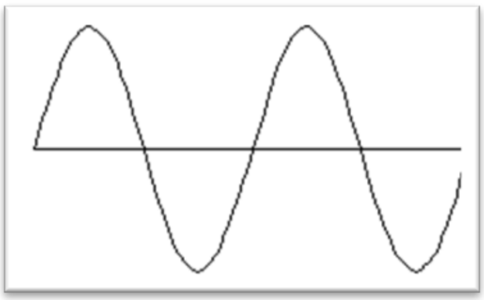


Figure 1: A True Sine Wave Depiction [32]

Some appliances like bread makers, light dimmers, and some battery chargers require a sine wave to work. Pure sine wave inverters are more complex and cost more.

2. Modified Sine Wave

A modified sine wave inverter actually has a waveform more like a square wave, but with an extra step or so. A lot of equipment will work well on modified sine wave inverters, including motors, household appliances and other items. Some types of loads can be problematic and do require a pure sine wave converter.

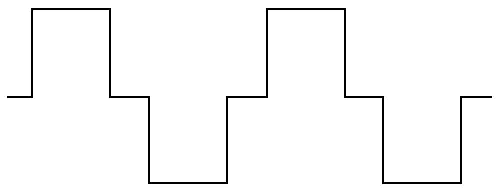


Figure 1.1: A Modulated Sine Wave Depiction, [32]

3. Square Wave

A square wave is very simple, with the d.c. supply switched between positive and negative. There are very few, but the cheapest inverters are square waves. A square wave inverter will run simple things like tools with universal motors without a problem, but not much else.

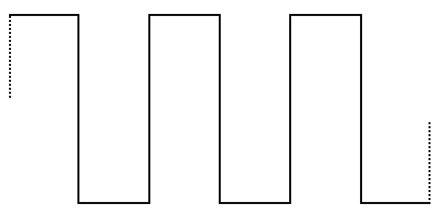


Figure 1.2: A Square Wave Depiction, [32]

2.2.2 What Is An MPPT And Why It Is Important To Solar Panels?

Maximum power point tracking (MPPT) is a technique used with energy sources with variable power, like solar panels, to maximize energy harvesting! An MPPT solar charge controller is an essential device for solar setups. MPPTs are intelligent DC-DC converters. They regulate current and voltage to safely charge batteries and power inverters. Aside from regulation an MPPT uses a clever algorithm that tracks a solar panel's maximum power point. The proper explanation gets technical but the easiest way to put it is

"Using an MPPT for solar, helps you gather the most energy your solar panels can provide"

2.3 Working of an MPPT.

MPPT, or Maximum Power Point Tracking, is a critical technology in solar power systems that optimizes energy conversion efficiency. Its operation revolves around continuously adjusting the operating conditions of a solar panel to ensure it operates at its maximum power point (MPP).

At its center, MPPT includes observing the result voltage and current of the solar powered charger and contrasting them and anticipated values at different working places. By investigating this information, the MPPT regulator progressively changes the working circumstances, frequently through fluctuating the obligation pattern of a buck or lift converter, to follow the MPP.

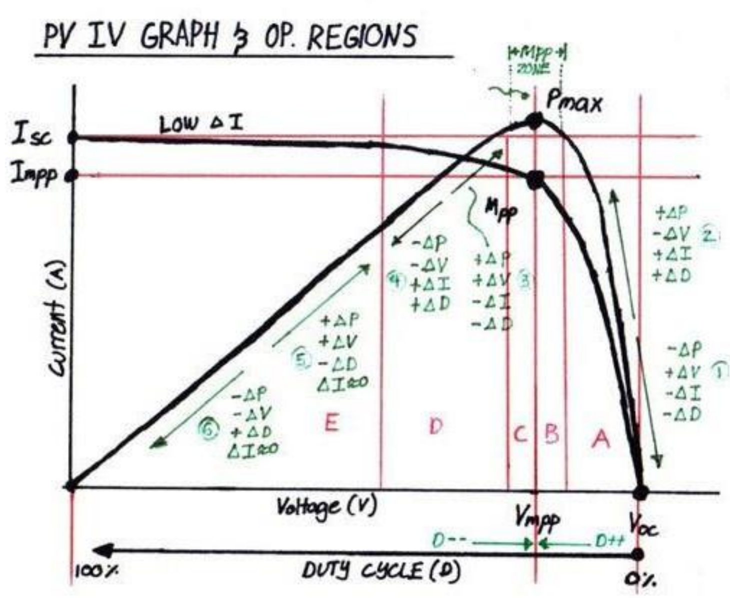


Figure 2: A Hand-Drawn VI Curve for a Generic Solar Panel. [33]

To outline, think about the Voltage-Current (VI) bend of a solar based charger. This bend portrays the connection among voltage and current result under changing states of daylight power and temperature. At a particular point on this bend, known as the MPP, the solar based charger produces the most extreme power yield. By changing the obligation pattern of the converter, the MPPT framework looks to keep up with the working place of the solar powered charger at or close to this MPP.

For instance, when the duty cycle is increased, more power is transferred from the solar panel to the load, causing the operating point to move along the VI curve towards higher power output. Conversely, decreasing the duty cycle shifts the operating point towards lower power output.

By continuously adjusting the operating conditions to track the Maximum Power Point, the MPPT system ensures that the solar panel operates efficiently under varying environmental conditions, maximizing power output and overall system performance.

Also, in the prementioned VI-Curve notice how the Voltage and Current both are maximum at a specific time, the MPPT system keeping this in record, aligns the duty cycle as to create the maximum output possible, keeping the losses in check.

2.4 Issues in Commercially Available MPPTs:

The commercially available MPPTs are no doubt robust and up to the par, but from an engineering perspective they do not offer the features and technologies one can offer withing the price bracket of these MPPTs, moreover the Commercially available MPPTs are completely analogue in nature, having fixed PWM generation and are fixed to a certain input and output voltages.

The commercially available MPPTs are not programmable or flexible to any degree hence no change regarding the I/O of the MPPT can be changed neither can they be applied to systems of varying form factors.

Another major issue with the commercially available MPPTs is that they are all based on Asynchronous Buck designs which are easier to produce and manage but offer lesser efficiency and more losses due to heat and leakage currents than synchronous buck designs.

The commercially available MPPT's are volatile in nature as they offer no protection or safety precautions in their design. For instance, if you apply a higher than rated voltage on a commercially available MPPT it is at the risk to having permanent damage to the MPPT, PV Panels due to reverse currents & the Batteries due to overcharge or different than recommended charging patterns.

2.5 Flexibility of the Project.

The Main Feature of the project is to design an MPPT controller to convert any basic Inverter to a Smart Solar Inverter.This means that with slight simple modifications in the firmware code of the MPPT, which quite simply can be uploaded through a software update to update the code, we can change its input and output voltage ranges and by minute Hardware changes we can also change the max power range of the MPPT.

This means that the MPPT being designed is robust and yet flexible to changes as per the requirements, which would be helping in the further development of this Project and make working with the MPPT much easier and user friendly.

The MPPT in the project can be connected to any battery type be it Li-ion, LiFePO4, Lead Acid, NiCad or Tubular Batteries, the MPPT just has to be programmed for the battery type and charges all the battery types to their recommended charging currents and charging patterns

2.6 Machine Learning Algorithms:

Machine Learning in Solar Energy Forecasting:

The advent of machine learning (ML) techniques revolutionized solar energy forecasting by leveraging data-driven approaches. ML algorithms, such as support vector machines (SVM), artificial neural networks (ANNs), random forests, and gradient boosting machines (GBMs), excel in capturing nonlinear relationships and patterns from historical weather data.

Hybrid Forecasting Approaches:

Hybrid forecasting for determining strategies join the qualities of actual models and ML based calculations. These methodologies incorporate actual boundaries (e.g., solar powered calculation, overcast cover) with authentic climate information to further develop anticipating exactness. Two step models are especially viable in taking care of nonlinearities and vulnerabilities intrinsic in solar powered energy expectation.

Data Sources:

One of the basic progressions in solar based energy determining is the combination of reciprocal information sources. Customarily, gauges depended entirely on noticed climate information or expectations from meteorological offices. Notwithstanding, consolidating the two sources — real perceptions and determined information — offers a more complete and precise reason for expectations.

Two-Step Prediction Process:

A clever methodology building up forward movement is the two-step expectation process. This strategy includes:

1. Base Model: Using weather conditions estimates to foresee solar-oriented power age.

2. Assistant Model: Consolidating extra factors (e.g., solar-based radiation) for improving prescient exactness.

Machine Learning Algorithms for Solar Energy Forecasting: Various ML algorithms are applied in solar-based energy prediction:

Decision Tree: Gives standard forecasts considering direct connections.
Support Vector Regression (SVR): Successful in taking care of nonlinearities and complex datasets.
Random Forest: Multiple decision trees to improve accuracy.
Gradient Boosting: Model complex connections and examples through interconnected layers of hubs.
Ensemble method: Join various models for updated perceptive power.

1. Joining of Constant Information: Upgrading models to integrate ongoing weather conditions refreshes for dynamic anticipating.

2. Vulnerability Measurement: Creating techniques to evaluate and relieve vulnerabilities in solar-based energy prediction.

3. Model Interpretability: Upgrading the interpretability of ML models to work with decision-production for lattice administrators.

4. Information Combination Methods: Investigating progressed information combination procedures to coordinate assorted information sources flawlessly.

CHAPTER 3: METHODOLOGY

3.1 Introduction:

This chapter focuses on the system architecture and design of the smart solar inverter monitoring and troubleshooting with predictive insights. It outlines the components, connectivity, and integration of electronic components, the making of the Schematics and its working, communication protocols, deep learning models, and the 3D box design for deployment.

3.2 System Architecture:

The system architecture for the smart solar inverter monitoring and troubleshooting with predictive insights is based mainly on an MPPT to control the input solar power and perturb it to maximum possible value.

The MPPT itself keeps a check on the voltages & current of the Solar Input and the output voltages & current to the battery hence in case of any issues the MPPT will be responsible for monitoring and troubleshooting the Issues that arise.

The kit after perturbing power and safety checks relays the information to a mobile APP through wireless telemetry to keep the user aware of the proper working of the Inverter and keeping sure that are the issues are reliably relayed to the end user. The kit also offers onboard display of the required information and gives real time perturbation and nominal duty cycle values to check for the kit's efficiency in the said time.

The kit also uses complex machine learning algorithms using weather data to predict the production hence giving the user a foresight to their power generation, this also allows the end user to analyze their load patterns accordingly.

3.3.1 Block Diagram:

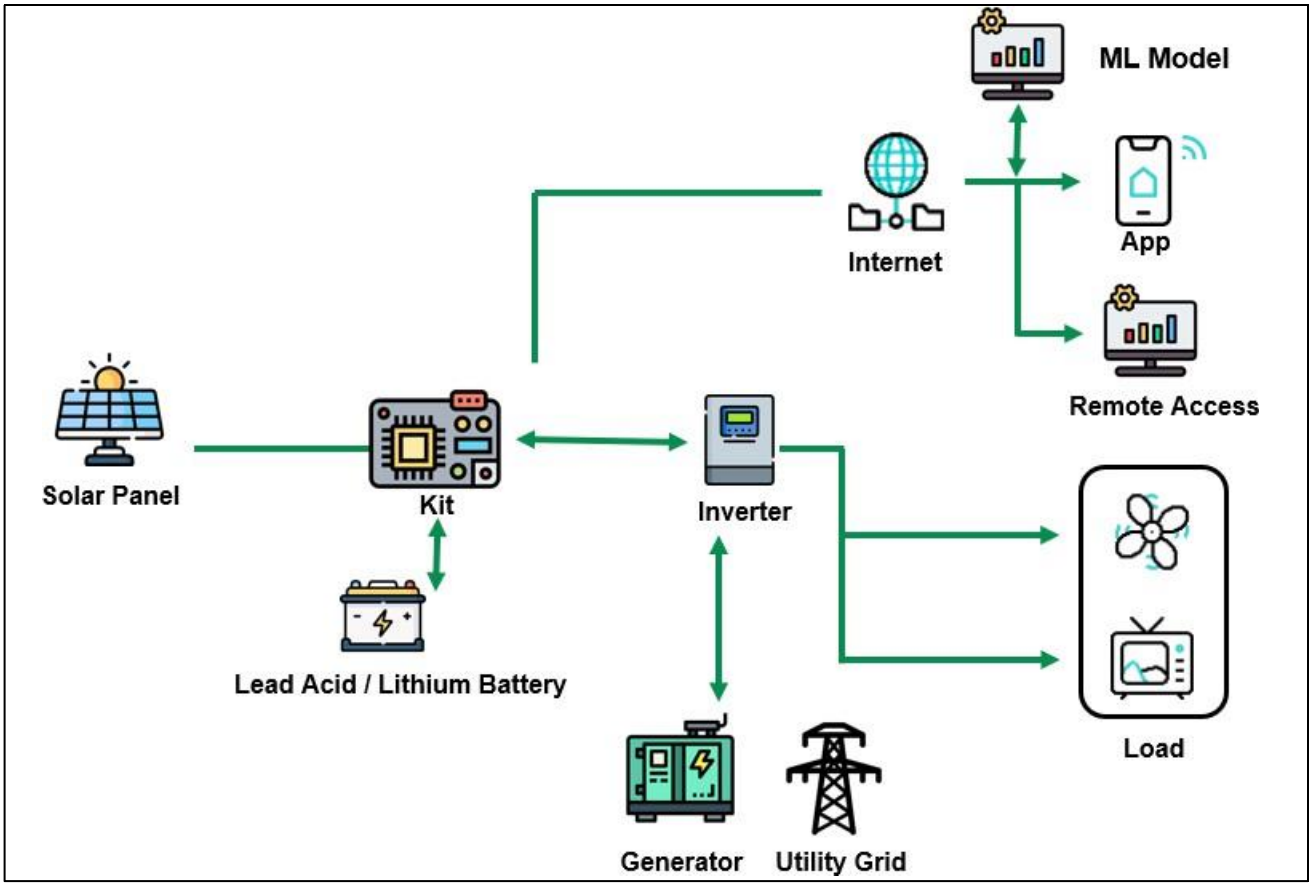


Figure 3: Project Block Diagram

3.4 System Design:

For easier understanding of the system design, we shall divide the project into its parts and shall explain each part's design separately, following are the system parts

1. MPPT Calculations
2. MPPT Fabrication

3. ESP-32 microcontroller programming
4. Construction of the casing using CAD.
5. APP Development
6. Communication Protocols
7. Machine Learning Algorithms for Predictive Insights

We shall discuss each of the following in detail

3.4.1 MPPT Calculations:

When designing an MPPT the main things that should be accounted for are the operating voltages and currents, which would define the power range of the MPPT controller hence we delve into the design parameters for the MPPT controller.

In Order for the MPPT controller to be designed we first need to find out the inductor and capacitor values for smooth operation of the LC filter in the range. The inductor current rating that one would often find in prebuilt inductors refer to something called the inductor saturation current. This refers to the applied DC current at which the inductance value drops a specified amount below its measured value with no DC current.

Some manufacturers will rate their parts for a 30 % drop in inductance. Remember that inductors are predominantly fast energy storage devices. Energy is stored through a magnetic field generated by the current flowing through the inductor. Materials can only store a specific amount of energy an inductor can take in. When an inductor can no longer absorb energy, the inductor saturates as the inductance decreases as well.

Building an inductor and getting the required number of turns to get the required inductance is easy! But determining the inductor current from one’s toroidal inductor design is something that has haunted engineers.

So, to calculate the inductor design for an operational range of 80V 13.13A & the following design parameters

1. $V_{mp} = 80V$ (Maximum Solar Panel Voltage)
2. $I_{mp} = 13.13V$ (Maximum Solar Paner Current)
3. $V_{batt} = 50V$ (Output Voltage to the Battery)
4. $f_{sw} = 39kHz$ (MPPT PWM Switching Frequency)
5. $\%I_{ripple} = 35\%$ (Maximum Allowable Ripple Current)

Power:

We use the following formula to calculate the Power Rating:

P=VI.. (1)

The rated voltage and current tell us that the predominant output of the MPPT is maximum at 1050W or 1KW.

Ripple:

Now knowing the power rating of the MPPT we can move toward the calculations of the ripple current. The ripple current is defined as the maximum continuous current through the MOSFETs.

To calculate the ripple current of the MPPT

$$I_{ripple} = \frac{V_{mp} \times I_{mp}}{V_{batt}} \times \frac{\%I_{ripple}}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Upon plugging in the values, we get

$$\boldsymbol{I_{ripple} = 7.35A}$$

Duty Cycle:

We now move toward the calculation of the duty cycle for the MPPT we use the following formula

$$D = \frac{V_{batt}}{V_{mp} \times 0.96} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

We use 96% target efficiency as 100% efficiency is not possible.

We get Duty Cycle to be: p

D=0.65104 or 65.104%

Peak Inductor Current:

The peak inductor current is the maximum current passing through the inductor.

$$I_{pk} = \frac{P}{V_{batt}} + \left(\frac{P}{V_{batt}} \times \frac{\%I_{ripple}}{2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

We get the value for peak inductor current as **24.68 A.**

Inductance:

Find a suitable toroidal core (T-130 or larger). Yellow #26 iron powder core material is a common choice for the toroidal cores used in buck regs (you can go with these). Although we went with a sendust (Kool Mµ by Magnetics Inc.) since it is known to have 40-50% lesser core losses than of the regular iron powder core material.

$$I = V_{mp} - V_{batt} \times \frac{\frac{V_{batt}}{V_{mp} - 0.96}}{f_{sw} \times \frac{P}{V_{batt} \times \%I_{ripple}}} \times 10^6 \ldots\ldots\ldots\ldots \text{(5)}$$

We get the required inductance as **68.1 uH**

Capacitance:

For the LC filter we also need to find a specific capacitance to resonate with the inductor. To calculate it we get the formula as.

$$C = \frac{V_{mp} \times I_{mp}}{V_{batt}} \times \frac{\% I_{ripple}}{8 \times f_{sw} \times 1000 \times V_{ripple}} \times 10^6 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

We get the capacitance as: **471.3 uF.**

3.4.2 MPPT Design:

Two designs for a buck regulator:

1. The asynchronous buck converter is frequently employed in various applications. It typically operates with an efficiency ranging from 75% to 87%. However, it is not the most energy efficient option due to significant power loss caused by the presence of a diode. Nevertheless, it is a straightforward and uncomplicated converter to implement. These Types of Buck Converters are easy to operate and modify but due to their inefficiency they are omitted here.

2. A synchronous buck converter is a type of electrical device which uses a MOSFET instead of a diode , these are much more uncommon but are exceptionally energy efficient because Power loss minimized by substituting the Diode with a MOSFET, these types of buck converters provide a standard efficiency of 88-98% , however designing this type of buck converters can be a challenging task to do without prior expertise.

1. Utilizing an external Analog-to-Digital Converter (ADC):

In order to address the problem, it is advisable to employ an external I2C ADC that offers exceptional accuracy. We have chosen the ADS1115 produced by Texas Instruments. The goal of utilizing an external ADC (Analog-to-Digital Converter) is to convert analog signals into digital format for further processing or analysis. These specialized external ADCs were purposefully designed to exclusively perform the function of converting analog signals to digital signals, and they demonstrate exceptional performance in this role. Notice the presence of unpredictable variations in sensor measurements when they are linked to an Arduino Uno. It is advisable to employ an external analog-to-digital converter (ADC) to minimize and reduce the occurrence of variations in the recorded values.

The ADS1x15 ADCs are supplied with a built-in internal voltage reference. This suggests that the voltage source of your ADC does not have an impact on the readings of your analog values. This decreases its susceptibility to electrical interference in the power source of a system. The device includes a built-in programmable operational amplifier, which enables the user to choose between several levels of amplification. The most notable characteristic of the ADS1115 is its 16-bit ADC resolution. The data is encoded with a 16-bit representation and has a sampling rate of 860 samples per second. A 16-bit system would offer a numerical range of 65,536 to accurately represent various voltages and currents. This exceeds the Arduino Uno's analog-to-digital converter (ADC) by a factor of 64. The MPPT configuration presently offers a voltage sensing resolution of 1.22 millivolts and a current sensing resolution of 0.457 milliamperes. It operates at 80 volts and 30 amperes.

The subject under consideration is the selection between the ADS1115 and ADS1015.
The main question is which one is essential. While the chips may possess somewhat varied specifications, they are nonetheless compatible for usage with Adafruit's Arduino ADS1x15 library. Whether the ADS1115, which provides a resolution of 16 bits and a sampling rate of 860 samples per second, or the ADS1015, which has a resolution of 12 bits and a sampling rate of 3,300 samples per second? The ADS1115 was unnecessary for this project, as its resolution surpassed the criteria for measuring 80V 30A. We opted to employ the ADS1015 for the thorough examination and documentation of the full project.
Both the ADS1015 and the ESP32 include a 12-bit resolution for their Analog-to-Digital Converters (ADCs). Nevertheless, there can be compelling justifications to choose the ADS1015 over the ESP32, despite their similarities. The resolution lies in achieving stability. We produced numerous variations of the board. After doing experiments with the Arduino Nano, Arduino Uno, and ESP32 microcontrollers, we observed that their analog-to-digital converters (ADCs) lack the same degree of reliability as a dedicated external ADC such as the ADS1x15. Although efforts were made to improve stability by unlocking the internal ADC Vref of the ATmega328P and ESP32, the performance remained subpar compared to an external ADC. It is crucial to

acknowledge that because to the enhanced PWM resolution, precise detection of minor fluctuations in voltages and currents is now essential for the flawless operation of the MPPT perturbation approach. Even minor disruptions and unintentional motions in the sensor readings greatly affect the tracking of the Maximum Power Point (MPP). It is strongly advised to utilize an ADC.

2. Benefits of utilizing an ESP-Wroom-32 module:

The WROOM32 module is very economical. It is Arduino-compatible, enabling you to utilize it in the same manner as any other Arduino board! The ESP32 is a powerful and reliable microcontroller with two 32-bit cores that operate at a high speed of 240MHz. The device is equipped with built-in WiFi and Bluetooth capabilities, avoiding the need to buy expensive modules.

The crucial factor was the 16-bit PWM resolution. A greater pulse width modulation (PWM) resolution is strongly favored in a buck converter-based maximum power point tracking (MPPT) system. Higher resolution leads to less increments of voltage and current. Reducing the bit resolution of the PWM allows for an increase in the PWM frequency.

3.4.3 The Code Prospects:

It is of the utmost importance that the MCU handles the technical part of the MPPT well. As explained earlier the External 1015 ADC allows highly quantized values for the voltages and currents to make quick and robust changes to handle the power point tracking.

The code of the MCU enables it to do the following things

1. Main Firmware
2. Reading sensors
3. Device protection
4. Charging Algorithms
5. Handle system processes.

6. On-board telemetry
7. LCD Menu

3.5 Data Collection for Machine Learning:

Data collection is an important first step that lays the foundation for accurate and reliable solar energy models. This section describes the general approach adopted in collecting , atmospheric properties and solar energy data for analysis and modelling.

NASA Power API, gives the detailed weather data needed for solar power forecast.

Data Extraction Process: The data extraction process involves notifying the NASA Power API using specific parameters such as geographic coordinates. Depending upon the location. By specifying the desired time range (historical data) or getting real-time updates, the API delivered weather-related data at regular intervals, ensuring a detailed dataset for analysis.

Solar Data Collection In addition to meteorological features: Solar data is collected directly from solar energy inverters installed at the project site. Solar inverters are important components in converting. Solar energy into usable electricity, providing instantaneous energy production at regular intervals.

This synchronization helps combine weatherrelated variables (temperature) with relevant producer to create compound data for analysis. Good security needs to be checked and information provided first. This includes data cleaning to remove replacements or invalid entries, normalization for different data, and electronic devices to optimize solar forecast models. Weather signatures and solar data are securely stored and optimized for easy data management. Using appropriate data storage

solutions ensure accessibility, scalability and integrity throughout the analysis and modeling process.Collect solar data from inverters in the field. Through careful synchronization, integration, andprioritization, the best information is created and forms the basis for ensuing observations, models, and solar forecast studies.

3.6 Data Preprocessing:

The information preprocessing step is significant in changing crude information into a coordinated organization appropriate for quantitative displaying and examination. This segment makes sense of the broad preprocessing steps taken to set up the dataset for exact solar powered energy gauging.

1. Evacuation of Month and Year Sections: The dataset went through refinement by eliminating the repetitive Month and Year segments. Since these factors didn't straightforwardly add to the prescient displaying of solar based power age, their avoidance smoothed out the dataset for centered investigation.

2. ONE-HOT Encoding for Clear cut Factors: Elements inside the atmospheric conditions' figures, including strain and Wind Speed, were encoded using the ONE-HOT encoding procedure. This change changed over straight-out factors into various twofold factors, each tending to an undeniable arrangement or level inside the principal part. This approach ensured comparability with estimations that require numerical data.

3. Production of Week Record Variable (Weeknum): To catch occasional varieties and worldly examples, seven days List variable (Weeknum) was created. This variable efficiently doles out a list to every week all through the dataset, traversing from the underlying week to the last seven day stretch of every year. This ordering works with the demonstrating of occasional patterns (summer and winter) and vacillations in solar oriented energy yield.

4. Consolidation of Season of-Day Data (TimeZone): Perceiving the significance of season of-day on solar-based irradiance and power age, the TimeZone variable was utilized. This variable sectioned the day into hour stretches. By consolidating time-subordinate data, the dataset became loaded up with information setting fundamental for determining.

5. Removal of Outliers from the data: In the underlying stage, a subjective information examination was finished to recognize and address absent or adverse outcomes. Missing focuses are determined utilizing proper methods (like mean attribution) to guarantee the exactness and culmination of the informational index. Anomalies are additionally distinguished and eliminated for additional investigation.

6. Transformation Scaling and Standardization Scaling methods like Min-Max scaling or Z-score standardization are utilized to quantify the scale and scope of numbers. This standardization cycle builds the assembly and productivity of AI models by lessening the significance of the upsides of the preparation test.

7. Data Integration and Validation After pre-processing, the converted data from weather forecasts and solar measurement are combined into a combined file. This combination of data is validated to verify data consistency, compliance with recording restrictions, and compliance with project objectives. Validation checks include cross-validation procedures to assess the robustness and generalizability of the model.

8. Documentation and Metadata It comes with detailed information about data preprocessing, preprocessing steps, transformations, and data structures. Metadata describing each variable, coding scheme, and results for the solar forecast are documented to facilitate clarity, repeatability, and interpretation of the modeling process.

Problem Statement:

In this study, our aim is to build a model that predicts solar power generation one day ahead of the actual operation. The base model identified the best function f^* in which the predictors were limited to the weather forecast variables.

$$f^* = argmin_f \; L\left(y_{t+1}, \widehat{y}_{t+1}\right) \text{ s.t. } \widehat{y}_{t+1} = f\left(\widehat{\mathbf{F}}_{t+1|t}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$

where **F**t**+1|**tF^t**+1|**t

is a vector of weather forecasting available at day (t) and targeted for day $t + 1$ (The hat notation emphasizes that this quantity is forecasted.

yt+1yt+1

is a quantity of power generation at day $t + 1$, and LL is a cost function where this study adopted the measure of Mean squared error (MSE) as a popular model.

Though a few variables in weather observation were missing in weather forecasts, this study aimed to fully exploit weather information for building prediction process. That is, the weather observation variables were predicted using weather forecast variables. This auxiliary model aimed to find the best performing function $g*$, such as

$$g^* = argmin_g \, L\left(\mathbf{O}_{t+1}, \widehat{\mathbf{O}}_{t+1}\right) \text{s.t. } \widehat{\mathbf{O}}_{t+1} = g\left(\widehat{\mathbf{F}}_{t+1|t}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(8)}$$

Where $\mathbf{O}t+\mathbf{1}Ot+\mathbf{1}$ is a vector of weather observation variables that are known to be related to solar power but not included in weather forecast.

Finally, the main model aimed to use the two previous models by including both

1. **State Prediction:**
   $$\hat{F}_{t+1|t} = AF_t + Bu_t \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(9)}$$
2. **Observation Prediction:**
   $$\hat{O}_{t+1} = C\hat{F}_{t+1|t}$$

as predictors.

The main model identified the best function $h*$ such that

$$h^* = argmin_h \, L\left(y_{t+1}, \widehat{y}_{t+1}\right) \text{s.t. } \widehat{y}_{t+1} = h\left(\widehat{\mathbf{F}}_{t+1|t}, g^*\left(\widehat{\mathbf{F}}_{t+1|t}\right)\right) \quad \ldots\ldots\ldots\ldots\ldots \text{(10)}$$

where $g*$ is obtained from the auxiliary model.

The base model provides a baseline for comparisons to the main model, which includes generated predictors. Since predictive relationships are complex and difficult to grasp, this study tests several machine learning algorithms, such as linear regression, SVR, GBM etc. which are suitable for the structure of the data and the problem. Before applying the machine learning algorithms, proper scaling is performed. Specifically, distance-based methods, including GBM and SVR, called Z-score normalization, in order to carry comparable importance in model generation process. To calculate Z-score, each variable x is subtracted by its mean μ and divided by its standard deviation σ, that is, $z = (x - \mu)/\sigma$. RNN needs a min-max scaling to a bounded range, such as between 0 and 1, in these experiments. The normalized value can be calculated by $(x - min(x))/(max(x) - min(x))$. This step is necessary so that all variables are in a comparable range before fed into a network.

3.7 Data Characteristics:

1. **Hour**: This column represents time, typically ranging from 0 to 23H for a 24-hour format. The values are integers representing different hours of the day.
2. **Temp (Temperature)**: If the temperature is perfect in your data set, this means you will use Celsius or Fahrenheit regardless of negative temperature (below zero). For example, if you are dealing with the outside temperature recorded in the climate zone, you will find that most of the results are good.
3. **Dew (Dew Point)**: Like temperature, dew point can be positive or negative. Dew point is the temperature at which air becomes saturated and dew forms. If the dew point values are all positive, this means that the temperature has not yet fallen below the dew point in the data set. This may be due to the nature of the data set (i.e. it covers an area where the dew point is higher than the temperature).
4. **Humidity**: Humidity values are typically expressed as percentage, ranging from 0% (dry) to 100% (saturated with moisture). Humidity values are always positive (+), representing the amount of moisture in the air relative to its max capacity.
5. **Pressure**: In air and in most engineering environments, pressure is expressed as an absolute value (e.g. in pascals or millibars), which is always fine. But in air pressure readings they are generally positive.
6. **Wind Speed**: Wind speed is a scalar quantity representing the speed of wind flow. Wind speed values are typically positive, representing the magnitude of the wind regardless of direction.
7. **Power:** The power value can be positive only; it shows how much power is produced in that specific hour by the solar panels.

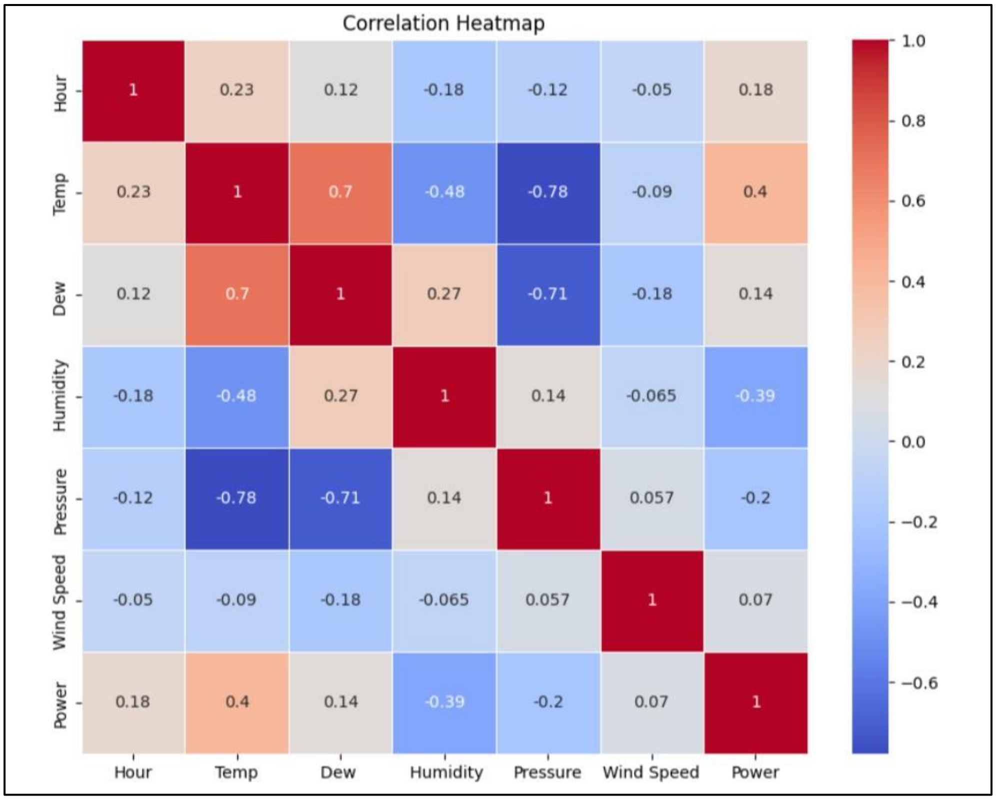


Figure 4: Correlation Heatmap

1. **Hour Histogram:**

- The histogram for the 'Hour' column shows the distribution of hours in your dataset.
- Each bar in the histogram represents a range of hours (e.g., 0-1, 1-2, ..., 22-23).
- The height of each bar indicates the frequency or count of data points falling within that hour range.
- A taller bar shows that more data points are around that particular hour range.
- This histogram helps see the patterns across different hours, which can be useful for understanding trends in the data.

2. **Temp (Temperature) Histogram:**

- The histogram for the 'Temp' or Temperature column displays the distribution of temperature values in the dataset.

- Each bar represents a range of temperatures (e.g., 0-10°C, 10-20°C, ..., 30-40°C).
- The height of each bar indicates how many data points are falling within that range.
- A taller bar signifies that more data points of temperature are within that particular temperature range.
- This histogram allows us to see the spread of temperatures and identify any dominant temperature ranges or outliers.

3. Dew (Dew Point) Histogram:

- The histogram for the 'Dew' column shows the distribution of dew point values.
- Like the Temp histogram, each bar here also represents a range of dew point values.
- The height of each bar indicates the frequency (Number of) of data points having dew points within that range.
- A higher bar suggests that more data is falling within that specific point range.
- This histogram helps in knowing the range of number of dew points in the dataset and identify common ranges.

4. Humidity Histogram:

- The histogram for the 'Humidity' column shows how much values are across the dataset.
- Each bar represents a range of humidity percentages (e.g., 0-10%, 10-20%, ..., 90-100%).
- The height of each bar indicates the number of data points with humidity values falling within range.
- Heighted bars show more data points percentages within that ranges.
- This histogram assists in seeing the distribution of humidity and getting any humidity values within certain ranges.

5. Pressure Histogram:

- The histogram for the 'Pressure' column gives the spreading of pressure values in the main dataset.
- Each bar represents a range of pressure values (e.g., 900-950 mb, 950-1000 mb, ...).
- The height of each bar shows how many data points have pressure readings within that range.
- Heighted bars indicate a higher frequency of data points with pressure values within those specific ranges.
- This histogram helps in knowing the distribution of pressure readings and identify the common pressure ranges or outliers.

6. Wind Speed Histogram:

- The histogram for the 'Wind Speed' column shows how much WS values are distributed in my dataset.
- Each bar represents a range of values (e.g., 0-5 m/s, 5-10 m/s, so on).
- The height of each bar indicates the frequency of data points falling within that range.
- More height bars suggest a higher frequency of data points having wind speeds within those wind speed ranges.
- This histogram helps us visualize the distribution of wind speeds and identify changing wind speed ranges or variations.

7. Power Histogram:

- The histogram for the 'Power' column shows the distribution of power values in my dataset.
- Each bar represents a range of power values (e.g., -100 to -90, -90 to -80, ..., 90 to 100).
- The height of each bar indicates the frequency of data points with power values falling within that range.
- Taller bars signify a higher frequency of data points having power values within those specific power ranges.
- This histogram helps in showing the spread of power values and identify common ranges.

By examining the histograms, we can gain visions into the spread patterns, tendencies, and variety of each variable in the dataset.

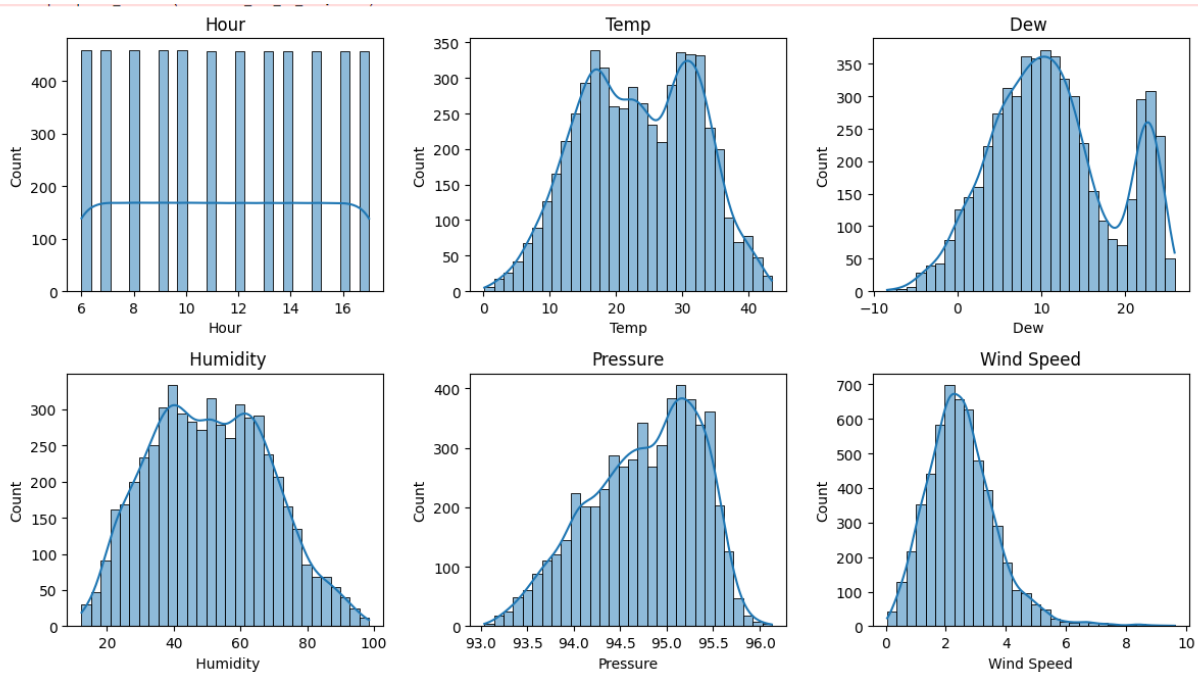


Figure 4.1: Parameter Values

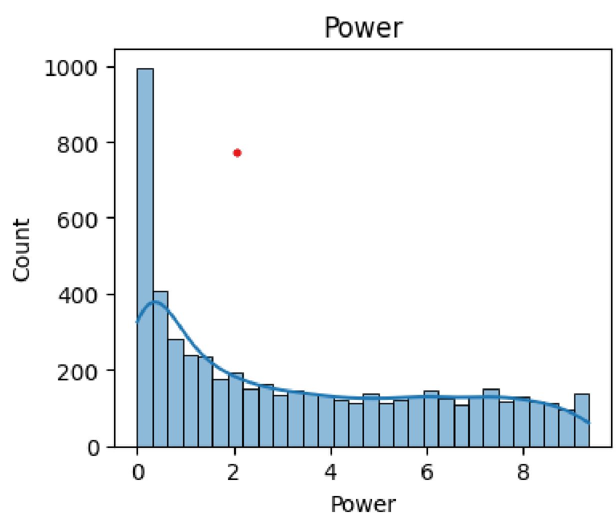


Figure 4.2: Power Graph

3.8 Machine Learning Model:

1. **Decision Tree Algorithm**:

    - Decision tree regressor algorithm builds regression models in a tree structure (step) format.
    - It divides the dataset into smaller sub-groups based on feature values, that creates decision nodes.
    - Each decision node depends on decision based on a feature, that leads to further splitting until reaching leaf nodes with the predicted values of model.
    - Grouping data by time (Hour) can improve prediction accuracy by capturing time-based patterns and trends that decision trees can learn from.

2. **Gradient Boosting Regressor**:

    - Gradient boosting is an ensemble model that builds a step wise algorithm that uses decision trees as weak learners.
    - It optimizes a loss function by repetition method, adding models that corrects error made by the previous models by learning through their errors.
    - Each successive model focuses on reducing the residual errors of the combined model (whole model) altogether.
    - Time-based grouping can enhance prediction accuracy by allowing the model to get temporal data (dependencies) and sequence patterns.

3. **Random Forests**:

    - Random forests are based on ensemble learning, combining multiple decision trees (stacking) to improve accuracy of the model.
    - Each tree in the Random Forest model is trained on a random subset-group of data and features, reducing overfitting (over learning) of the model and improving randomization of the data.

- Random forests compiles predictions from individual trees to make final predictions.
- Grouping data by time can benefit random forests by capturing the time-based relationship and abundancy in the data.

4. **Linear Regression**:
    - Linear regression is a supervised learning algo that finds the linear relationship between input variables (x) and output variable (y).
    - It assumes a linear relationship between x and y variables and estimates coefficients to fit a straight line that represents the data.
    - Time-based grouping can increase linear regression predictions if there is a clean linear trend or relationship between variables over time (x and y variables).

5. **Support Vector Regression (SVR)**:
    - SVR is also a supervised learning algorithm used for regression problems.
    - It predicts continuous values by finding the suitable fit line (hyperplane) that maximizes the margin between data points and the hyperplane.
    - SVR (Support Vector Regression) follows the same methods as Support Vector Machines (SVM) but for regression problems.
    - Grouping data by time can help SVR get time-based patterns and improve its ability to model nonlinear relationships over time.

In summary, grouping data by time can significantly improve the accuracy of predictions made by these machine learning models. Time-based grouping allows the models to get temporal dependencies, seasonal patterns, and trends that are important for accurate predictions in time series or temporally structured datasets. Each of the mentioned models has its own strengths and suitability depending on the nature of the data and the underlying relationships between variables over time.

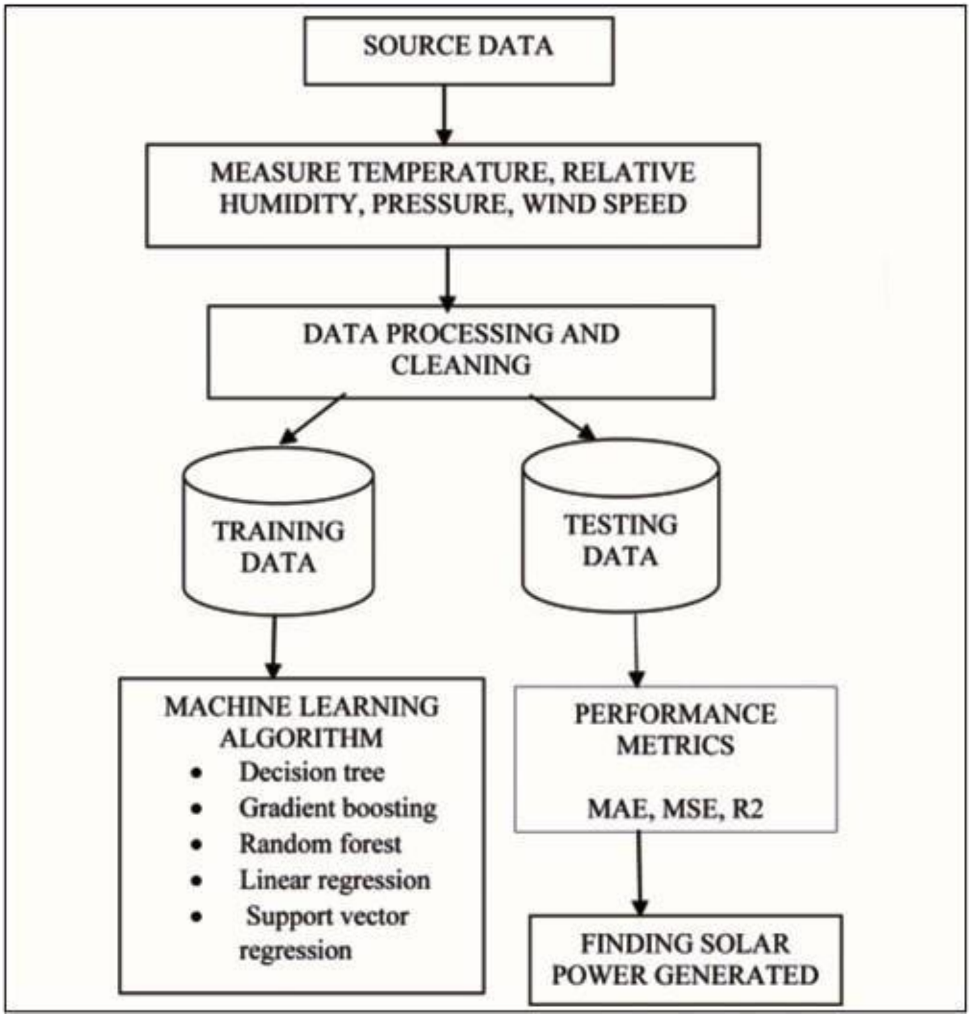


Figure 4.3: Machine Learning flow diagram

CHAPTER 4: IMPLEMENTATION

4.1 Introduction:

In this Chapter we shall move towards actually implementing the acquired knowledge about the Smart MPPT, On-board and Wireless telemetries and the working of MPPT and designing it

We shall focus more on the technical aspects of this project rather than indulging in the theoretical background of the said project which has already been explained in the previous projects.

This chapter also deals in the hardware portion of the Project, subjecting to the implications of electrical components, their usage and reasons for using certain components.

4.2 Hardware Implementation:

The equipment execution of the Savvy man-made intelligence based telehealth checking framework involves incorporating and designing a few parts and gadgets to work with the get-together and transmission of fundamental signs information.

The following is an itemized depiction of the equipment execution:

1. The ESP32 microcontroller capabilities as the framework's focal handling unit. It has the advantage of synchronizing the elements of the different equipment parts. The ESP32 is chosen for its capability in remote correspondence, information handling, and energy productivity.

2. The framework utilizes various sensors to compute the essential boundaries. The sensors utilized in this framework might comprise of a temperature sensor, an ACS-712-30A current sensor, and voltage dividers. The sensors are connected to the ESP32 chip, as a rule through simple or computerized interfaces.

3. The framework coordinates a few correspondence modules to work with the transmission of information. These modules might integrate Wi-Fi network. Wi-Fi empowers remote correspondence over a particular reach,

4. A 3D box or nook is made to contain and shield the equipment parts in an easy-to-understand way helpfully. The plan of the walled in area ought to focus on elements like cost, ease of use. The plan ought to work with simple admittance to the sensors and assurance successful intensity scattering through adequate ventilation.

5. The equipment execution requires right wiring and associations, which are urgent. It is important to accurately interface the sensors, microcontroller, correspondence modules, and power supply parts, sticking to the specified electrical and information association principles. This involves ensuring the respectability of signs, restricting obstruction, and tying down associations with stay away from detachments or free associations while in activity.

4.2.1 The Complete Schematic Diagram:

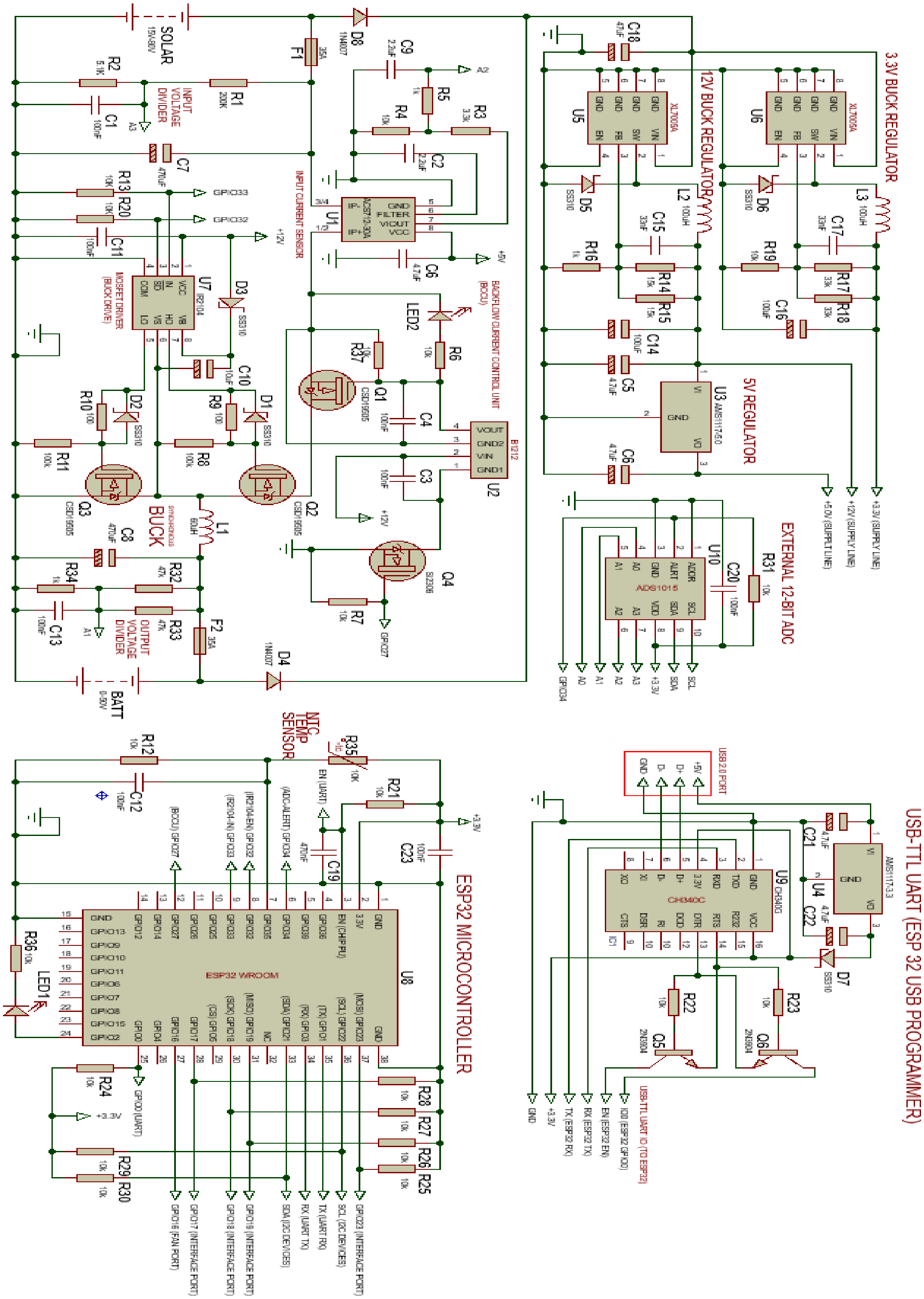


Figure 5: Complete Hardware Schematic Diagram

In this Schematic Diagram there are the following parts to the hardware:

1. 3.3V and 12V Fixed Buck converters
2. Current sensing
3. Backflow current control
4. Voltage sensing
5. Synchronous buck
6. USB-TTL-UART Programmer
7. ESP-32 Microcontroller

We shall look into each with greater depth of understanding.

4.2.2 3.3V and 12V Fixed Buck converters

This Piece of the circuit gives 3.3V and 12V and by utilizing a different voltage controller gives 5V stable results. The 12V result is utilized to control the MOSFET drivers and the voltage controller, the 3.3V result is utilized to drive the MCU in the mean time the 5V is utilized to control the various ICs utilized.

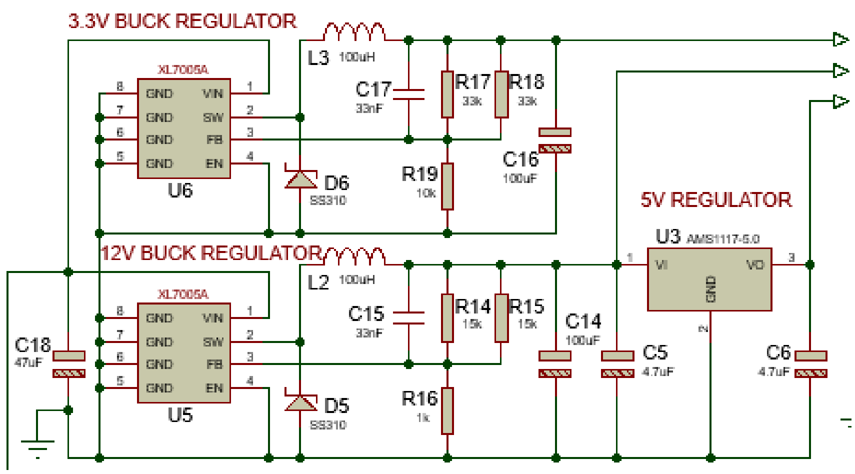


Figure 5.1: Buck Regulator

- U5 and U6 are buck regulators with an output voltage of 80V and a current rating of 0.4A. These regulators are responsible for providing a stable and controlled voltage to all the other components in the MPPT system.

- U6 is configured to provide a constant output voltage of 3.3V with the use of resistors R17, R18, and R19. This provides power to all the components that require a voltage of 3.3 volts. The output of U5 is adjusted to a fixed voltage of 10.625V by resistors R14, R15, and R16. This provides a voltage of 10.625V to the cooling fan port, the BCCU, and the driver gate drive supply pin of the MOSFET. Initially, the voltage was set at 12V, but we had to lower it in order to minimize switching losses and reduce the power consumption of the cooling fan. However, all components would still function properly with a voltage of 10.625V.

- U3 is a linear regulator that is coupled to the 10.625V output of U5. This supplies the necessary 5 volts for the U1 to function. I acknowledge the minimal losses associated with this, as the U1 necessitates a small amount of current.

4.2.3 Current Sensing:

This part focuses on the measuring the input current of the MPPT, Originally, we were using a shunt resistor to measure the current but it had high adverse effects on the system's efficiency. We ended up using an ACS-712-30A current sensor with bidirectional current sensing, and upto 30A of current measurement.

This current sensor loses little to no voltage and helps with the system efficiently and provides accurate current readings to the MCU

Following is the circuit diagram:

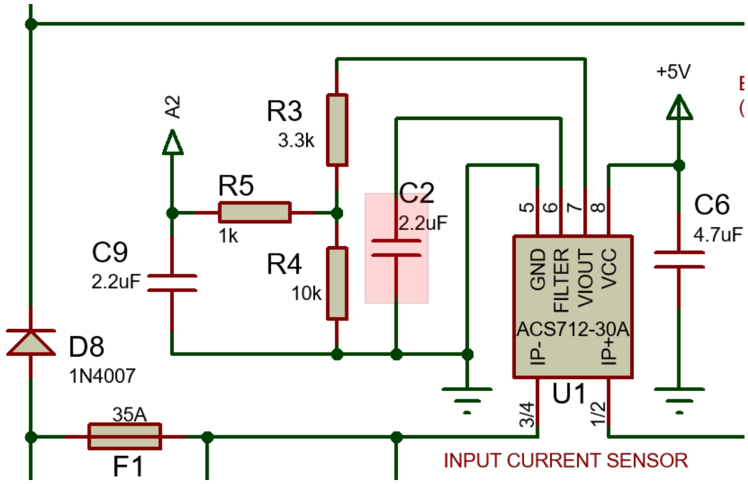


Figure 5.2: Current Sensor

- U1 is an ACS712-30A bidirectional current sensor integrated circuit (IC) that is isolated and has a current rating of 30A.

U1 has the capability to transmit and receive data in both directions, but we are only interested in using it as a sensor that measures current in one way. The -IP and +IP pins when given a current , it varies inversely with the voltage output reference , this means that the positive change in current would result in dropping of the output voltage.

- R3 and R4 form a voltage divider circuit that reduces the 2.5V output from U1's analog output to a level slightly below U10's 2.048V voltage reference. This ensures that the sensor readings are not above the ICs rated limits

- The datasheet for U1 (ACS712) mentions C2 as a filter capacitor. Augmenting C2 leads to a reduction in U1's current sensing bandwidth.

4.2.4 Backflow Current Control:

Both synchronous and asynchronous buck converter topologies exhibit a phenomenon known as "body diode current leakage." This issue has been prevalent in the majority of do-it-yourself synchronous buck maximum power point trackers (MPPTs). Efforts were made to rectify the issue with the high-side reverse blocking MOSFET, but frequently resulted in inadequate switching of Q1. Irrespective of whether Q2 is activated or deactivated, the inclusion of a diode within the MOSFET Q2 results in the flow of current from the batteries back to the solar panels when the input voltage is lower than the output voltage (Solar Panel Voltage < Battery Voltage). This occurs when solar panels generate reduced voltages during twilight, sunrise, and nighttime periods. Our goal is to achieve maximum efficiency, and adding diodes at the input is our least preferred option.

The Solution:

To prevent current from flowing back, a diode can be added at the input, specifically before Q2. This solution is applicable to all buck topologies. Diodes induce voltage dips, resulting in power dissipation. Once again, it is necessary to substitute the input diode with a different N-channel MOSFET. However, this time it should be linked in the opposite direction of Q2. This design is referred to as a reverse blocking MOSFET. When the body diodes of Q1 and Q2 are facing each other, current leakage in both directions is prevented until both MOSFETs Q1 and Q2 are activated. Now the task at hand is to effectively activate and deactivate the recently inserted Q1. Applying voltage directly to the gate pin of Q1 is not feasible because to its high-side positioning, which is far from the ground. In order to resolve this issue, we will allocate a separate DC-DC converter specifically designed for the purpose of switching it.

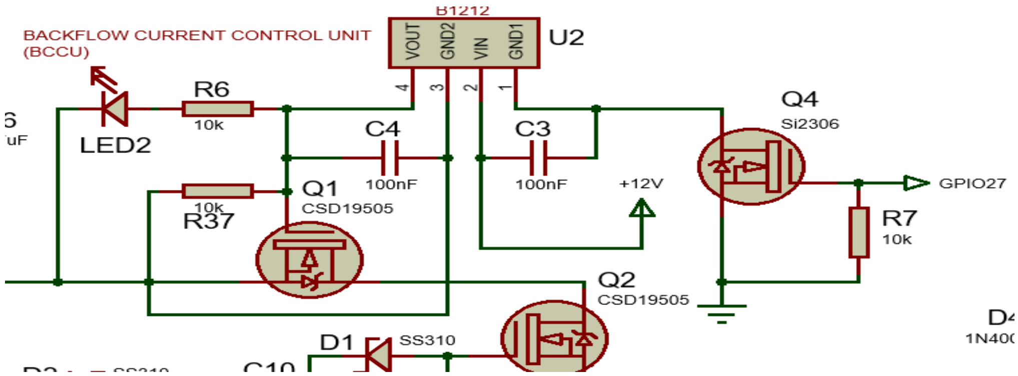


Figure 5.3: Back-Flow Current Control Unit

The specific DC-DC converter selected is the B1212S it is more economical compared to purchasing a specialized high-side MOSFET driver designed for a specific purpose. The isolated DC-DC converter and MOSFET combination has a modest benefit in that it can operate at a duty cycle of 100%.

The isolated DC-DC converter establishes a distinct potential difference between the source and gate pins of R37 is a resistor connected to the gate of Q1. Its purpose is to discharge the gate charge of Q1 when there is no power supplied to the input of U2.

Q4 controls the activation of the PV backflow prevention device. When GPIO27 emits a HIGH signal, Q4 becomes conductive and establishes a pathway for current to supply power to U2, which is the isolated DC-DC converter. When U2 is activated, it generates a 12V isolated voltage at its output. This voltage is then delivered to the gate and source pins of Q1, which powers Q1 and allows the connection from Vin to Q2's drain pin to be closed. Setting GPIO27 to a low state has the reverse effect of what I intended and causes Q1 to switch off.

4.2.5 Voltage Sensing:

This part focuses on the measuring the input and output voltages of the MPPT, intuitively the voltage dividers by far are the best method to measure the voltages

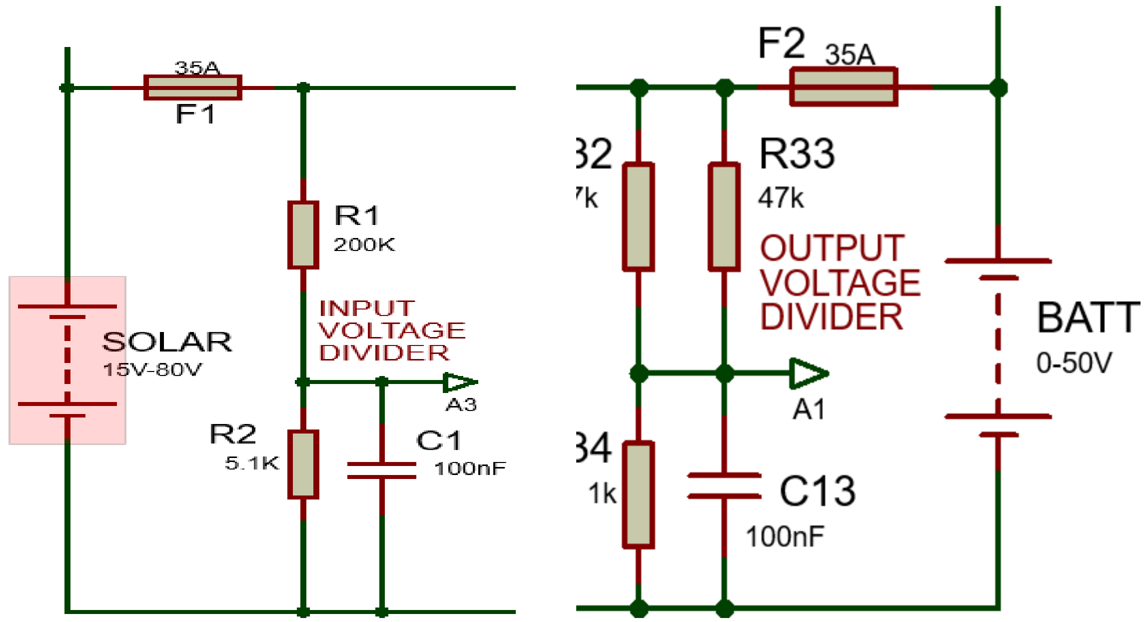


Figure 5.4: Voltage Sensing

In this part:

- R1 and R2 provide a voltage divider that converts an input voltage range of 0-80V to an output voltage range of 0-1.989V. This voltage is lower than the 2.048V voltage reference provided by the external ADC U10.
- C1 serves as a bypass capacitor to filter out any noise present in the output of the input voltage divider.

The R32, R33, and R34 components create a voltage divider circuit that converts an input voltage range of 0-50V to an output voltage range of 0-2.04V. The voltage is below the 2.048V reference voltage of the external ADC U10. It is near the Vref in order to optimize the resolution of the ADC, but not so close that it could result in clipping.

- C13 serves as a bypass capacitor to filter out noise from the output of the voltage divider.

4.2.6 Synchronous Buck:

The synchronous buck is the main part of the MPPT which provides the MPPT with the PWM signal it requires to function properly and at its MPP as explained in the previous chapter.

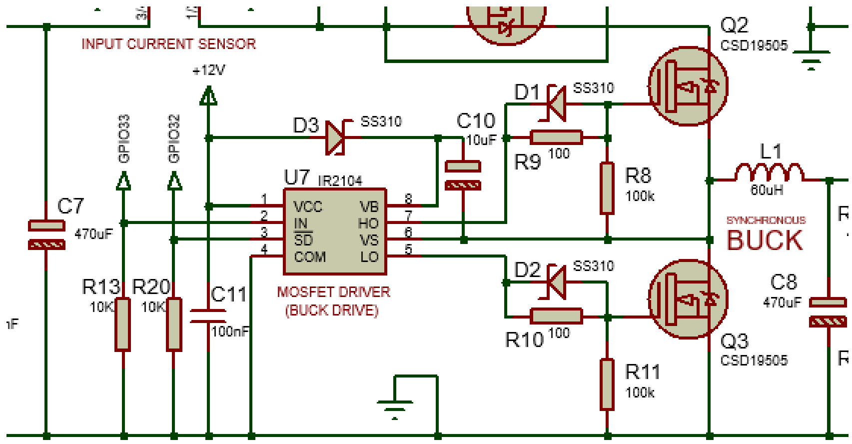


Figure 5.5: Synchronous Buck

In this part:

- Q2 and Q3 are N-channel MOSFETs, with Q2 being the high-side MOSFET and Q3 being the low-side MOSFET. They are connected in a configuration known as a half bridge, which allows for switching operations.
- L1 functions as an inductor in the MPPT's synchronous buck, serving as a highly efficient energy storage component with rapid response capabilities.
- C7 and C8 serve as bulk or bypass capacitors to mitigate ripple voltages in the input and output of an SMPS buck unit, which are induced by its rapid switching characteristics.
  The U7 is a half-bridge MOSFET driver, specifically the IR2104 model, which is fitted with a charge pump.
- R8 and R11 serve as pull-down resistors to prevent Q2 from floating at startup.
  R9 and R10 serve as gate resistors to restrict the transient currents supplied by U7 for activating the gate pins of Q2 and Q3.
- D1 and D2 are Schottky diodes that serve as efficient pathways for discharging the gate charges of Q2 and Q3 when either of them switches off.

- D3 is a Schottky diode used to prevent any reverse flow of current in the 12V supply line during the charging of C10.
- C10 functions as a bootstrap capacitor employed by the U7's charge pump to supply adequate power to the high-side N-channel MOSFET Q2.
- C11 is the specified bypass capacitor for U7, as indicated in the datasheet.

Resistors R13 and R20 are crucial for pulling down the voltage on U7's logic pins, so preventing them from floating. This fix addresses a persistent issue with do-it-yourself Maximum Power Point Tracking (MPPT) designs. In the absence of this feature, the connection of a USB cable to your computer while your MPPT is functioning will result in the pins of the MCU being in a state of floating during operation. Consequently, the buck section of the MPPT occasionally malfunctions and inadvertently activates Q2 or Q3, resulting in the release of smoke. Make sure to include these resistors to guarantee that the MPPT's buck converter is deactivated while the GPIO pins are in a floating state.

4.2.7 USB-TTL-UART Programmer:

To use onboard programming of the MCU and to reduce the size of the resulting product we have used a separate USB TTL programmer, this programmer works on the CH340 basics of the MCU programmer like the ones sold commercially.

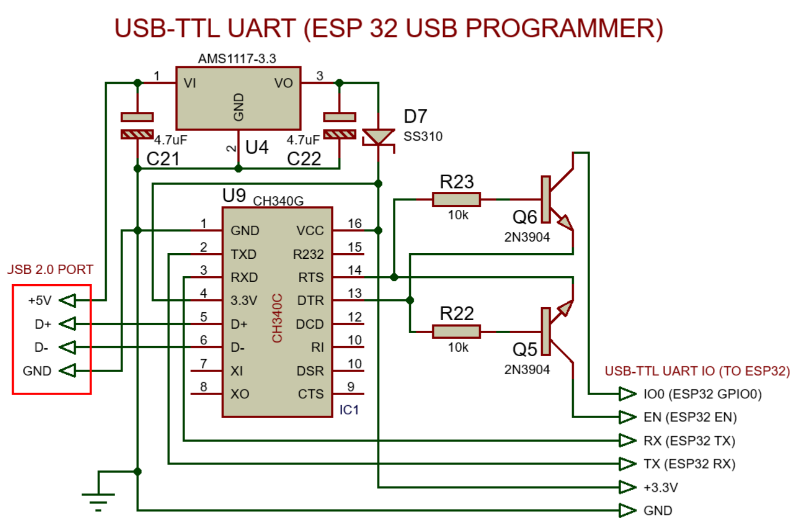


Figure 5.6: ESP-32 USB Programmer

- U9 is a CH340C chip that functions as a USB-TTL UART for USB serial communication and programming the ESP32 over USB.
- U4 is a 3.3V regulator that regulates the 5V input of the USB port. This is necessary because our ESP32 operates on 3.3V logic.
- C21 and C22 are typical bulk resistors used for the U4 regulator.
- D7 is a Schottky diode with a low forward voltage (Vf) to prevent current from flowing back to the USB port when the system is powered by solar panels or batteries. The 1N4007 can serve as a substitute.

4.2.8 ESP-32 Microcontroller:

The ESP-32 Microcontroller acts as the main MCU for the Project, this MCU is responsible for controlling all the needs of the MPPT and the Telemetry Features.

The ESP must be installed in this method:

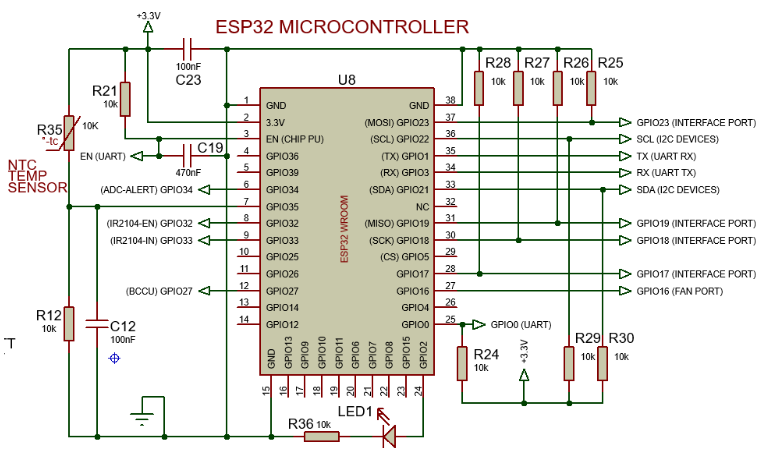


Figure 5.7: ESP-32 Hardware Integration

U8 serves as the microcontroller for the system, specifically the ESP32.

- R25-R28 are pull-down resistors used to prevent the buttons' pins from floating.
- R29 & R39 are pull-up resistors for the I2C port.
- C23 is a bypass capacitor that reduces ripples in the ESP32's 3.3V line.

- R21 & R24 are pull-up resistors for the ESP32's EN pin, which is crucial for the UART functionality.
- LED1 and R36 form a basic LED indicator connected to the ESP32's default LED indicator pin.
- R35 is a 10k NTC thermistor used as a temperature sensor.
- R12 is a pull-down resistor that, together with R35, creates a voltage divider to establish a simple temperature sensor.
- C12 is a bypass capacitor that filters the analog output of the temperature sensor.
- The analog output of the temperature sensor unit is connected to GPIO35, utilizing the ESP32's internal ADC.

4.3 Software Development

In this part we will be developing and deploying the machine learning model on the firebase. This part explains the details and the processes that were done in order to successfully run our model on the cloud.

4.3.1 Implementation & Deployment of Machine Learning Model on Cloud:

Information preprocessing and model development were completed as recently referenced. Following this, the model was sent for genuine application. This involved various essential advances:

1. Change to .tflite Organization: The AI model went through a change cycle to change it into a .tflite (TensorFlow Light) document. This configuration is intended to be exceptionally productive and utilize least assets when conveyed on portable and cloud stages, bringing about ideal execution.

2. Sending on Firebase: The .tflite model document was sent on Firebase, a cloud stage known for its versatility and arrangement of framework and administrations for application facilitating and execution.

3. Mix with Portable Application: The carried out model was flawlessly integrated into a versatile application explicitly produced for gadgets, for example, cell phones and tablets. •The application capabilities as the stage through which clients can enter information and acquire estimates.

The framework integrates a computerized methodology for recovering and foreseeing information, using a Programming interface like the NASA power for climate dataset. The framework capabilities in the accompanying way:

1. **Data Input via API:**
   The framework uses the NASA power for climate dataset Programming interface to recover climate information, explicitly 24-hour information. This information is utilized as the test input for the AI model.

2. **Prediction Generation:**
   The information got from the Programming interface is inputted into the operationalized AI model. The model produces conjectures for solar-based power for either the next day or week, contingent upon the accessible information.

3. App Display and Analysis:

The model's forecasts are exhibited on the connection point of the versatile application. Clients can notice the projected solar-based power creation and study designs, varieties in climate, and likely effects on power.

3. **Implementation by automation:**
   The framework works independently multiple times everyday, ensuring reliable updates and exact gauges got from continuous meteorological circumstances. This mechanized works on the

framework's responsiveness and steadfastness in conveying continuous bits of knowledge.

4. **Solar Production Insight:**

The execution of the AI calculation, establishment on Firebase, fuse into a portable application, and computerized information assortment and estimating methodology comprise an exhaustive answer for assessing solar based energy creation utilizing meteorological information. This arrangement permits clients to just gain prescient data and remain refreshed about the impacts of climate on solar based energy creation.

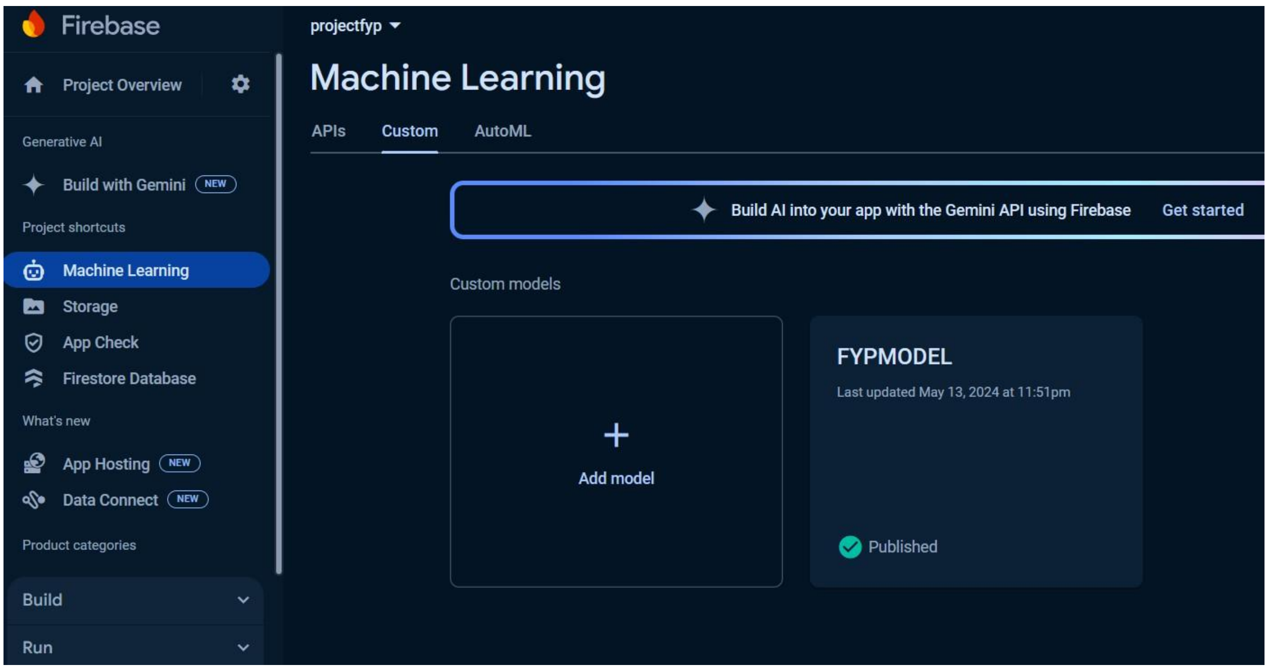


Figure 6: Machine Learning Model Deployment

4.5 Software Design & Integration

In this part we will be discussing in detail about the backend part and also the front end. This part is about mobile app development, esp-32 coding for cloud linking and uploading data to the cloud which is being received through serial communication. This part also discusses about the firebase deployment and its need for our project.

4.5.1 IoT Data Flow Architecture

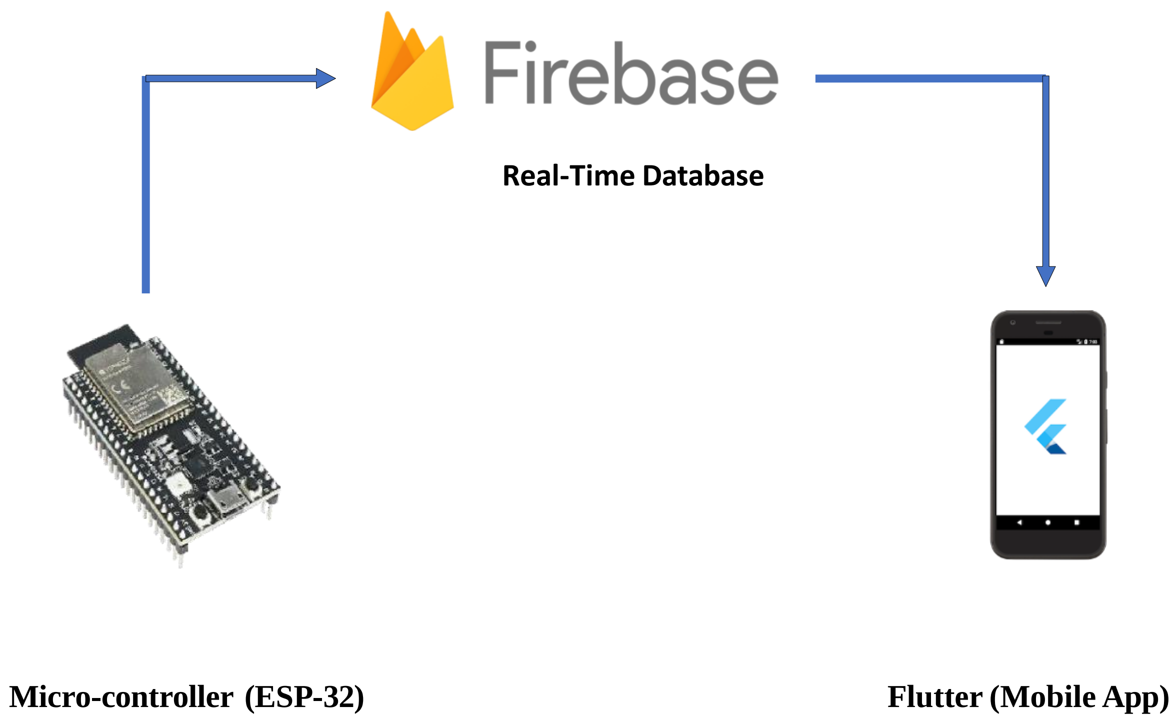


Figure 7: IoT Data Flow Architecture

4.6 System Architecture and Development Process

4.6.1 Cloud Deployment (Firebase):

Firebase was chosen as our cloud solution due to its versatility. It provides us with cross-platform support & real-time database and many more countless features. This allowed us to seamless communication between our hardware components and the cloud infrastructure, ensuring on spot data synchronization.

Additionally, Firebase's scalability and top-notch security features provided us with assurance in handling potential future expansions for muti-user database while maintaining data integrity and user privacy.

Its effortless integration with Flutter further streamlined our development process, and thus allowed us to focus on delivering a feature-rich mobile application with enhanced UI, profile management, remote access and real-time data visualization capabilities.

Moreover, firebase also allows us to use the machine learning tools on the cloud. It also allows us to deploy a Machine Learning model, due to these multiple features it became our choice as we have also utilized machine learning.

4.6.2 Firebase Live Data:

We used real-time database to make sure that our data on firebase repository stays in sync with the values being sent from solar inverter system, after which the values can be sent to our app in real-time.

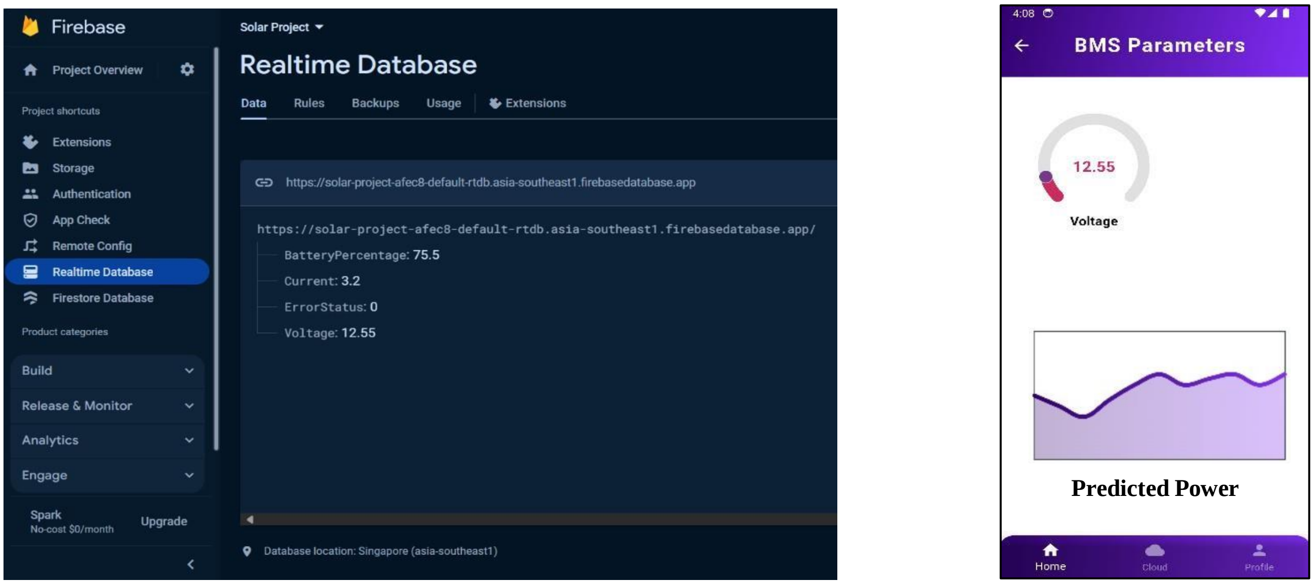


Figure 7.1: Firebase Live Data

In the pictures above we can see that live data is being transmitted and being displayed on the mobile app, this was captured during development phase for testing purpose so actual UI may differ. The graph you are seeing is just a preview of how we will be displaying our predicted model using our machine learning model. (The finalized version may differ slightly).

4.6.3 Storage

We also utilized storage feature of our cloud where users can upload their data. We can also handle multiple-users by authorizing each user a dedicated folder for their uploads.

This approach offers several benefits:

1. **Multi-User Data Management**: Users can provide upload pictures, video, and files directly via app to the “Cloud” portion specified in the mobile app which basically directly uploads

their data to the storage folders dedicated to the users on firebase which can then be accessed by the backend team.

2. **Efficient Problem Rectification**: By uploading data and on the cloud the backend team can easily & efficiently allocate their resources to solve issues which are being faced by the users.

Overall, integrating cloud storage for user uploads enhances the platform's ability to address user issues and also improving the overall user experience. We have attached an example below:

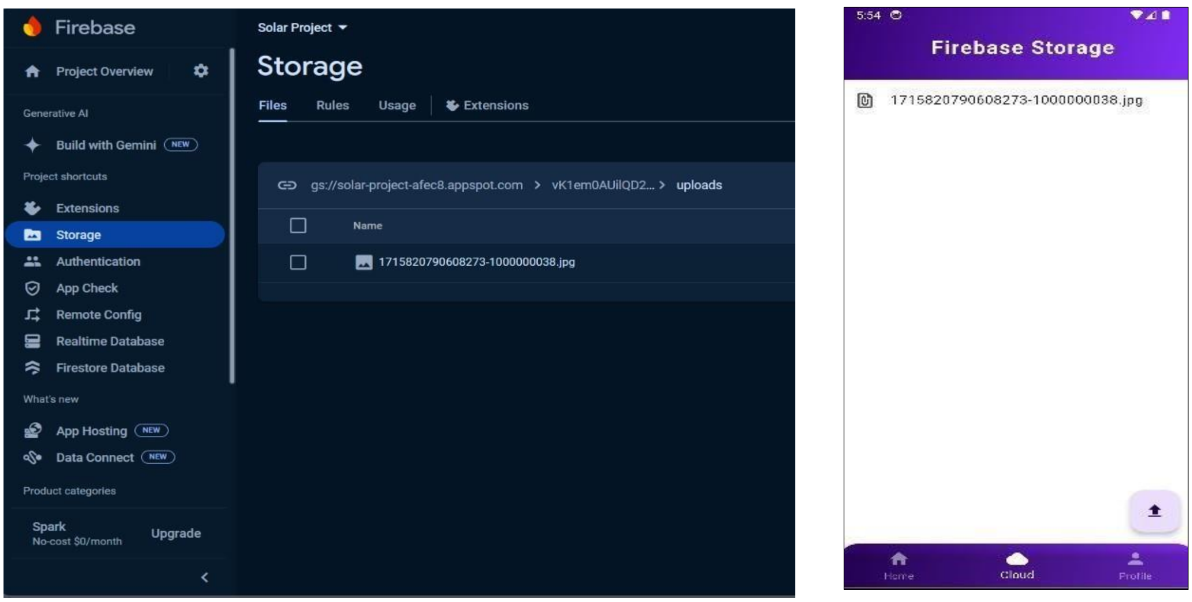


Figure 7.2: Firebase File Storage

4.7 App Development (Flutter):

Our mobile application was developed using the Flutter, powered by the Dart programming language. The app interface was specifically designed for ease in visualizing the important parameters of our solar inverter system. These parameters are being obtained via real-time data which is being maintained and constantly updated in the cloud.

Flutter became our first priority after carefully researching and looking at the current trends. It allows us to seamlessly serve users on the Android platform. With its shared codebase, there's also the potential for future expansion to include iOS app development which can be done seamlessly. One of the features that makes Flutter unique is it's hot-reload feature which basically allows for quick changes to be made on spot without fully restarting the code build and thus allowing for quick changes to be seen so on spot adjustments can be done if needed. It is a great feature for debugging.

Additionally, its extensive collection of customizable plugins and design elements, combined with its excellent Application Programming Interface (API), seamlessly integrated with other software, empowering us to design and communicate precisely with other software and thus fulfilling our project's requirements.

Flutter provided the stability and support necessary for the successful implementation of our mobile application, perfectly aligning with our project goals of designing an app which can connect to cloud and display the data and at the same time maintaining a visually appealing customized UI.

4.7.1 UI

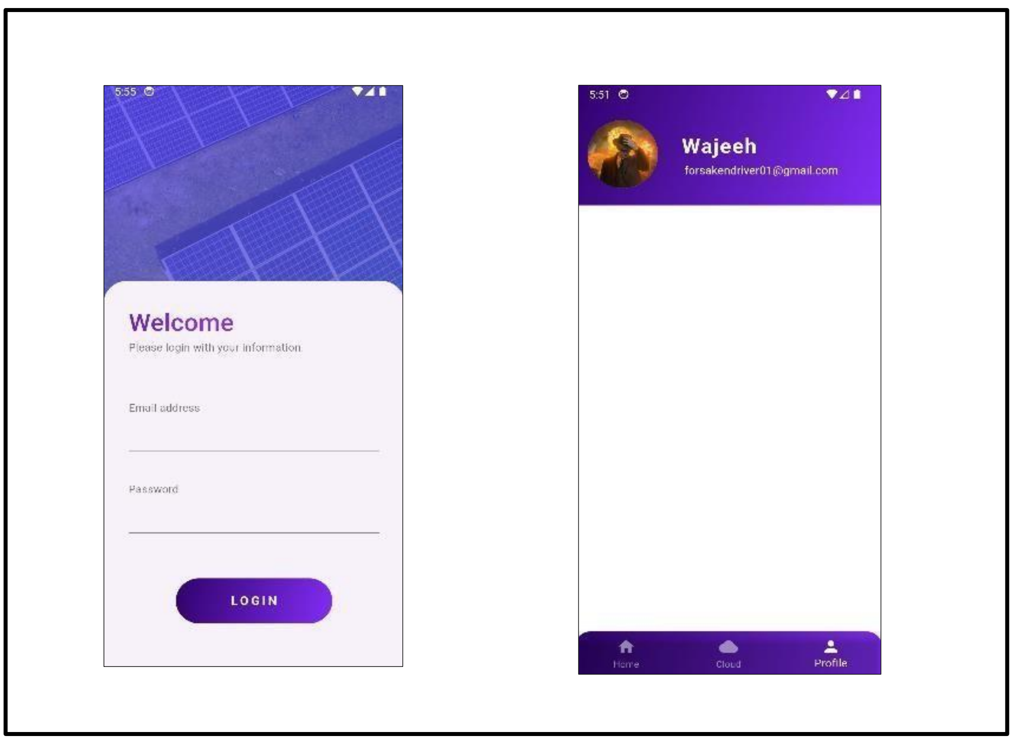


Figure 7.3: Partial Preview of our Mobile App UI

4.7.2 Login:

For login we ensured that only the authorized users can log in. We did not implement sign up option as out purpose was to show the solar system parameters that the authorized users who have these smart solar inverters can access their data.

4.7.3 Dependencies:

These are the list of dependencies that we used for out app development.

1. cupertino_icons: ^1.0.8
2. firebase_core: ^2.31.0
3. firebase_auth: ^4.19.5
4. firebase_storage: ^11.6.6
5. firebase_database: ^10.5.5
6. file_picker: ^8.0.3
7. path_provider: ^2.1.3
8. permission_handler: ^11.3.1
9. device_info_plus: ^10.1.0
10. syncfusion_flutter_gauges: ^25.2.3
11. iconsax_flutter: ^1.0.0
12. get: ^4.6.6

13. fl_chart: ^0.68.0

4.7.4 Explanation:

We used “main.dart” file to call the in which other pages were invoked by reference. This allowed us to implement a specific task in a specific .dart file. The “images” folder was created to store all the visual data used in the UI of the mobile app.

A google-services.json file was used to create a link between our mobile app and the firebase. It was generated by generating it from the firebase which basically holds all the linking url and name of the project which allowed us to create a link between our app and the cloud.

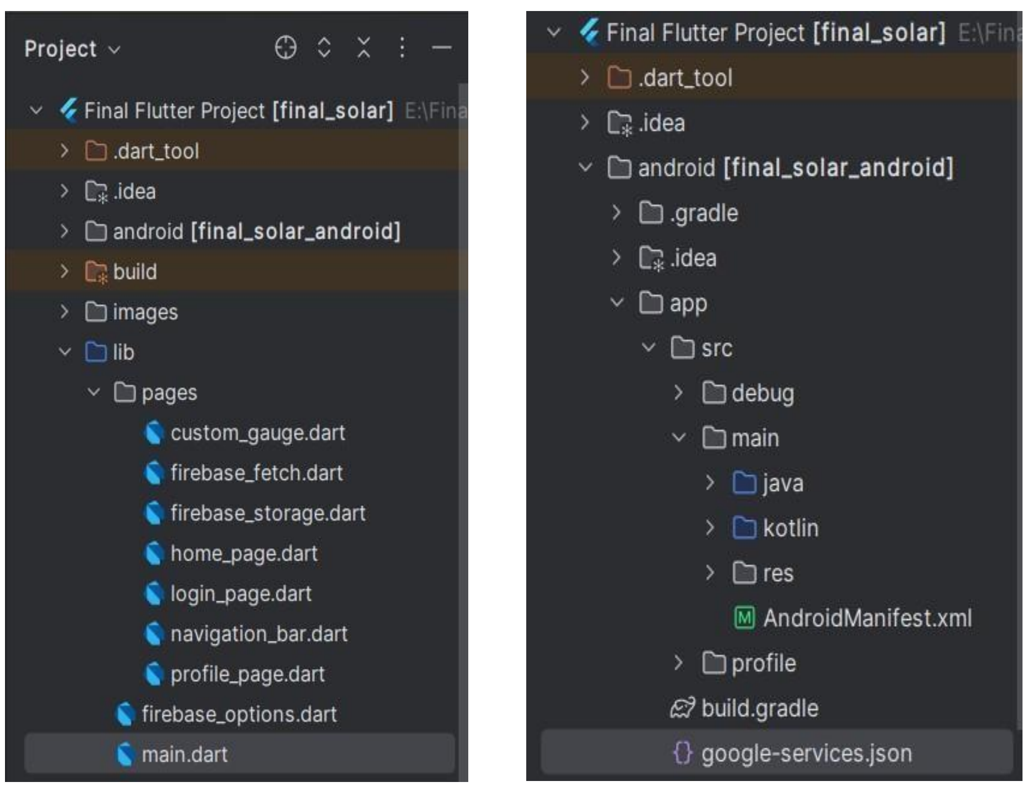


Figure 7.4: File Management in Flutter

Following libraries were used to upload data to storage folder:

- import 'dart:io';
- import 'package:flutter/material.dart';
- import 'package:path_provider/path_provider.dart';
- import 'package:permission_handler/permission_handler.dart';
- import 'package:firebase_storage/firebase_storage.dart';
- import '../utils.dart';

4.8 ESP32:

The ESP32 microcontroller was programmed to serve as the central hub for facilitating seamless communication between various hardware components and the cloud infrastructure. It is the central part of our hardware with impressive features such as its dual-core processor which has an amazing operating frequency of 240MHz, built-in Wi-Fi functionality for data transmission, we optimized the code to ensure reliable performance and efficient data transmission.

4.8.1 Code:

The code for linking to the cloud and uploading the data coming via serial communication to the cloud is show below:

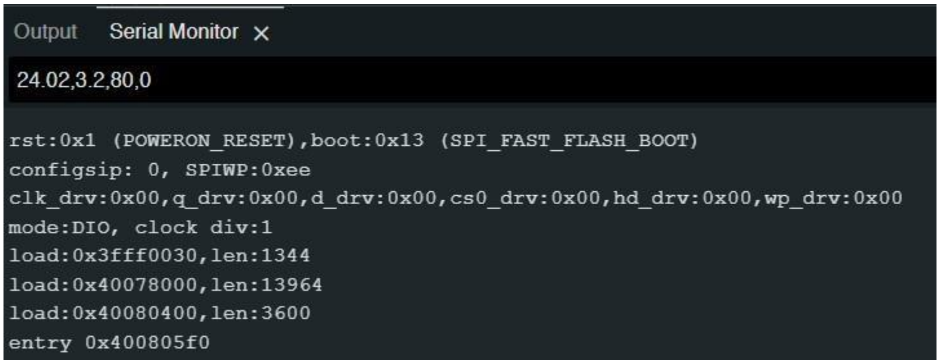
```
#include <WiFi.h>
#include <Firebase_ESP_Client.h>

/* 1. Define the WiFi credentials */
#define WIFI_SSID ""
#define WIFI_PASSWORD ""

/* 2. Define the API Key */
#define API_KEY ""

/* 3. Define the RTDB URL */
#define DATABASE_URL ""

/* 4. Define the user email and password that already registerd or added in your project */
#define USER_EMAIL ""
#define USER_PASSWORD ""


FirebaseData fbdo;
FirebaseAuth auth;
FirebaseConfig config;

void setup() {
  Serial.begin(115200);
  delay(1000);

  // Connect to Wi-Fi
  Serial.print("Connecting to Wi-Fi");
  WiFi.begin(WIFI_SSID, WIFI_PASSWORD);
  while (WiFi.status() != WL_CONNECTED) {
    Serial.print(".");
    delay(500);
  }
  Serial.println("Connected to Wi-Fi");

  // Initialize Firebase
  config.api_key = API_KEY;
  auth.user.email = USER_EMAIL;
  auth.user.password = USER_PASSWORD;
  config.database_url = DATABASE_URL;

```

```
  Firebase.reconnectNetwork(true);
  fbdo.setBSSLBufferSize(4096, 1024);
  fbdo.setResponseSize(2048);

  Firebase.begin(&config, &auth);
  Firebase.setDoubleDigits(5);
  config.timeout.serverResponse = 10 * 1000;
  Serial.println("Firebase initialized");
}

void loop() {
  // Check if Firebase is ready
  if (Firebase.ready()) {
    // Check if there's data available on Serial Monitor
    if (Serial.available() > 0) {
      // Read the incoming data
      String data = Serial.readStringUntil('\n');
      Serial.println("Received data: " + data);

      // Parse the incoming serial data
      float voltage, current;
      int batteryPercentage, errorStatus;
      if (sscanf(data.c_str(), "%f,%f,%d,%d", &voltage, ¤t, &batteryPercentage, &errorStatus) ==
4) {
        // Update Firebase database with the parsed values
        Firebase.RTDB.setFloat(&fbdo, "/Voltage", voltage);
        Firebase.RTDB.setFloat(&fbdo, "/Current", current);
        Firebase.RTDB.setInt(&fbdo, "/BatteryPercentage", batteryPercentage);
        Firebase.RTDB.setInt(&fbdo, "/ErrorStatus", errorStatus);

        // Check if data was sent successfully
        if (fbdo.httpCode() > 0) {
          Serial.print("Setting data failed with HTTP code: ");
          Serial.println(fbdo.httpCode());
        } else {
          Serial.println("Data sent to Firebase successfully!");
        }
      } else {
        Serial.println("Invalid data format. Please send data in the format: '4.05,5.55,40,10'");
      }
    }
  }
  delay(1000); // Delay before checking for new data
```

```
}

```

4.8.2 Testing:

For testing purpose, we connected the ESP-32 with our mobile hotspot from which it was connected to the internet and then we sent values using the serial monitor of Arduino IDE.



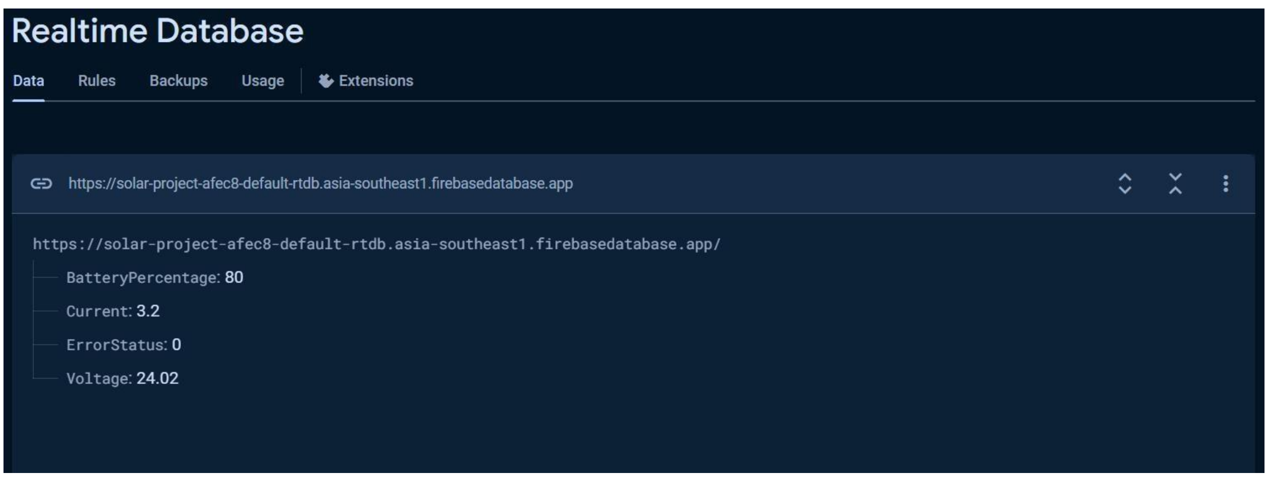


Figure 7.5: Firebase Realtime Data Linkage with ESP-32

From the above two images we can see that the data sent via Arduino IDE serial monitor to esp-32 was sent to firebase and updated immediately.

CHAPTER 5: RESULTS

5.1 Introduction:

This chapter presents the results and analysis of the Smart Solar Inverter Monitoring and Troubleshooting. It provides an evaluation of the system's performance, accuracy of the deep learning models, and user feedback. The analysis aims to assess the effectiveness, reliability, and usability of the system in real-world scenarios.

5.2 Performance Evaluation:

We have used two solar panels with a power output of 320W each, which are connected in series and were connected to the Maximum Power Point Tracking (MPPT) system. We performed an efficiency curve test by connecting voltmeters and ammeters to the input and output ports of the MPPT. Subsequently, we established a connection between a variable load controller and a nichrome water bath, which served as a high-power load. As we augmented the load, we documented the associated voltages and currents in order to calculate the power input and power output for each row. Upon applying the efficiency formula, we proceeded to put the data points on a graph in order to determine the efficiency curve.

Surprisingly, it achieved a conversion efficiency of 98.6% when operating at 270W, with an input voltage of 61.4V and an output voltage of 27.00V. we could not determine the endpoint of the graph since the ammeters on my pocket digital multimeter were restricted to a maximum of 10A.

Vin	Iin	Vout	Iout	Pin	Pout	% Eff
61.49	0	26.95	0	0	0	0
61.49	0.061	26.95	0.0245	3.75089	0.660275	17.60316
61.45	0.2065	26.97	0.3542	12.68943	9.552774	75.28138
61.4	0.3889	26.95	0.7684	23.87846	20.70838	86.7241
61.36	0.563	26.96	1.178	34.54568	31.75888	91.933
61.33	0.7134	26.94	1.503	43.75282	40.49082	92.54448
61.29	0.8933	26.95	1.912	54.75036	51.5284	94.11519
61.26	1.002	26.95	2.157	61.38252	58.13115	94.7031
61.21	1.219	26.94	2.654	74.61499	71.49876	95.82359
61.19	1.387	26.94	3.027	84.87053	81.54738	96.08445
61.14	1.538	26.94	3.369	94.03332	90.76086	96.51989
61.12	1.645	26.93	3.607	100.5424	97.13651	96.61248
61.07	1.889	26.93	4.157	115.3612	111.948	97.04128
61.05	1.996	26.93	4.393	121.8558	118.3035	97.08482
61.02	2.171	26.93	4.787	132.4744	128.9139	97.3123
60.98	2.309	26.92	5.096	140.8028	137.1843	97.43009
60.94	2.52	26.91	5.564	153.5688	149.7272	97.49848
60.9	2.656	26.91	5.879	161.7504	158.2039	97.80742
60.86	2.829	26.91	6.262	172.1729	168.5104	97.87277
60.83	3.002	26.9	6.65	182.6117	178.885	97.95924
60.79	3.175	26.89	7.034	193.0083	189.1443	97.99802
60.75	3.35	26.88	7.419	203.5125	199.4227	97.9904
60.72	3.514	26.87	7.797	213.3701	209.5054	98.18874

Table 1.1: Performance Evaluation Table

We see that with two 320W Solar Panels we have reached 98.6% efficiency and keeping at high 90% efficiencies for the most part.

5.3 Results of the Machine Learning Algorithms:

Information readiness and fastidious model choice are fundamental for working on the exhibition of AI models. Right away, our dataset included lines with zero qualities and numerous repetitive sections. The presence of these inconsistencies adversely affected the model's presentation, prompting forecasts that were 15-20 percent less precise contrasted with the discoveries accomplished subsequent to preprocessing. This part will inspect the upgrades got by information preprocessing and present an intensive correlation of various relapse models. We will give a clarification with respect to why Slope Supporting Relapse is the best suitable strategy for anticipating solar oriented power in our particular issue.

Data Preprocessing

Information preprocessing alludes to the means taken to clean and change crude information into a configuration that is reasonable for investigation.

Preceding preprocessing, the nature of our dataset was hindered because of the incorporation of zero qualities and insignificant sections. These qualities prompted significant commotion and missteps during the preparation of the model. To handle these issues, we executed the resulting preprocessing methodology:

1. **End of Lines with Zero Qualities:** Columns that included zero qualities were avoided to keep up with the honesty of the information.

2. Segment Choice: Unnecessary sections were found and wiped out, focusing exclusively on the highlights appropriate to our expectation objective.

3. Standardization: The information went through standardization to normalize all elements to a practically identical scale, consequently working on the model's ability to effectively learn.

The preprocessing processes prompted a dataset that was cleaner and more trustworthy, bringing about an impressive improvement in the expectation execution of the models.

Model Performance Comparison

Following the preprocessing stage, we continued to prepare and survey numerous models, in particular Random Forest, SVR, Gradient Boosting, Decision Tree. The assessment of these models was directed utilizing three essential measurements: Mean Squared Error (MSE), Mean Absolute Error (MAE), and R-squared (R2). The discoveries are briefly introduced in the table gave:

Model	**MSE**	**MAE**	**R-squared (R2)**
Random Forest	0.0285	0.74	81
Gradient Boosting Regressor	0.0205	0.80	87
Linear Regression	0.0832	0.95	53
Support Vector Regression	0.1072	3.10	48
Decision Tree	0.0331	0.89	80

Table 1.2: Model Performance Comparison

Analysis of Model Performance

1. The Random Forest model exhibited great execution, with a MSE (Mean Square Error) of 0.0285, a MAE (Mean Absolute Error) of 0.74, and an R2 worth of 81. The gathering idea of random forest, which totals the forecasts of a few choice trees, upgrades its power and precision. In any case, the R2 worth of the model was to some degree sub-par compared to that of the Angle Helping Regressor, but as yet being moderately great.

2. The Gradient Boosting Regressor (GB) model is worth better execution analyzed than different models, with the most elevated R2 worth of 87. The Mean Square Error (MSE) was 0.0205, while the Mean Absolute Error (MAE) was 0.80. The uncommon viability of Inclination Supporting can be credited to its iterative helping strategy, wherein each ensuing model undertakings to correct the errors of its ancestor. Thus, the last model is portrayed by an elevated degree of exactness and versatility.

3. Linear Regression showed the least fortunate presentation contrasted with different models, with a Mean Square Error (MSE) of 0.0832, a Mean Outright Blunder (MAE) of 0.95, and a R-squared (R2) worth of 53. The straightforwardness of the model and its supposition of direct connections among's attributes and the objective variable have limited its viability in tending to this many-sided challenge.

4. Support Vector Regression (SVR) exhibited a healthy degree of execution, as shown by a Mean Square Error (MSE) of 0.1072 and a Mean Absolute Error (MAE) of 3.10. The R2 worth of 48 proposed that Support Vector Regression (SVR) was not appropriate for precisely anticipating the result in this test. The multifaceted idea of changing SVR's hyperparameters and its weakness to highlight scaling were factors that prompted its similarly mediocre presentation.

5. The Decision Tree model displayed acceptable execution, with an MSE (Mean Square Error) of 0.0331, a MAE (Mean Absolute Error) of 0.89, and a R2 (Coefficient of Assurance) worth of 80. Although Random Trees are clear and effectively justifiable, they can be inclined to overfitting, which could represent their moderately lower execution when contrasted with outfit techniques.

Justification for Gradient Boosting Regressor

The Inclination Supporting not entirely settled to be the prevalent model in light of multiple factors:

1. The model has the most elevated R2 worth of 88, and that implies it makes sense of a bigger extent of the change in the objective variable contrasted with different models. This demonstrates that it fits the information better.

2. The model exhibits unrivaled exactness with few huge slip-ups, as confirmed by its low Mean Square Error (MSE) of 0.02 and Mean Absolute Error (MAE) of 0.80.

3. The supporting system of Slope Helping includes iteratively bringing down errors by gradually adding models, which works on its ability to catch many-sided designs in the information. Each progressive model focuses on redressing the slip-ups made by its ancestors, bringing about a last model that is especially exact and strong.

4. Adaptability and Customization**:** It offers the capacity to change and improve its presentation by controlling different hyperparameters, including the learning rate, number of assessors, and most extreme profundity of trees. This versatility takes into consideration the improvement of a redid model that is explicitly intended to match the extraordinary qualities of the dataset.

5. Inclination Supporting is capable at handling a mix of mathematical and downright data, delivering it adaptable and proficient for an extensive variety of datasets.

Generally, the SVR has uncommon execution in our solar based power estimate issue, as shown by its most prominent R2 esteem and negligible mistake measurements. In this manner, it is the most proper model for our necessities. The model's ability to deliberately redress mistakes and catch complicated information designs ensures strong and exact expectations, thus approving its decision as the chief model for this examination.

Actual vs Predicted Power:

Actual Power	Predicted Power
0.0	0.0
166.77	191.7855
1050.62	1208.213
1827.69	2101.8435
3853.74	4231.0
7047.63	7704.0
8382.17	9110.0
7742.11	8403.0
6310.12	6956.0
3339.31	3840.2065
898.13	1032.8495
18.06	20.769
0.0	0.0
62.03	71.33449999999999
229.71	264.1665
341.3	392.495
405.6	466.44
542.13	623.4495
643.03	739.4844999999999
507.5	583.625
264.63	304.3244999999999
361.09	415.2534999999999
228.52	262.798
5.8	6.669999999999999
1.35	1.5525
600.26	690.299
648.47	745.7405
668.26	768.4989999999999
405.6	466.44
495.63	569.9744999999999
749.38	861.7869999999999
613.35	705.3525
507.01	583.0614999999999
699.92	804.9079999999999
124.25	142.8875
1.46	1.679
0.0	0.0
481.86	554.139
3462.97	3982.4155
6699.4	7704.309999999999
8425.2	8988.0
9121.66	9329.0
9135.51	8704.8
8464.77	8264.1

Figure 8: Actual vs Predicted Power:

Graph of Actual vs Predicted Power values for complete test data:

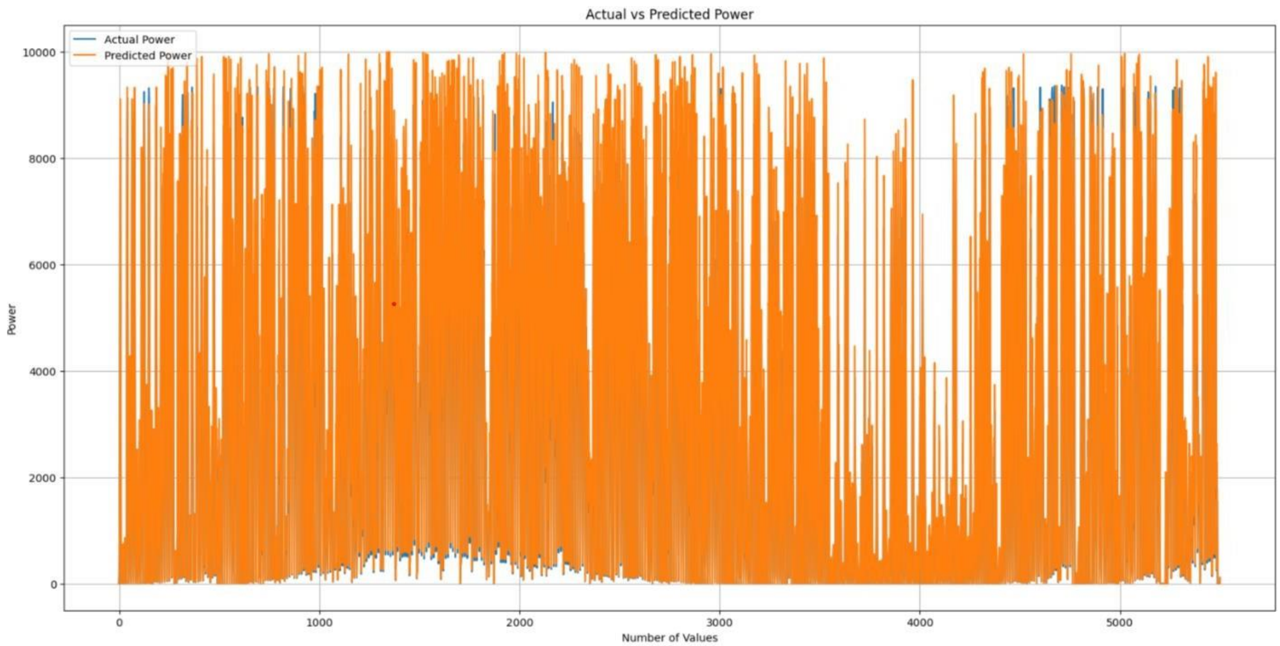


Figure 8.1: Complete Test Data (Actual vs Predicted Power)

Graph for Actual vs predicted for 100 values to understand how good our model is behaving:

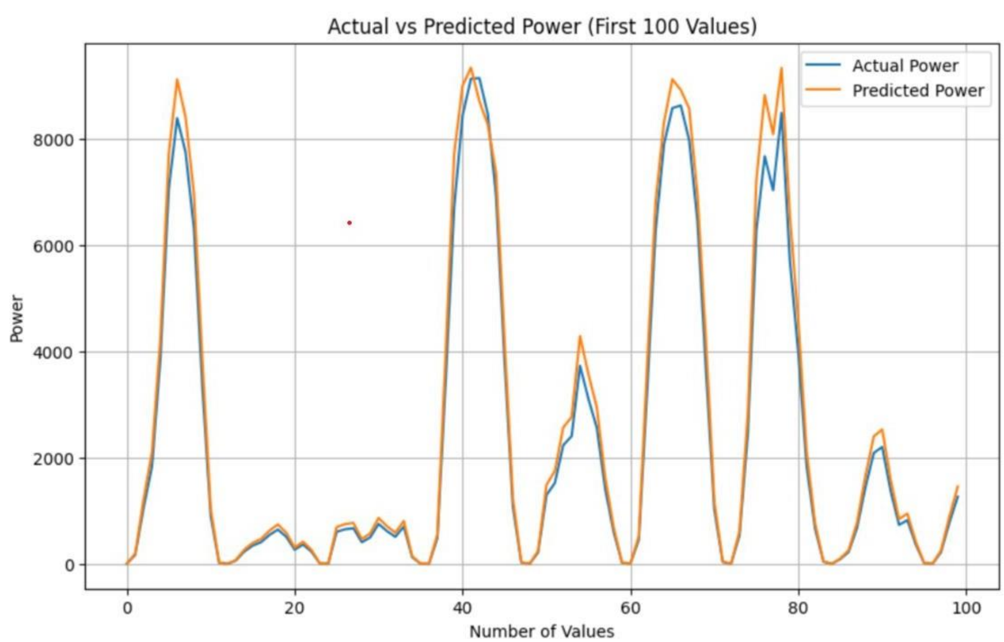


Figure 8.2: Values Model Analysis (100 Values)

CHAPTER 6: DISCUSSION AND FUTURE ENHANCEMENTS

6.1 Introduction:

In this chapter, we delve into a comprehensive discussion of the findings from the Project and explore potential future enhancements. We analyze the implications of the project, address the challenges encountered during implementation, and provide recommendations for further improvement.

6.2 Discussion of Findings:

After extensive testing and evaluation, the Smart Solar Inverter troubleshooting and monitoring system has exhibited promising results. The system accurately measures the input and output voltages and successfully embeds the MPPT on its tracking mode.

6.3 Challenges and Limitations:

During implementation of parts, we encountered many challenges the first and foremost was the Tracking mode of the MPPT and how to control it and make it efficient, more over the choice of components was another strong challenge to overcome and keep the parameters in check while testing of the schematics and hardware testing proved another challenge.

6.4 Future Enhancements:

1. **Increased Power Ratings:** The kit is designed to accommodate higher power ratings, enabling the transfer of larger and more powerful systems.

2. **Edge computing**: It can be utilized to achieve real-time optimization by doing MPPT optimization directly within the solar inverters. This approach reduces latency and enhances responsiveness. By implementing sophisticated algorithms directly on the edge devices, the

system can adjust to quickly changing environmental circumstances and optimize energy production in real-time without depending on centralized processing.

3. **Mixture MPPT Methods:** Examining half breed MPPT procedures that coordinate different streamlining calculations, The MPPT strategy can give prevalent proficiency and strength in numerous settings by powerfully exchanging between advancement approaches in view of info boundaries and framework qualities.

4. **Execution of Augmented Reality (AR) or Meta:** The presentation of AR or Meta interface for support and investigating position can advance tasks and limit times of idleness. Experts can upgrade their upkeep exercises by superimposing computerized data onto Meta based virtual hardware. This permits them to acquire ongoing execution information, diagnostics, and bit by bit fix guidelines promptly in their view, bringing about quicker and more exact support undertakings.
5. **Using ML (Machine Learning) models:** For calculations of energy prediction could upgrade long haul arranging and framework reconciliation strategies. Through the assessment of past information, meteorological examples (Historical Data), and other appropriate factors, machine learning models have the ability to gauge impending energy production levels with extraordinary accuracy. This engages service organizations to upgrade network activities, plan for the incorporation of sustainable power sources, and address likely inconsistencies between energy market interest.
6. **Integrating dynamic voltage**: Guideline abilities into brilliant solar powered inverters, the strength and steadfastness of the lattice can be gotten to the next level. The inverters can direct voltage and control receptive power by changing result voltage levels because of lattice conditions and vacillations popular. This incorporates sustainable power sources into the network without influencing power quality.

6.5 Social and Ethical Implications:

The telehealth checking framework conveys significant social and moral outcomes that require exhaustive thought. This segment investigates the potential benefits and moral worries connected with the framework, underlining the meaning of mindful creation and execution of telehealth advancements.

Benefits of the Undertaking: The venture's goal is to offer more reasonable choices to the exorbitantly monetarily open MPPTs and brilliant inverters, while additionally working on the use of MPPT innovation for amateur clients.

Beating Innovative Snags: The Environmentally friendly power Area is seen as profoundly unpredictable by the overall client. This undertaking tries to limit that gap and proposition the run of the mill client a direct and versatile plan.

By considering these social and moral outcomes, the framework can be made in a way that maintains client freedom and encourages fair admittance to energy administrations in power frameworks. Embracing capable practices in the turn of events and execution of Solar based advancements will improve their general achievement and acknowledgment, ultimately helping clients.

CHAPTER 7: CONCLUSION

In general, the project expects to join trend setting innovations in the sustainable power industry, including the improvement of a MPPT framework with locally available and remote telemetry, the utilization of machine learning and mobile APP(UI) made on flutter for observing and control, and the execution of ML for power predictions. This mix denotes a critical progression in the field.

The objectives are successfully accomplished for the working on the productivity of solar based power inverter and giving smooth observing and control through cautious plan and execution. The blend of machine learning and mobile APP (UI) has worked with the arrangement of an easy to use and natural connection point, empowering clients to get significant execution data continuously and remotely change MPPT boundaries.

Considering proactive changes to further develop MPPT settings as indicated by anticipated ecological conditions. This prescient capacity not just streamlines how much energy gathered from solar powered chargers, yet in addition works on the framework's capacity to endure and keep up with execution despite changing atmospheric conditions.

By saddling the abilities of these advancements, the project exhibits the progressive limit of sustainable power management in handling overall energy. Besides, it remains as proof of the creativity and innovation moving the sustainable power industry ahead, setting the way for a future energy system that are both harmless to the ecosystem and fit for enduring difficulties.

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APPENDIX-A

Depth of Knowledge Required (WP1 >>> WK3, WK4, WK5, WK6, or WK8):

This project requires forefront in-depth engineering knowledge in several areas, including photovoltaic The Fundamental understanding of PV systems (WK3), Implementation of machine learning algorithms (WK4), design and implementation of MPPT systems (WK5), Integration of MPPT into UPS systems (WK6) and real-time monitoring and cloud-based data logging (WK8).

Depth of Analysis Required (WP3):

The development and integration of MPPT systems into existing UPS frameworks involve modeling and analysis to optimize power storage and predict PV production accurately using machine learning.

Interdependence (WP7):

The project is highly interdependent, involving many component parts and sub-problems. Integrating MPPT with UPS systems, real-time data logging, cloud-based monitoring, and predictive analytics using machine learning are all interconnected parts that must work seamlessly together to achieve the desired outcome.

	WP1						WP2	WP3	WP4	WP5	WP6	WP7
	WK3	WK4	WK5	WK6	WK7	WK8						
PLO1 (WA1)	X											
PLO2 (WA2)		X						X				X
PLO3 (WA3)			X									
PLO4 (WA4)												X
PLO5 (WA5)				X								
PLO6 (WA6)						X						
PLO7 (WA7)												
PLO8 (WA8)												

APPENDIX-B

SUSTAINABLE DEVELOPMENT GOALS FOR FYP

FYP TITLE: Remote Cloud-based Inverter Monitoring & Troubleshooting

FYP SUPERVISOR: Dr. Mahrukh Liaqat

GROUP MEMBERS:

	REGISTERATION NUMBER	NAME
1	348080	Humayun Ahmad
2	359587	Muhammad Wajeeh Ullah Kakar
3	337029	Muhammad Saad Ali

SDGs:

	SDG No.	Justification after consulting
1	**7**	Our project is in accordance with the following targets **7.2, 7.3, 7.b**
2	**9**	Our project is in accordance with the following targets: **9.4, 9.5, 9.b**
3	**11**	Our project is in accordance with the following targets: **11.b**

FYP Advisor Signature: ....

APPENDIX-C

Solar FYP

ORIGINALITY REPORT

17%	17%	4%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.instructables.com Internet Source	8%
2	res.mdpi.com Internet Source	3%
3	jes.utm.md Internet Source	3%
4	how2electronics.com Internet Source	1%
5	datasciencedojo.com Internet Source	1%
6	www.mdpi.com Internet Source	<1%
7	journal.esrgroups.org Internet Source	<1%
8	escholarship.org Internet Source	<1%
9	www.journaltocs.ac.uk Internet Source	<1%