DESIGN AND IMPLEMENTATION OF AN EV CHARGING STATION: A SUSTAINABLE SOLUTION FOR BRAC UNIVERSITY

By

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A Final Year Design Project (FYDP) submitted to the Department of Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree of Bachelor of Science (B.Sc) in Electrical and Electronic Engineering.

Department of Electrical and Electronic Engineering
Brac University
September 2025

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Academic Technical Committee (ATC) Panel Member:

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Department of Electrical and Electronic Engineering
Brac University
September 2025

Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is my/our own original work while completing degree at Brac University.
2. The Final Year Design Project (FYDP) does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The Final Year Design Project (FYDP) does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

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Approval

The Final Year Design Project (FYDP) titled "DESIGN AND IMPLEMENTATION OF AN EV CHARGING STATION: A sustainable solution for BRAC University" submitted by

1. Ishrak Amin Joarder (21121034)
2. Nafis Shahriar Ahmed (20321059)
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4. Iftikhar Obaid Aurnob (20221023)

of Summer, 2025 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science (B.Sc) in Electrical and Electronic Engineering on September 2025.

Examining Committee:

Academic Technical Committee (ATC):
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Professor and Chairperson, Department of EEE
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Ethics Statement

We thus state and certify that this Final Year Design Project titled “Design and Implementation of an EV Charging Station: A Sustainable Solution for BRAC University” complies with all requirements for completion of the Final Year Design Project set by the BRAC University Authority and the Department of Electrical and Electronic Engineering of BRAC University, in partial fulfillment of the requirement for the degree of Bachelor of Science (B.Sc.) in Electrical & Electronic Engineering. This report has been prepared through the collective effort of all members of the group, including our system design, simulations, test results, analyses, and prototype development. All referenced materials and external resources have been properly cited under the guidance of our ATC Panel.

A plagiarism index of this report has been checked and the final similarity score was 8% according to Turnitin report.

Abstract

Currently, the accessibility and practicality of charging infrastructure are the main barriers to the broad adoption of electric vehicles. In order to solve this problem and aid in the shift to a more environmentally friendly transportation system, this initiative suggests creating a charging station for electric vehicles powered by both renewable and grid energy. The charging station will give EVs a sustainable and clean supply of electricity by utilizing solar panels and electricity from the grid. In order to lessen our dependency on fossil fuels and lessen the environmental effects of using conventional ways of power generation, this project intends to investigate the viability, technical issues, and possible advantages of putting such a charging station into place.

Keywords: Electric Vehicle (EV), Solar Photovoltaic (PV), Hybrid Grid System, MPPT Charge Controller, Battery Energy Storage, Power Conversion, Renewable Energy, Sustainable Transportation.

Acknowledgement

We are immensely grateful to our ATC Chair **Associate Prof. Dr. Abu S.M. Mohsin**, Professor in the Department of Electrical and Electronic Engineering at BRAC University, for his invaluable guidance throughout our Final Year Design Project. For the project to be completed successfully, his unwavering support and guidance throughout the year in the areas of system design and implementation, data gathering, problem solving, and paperwork-related concerns was essential. Additionally, we appreciate the direction, assistance, and mentoring given by our ATC panel member **Taiyeb Hasan Sakib**, senior lecturer in the Department of Electrical and Electronic Engineering at BRAC University.

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Chapter 1

Introduction

1.1 Introduction

EVs can greatly decrease the Greenhouse Gas Emissions and reliance on Fossil Fuels. However, now the issue of access and practicality to charging points is the key barrier to the proliferation of EVs. In this regard, we propose in this proposal to install an electric vehicle charging station that operates on a renewable energy source. It is achieved using a solar panel that also grid power to supply sustainable and clean Energy to EVs that charging EVs using renewable energy can not only contribute to the minimization of the use of fossil fuel but also lessens the environmental impact that the traditional ways of power generation have. This project will aim to resolve the problems encountered in deploying EVs and discuss the potential and positives as well as the technical issues of the functioning of an electric vehicles charging station on renewable energy. Also, It is geared towards making contributions in terms of how transportation could be more sustainable.

1.1.1 Problem Statement

Bangladesh is heading towards the future with a clean energy source and integration of Electric Vehicles. Envisioning a developing country, there is the great opportunity to lead and Brac University is one of the best higher educational institutions of Bangladesh which can be an example of clean energy. Brac University does not have an electric vehicle(EV) charging point in the parking area. The Brac University parking area has a place where an EV charging station can be placed. The static bar chart in Figure 1 shows how EV in the various countries in the world is used. It shows the need for charging infrastructure worldwide.

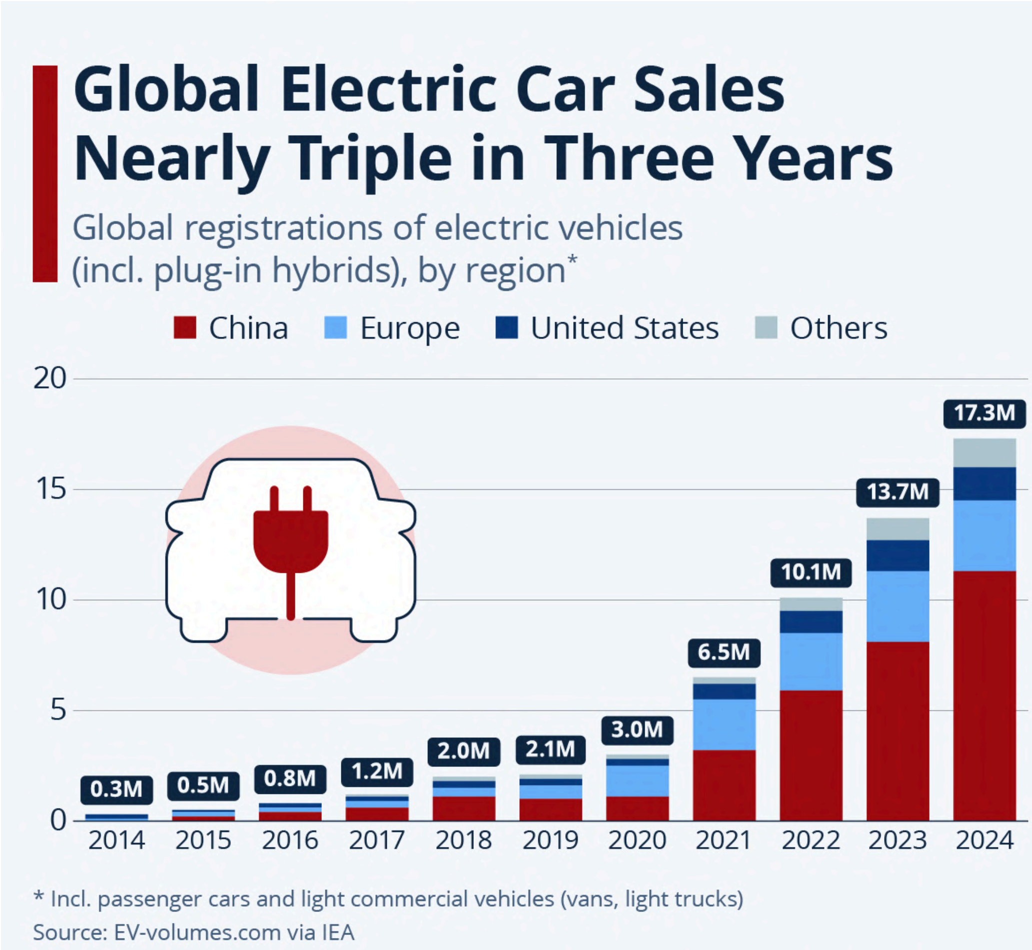


Figure 1: Bar chart representing the increase of EV usage [1].

The BAILNeF (2016), an automotive sector development strategy, already received a seed investment of US$200m by Bangladesh Auto Industries Ltd (BAIL) to start manufacturing electric cars in 2021 [2]. In Bangladesh, the Government has also sanctioned electric vehicle production and charging infrastructure regulations and standards. Several private organizations (e.g., Nitol Motors) along with foreign investors (for example, Omega Seiki is one of the affiliates of Anglian Omega Network from India and Ricardo-AEA is a UK-based energy and environmental consulting firm) plan to invest substantial amount of money in Bangladesh to initiate electric vehicle development projects [3]. For the purpose of this research the two design-oriented methodologies for designing EV charging station solutions at a selected site of Brac University parking lot are:

- Solar to charger: Solar power used for charging
- Solar + Grid Hybrid Charging Station:A solution for charging EV Charging station with both solar and grid power

There are solar panels on the rooftop of Brac University that can be utilized for drawing power supply for the charging station. It will provide clean, renewable energy. But it's going to be a problem at night. An alternative system could be constructed, however, that integrates grid power with solar power and has a battery to store the energy.

1.1.2 Background Study:

The charging system was implemented in the study “Solar Energy based Net Metered Easy-Bike Charging Station in Bangladesh” by the author [5]with a grid-tied net metering system. There was no battery energy storage system in the system. The solar-generated electricity is exported to the grid only during the day. The EVs were only charged via the grid whenever electricity was required. Unfortunately, the authors’ simulation of their system in PVsyst in various azimuth orientations showed that the south direction produced the most significant power. According to the authors, their approach led to a payback period of 45 months since there was no BESS. The system would cost more than twice if a BESS was used. GHG emissions from such a system were 89.63 kg CO2-eq/MWh, which is much less than Bangladesh’s grid emission factor of 670 kg CO2-eq/MWh. Demand Side Management was proposed to reduce peak load demand in another study titled “Bangladesh Power System Peak Demand Shaving through Demand Side Management of the Battery Operated EVs Load” [6]. According to the paper, the EVs were connected to the grid mostly from 9- 10 p.m. The present battery capacity of the vehicle is 8-11 kWh. Therefore, the authors’ load will be reduced by 700 MW if 70% of the vehicles are loaded during the off-peak.A GLOBAL GHG increase is observed in recent years. This emission is caused by three-quarters of the total Global GHG emissions from various sectors [5]. The energy sector is the leading Global GHG emission sector. The energy sector mainly responsible for GHG emissions source suggests that to counter such emissions, the European Union (EU) has proposed to ban ICE Engine-Vehicles by 2035 and shift to EVs. As this sector contributed to 12% GHG, such a ban would significantly reduce pollution. More than 1,000,000 electric vehicles (EVs) are contributing to Bangladesh’s EVs leading to power.

Each year, 15810 cars are added to this number[5]. ChargePoint announced ChargePoint Express Plus, an ultra-fast DC charging framework with a maximum production of 400 kW. It has the capacity to charge vehicles at voltages ranging from 200 V to 1000 V, including current 400 V cars, 750 V buses, and future 800 V vehicles. The modular Express Plus platform was created for corporates and high-traffic corridors and connectivity termini. It can fast charge the latest electric vehicles available on the market, such as the Chevy Bolt EV. It can also charge future electric vehicles, such as the Tesla Model 3, and is prepared to offer the quickest available charging speed for electric vehicles unveiled in the following several years. Figure 2 is the explanation of various kinds of charge docks Level 1, 2, and 3 Tesla Charger Explanation:

- Many Tesla owners are unaware that they can actually run the adapter to Power with a usual 120V home outlet. It's more commonly known as "trickle" charging since charging takes a lengthy amount of time.
- Not at all. A "Level 2" EV charger is just an EV charger that needs a 240-volt split-phase circuit, the same that's required for electric dryers. Electric vehicles, on the other hand, differ greatly in how long it needs to charge. Some electric cars, for example, take longer to recharge than an LG clothes dryer.
- A Tesla car could be quickly charged in 30 minutes from 0 to 170 miles utilizing a Level 3 Supercharger. In roughly 40 minutes, the vehicle could reach 80%.

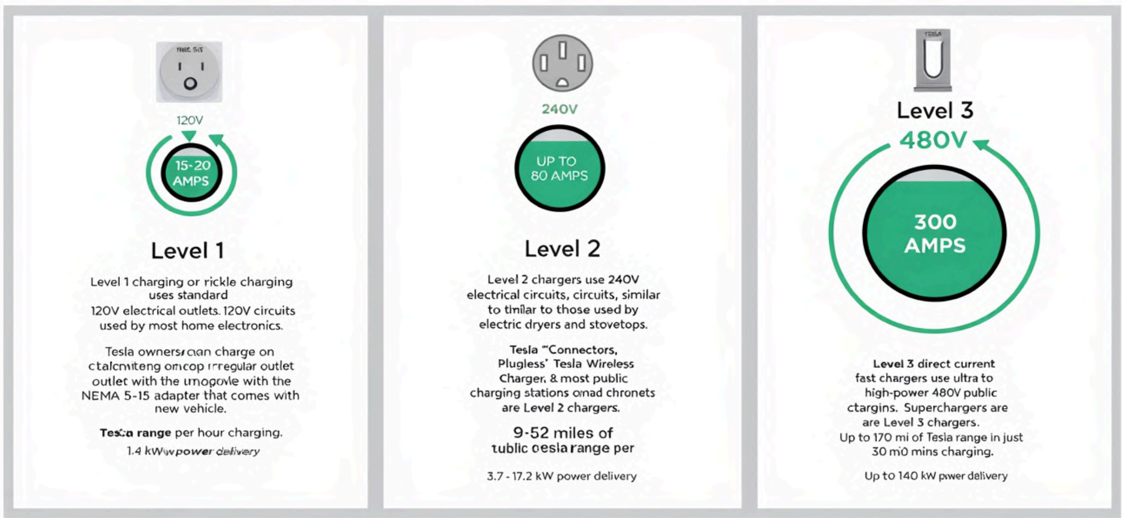


Figure 2: Tesla Charger classification with time duration [4]

1.1.3 Literature Gap

Although research on the subject of electric vehicle V charging infrastructure has come far, there are several key gaps in the literature. Particularly in college campuses such as Brac University.

1. **Driver Behavior and Battery Consumption**

The vast majority of existing research is built on modeling designs created at the national or urban level. Most assume that their travelled distance is uniformly divided over each and every hour of the day. Meanwhile, the models tend to ignore well-documented behavioral patterns, vitally important in a campus environment, such as detours, scheduled parking, and clustered trip cycles [8].

2. **Combining Various Charger Types**

Much of the evidence has concentrated on the local commerce, generally fast makers common within metropolitan and interstate commerce. There is limited research that fits a campus environment and adequately covers the combined use of slow, semi-rapid, and rapid chargers [9].

3. **Campus Systems: Renewable Energy and Storage**

Energy generation through solar systems and battery storage applied to the V charging at the campus level. Studies show that an insignificant level of research has been carried out on campus EV charging systems, despite the number of prior years investigating renewable integration [10].

4. **Optimizing in Real Time for Sustainable Operations**

Real-time, data-driven optimization techniques for charging management in institutional settings have not received much empirical attention. Universities continue to be underrepresented in the literature despite their variable loads and potential for on-site renewable energy [11].

5. **The Setting of Developing Nations**

Context-specific findings have been hard to extrapolate on the research on developing countries. This area has primarily not been incorporated into previous literature as the burden of high-energy prices and lacking grid reliability makes campus specific solutions complex [12].

1.1.4 Relevance to current and future Industry

Electric vehicle charging stations based on renewable energy are very significant in the current and future industry for several reasons. Initially, given that many governments and consumers are seeking to reduce greenhouse gas emissions and use more environmentally friendly vehicles, the demand for electric vehicles has and continues growing very quickly. To meet this demand, a reliable and sustainable recharging infrastructure is necessary. Most high-quality EV charging stations are based on renewables as they can generate, collect, and produce electricity from natural and sustainable work sources like sun and wind. This is very critical as it reduces general admin cost and the globe's overall dependence on fossil fuel. Second, charging with electric vehicles is related to energy storage and grid infrastructure, which can be resolved with EV charging stations. Since they produce electricity where people charge, the pressure on the grid and the need for expansive batteries are eliminated.

Renewable re-chargers could be more affordable and efficient than conventional fuel-based stations due to this. Finally, rechargers based on renewables can assist combat climate change and the transition to the new industry. With the globe prepared to employ renewable power sources, these charging stations are critical in ensuring less overall emissions and a better atmosphere. All EV charging stations are constantly increasing their service to keep pace with the growing demand for electric vehicles.

1.2 Objectives, Requirements, Specification and constraints

The following parts looked deeply into the project's targets, specification, needs, and constraints to ensure that whatever the outcome is, it is ready: the type of resources needed to fulfill the project's unique needs; a better understanding of the several requirements and constraints of the project and how they might be applied. All of these make sure that we have a better understanding of the project, which allows us to better plan and execute it.

1.2.1. Objectives

The primary objective of this project is to design and implement a prototype solar-powered EV charging station capable of demonstrating sustainable and efficient charging for electric vehicles using renewable energy.

The system integrates solar photovoltaic (PV) generation, battery storage, and an MPPT solar charge controller to optimize energy conversion and management.

The specific objectives include:

- To plan and design a prototype EV charging station which is powered by a solar photovoltaic system.
- To design and assemble a MPPT (Maximum Power Point Tracking) solar charge controller to high efficiency utilization of the PV panels.
- To model and model the energy flow of the system with the help of Proteus, HOMER Pro, and MATLAB Simulink.
- To measure the performance of the system, in the total energy production, power consumption, and power management.
- To conduct the cost-benefit analysis of the cost of operation of the renewable technology versus the grid-based charging.

- Targeting the benefits of the environment such as the carbon emission reduction due to renewable integration.

- To show scalability by comparing prototype findings with a full size EV charger station model of BRAC University.

1.2.2 Functional and Nonfunctional Requirements

FUNCTIONAL REQUIREMENT

To attain operational efficiency and desired output levels, the system has the following functional requirements:

- The system should be able to provide a necessary amount of power to power EVs that is equivalent to the estimated energy requirements:
    - Full-scale model: 10 electric cars (30 kWh each) + 10 e-bikes (10 kWh each) + station load (10 kWh) = 410 kWh per full cycle.
    - Prototype model: 1 battery load (0.00252 kWh) + station load (0.208 kWh) = ≈ 0.2105 kWh/ operation cycle.
- To optimize the PV under changeable irradiance the system will have to control the flow of the solar energy with an MPPT charge controller.
- The prototype should have the ability to store and control power through DC battery bank to ensure its uniform functioning and demonstration.
- The system has to be capable of charging the vehicle and loads associated with internal operations simultaneously.
- The design should entail real time monitoring.
- The outcomes of the simulation should be the validation of the feasibility of the system, cost-efficiency, and reduction of emissions.

NON-FUNCTIONAL REQUIREMENT

The non-functional requirements specify the system quality and performance requirements in general:

- **Efficiency:** The MPPT controller is supposed to be able to operate at an energy conversion efficiency of over 90%.

- **Scalability:** The prototype will be scalable to the complete BRAC University EV charging operation (with up to 410 kWh capacity).

- **Sustainability:** The system must encourage the use of renewable energy.

- **Cost-effectiveness:** The overall cost per charging cycle ought to be kept as low as possible, about 2.53 BDT per charging cycle of a prototype, and 4,920 BDT per charging cycle of a full-size prototype.

- **Environmental impact:** The system must show a recorded reduction of carbon emission as compared to the traditional grid charged power.

- **Maintainability:** The system must be easy to inspect, maintain and up-date.

1.2.3 Specifications

An EV charging station system has a number of built in sub systems that are meant to maintain the availability and efficiency of achieveable charging infrastructure. Sungiven power generation systems include high-efficiency Mono PERC panels with a power output of 545W to produce power in the volume the MPPT charge controllers can handle a solar input power of up to 10000 Wp. Energy storage systems include lithium-ion or lithium-polymer battery banks capable of handling over 3000 charge-discharge cycles for optimal long-term performance. Power conversion and charging subsystems include DC-DC boost convertors, AC-DC rectifiers, and three-phase inverters that can be utilized regardless of the source of power since they can operate using both renewable and grid power supply. Such solutions also require a variety of safety features, including GFCI protection and overcurrent devices, so that users and equipment operate per electrical safety standards. The detailed technical specifications of each sub-component are provided in Table 1.1 below. Table 1.1. Proposed technical specifications for an EV solar-powered station.

Table 1.1. System specifications

Subsystem	Component	Specifications
Solar	Solar Panel	Panel Type: Mono PERCMaximum Power: 545WVoc: 49.65VIsc: 13.92AVmp: 41.80VImp: 13.04A
	Solar charge controller	Type: MPPTMaximum supported panel power: 10,000 Wp

	Batteries	Type: Li-ion or Li-polyLife Cycles: 3000+Voltage per cell: 3.7 V
Charging	DC to DC Boost Converter	Output Voltage: 60VOutput Current: 15AOutput Ripple: 2% (max)
	AC to DC Rectifier	Input Voltage: 230 VOutput Voltage: 60 V
	DC to AC Inverter	Phases: 3Output Phase Voltage: 230 VWaveform: SineFrequency: 50 Hz
Safety and Protection	GFCI	Trip Current: 6 mARated Current: 15 A
	Overcurrent	Rated Voltage AC: 230 VRated Current AC: 100 ARated Voltage DC: 60 VRated Current DC: 15 A

1.2.4 Technical and Non-technical consideration and constraint in design process

Space Constraints

● Limited space available at the BRAC University parking lot requires optimal layout design.

Budget Constraints

● Budget allocation must cover installation, operation, and maintenance costs while maintaining
affordability for users

Regulatory Constraints

● Must Adhere to Bangladeshi electrical and building codes

● Obtain necessary permits for construction and operation

Power Supply

● The local grid may have limitations on maximum power delivery, necessitating energy storage or on-site renewable energy integration

Environmental Constraints

● Design should minimize environmental impact and ensure compliance with BRAC University's sustainability goals

Operational Constraints

● Ensure no disruption to the regular parking availability for non-EV vehicles during installation and operation.

Charging cost

- Cost needs to be less as we are working for Brac University therefore students will be charging

1.2.5 Applicable compliance, standards, and codes

Table 1.2. Applicable standard and codes

Subsystem	Standard	Definition
Appliance couplers for household and similar general purposes	IEC 60320-1	Appliance couplers for household and similar general purposes
Charging Socket	(IEC C15 connector - T jack)	N/A
Outlet	NEMA 14-50	Wall socket with 50-amp maximum amperage
Supply Station	IEC 61851-1	Electric vehicle conductive charging system - General requirements
Solar Module	BDS IEC 61215	Terrestrial photovoltaic (PV) modules - Design qualification and type approval
Solar Module	BDS IEC 61853	Photovoltaic (PV) module performance testing and energy rating

Solar Module	BDS IEC 61730-1:2019	Photovoltaic (PV) module safety qualification part 1: Requirements for Construction
Solar Module	BDS IEC 61730-2:2019	Photovoltaic (PV) module safety qualification part 2: Requirements for Testing
Inverter	BDS IEC 62109-1	Safety of power converters for use in photovoltaic power systems - Part 1: General requirements
Inverter	BDS IEC 62109-2	Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters
Inverter	BDS IEC 61683	Photovoltaic systems - Power conditioners
Inverter	BDS IEC 62116:2020	Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention
Solar Charge Controller	BDS IEC 62509	Battery charge controllers for photo voltaic systems
Battery	BDS IEC 61427-1	Secondary cells and batteries for renewable energy storage

Battery	BDS IEC 60086-4	Primary batteries - Part 4: Safety of lithium batteries

1.3 Systematic Overview/summary of the proposed project

The proposed project named "Design and Implementation of an EV charging station: A sustainable solution for BRAC University" will, by formulating a reliable, renewable-driven charging infrastructure, facilitate sustainable transportation in campus while energy optimization and storage unit will be ensured through the use of an MPPT charge controller and Li-ion or Li-poly batteries, and solar energy harvested by Mono PERC panels. In addition, GFCI and overcurrent protection systems and DC-DC boost converters, AC-DC rectifiers, and DC-AC inverters would maintain smooth power flow to meet constantly changing charging needs and enable safe and reliable operation of the system, which will be a fully operational experimental model suitable for large-scale integration of modern charging technologies with "clean" energy and thus capacity of for the carbon footprint reduction helping Bangladesh in the processes of its transition to sustainable development.

1.4 Conclusion

EVCSs which rely on sustainable produced energy are vital to the industry's current and future because of their way to reduce the carbon footprint of electric vehicles, a decrease in reliance on fossil based fuels and support for the sustainable development of electric vehicles. Powering EVCS with sustainable produced energy may also exacerbate the fossil fuel-free need and assist with a transition to a more sustainable energy structure. Consequently, the development of more EVs in the region has also necessitated the implementation of more EVCSs. Sustainable produced energy sources might ensure that this inevitability will be met in a sustainable and environmentally friendly method.

Chapter 2

Project Design Approach

2.1 Introduction

In the process of engineering design, multiple design methods are important as it provides separate options to explore for an engineer. This can help engineers select the best response for a specific project. Potential risk factors, competing approaches and potential costs/benefits of each design can be identified when engineers consider multiple design strategies. Moreover, engineers can use a range of design methods to suit their strengths and play down their weaknesses while recognizing the needs of their clients or customers. Ultimately, the use of different design methods give you an opportunity to explore themes and make sure that your end product meets the client's needs.

2.2 Identify multiple design approach

Some design approaches that could meet our requirements are:

- Design approach 1: **Grid to Vehicle(G2V)**
- Design approach 2: **Solar and Grid Hybrid (SGH)**
- Design approach 3: **Solar to vehicle (S2V)**

2.3 Description of multiple design approach

CHARGER BLOCK DIAGRAM

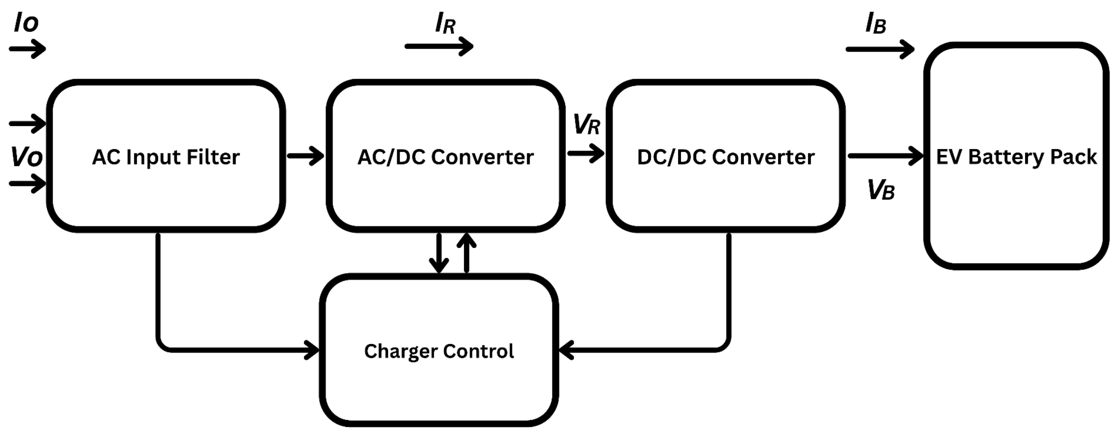


Figure 3: Charger block diagram [13]

BLOCK DIAGRAM AND WORKING PRINCIPLE

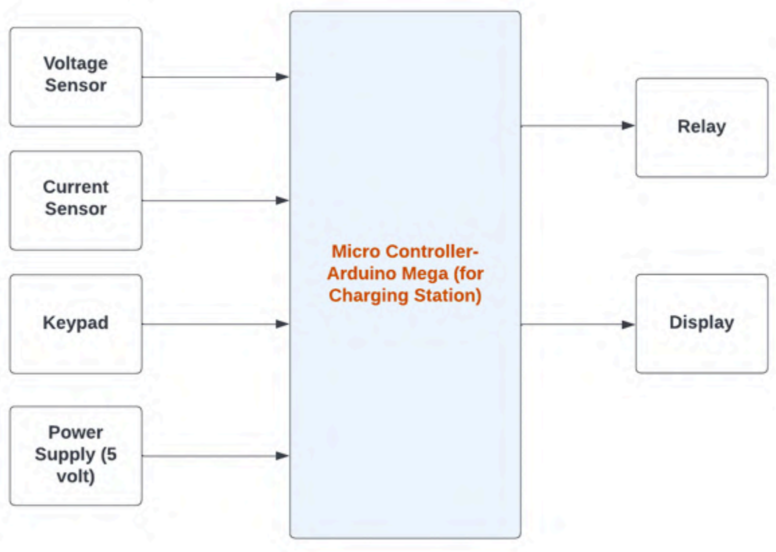


Figure 4: Inputs & Outputs of the Charging Station

Abilities for the Arduino Mega input/outputs Connection between and output to inputs of the micro-processor can be seen above in Figure 4. The inputs are a keypad that takes in an input for how much of Electric charge the car is demanding, 5Volt DC power supply, to run the circuit relating to PWM voltage and current level sensors which measures both (voltage as well as current) from lead acid battery and grid.

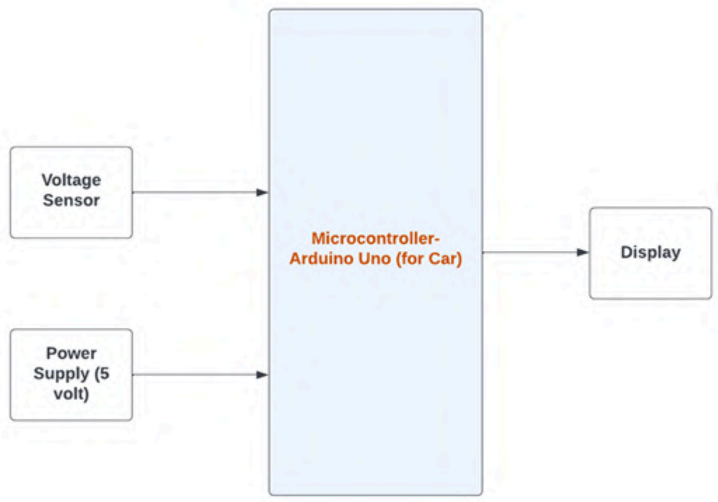


Figure 5: Inputs & Outputs of the Electrical vehicle

The Arduino Uno microcontroller's inputs and outputs are shown in Figure 5. The electric vehicle's two inputs are a 5 volt DC power supply that powers the vehicle's circuitry and a voltage sensor that measures the voltage level of the lithium-ion battery, which serves as the vehicle's battery.

Design approach 1 (GRID TO VEHICLE)

The G2V is the control case for this project that uses typical grid electricity to charge. This process necessitates a multi-stage power conversion to convert 230VAC grid power into regulated DC output that is suitable for EV battery charging. It needs to solve a series of technical problems, such as voltage transformation, AC-DC conversion, ripple filtering and high accuracy voltage regulation at the same time including efficient real-time monitoring and intelligent control for safety charging. Grid-dependent systems may be easy to operate and reliable, but they are not flexible to work with renewable energy and fail to cope with power outages which leads to the design of Hybrid and solar based alternatives in later design methods. The detailed block schematics and flow of signals in the G2V system is given in Figure 6.

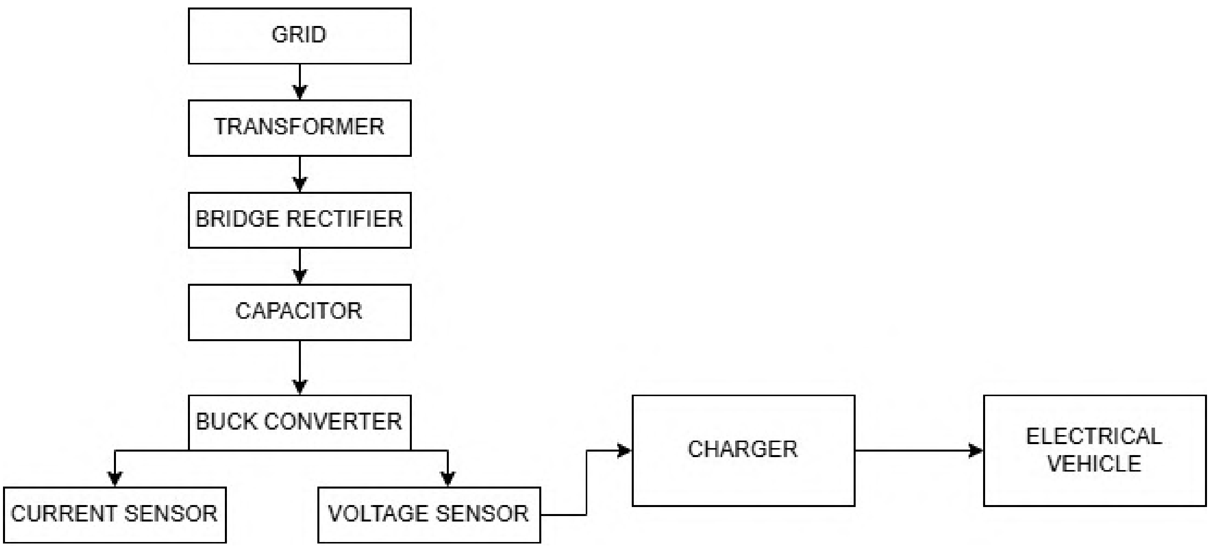


Figure 6: Grid To Vehicle Flow Chart

DESIGN APPROACH 2 (solar grid hybrid to vehicle (H2V)

As such, the Solar-Grid Hybrid-to-Vehicle system may be described as an optimal charging solution as it provides the opportunity to integrate renewable solar energy with grid-based power access for sufficient sustainability and reliability. More specifically, the Solar-Grid H2V leverages solar power while the sun is shining and supplements its supply with grid power during low-sunlight periods. To begin with, the system centers on the grid-tied inverter that ensures bidirectional electrical potential flow from the solar panels and to them, electrical grid, batteries, and the EV charger, as illustrated in The solar panels generate DC electricity that the inverter translates into grid-synchronized alternating current for use and recharging operations. The station batteries play an equally crucial role as they offer energy buffering features. They store excess solar generation for later power use and support system operation in case of grid outages and its peak demand cycle The solar station operates by exporting the surplus solar back to the grid using the inverter For this case, the system may generate additional income or get additional credits for the courtesy of net metering. However, whenever more power is needed than what the panel can produce, the system imports grid-based electricity. Ideally, the system is efficient and cost-effective while supporting a substantial cut in carbon emissions levels compared to the conventional grid-based charging systems as can be seen in Figure 7.

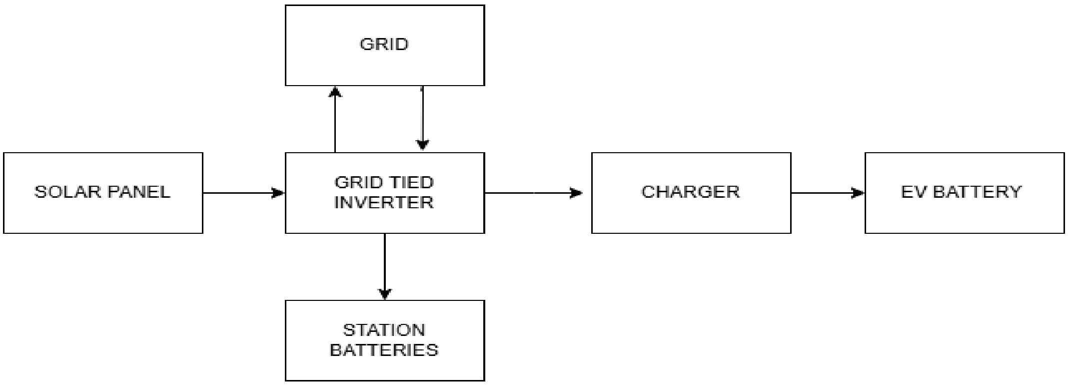


Figure 7: Block Diagram of Solar Grid Hybrid To Vehicle

Detailed Block Diagram of Solar Grid Hybrid To Vehicle (H2V)

The entire Solar-Grid Hybrid-to-Vehicle system will require interconnecting multiple subsystems, intelligently switch to power sources and performance monitoring to ensure maximum performance/reliability. The system architecture can be separated into three primary functional blocks, namely the solar power generation subsystem, the grid backup subsystem, and the vehicle charging subsystem that are linked by a central control unit that is implemented using a microcontroller. The solar subsystem will provide the necessary primary dependence on the resources of renewable energy by collecting DC power with solar sellers, regulating it through charging properties with the help of a charge controller, and storing the energy through the use of station batteries in the prototype version, which in this case is lead-acid batteries. The grid subsystem is used to supply secondary power back-up and with the help of a typical AC-DC conversion chain and transformer-based voltage step-down, bridge rectification, capacitive filtering, and buck converter regulation, offers DC signal stability. The design has an important characteristic, the intelligent selection mechanism of sources that are designed by means of a relay-based switching in the control of the Arduino Mega microcontroller. This system constantly checks the voltage of the two systems the solar system and the grid system and decides which one to use as the source of power using sophisticated logic of availability and priority. The user can operate the system through a keypad board with the choice of the preferred charging paths. Voltages, currents, charging, solar and grid power source, and other real-time system parameters are shown on a 20x4 LCD display. A number of voltage meters and current sensors are also provided in the system to constantly provide feedback to the Arduino microcontroller. This feedback is used to control the system by the microcontroller that stops charge delivery when the user determines the charge level to vehicle battery attained. To further control the power supplied to the lithium-ion battery pack, the developed vehicle unit employs an additional buck regulation converter, and the connection units are regulated by relays to provide safe and regulated power. The applied multi-level architecture effectively proves the existence of the scalable EV charging system integrating renewable and grid energy sources and managed with the help of an intelligent principle of power source selection. Figure 8 is a system block diagram that includes all the required elements, signal routes, and control processes.

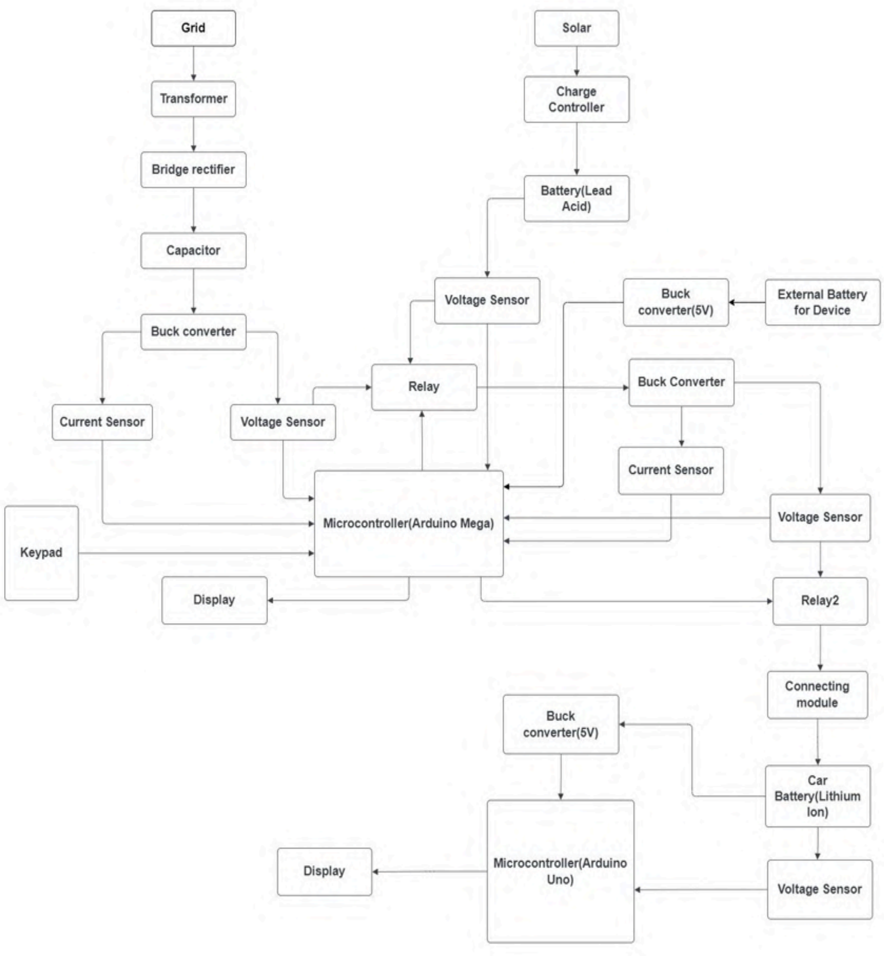


Figure 8: Detailed Block Diagram of Solar Grid Hybrid To Vehicle

This connection includes three types of sources of power such as Solar, Grid and Vehicle which are controlled by an Arduino Mega microcontroller. Solar power is the primary source, and its flow is controlled by a charge controller that regulates the flow of energy from the PV panels to the lead-acid battery. Voltage and current sensors are attached to all inputs from the PV panels and the Grid, and their data is sent to the microcontroller. The relay automatically switches the flow of power input depending on the inputs from the sensors. Grid power is reduced from 230 V to 27.5 V using a transformer, smoothed to 36.7 V DC, and then regulated to 26 V using a buck converter. A keypad allows the user to enter the amount of battery charge as a percentage, which is displayed on the 20×4 LCD. Upon successful connection of the set battery charge, the Arduino sends a signal through the relay to disconnect the network to the battery.

DESIGN APPROACH 3 (Solar panel to vehicle (s2v))

Solar-to-Vehicle (S2V) is a complete off-grid recharging system that can work independent of the utility, utilizing only solar generation and batteries. This possibility represents the maximum sustainability and energy autonomy, being perfectly suited for off-grid sites or for applications that demand zero emission operation: however it remains necessary to execute a proper system sizing in such a way that we can assure reliability during long periods of weather without solar radiation. The design is based on the idea of MPPT (Maximum Power Point Tracking) controller, which regulates solar panel emulation depending on ambient conditions to achieve a maximum available power. The MPPT controller is responsible for bi-directional power transfer from station batteries, storing energy back to the banks when production exceeds station needs and sourcing stored energy if photovoltaic generation is deficient. Station batteries play an important role in this configuration to serve as a buffer when the sunlight intensity is low and to ensure charging ability throughout the night or at times of cloudy weather without access to grid support. An inverter changes the DC power from the solar-battery system to AC for use with standard EV charging infrastructure, which then performs final conditioning to provide regulated DC power to the vehicle battery. While this 100% renewable approach removes reliance on the grid and the cost of energy, it requires larger solar arrays and battery capacity compared to a grid-tied system in order to provide power during all seasons. The S2V system structure and power flows are shown in Fig. 9.

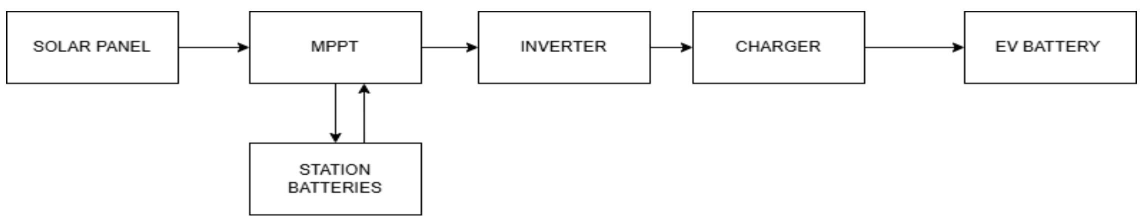


Figure 9: Block Diagram of Solar to Vehicle(S2V)

The charging of electric vehicles by solar PV charger frameworks is framed in Figure 10. Regarding the and the maximum power point tracking techniques of pulse width modulation are expected to contribute to the improvement of solar power generation energy factors. The framework of EV-PV charger includes the charging system PV system, network grid, and electric vehicle equipment supply equipment with the goal of directly charging the EV through PV electricity. During that period, Europe's standards for the charging architecture linked to DCDC link CHAdeMO system-based combined charging standard CCS for assigned dynamic, fast charging V2X-charging systems via rapid charge-based DCDC link systems. Dynamic charging is accomplished by changing the output power, or the charging power limit is changed for an extended period [13].

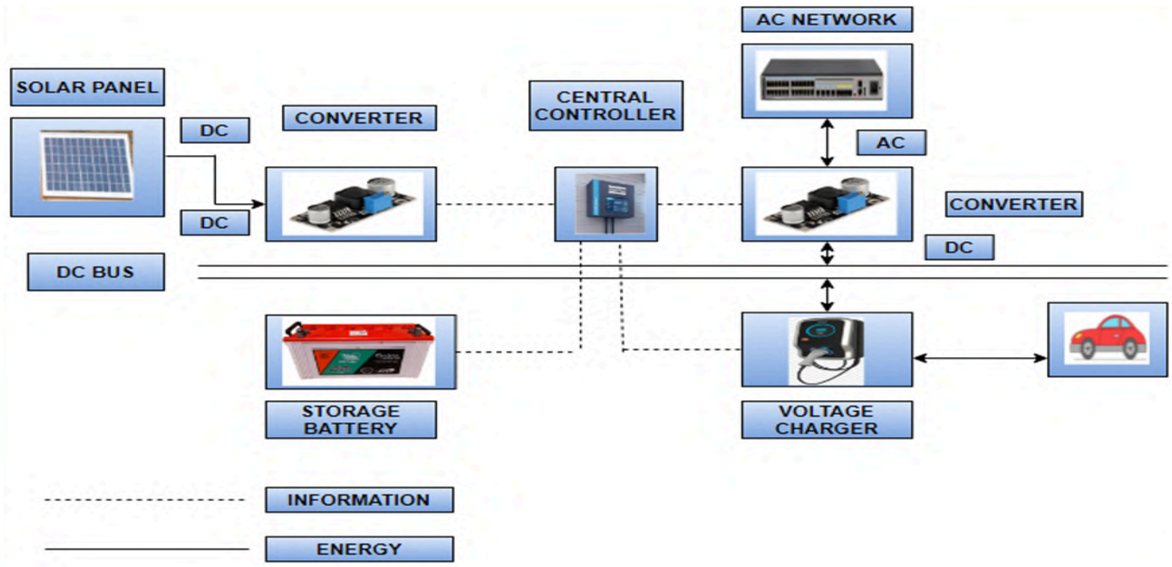


Figure 10: Detailed Block Diagram of Solar to Vehicle (S2V).

2.4 Power Consumption and Analysis of Multiple Design Approaches

2.4.1 Power Consumption

Table 2.1: Total Power Consumption – Full-Scale EV Charging Station

Component	Quantity	Battery Capacity per Unit (kWh)	Total Energy Required (kWh)	Remarks
Electric Cars	10	30	10 × 30 = **300**	Full charging for 10 cars
E-Bikes	10	10	10 × 10 = **100**	Full charging for 10 e-bikes

Charging Station (Operational Load)	1	10	**10**	Internal consumption (lighting, control systems, etc.)
Total Power Consumption	–	–	**410 kWh**	Required for one full operational cycle

Table 2.1 shows the estimated total power consumption for full-scale EV charging station. It plans to be able to charge ten electric cars and ten e-bikes at a time, as well as cover the station's own power consumption. The total for a complete charging cycle is then obtained by adding the frequency contribution of computed energy for full-scale operation, which is 410kWh.

Table 2.2: Total Power Consumption – Prototype Model

Component	Quantity	Power Rating / Battery Capacity	Energy Required (kWh)	Remarks
Battery (Prototype Load)	1	8.4 W = 0.00252 kWh	**0.00252**	Single small-scale battery charged
Charging Station (Operational Load)	1	124.8 W = 0.208000416 kWh	**0.2080**	Power used by prototype station itself
Total Power Consumption	–	–	**≈ 0.2105 kWh**	Per complete operation cycle

The overall power consumption of the prototype version implemented for the project is displayed in Table 2.2. The developed prototype does not only charge one battery of the small-scale at a portion of the magnitude and provides the power consumption due to the station. The total calculated energy use is approximately 0.2105 kWh, revealing that the energy need is reduced relatively if compared to the real model.

2.4.2 Multiple Design Approaches Analysis

To analyze the advantages and disadvantages of each design approach and select the best one depending on our needs, we have first modelled our off grid approach in PVSyst.

Off grid system

Simulation parameters

- Tilt 23.8° and Azimuth 0°
- 72 Modules – 18 in series, 4 in strings, 545 W each
- Fixed power consumption of 100 kWh per day

- 170 kWh of battery capacity – 2 in series, 35 in parallel
- Each battery is 48 V with 51 Ah capacity
- Depth of discharge (DOD) set to 80%
- Soiling loss set to 3%
- Inflation set to 5% per year
- Project lifetime 30 years

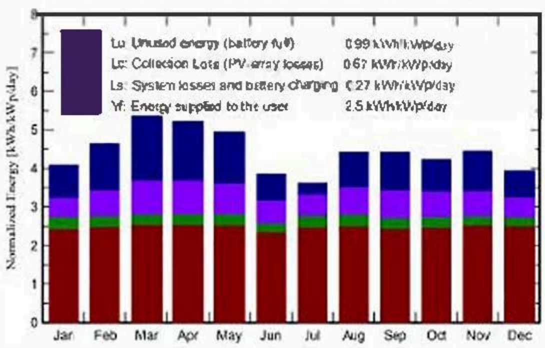
System Production

Available Energy	250666 kWh/year	Specific production	149666 kWh/kWp/year
Used Energy	150600 kWh/year	Performance Ratio PR	56.37 %
Excess (unused)	100066 kWh/year	Solar Fraction SF	97.94 %

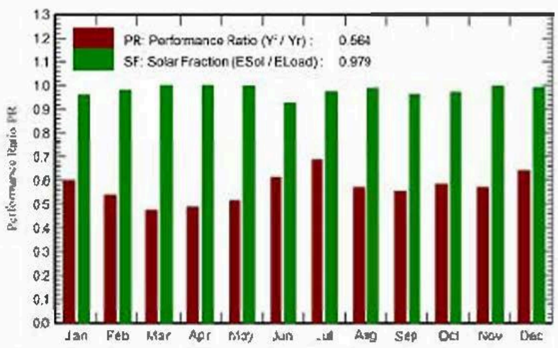
Loss of Load

Time Fraction	2.6 %
Missing Energy	752 kWh/year

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	103.3	120.6	20384	7194	123.7	12537	3100	0.960
February	112.1	124.1	20500	9296	53.1	11573	2800	0.981
March	153.8	158.7	25718	14423	0.0	13060	3100	1.000
April	156.5	149.1	24077	12775	0.0	12638	3000	1.000
May	163.3	145.4	23541	11297	2.3	13051	3100	0.999
June	125.4	109.2	3664	5454	219.4	11716	3000	0.927
July	120.5	105.7	17184	2398	78.6	12727	3100	0.975
August	141.9	129.7	21026	7689	36.8	12904	3100	0.988
September	128.0	125.9	20307	8149	115.6	12150	3000	0.961
October	118.2	125.1	20249	7038	86.1	12697	3100	0.972
November	109.2	127.4	20998	8531	8.3	12605	3000	0.997
December	97.6	116.4	19478	5822	28.2	12942	3100	0.991
Year	1529.9	1537.5	250666	100066	752.1	150600	36500	0.979

Legends

GlobHor	Global horizontal irradiation	E_User	Energy supplied to the user
GlobEff	Effective Global, corr. for IAM and shadings	E_Load	Energy need of the user (Load)
E_Avail	Available Solar Energy	SolFrac	Solar fraction (EUsed / ELoad)
EUnused	Unused energy (battery full)		
E_Miss	Missing energy		

Figure 11: Off_Grid System Results From PVSyst

The off-grid solar PV system is simulated for a tilt angle of 23.8° and azimuth angle of 0°, designed to capture the annual solar energy under average performance conditions. The photovoltaic system is composed of 72 PV modules (for a total installed capacity of around 39.24 kWp, each one rated at 545 W) divided in four parallel strings (18 modules in series).

Generated energy is stored in a 170 kWh battery bank (2 × 35 cells connected in series and parallel, nominal voltage of 48 V, and nominal capacity of 51 Ah/cell) with an average DOD of the SoC of approximately 80%. The system is sized with 100 kWh daily energy demand, taking into consideration 3% soiling losses and 5% per annum annual energy escalation for a project lifespan of 30 years.

From the simulation results:

- **Annual available solar energy:** ~250,666 kWh
- **User energy consumption:** ~150,600 kWh (load: 36,500 kWh)
- **System losses and unused battery energy:** ~100,066 kWh/year
- **Missing energy (unmet load):** 752 kWh/year (**2.6% loss of load time fraction**)
- **Performance Ratio (PR):** 56.37%
- **Solar Fraction (SF):** 97.94%
- **Specific Production:** 149,666 kWh/kWp/year

Based on PVSyst, the yearly available solar energy is 250,666 kWh and out of that, 150,600 kWh is appropriately utilized by the load whereas 100,066 kWh becomes not-used (excess) due to full state of battery. The attained solar fraction (SF) is 97.3%, which means that almost solar energy meet the total demand load. The Performance Ratio (PR) of the system is 56.37%, indicating losses in webcam, PV array, wiring, charge controller and battery due to people error as well as environment condition as it usually happens in stand-alone (off-grid) system.

ENVIRONMENTAL IMPACT USING HOMER PRO

Hybrid Solar-Grid (H2V): The quantified environmental performance of the H2V Hybrid Solar-Grid charging system shows a significant reduction in emissions compared to traditional grid-only alternatives, confirming the advantages of renewables integration. As shown in figure 12 below, the H2V configuration's annual emission profile indicates the externalized costs of the system in six key atmospheric pollutants. Specifically, the system emits 157,961 kg of carbon dioxide annually, which represents the greenhouse gas emissions associated with consumption of grid electricity during periods of low or insufficient solar generation. The system emits zero kg/yr of carbon monoxide, hydrocarbons, and particulates, meaning that the grid source or solar components may not be significant contributors to these air pollution or their amounts are below measurability. On the other hand, the system releases

685 kg/yr of sulfur dioxide and 335 kg/yr of nitrogen oxides, which are the common pollutants from fossil fuel combustion in grid generations and responsible for acid rain and respiratory issues. These pollutants show the hybrid nature of the system since the current grid system in Bangladesh mostly utilizes natural gas and coal-powered plants for generation. Compared to a full grid-only system, modest emission emissions reaffirm the environmental enticement of solar photovoltaic components, which directly substitute lin-based generation during daylight hours or periods of high irradiance. The emission profile recorded herein serves as a grounding point for analyzing the sustainability merits of the hybrid approach and an attractive milestone to fulfilling the project aims.

Quantity	Value	Units
Carbon Dioxide	157,961	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	685	kg/yr
Nitrogen Oxides	335	kg/yr

Figure 12: H2V Emissions

Grid-to-Vehicle: The G2V charging has by far the highest environmental impact as it consumes only electricity derived from the utility grid, with no contribution based on renewable energy allocations. The annual emission profile for the G2V system is shown in Fig. 13, which indicates the environmental impact of traditional grid-reliant charging stations. The system generates 1,148,168 kg carbon dioxide (CO2) in a year or approximately 1.15 metric tons in green house gas emission- one step towards altering the climate of the globe and raising the concentration of the atmosphere in carbon dioxide. In analogy with the hybrid system, zero emissions are measured for CO, unburned hydrocarbons and particles which means that either the combustion processes in the power generation plant infrastructure of the grid fall within detection limit values or emission levels are below such thresholds. But the scheme also emits far more pollution: 4978 kg/yr of sulfur dioxide (SO_2) and 2,434 kg/yr of nitrogen oxides (NO_x), both noxious byproducts of burning fossil fuels in power plants. These are precursor pollutants that cause acid rain, ground level ozone (smog), and respiratory health problems for urban dwellers. Emission intensities in the G2V case are about 7.27 times higher for all pollutants (CO_2, SO_2 and NO_x) than those measured with the hybrid system, reinforcing no solar energy supply and more grid fossil fuel-based generation hours. The emissions are then proportional to grid electricity consumption, and the solar-integrated hybrid system effectively replaces around 86% of the grid-related emissions. This quantitative evidence is convincing in favor of sustainable grid renewable energy-integrated charging solutions and focuses on hybrid or solar-based over conventional grid-only systems, when considering Bangladesh's national climate commitment as well as sustainability target set by BRAC University.

Quantity	Value	Units
Carbon Dioxide	1,148,168	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	4,978	kg/yr
Nitrogen Oxides	2,434	kg/yr

Figure 13: G2V Emissions

Pollutant Emission:

Table 2.3: Pollutant emission

Pollutant	G2V Emission	H2V Emission	Reduction in H2V	Remarks
Carbon Dioxide (CO_2)	1,148,168 kg/yr	157,961 kg/yr	↓ **990,207 kg/yr (~86%)**	Major reduction due to solar power replacing grid usage
Carbon Monoxide (CO)	0 kg/yr	0 kg/yr	–	Not emitted by either system
Unburned Hydrocarbons	0 kg/yr	0 kg/yr	–	Not present in either case
Particulate Matter	0 kg/yr	0 kg/yr	–	No particulate emissions from either
Sulfur Dioxide	4,978	685 kg/yr	↓ **4,293 kg/yr**	Reflects a cleaner energy

(SO_2)	kg/yr		**(~86%)**	mix in H2V
Nitrogen Oxides (NOx)	2,434 kg/yr	335 kg/yr	↓ **2,099 kg/yr (~86%)**	Sharp drop, indicating reduced fossil fuel reliance

Important Takeaways:

- Grid purchases account for the majority of G2V's lifetime costs, making it grid-dependent.
- Despite having a large upfront capital investment, H2V has much lower operating costs—or even negative ones—which suggests improved long-term cost effectiveness.
- By using renewable energy, H2V systems enhance sustainability and provide possible revenue or savings.

While G2V is suitable for low cost or temporary implementation, it requires reliance on the grid increasing operational expenses. Higher initial cost for H2V, but lower running costs and the ability to gain a premium through feed-in tariffs etc with renewable energy sources will make this technology more economic and sustainable over the life of these vehicles.

CHARGING TIME

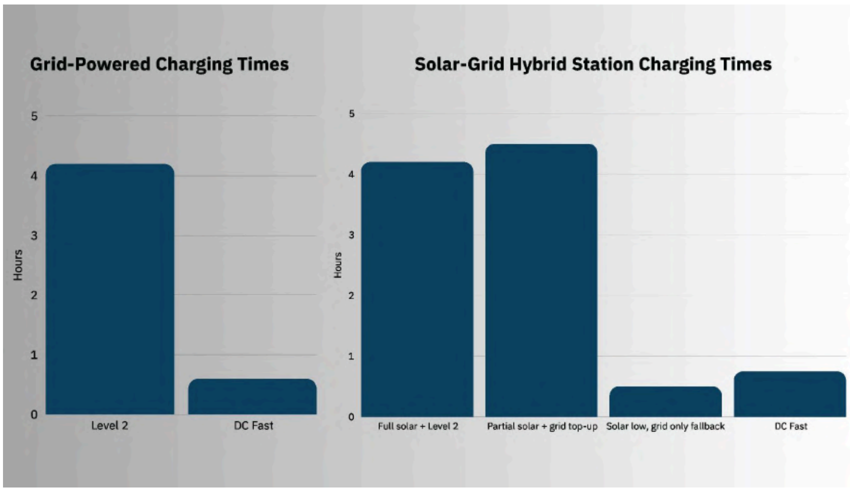


Figure 14: Difference in Charging Time

1. G2V System

All charging modes are entirely reliant on the grid.

Durations of charging:

- DC Fast: approximately 45 minutes (fast charging standard).
- Depending on the power source and vehicle battery size, Level 2 Charging (Grid) takes approximately 4.5 hours.

2. The H2V System

- More adaptable charging options through the use of solar
- Level 2 + Full Solar: about 4 hours; slower, but renewable.
- Partial solar + grid: approximately three hours — a more effective hybrid.
- Grid-only fallback (low solar): approximately two hours — corresponds to G2V.
- DC Fast: approximately one hour, equivalent to G2V.

2.5 Conclusion

More flexible and efficient charging solutions are offered by H2V, especially under moderate-to-high levels of solar irradiation. (2) Level 2 Charging It takes longer time for the G2V, which is static and grid based. Both systems juice up quickest (in around an hour) with DC Fast Charging. H2V has the advantage over those regions with good solar resources that it is an EV without additional load to the grid and slower charging.

Chapter 3

Use of Modern Engineering and IT Tools

3.1 Introduction

More flexible and efficient charging solutions are offered by H2V, especially under moderate-to-high levels of solar irradiation. (2) Level 2 Charging It takes longer time for the G2V, which is static and grid based. Both systems juice up quickest (in around an hour) with DC Fast Charging. H2V has the advantage over those regions with good solar resources that it is an EV without additional load to the grid and slower charging.

3.2 Tool Selection Criteria

Tools were chosen by matching their capabilities to project needs:

Technical criteria:

- Multi-source hybrid system modeling
- Hourly/chronological and dynamic simulations
- Validated component libraries and empirical models
- Sensitivity analysis and optimization features
- Support for hardware-in-the-loop / embedded-code co-simulation (where applicable)

Selected tools and role:

- **HOMER Pro** — techno-economic optimization, NPC/LCOE calculation, sensitivity studies for grid, PV and storage sizing.
- **MATLAB/Simulink (Simscape Electrical, Control Toolbox)** — component-level dynamic models, converter and battery behavior, control algorithm development and transient testing.
- **PVsyst** — detailed PV array design, horizon/shading analysis, hourly yield and loss breakdown compliant with industry standards.
- **Proteus Design Suite** — schematic/SPICE simulation and microcontroller co-simulation for MPPT and power-electronics prototyping.

All tools selected are widely used in academia and industry and have validation against empirical data, supporting credible simulation outputs.

3.3 Application of Tools

3.3.1 HOMER Pro — Techno-economic Optimization

A A (app HOMER Pro (generally refer to Content"))) used hourly time step simulations and brute force search of systems combinations for efficient system designs selection. The modeled architectures: Grid-to-Vehicle (G2V), Solar-to-Vehicle (S2V) and Solar-Grid Hybrid (H2V). The use case inputs were PV capacity, battery size and inverter ratings, NASA SSE solar data for Dhaka (23.8°N, 90.4°E), tariff design information and EV campus load profile information197-200. Crucial sensitivity factors: PV (0–50 kWp), battery (0–200 kWh), grid price (±20%), discount rate (5–10%).

Outputs: NPC, LCOE, annual operating cost, renewable fraction, and emissions (CO_2, SO_2, NO_x).
Key finding: H2V was optimal—balanced economics and reliability (≈>95% load-serving capability) and reduced emissions (~86% vs. G2V).

3.3.2 MATLAB/Simulink — Dynamic Modeling & Control

MATLAB/Simulink implemented detailed models and control logic:

- PV single-diode five-parameter model (temperature and irradiance dependence)
- MPPT (adaptive P&O) and DC-DC converter models (average and switching representations)
- Battery equivalent circuit with SOC-dependent dynamics
- Grid interface and fault scenarios

Simulations evaluated charging efficiency, transient response (settling time, overshoot), MPPT tracking efficiency under variable irradiance, SOC trajectories, and protection logic. Results were compared with manufacturer curves and literature benchmarks for validation.

3.3.3 PVsyst — PV Design and Yield Assessment

For BRAC University location at 23.8°N, 90.4°E, the meteorological data of analyses were generated in Meteonorm and simulated TMY in hourly resolution through PVsyst along with horizon shading evaluation, module level thermal loss, and the whole loss-diagram investigation: soiling through TMY, mismatch, and wiring, conversion and battery-round-trip loss including the other PVsyst output of annual kWh, monthly production, specific yield expressed in kWh/kWp, and performance ratio or PR, The tilt angle, boundary configuration, and module type Monocrystalline PERC, 545 Wp, were altered from distinct design iterations.

3.3.4 Proteus — MPPT and Circuit Validation

Proteus facilitated schematic capture, SPICE transient analysis, and microcontroller co-simulation for the MPPT controller. Activities included power-stage verification (inductor/capacitor sizing, MOSFET selection), thermal/junction checks, and embedded-code testing of the P&O algorithm.

Verified performance: output regulation within ±2%, MPPT efficiency >97% in steady state, and safe response under simulated faults.

3.4 Conclusion

A focused multi-tool workflow gave complementary analyses at both time and abstraction scales: annual techno-economic optimization (HOMER), millisecond-level dynamics and controls (Simulink), PV yield and loss diagnostics (PVsyst), circuit/prototype validation (Proteus). This method made it easier to de-risk technically, justify design decisions quantitatively and set a simulation baseline for physical prototyping as well as the later optimization, validation and economics chapters. Proficiency in tools is also indicative of practical skills for modern renewable-energy engineering.

Chapter 4

Optimization of Multiple Design and Finding the Optimal Solution

4.1 Introduction

Project planning and development are crucial for EV charging stations that utilize power from renewable sources. An efficient optimization ensures that the resulting solution is both technically and economically/environmentally viable due to the variety of design alternatives (grid-connected, off-grid, or hybrid solar systems). To determine the best and most economical configuration for BRAC University, a number of system designs were evaluated through advanced simulation and analysis techniques such as HOMER Pro, MATLAB/Simulink, as well as PVsyst.

4.2 Optimization of multiple design approach

When developing the architecture for the proposed structure, four main subsystems were recognized with various design options. The best version is determined by a balance of cost, efficiency, ease of operation and reliability. Comparison of the alternatives will allow you to select the design model that will be appropriate in order to meet the goals of your project in a step-by-step manner. The identified subsystems and their decisions are reported in the following way.

Subsystem 1: Solar Panel Tracking and Tilt Mechanism

The effectiveness of solar energy harnessing requires good alignment of the panels to the direction of the sun. There were four configurations taken into consideration:

- **Fixed Tilt:** The panels are fixed to a fixed tilt angle that is optimized based on the latitude of the site. Such an approach is easy and has low maintenance but can have lower energy output per year.

- **Seasonal Tilt Adjustment:** The tilt is manually adjusted multiple times annually to the seasonal sun rise to enhance capture of energy without substantial mechanical complexity.

- **Single-Axis Tracking:**Panels turn in one direction (typically east-west), tracking the daily rotation of the sun and generating an energy output high by 15-25 percent of a fixed system.

- **Dual-Axis Tracking:** The panels are tracked on both azimuth and elevation axis and optimum orientation is maintained through the year and day. Whereas it is the most efficient, it is also expensive and expensive to maintain.

Subsystem 2: Inverter and Solar Controller Configuration

The inverter-controller system defines the quality of the power conversion and efficiency of the system. The two configurations were compared:

- **PWM Controller with Separate Inverter:** A simple configuration suitable for small-scale systems; however, it may result in lower efficiency and limited control flexibility.

- **MPPT Controller + Grid-Tied Inverter:** A developed design, this utilizes all the power that is available on PV arrays and can be seamlessly connected to the grid, yet more expensive and complex to operate at lower initial cost and reduced system complexity.

Subsystem 3: Battery Technology

The choice of energy storage has a major impact on the system life time, efficiency and cost. Three battery technologies were put into consideration:

- **Lead-Acid Battery:** Economical and more than usual it is restricted by reduced life span and decreased depth of discharge.

- **Nickel-Metal Hydride (NiMH) Battery:** Is more efficient and cheaper than lead-acid, however, has less energy density and cycle life.

- **Lithium-Ion Battery:** Lithium-ion offers high energy density, longer life, and better charge-discharge efficiency, which is why it is the most appropriate in the regeneratively powered systems of the present day, as it is more expensive to purchase.

Subsystem 4: Load Management Strategy

Good load management will guarantee good operation and efficient utilization of energy available. The analysis was made of the following strategies:

- **Plug-in upon Arrival:** Direct charging whenever vehicles are connected; simple but may cause peak load issues.

- **Battery Backup:** Battery Backup: It includes intermediate storage to smooth supply and demand to improve the stability of systems when the grid varies or the amount of solar energy is low.

- **Demand Side Management (DSM):** This is the use of smart control algorithms to schedule loads or shift loads to reduce peak demand and maximize the use of energy.

Design solution for subsystem 1: The angle of inclination and the orientation of the photovoltaic array is important in cost economics and annual energy yield. At a latitude of 23.8°N for the BRAC University site, incident solar radiation month-wise should ideally be equal to the inclination angle (latitude angle) for maximum collection throughout the year under consideration in case of fixed installation. However, other methodologies such as seasonal tilt correction or active tracking could have better performance with a higher complexity and maintenance. Two types of design configurations were considered for the photovoltaic panel mounting subsystem, fixed-tilt simple structure and seasonal tilt manually controlled. These solutions are compared in Table 4.1 with respect to the design approach, capital cost, increase in energy yield, maintenance effort and operational reliability.

Table 4.1 Design solution for subsystem 1

Parameter	Design Solution 1: Fixed tilt	Design Solution 2: Seasonal tilt adjustment
Method	Fixed tilt at optimum angle of 23.8 degrees.	Change tilt angle to optimise for summer and winter months
Cost	Low	Low

Design solution for subsystem 2: The power electronics interface between the solar PV array and the energy storage / distribution is extremely critical to achieve maximized energy harvesting efficiency of electricity while maintaining an acceptable degree of flexibility for various modes of system operation. You have two main alternatives concerning this subsystem: Use either separate charge controller and inverter modules – a single PCC (Power Conditioning Center) performing the required functionalities. The CC type -PWM or MPPT- has a remarkable effect on the actual PV array energy production when irradiance and temperature vary. PWM controllers function by just connecting the panel to battery, in a one-way connection at times when charging is required, and no correlating voltage loss as from not operating at its max power point. In comparison MPPT controllers use DC to DC conversion with sophisticated tracking algorithms (Perturb & Observe, Incremental Conductance), which keep the operating point of the panel at its peak to get 15-30% more energy versus a PWM controller– more in cold or cloudy conditions. The inverter topology (stand-alone, local AC-loads driven or utility-grid connected/plug-in, bidirectional power flow-enabled) expresses as well the possibility for an energy surplus due to solar generation from the PV deployment that is returned and fed back to the hosting utility-grid possibly obtaining credits under net-metering incentives. The comparison of the implementation cost for two alternative design solutions for charge controller and inverter unit sub-system is presented in Table 4.2 with regard to approach, efficiency conversion as well as complexity of system integration.

Table 4.2 Design solution for subsystem 2

Parameter	**Design Solution 1: PWM controller with separate inverter**	**Design Solution 2: MPPT controller with grid tied inverter**
Method	Use a PWM **controller** for power tracking and a separate inverter for backfeeding.	Use a **single module** for power tracking and backfeeding. **MPPT** is more efficient than PWM. A single module reduces cost and has better performance.
Efficiency	Low	High
Cost	Moderate	High

Design solution for subsystem 3:

Table 4.3: Design solution for subsystem 3

Parameter	**Design Solution 1: Lead-acid battery**	**Design Solution 2: Nickel-metal hydride battery**	**Design Solution 3: Lithium-ion battery**
Cycle life expectancy	500-1200	3000	3000-6000

Energy density (Wh/kg)	25-35	55.3	88.0-112.0
Self-discharge rate (per month)	4-6%	13.9-70.6%	1.5-2%
Memory effect	Absent	Present	Absent
Charge-discharge energy efficiency (%)	70	80	90
Battery management system required	No	Optional	Yes

Design solution for subsystem 4: The operational strategy for managing EV charging demand has profound implications for grid impact, system economics, user convenience, and infrastructure utilization. In contrast to uncontrolled plug-in on arrival charging where cars immediately start charging once connected, intelligent load management systems can be used to plan a change to off-peak periods, use battery buffering, or apply dynamic pricing to simultaneously meet a variety of goals. To the grid operator, the uncontrolled EV charging that is focused on the evening peak demand periods worsens the current capacity constraints, speeds up the aging of the infrastructure, and makes the utilization of expensive peaking power plants that have higher emission factors more reliant. On the other hand, demand-side management (DSM) policies of deferral charging to off-peak periods can be used effectively to tap into unexploited baseload generation capacity, decrease loading of distribution transformers, and decrease the costs of electricity purchase through exploitation of time-of-use tariffs. The intermediate system uses a Battery Energy Storage System (BESS) to enable instant charging once the vehicle arrives but slowly allows grid power to fill the station batteries to release grid loading during off-peak hours to refill the batteries in the vehicle, and removes the temporal connection between charging demand and grid loading. Moreover, BESS-based solutions also offer useful resilience to load shedding, a form of problem that has become common in the Bangladesh power system where the charging operation can continue during periods of grid load shedding. However, BESS-based strategies require substantial capital investment and must ensure sufficient storage capacity to meet anticipated demand during both normal operations and extended outages. Table 4.4 compares three load management approaches—plug-in on arrival, battery backup, and demand-side management—evaluating their operational methodology, grid loading characteristics, backup capability, user convenience, and infrastructure requirements.

Table 4.4 Design solution for subsystem 4

Parameter	**Design Solution 1: Plug-in on arrival**	**Design Solution 2: Battery backup**	**Design Solution 3: Demand Side Management**
Method	Plug-in when EVs arrive to recharge.	Plug-in when EVs arrive to recharge through **BESS** (Battery Energy Storage System), then switch over to the grid when BESS runs out.	Delay charge until **off-peak hour** starts.
Load on grid	Charged during **peak hours**.	Charged during **peak hours** (delayed slightly by BESS). BESS would not have sufficient charge during load shedding.	Charged during **off-peak hours**.
Backup	N/A	BESS would provide **backup** during load shedding.	BESS would provide **backup** during load shedding.

4.3 Identify optimal design approach

Solar Panel Tracking and Tilt

The fixed tilt configuration generates enough power for our project. As a result, we have decided to track and tilt solar panels using a fixed tilt configuration.

Solar Controller System

Despite being more costly than PWM controllers, MPPT controllers are far more efficient. Because the advantages exceed the disadvantages, we have decided to employ the MPPT controller in our project.

Battery Technology

Because lithium-ion batteries offer a better energy density and cycle life expectancy than lead-acid and nickel-metal hydride batteries, we have decided to use them for our project. Lithium-ion batteries also have a high charge-discharge efficiency and no memory effect.

Management of Loads

Demand side management is the strategy we have chosen for our project since it lessens the strain on the grid during peak hours and requires fewer station batteries, which helps to minimize the project's initial investment of funds.

4.4 Performance evaluation of developed solution

Our proposed design of MPPT charge controller has been simulated using Proteus. Here is the proteus simulation of the MPPT charge controller that we have made.

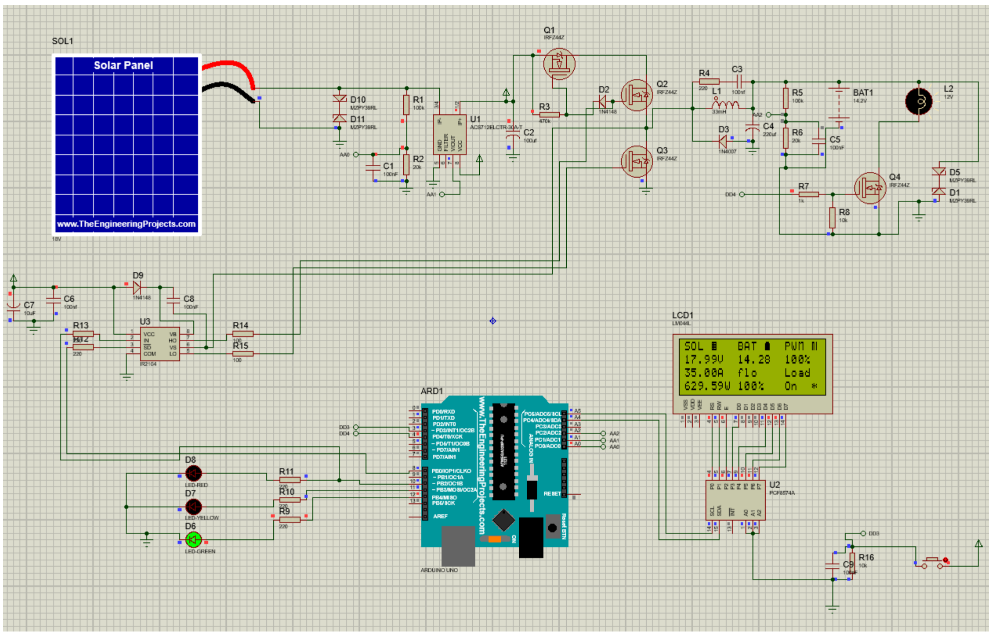


Figure 15: MPPT Charge Controller (Proteus)

Criterias Used:

EV battery capacity: 30 kWh (per report).

MPPT efficiency: 97% (Proteus results / design goal).

Inverter & other system losses: 95% (wiring, converter, miscellaneous).

Combined efficiency = 0.97 × 0.95 = 0.9215 (92.15%).

PV array sizes used for examples: 39.24 kWp (your 72 × 545 W array from PVSyst), 10 kWp, 5 kWp, 3.3 kWp (small rooftop).

Time (hours) = 30 kWh ÷ (PV_kWp × 0.9215).

Table 4.5: MPPT Charging Performance

PV array (kWp)	Effective DC power after MPPT & losses (kW) = PV × 0.9215	Solar-only time to full charge (30 kWh)	Hybrid — solar half used time (30 kWh)
39.24 kWp (your design)	36.16 kW	0.83 h (≈ 50 min)	1.66 h (≈ 1 h 40 min)
10 kWp	9.22 kW	3.26 h	6.51 h
5 kWp	4.61 kW	6.51 h	13.02 h
3.3 kWp	3.04 kW	9.87 h	19.73 h

The table model the expected time to fully charge a typical 30 kWh electric vehicle battery in two conditions of discharging: solar only and hybrid (solar + grid) charging mode. In the solar-only mode, all PV generation capacity is used for EV charging, and the overall system efficiency is given by the MPPT charge controller plus conversion components. In contrast, the hybrid mode considers that half of the PV system installations are reserved for feeding the vehicles and then remaining energy is supplied to other loads or stored. The charging time results are the obtained based on effective PV array power analysis after included conversion losses so as to allow comparison of how charging time will vary with system capacity and mode operation.

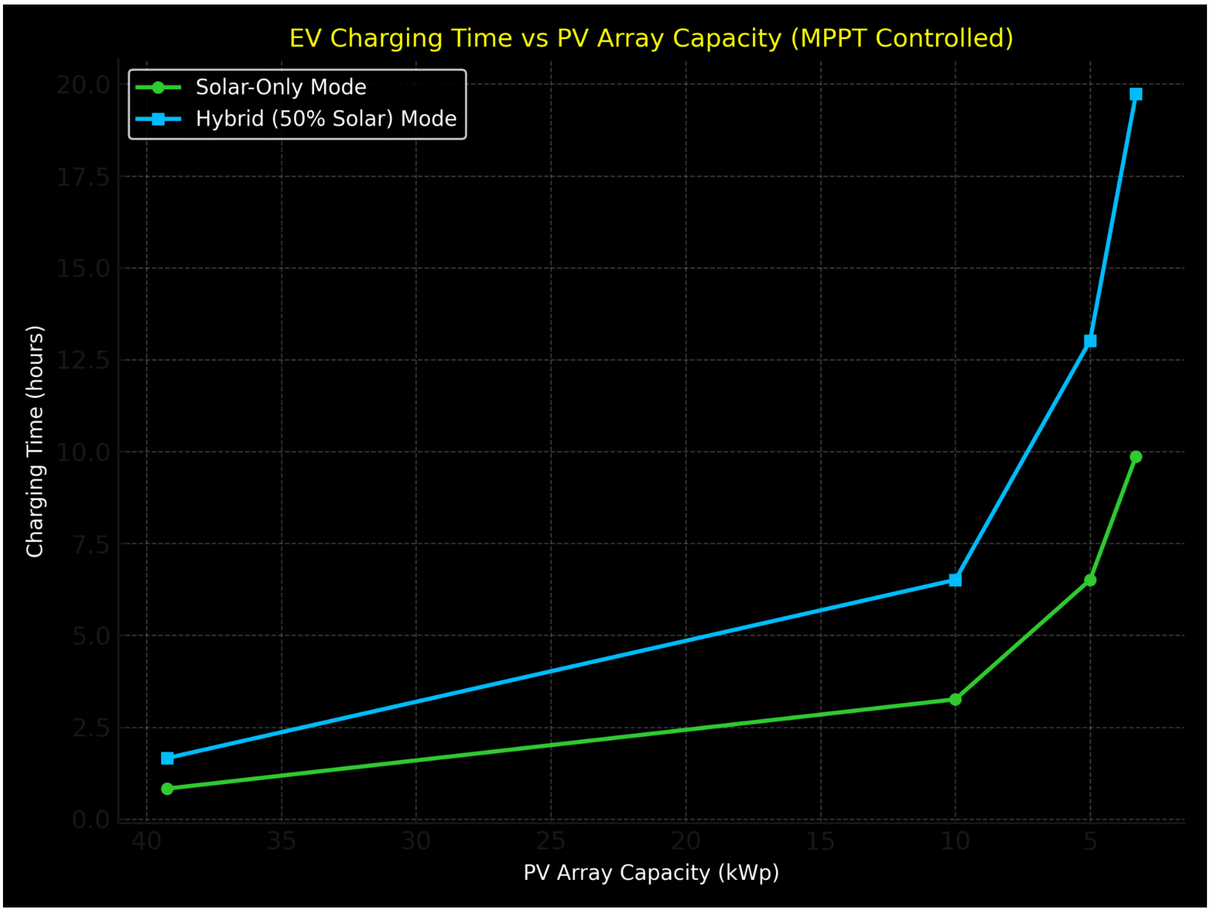


Figure 16: Charging Time vs PV Capacity

This graph in the figure 16 shows how the whole time taken to charge a 30 kWh electric vehicle battery decreases with increasing PV array capacity. It considers two operating modes—solar-only and hybrid (50% solar integration)—which are controlled by the MPPT charge controller. The reverse relationship shows that, when the PV capacity is increased, it allows for faster charging and half of the power (hybrid) only goes to the EV requiring also an increasing time of charge.

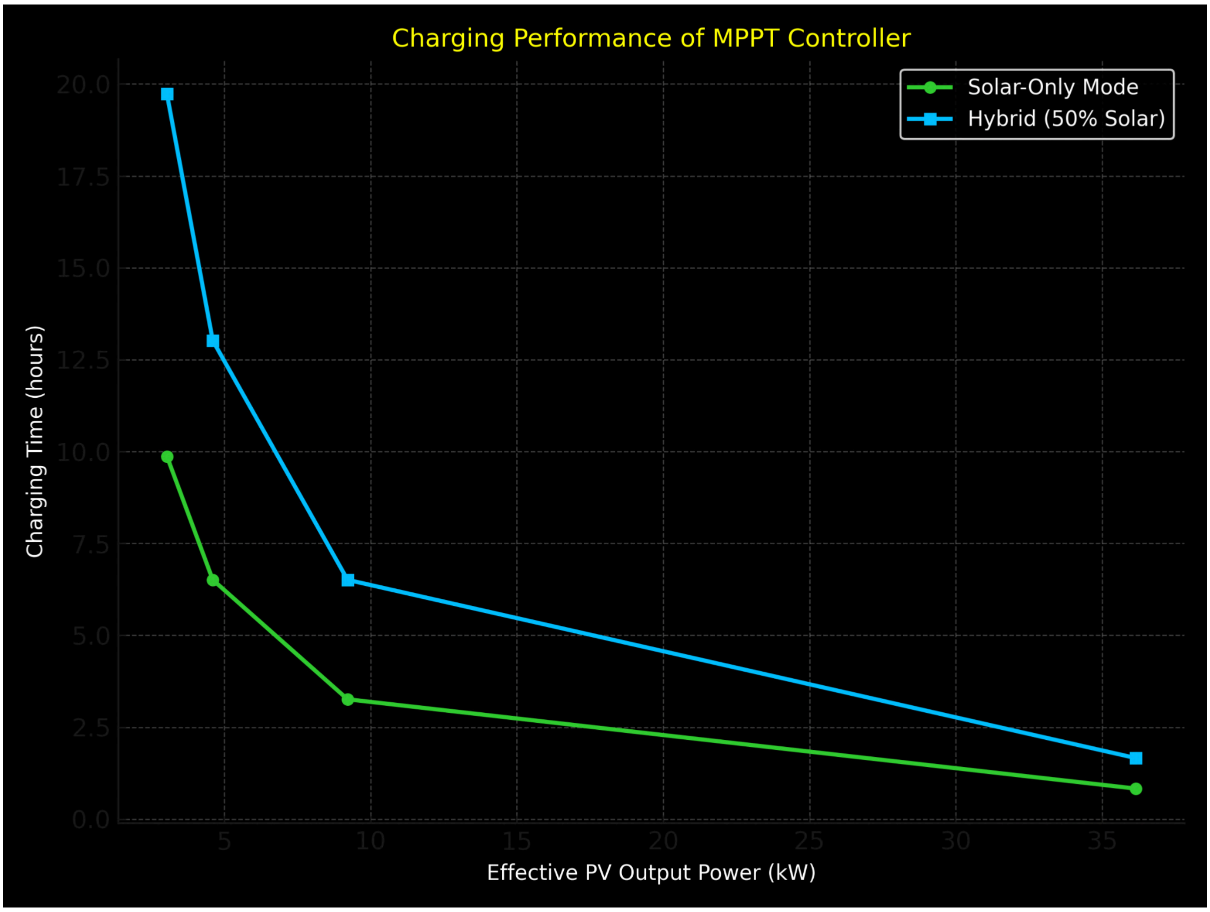


Figure 17: Charging Performance

The figure 17 shows the relationship between the actual output PV power itself (after MPPT and conversion) and its charging time. The efficiency benefit of MPPT controller is obvious and the decrease tendency in charging time remains unchanging with solar radiation increasing as shown in the plot. The charging time is longer with hybrid mode because the harvested solar energy contribution has reduced as expected, which reflects that the controller proportionally power tracks and upholds utilization of maximum available photovoltaic generated energy.

The forecasted charging times are optimistic estimates, based on full sunlight and stable function of the system. There are many actual charging time factors that can differ in practice, such as solar radiation strength by the cloudiness, temperature differences, seasonal changes and partial shading of PV module. Furthermore, EVs often cap the charging power according to their rated on-board charger or DC fast-charging system specifications regardless of PV generation, leading ultimately to reduced effective charge rates. The charging current decreases slowly naturally towards higher SOC of battery such as to increase total time required for full charge. So, while figures are provided as a theoretical guideline, 'in the wild' performance will depend on environmental factors, system usage and vehicle-specific charging profiles.

EVCS Simulation:

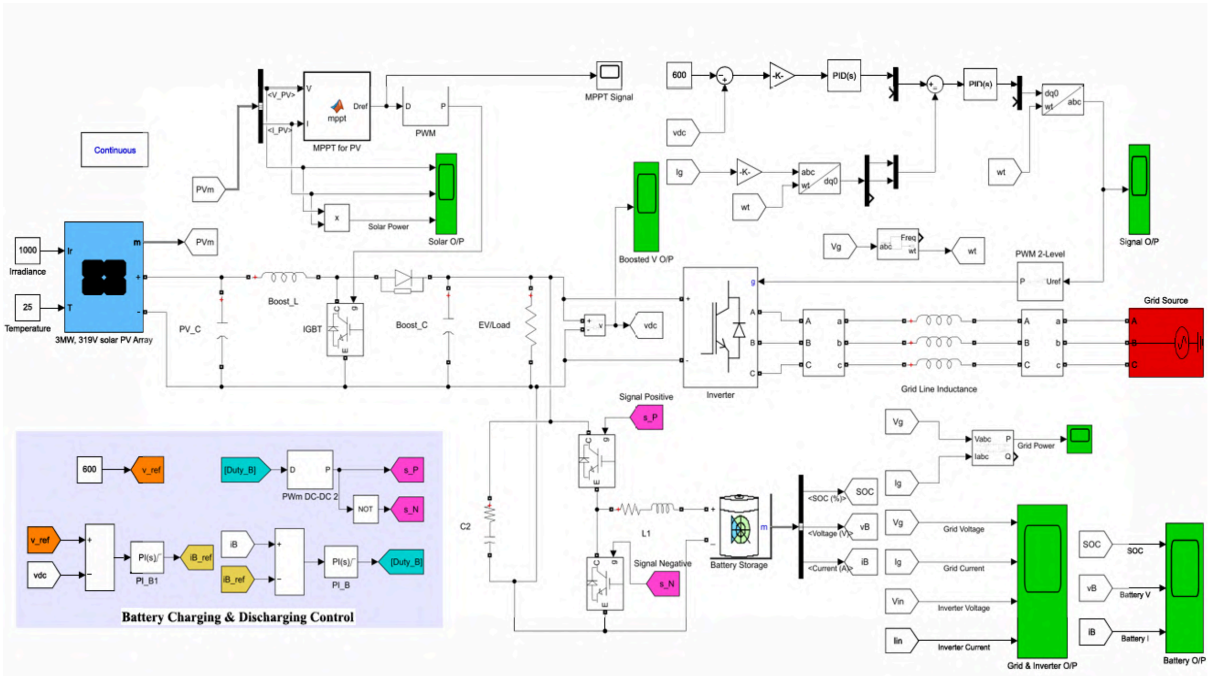


Figure 18: EVCS Simulation

We used MATLAB Simulink to model a grid-connected PV system with MPPT and battery energy storage. The system includes a solar PV array, boost converter, inverter, and grid interface. The MPPT controller modulates the duty cycle to obtain the maximum power, whereas the charge and discharge is controlled by the battery control. These tests were done to ensure that the system works effectively and to ensure that it is stable in various load and irradiance conditions.

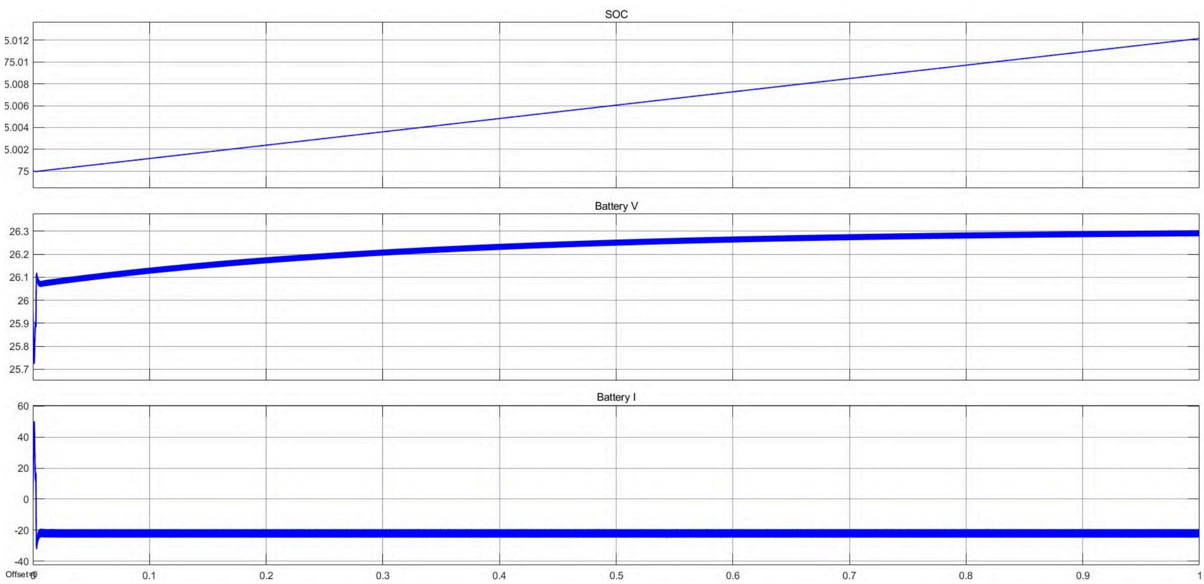


Figure 19: Battery SOC, Voltage, and Current vs. Time

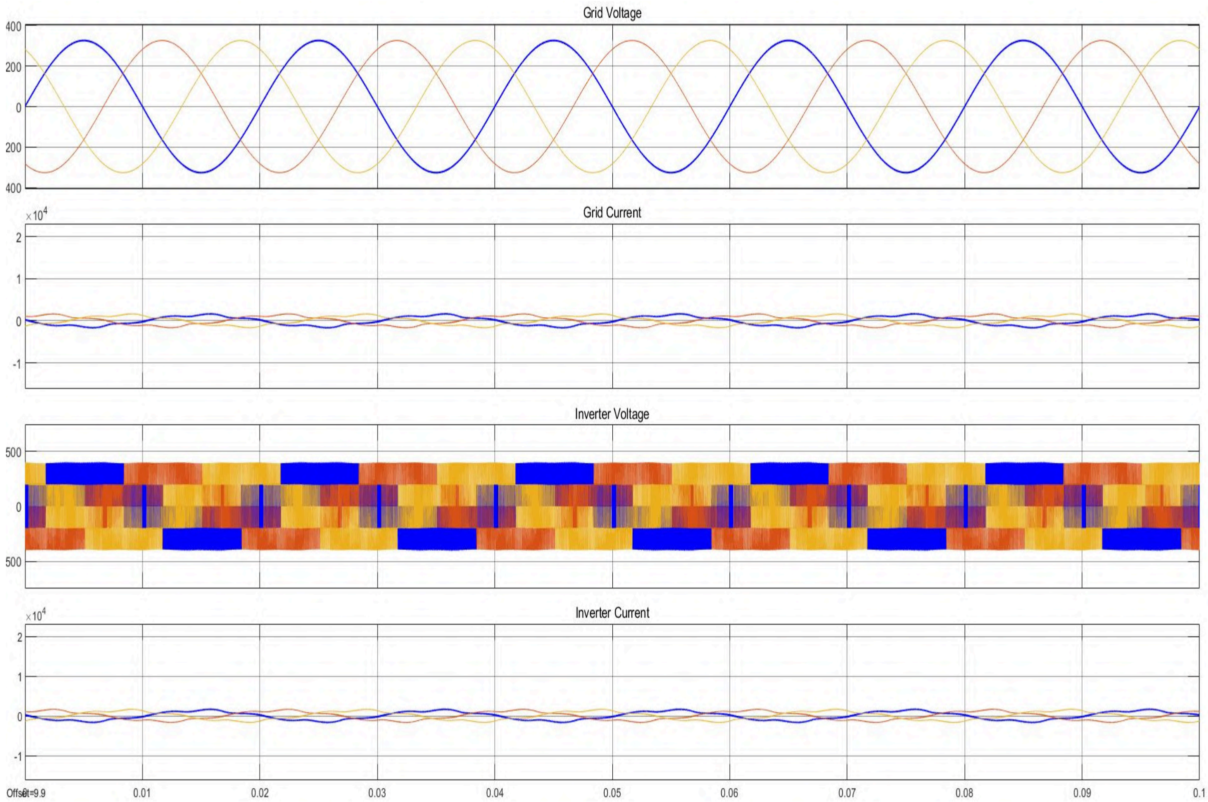


Figure 20: Grid and Inverter Output Profile Showing SOC Progression, Voltage Variation, and Current Flow Over Time

In Figure 20, the waveforms of voltage and current of the inverter and grid are shown in the simulation. The output of the inverter is equal to the grid voltage and current that ensures right transmission of power and stability. The results show the excellent overall performance of the inverter with no remarkable variations of the sinusoidal waveforms at the required power flow standard between inverter and grid under steady-state operating conditions.

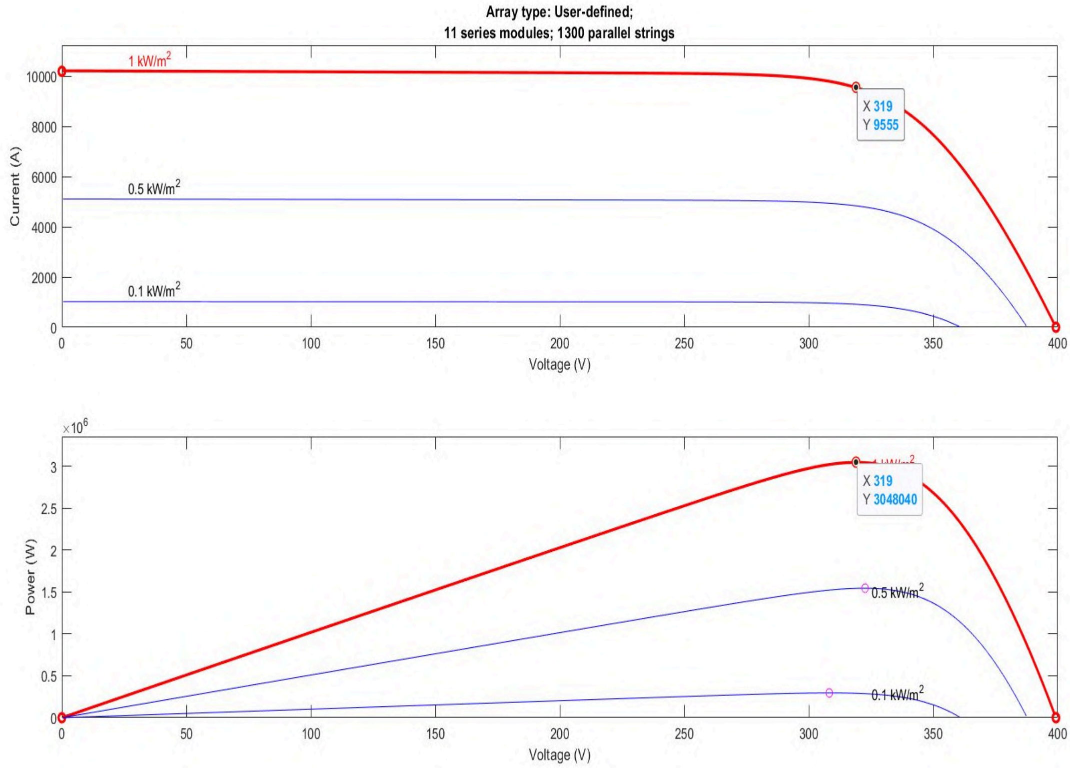


Figure 21: PV Configure (Current vs Voltage and Power vs Voltage)

In the figure 21, MATLAB Simulink was used to characterize the output of the solar array that was designed to be used in the system. In order to determine the maximum power point and to check the array configuration, we created a group of test cases. Figure 19 indicates the I-V (Currentvoltage) and p-V (Powervoltage) characteristic curves of the array at different levels of irradiance. Those would test the functionality of the array and would give the required information to calibrate the MPPT algorithm to make sure that the system can extract the maximum power as per our specifications.

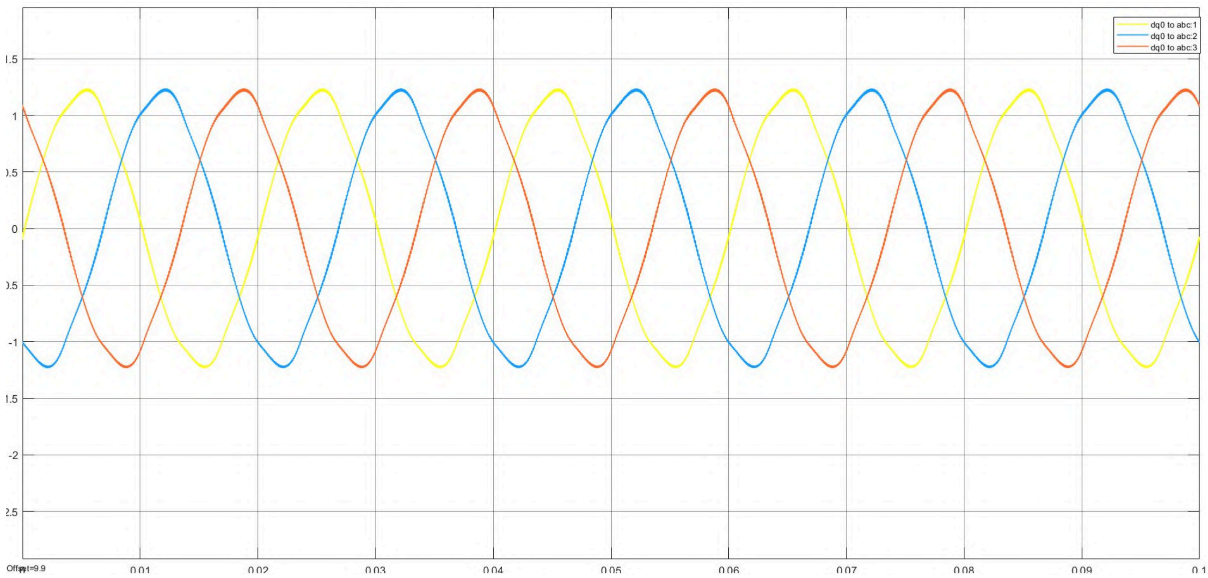


Figure 22: Inverter Control Signal (Time vs Amplitude)

To obtain the necessary signals of the controls in the inverter stage of the system, we went through MATLAB Simulink to produce them, which is shown in figure 22. Figure 20, titled "Inverter Control Signal," shows the three-phase sinusoidal signals that serve as the reference waveforms for the Pulse Width Modulation (PWM) generation. These sinusoidal references are 120 degree out of phase with each other and are essential for producing the balanced, three-phase output voltage required to operate the AC load. These results would verify the proper functioning of the control logic and ensure that the system is capable of delivering high-quality AC power in accordance with our specifications.

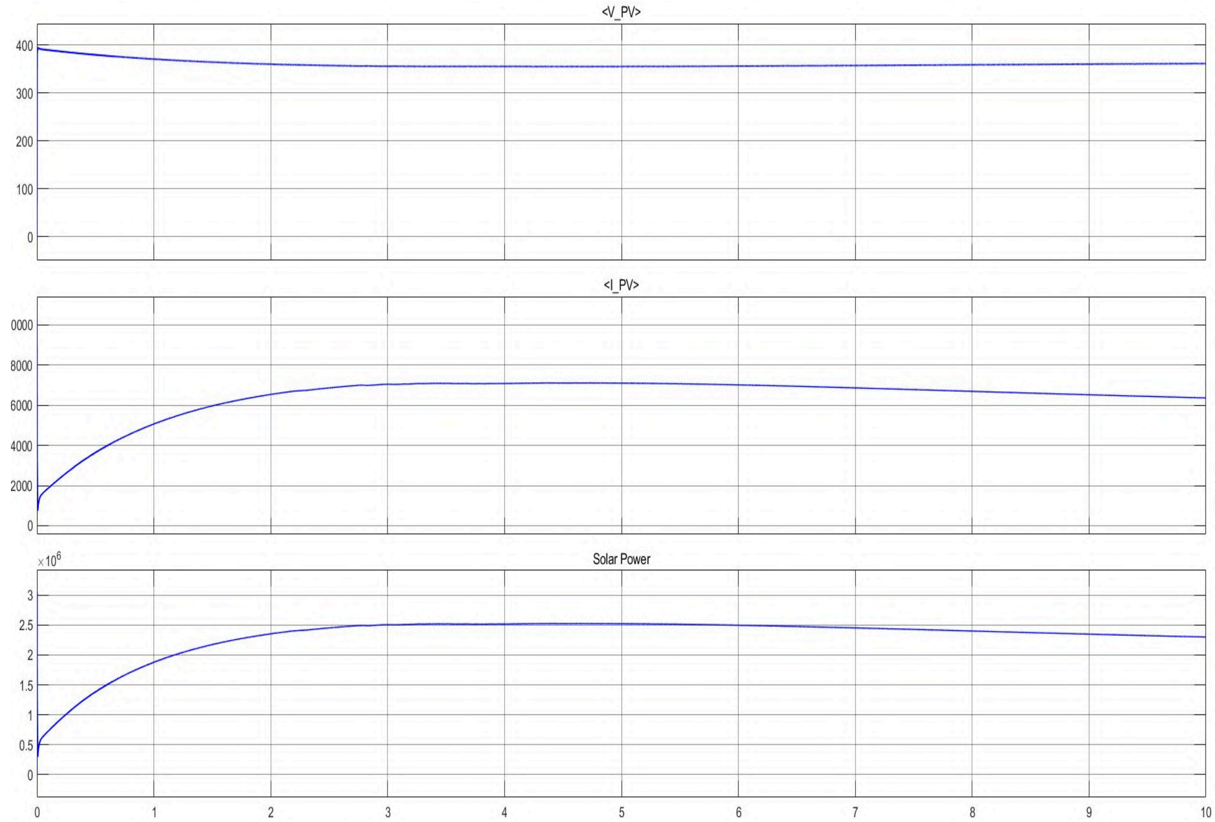


Figure 23: PV Output

The overall performance of the integrated solar array and its MPPT system is investigated by employing MATLAB Simulink. Figure 2 - PV Output The response of the system over a 10-second interval is represented in dynamic mode shows the with with respect to time (Solar Power) Solar Power (PV Power), as well as ⟨I_PV⟩, and ⟨V_PV⟩. It can be observed that the MPPT algorithm effectively increases the current and power of reaching instantaneous but maintains a steady state condition at about 4 s with only slight variation being voltage. These test cases were developed to check the correctness of the MPPT algorithm, and also to ensure that the system can settle quickly at high P_out, in good agreement with our requirements.

4.5 Conclusion

We have determined which design solution among the several subsystems is the best. For our project, we have decided to go with a tilt and MPPT controller with a fixed tilt arrangement for solar panel tracking. Because lithium-ion batteries have a longer cycle life, we have also chosen to use them for our project. Lastly, demand side management would be used to manage the load. Following the selection of the optimal design solution, we tested our system by running a simulation using MATLAB Simulation and proteus.

Chapter 5

Completion of Final Design and Validation

5.1 Introduction

After describing a complete design optimization and simulation-driven validation (described in the previous chapters), the work turned from a theoretical approach into materialization, by prototype construction. The hardware build stage is a key step to transform conceptual concepts into tangible testable systems that test design assumptions, control algorithm(s) validation and demonstrate real world feasibility. Full-scale realization of the proposed EVCS, associated with a 39.2kWp solar array (72Modules × 545 W), 170 kWh battery storage, the charging works which can support 10 cars and double that number of bikes, would require significant investment in terms of capital as well as space for installation alongside intricate electrical interfacing with Power Distribution System at university level. This type of a deployment is impractical for initial design validation and academic demonstration purposes in terms of time, cost, and facilities availability on undergraduate capstone projects (although it would eventually be required for operational service).

Accordingly, a scaled prototype has been developed that is functionally and technologically consistent with the full scale system, but which operates at power levels sufficiently low to enable testing in laboratory environments. The prototype incorporates all critical systems, such as solar power generation (including charge control), battery energy storage (including state of charge management), grid integration with intelligent source selection, and user authentication and parameter input interfaces; It features MBC algorithms for each stage of battery charging process, real-time monitoring and data visualization solutions, and full range of safety protections. The major design derating is the elimination of bi-directional grid-tie capability (ability to send excess solar generation back to the utility grid), because as previously noted, it would necessitate a grid-synchronous inverter, interconnection-compliant with IEEE 1547 standards, alignment with the university electrical services office and extensive permitting. Instead, it demonstrates the prototype of how to control energy flow using smart switching and battery buffering methodologies which represents the necessary control logic but does not model the real-world complexity of grid export hardware and communication cost/complexity.

The chapter shows the specifics of the full prototype development and gives a thorough description of its architecture along with a thorough examination of the motivations of its components selection and implementation strategy coupled with an experimental validation procedure and performance analysis. The scaled prototype demonstration system not only validates the principle of hybrid solar-grid charging, but also establishes that intelligent multi-source power management is practical, quantifies battery charging capability in varying conditions and is the proof to certify the sustainability and reliability assertions in the core of the project value proposition claim.

5.2 Completion of Final Design

5.2.1 Prototype Design Philosophy and Scaling Approach

The reduced scale prototype approach gave more focus on functional verification than on power capacity up sizing, achieving a 1:1000 scale reduction in vehicle battery (30 kWh to 8.4 Wh prototype pack) energy capacity with retained voltage ratio, control logic complexity and system architecture similarity with full scale version. This inferences enables significant demonstration of all the significant behavior of the system source selection algorithms, charging state machine transitions, user-interaction flows and safety protection activation all at fraction of the cost and risks of high-voltage, high-current power electronics.

The prototype operational capabilities include:

1. **Load shedding resilience:** EV charging proceeds during grid outages with station battery backup, solving the frequent power outages in electrical infrastructure in Bangladesh.
2. **Demand-side management:** Grid charging is available during off-peak, (user-configurable schedule) and the stored energy is then used to charge the vehicle during peak demand periods and lessens the grid stress and electricity expenses.
3. **Solar priority mode:** The renewable energy is used automatically when accessible and grid or battery sources are used as a backup to lack of solar production.
4. **Authentication of users and billing:** RFID-based access control and real-time cost accumulation and display.
5. **Multi-mode operation:** System may be set to be able to run in either a Grid-to-Vehicle (G2V), Solar-to-Vehicle (S2V) or Solar-Grid Hybrid (H2V) mode to compare with each other.

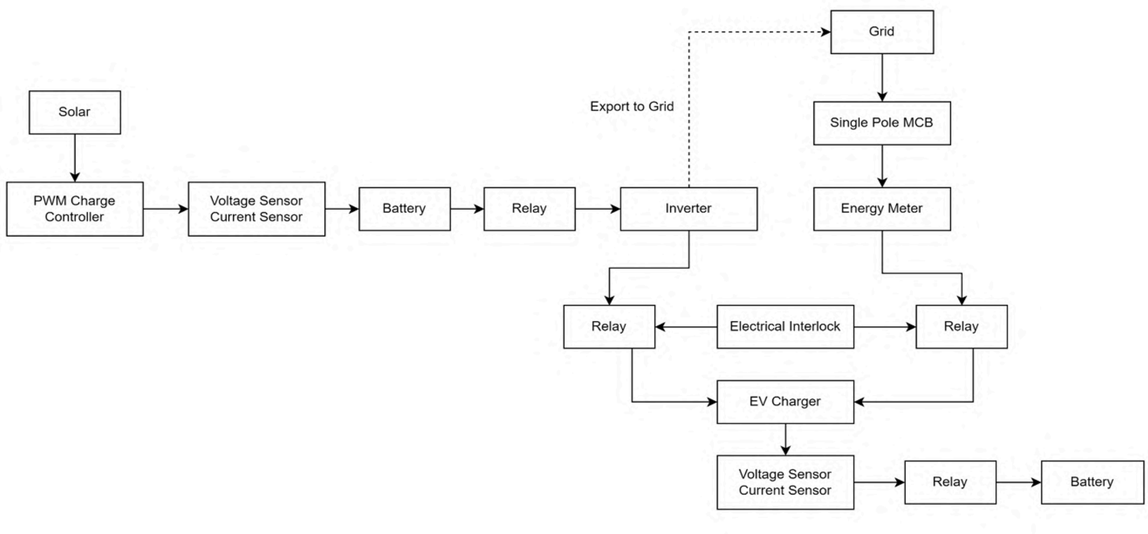


Figure 24: Work Flow Diagram

Figure 22 shows the system workflow diagram, which depicts the step-by-step flow of the process of user authentication to charging completion, whereas Figure 23 depicts the entire physical prototype assembly containing all sub systems glued and labeled.

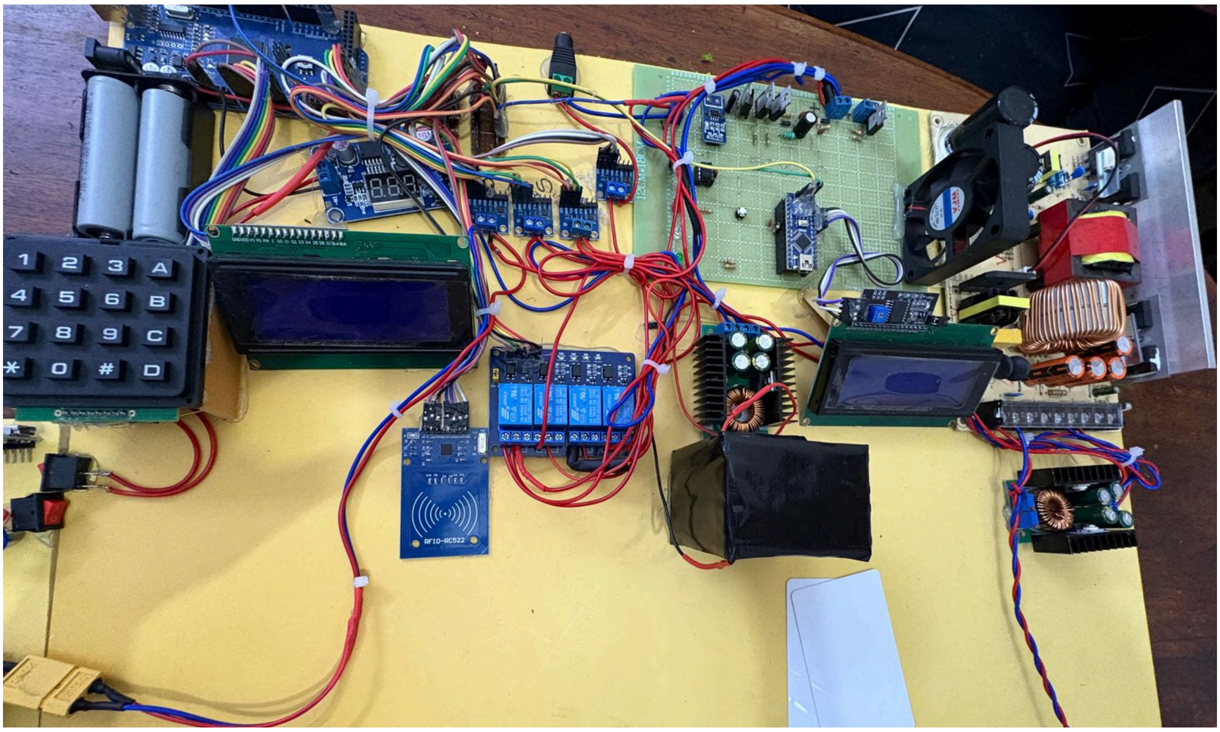


Figure 25: Complete System

5.2.2 Component Explanations

DC-DC Voltage Converter: DC-DC voltage converters are the basic Element of power electronics. They allow efficient transformation of voltage between different DC voltage levels, representing the main challenge: many subsystems work at various voltages that cannot directly connect. They need to be changed to proper values to ensure that energy distribution may be established. The charging station contains several voltage domains. First of all, there are solar panels producing DC voltage from 15V to 50V, depending on the irradiation and temperature. For the 545W Mono PERC, it is specifically noted in the datasheet that the Vmp parameter is equal to 41.80V. Other voltage domains are the battery, which is 24V nominal, the car battery at 12V nominal, the voltage equal to 60V rectified from 230V AC grid and control electronics that require 5V for microcontroller operation. The high voltage-stabilized power lines will produce a level shift that will be replicated and used at the output, while the energy from the battery will be supplied in the same line for circuit operation. So, in the prototype, a step-down buck converter was used to draw high to the low voltage configured as mentioned in Table 1.1. In this sense, the end-product, regularly, uses the small goods, while the Table 1.1 data lists the boundaries in the full power product. The buck converter used an SMPS topology – high-frequency PWM controller, responsible for the duty cycle generation, which converts power with 90% efficiency, using a high frequency that varies from 50 to 500 kHz, while linear technology may use it but will dissipate this power if it is not in use, which is about 10% efficiency with temperature dissipation. The buck converter configuration is seen in Figures 3, 6, 8. The same buck is used for specialization of the power path between the source selection and the final product used. This buck achieves control of the duty cycle using a microcontroller that enables an adaptive algorithm produced by a real-time power path feedback on voltage and current.

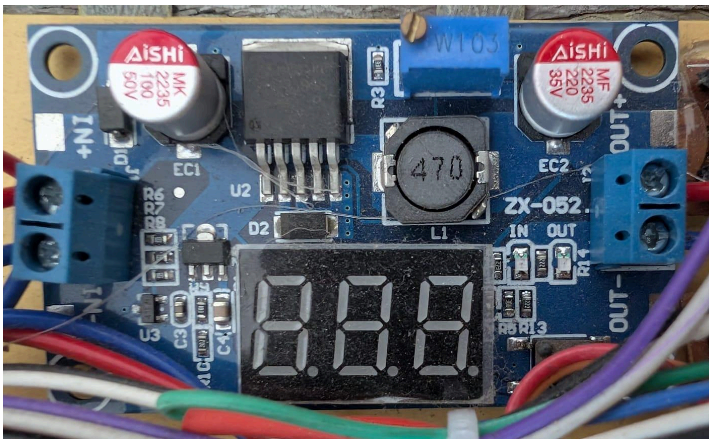


Figure 26: DC-DC voltage converter

Keypad: The next critical component is the keypad, primarily serving as the user input interface that permits the charging station operators to set the charging parameters, namely, the target SOC percentage to stop the charging process autonomously. It allows the end-users to determine the charging duration and energy consumption for their mobility requirements and how urgently they need the charged vehicle or EES. This can be verified from the prototype description and the block diagram of the system. The keypad directly interfaces with the Arduino Mega microcontroller as an input device for numeric charging parameters. The numeric type of input device used in the prototype was the 4×4 matrix keypad as indicated in the code appendix. The components in it include digits from 0-9, function buttons A, B, C, D, and control keys '* and#.' It addresses a practical requirement because not every EV charging session must reach a full SOC state, and some users just need 30 to 50% SOC, while some other ones are interested in more than 80% as they have a long-distance trip to make. This implies that the user controls the charging duration and the energy to minimize the time spent unnecessarily in charging since other users may be waiting for their turn in a private campus and the partial energy consumption of the full battery type leads to a lower battery wear and tear level. The exact cost of charging the unit can also be calculated based on the energy supplied to the battery since charging is cost dependent on the energy consumed from the socket. The user interaction path is indicated in the code which says, "Enter charging Percent:". Therefore, if the number entered is 7 and 5, the # will be used to confirm the end. The charging will start immediately, showing the progress of the charging. It is also used for cancellation services which are invoked when the user presses the C key. The security PIN may also be inserted from this point provided that the device combines RFID with the user secret password. The cancel key and D which forces an immediate start will override the DSM, but the rest of the keys are disallowed because of safety.

Figure 27: Keypad

I2C Sensor: The I2C communication protocol sensors, particularly INA226 voltage and current monitoring modules covered in detail in the code appendix, offer accurate, real-time measurement of electrical parameters at multiple points in the charging system. The measurements make it possible for the microcontroller-based control system to make informed choices on the power source to use, the stage of the charging algorithm to advance, initiate safety triggers, or display the user status. I2C is a serial communication protocol that is synchronous, multi-master, multi-slave and allows all the sensor devices to share only two communication wires: SDA for data, SCL for clock, in addition to the reference to the ground. The protocol's bus mechanism considerably simplifies the wiring compared to the parallel interface or stand-alone connection of the analog sensor. This was well demonstrated in the prototype as described in the code with four different I2C addresses defined, owing to the use of four separate INA226 modules to monitor a solar panel output, station battery, grid connection, and a car battery as discussed in Table 5.1 . Each INA226 sensor contains a shunt resistor, a differential amplifier, a 16-bit deviation ADC with I2C bus interface compact enough to provide bus voltage (±0-36V, shunt voltage (±81.92mV, and therefore, the calculated current, power and LYT in I2C registers. The 16-bit ADC with digital processing provides a much higher measurement accuracy than a 10-bit ADC naturally found in the Arduino microcontrollers. The precision ADC provided discertely high resolution levels of measurement when transitioning from open to normal charging phase or even during the constant-voltage phase. In addition, the digital signal interface omitted the need for calibration susceptibility and noise factor sictuating in analog signal wires. Table 5.2-5.4 shows that the following components are logged by sensors: the voltage-current of solar panel to calculate the solar power, the station battery measure showing the state of charge and closely monitor the charge/discharge process, grid connection of voltage and current logged for quantification and source detection, and the car battery to follow multi-stage charging, charged energy, and terrorizing off. The microcontroller used in polls the sensors at intervals denoting the display update frequency in the proper display times running the measured data.

The measurements further pass through the logic and relay control systems before projects for display and safety. The circuit closed to from the closed-loop safety circle of the intended system.

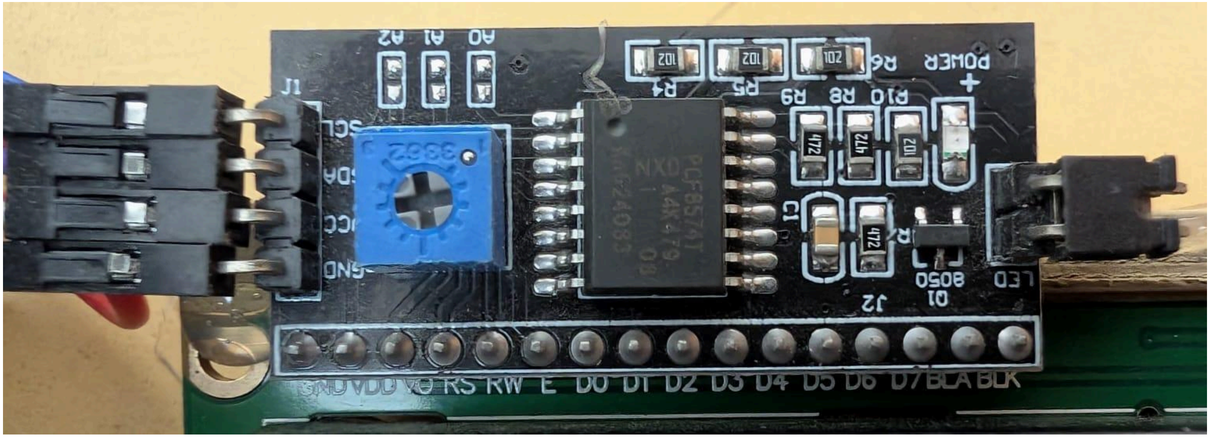


Figure 28: I2C Sensor

LCD 1620: 16 Characters × 2 Rows: The 16×2-character LCD display often simply named the LCD1602 or sometimes the 1620, acts as a compact status display module within the vehicle-side subsystem – the interface with the vehicle operators at the connection point, providing real-time feedback concerning battery voltage, current flow and, charge status. The vehicle subsystem in the system architecture requires its microcontroller and, therefore, display from which the battery parameters can be independently monitored from the main control system of the charging station operating the house-side subsystem as per the system architecture. In real-world implementations of EVs, this is analogous to the vehicle's decision to maintain its independent Battery Management System , with local monitoring of cell voltages, temperatures, and state of charge , regardless of the main charging station equipment. The 16×2 format size for the display gives just enough real estate to display the critical information required at a glance and, yet, small-sized to fit the thickness of the vehicle dashboard as well as the shallow sunlight above the vehicle's bonnet or the charging port near the driver's foils. The typical layout for the screen typically displays: Line 1: "V: XX.XV" in the first space , "I: X.XA" in the adjacent space , and Line 2: A percentage message "P: XXX%" or a message showing the charging status. Each line's 16-character width is conveniently arranged symmetrically on either side of the screen with just enough space left to display the units or other qualifiers in a manner that lets the operator understand which data belongs where. The second row's display allows the logical grouping and clear separation of elements or logically related characters. The LCD screen comes with the standard HD44780-compatible controller IC that writes data on the screen using only simple command/data protocols, and initially, written for 8-bit parallel buses but set to the usual 4-bit mode to save on GPIOs. This LCD control scheme's libraries are numerous and, most notably, it uses the built-in LiquidCrystal.h. The display feedback allows the vehicle operators to tactically confirm: that the station has indeed started the charge ; the driver does not have to take out their phone to confirm; check the completed percentage for operators not looking at the main station display ; decide if they have enough time before shopping or asking for refunds also; assess for an error like voltage has exceeded a dangerous level for the battery and, that the SOC is full, or the battery is fully depleted and is not charging; confirm the completed target SOC ; operator knows, return from lunch, an hour run, pick up the kids, work email, etc. The 1620 has a lower character capacity than the 2004, one of the reasons the former is used to only serve the house-side subsystem, keeping it relatively simple to use only a few GPIOs to control.

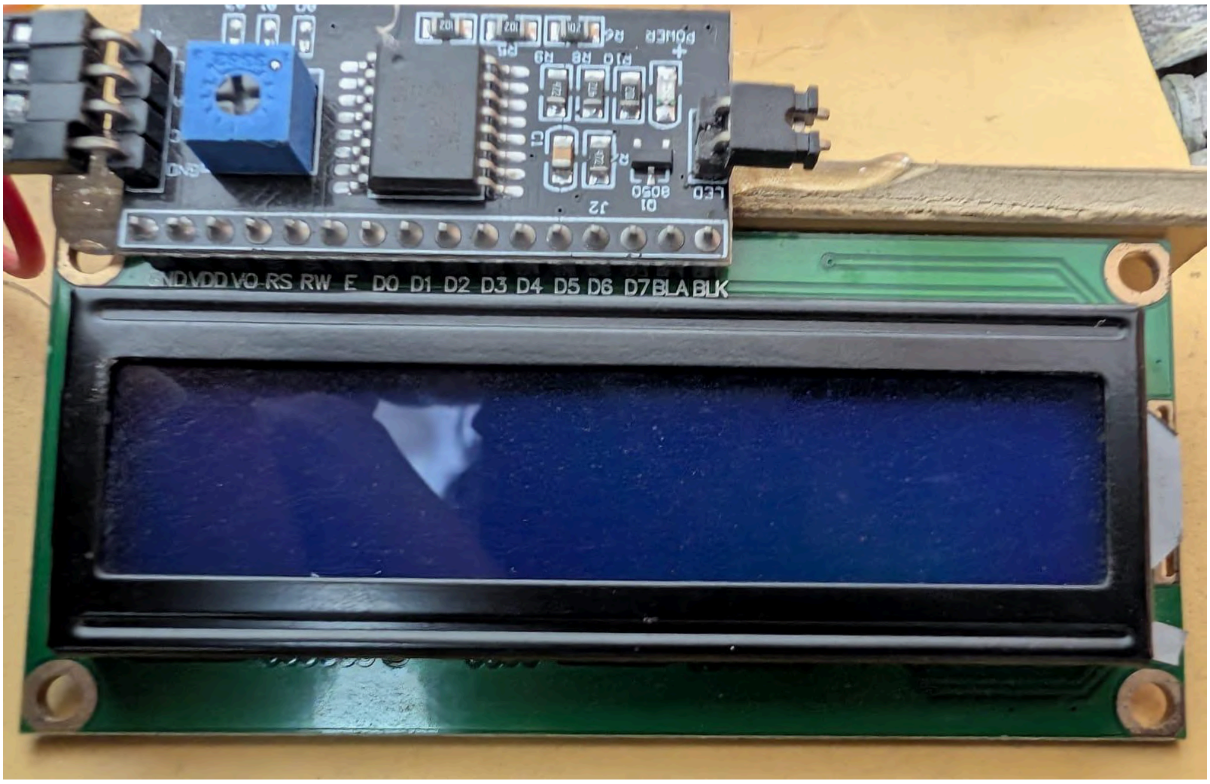


Figure 29: LCD 1620: 16 characters × 2 rows

LCD 2004: 20 Characters × 4 Rows: The 20×4 character LCD display serves as the charging station main control system's primary human-machine interface. Comprehensive real-time system status for multiple parameters involving solar generation, station battery status, grid operation, energy source, charging state, cost to date, and system mode settings is viewable all at once by users and operators. As detailed in the prototype description and extensively cited in the code appendix, this display interfaces via I2C communication protocol to the Arduino Mega microcontroller with a serial backpack adapter which compresses the parallel 16 GPIO interface pin to just 2 pins SDA/SCL in an I2C configuration. The coordinate is 0x27, and it is a slave universe. The 20×4 format meets 80 full characters total, higher than 32 for 16 by 2, providing a wealthier, more effective data corner that includes various subsystems: Row 1 indicates the solar panel correlation and the solar panel present in terms of solar voltage and power, while Row 2 indicates the station battery status and the current field to show voltage; row 3 remarks the network affiliation and the inter-flow of network and power, while Row 4 displays the loading rank, including the charging and made meter and the recharge field. This full-screen data display does not force users to browse multiple menus to obtain crucial information: a crucial expert is assured that their treatment is continuous and can monitor their implementation to the conclusion; an important manager can identify the system's conduct during development and assess them dry ; significant academic can answer various factors in sight during academic publication, and the payment from the expense is obvious and prompts the full understanding of the customer. The code appendix indicates that the display is better managed, such as a charge meter signal with unique icons that produce 6 charge meter icons and rotate it. It completely updates the charger meter background about each second with essential state parameters and changes the text content by operating mode – "on," "off," "bulk," and "floating" as determined by the charge controller software library. It signals the backlight is turned off when there are no users using the charging station or push the button as indicated in the backLight_timer() function in the code. The display is the primary "interface" of the system that tells non-technical persons about the connection state with simple parameters and provides architects with the full system parameters of view and optimization. Systems that start multiple devices to utilize the two-wire In complex systems can comprehend I2C devices by acquiring world competency.

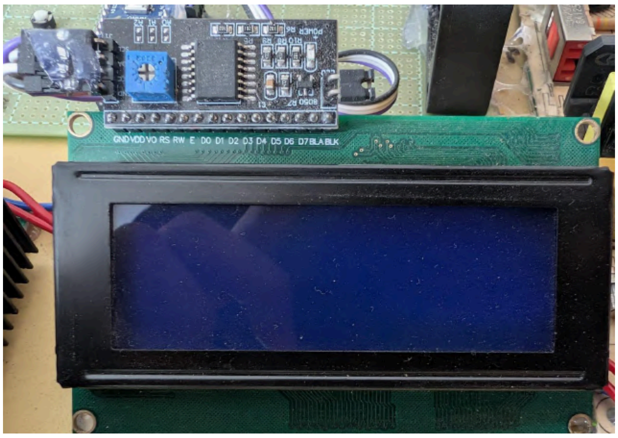


Figure 30: LCD 2004: 20 characters × 4 rows

Arduino NANO & Arduino Mega: The Arduino microcontroller boards serve as the embedded computational platforms that implement the intelligent control algorithms, decision-making logic, sensor data acquisition, user interface management, and safety protection mechanisms essential for autonomous charging station operation, with two distinct controllers employed for functional separation between the charging station subsystem (Arduino Mega) and the vehicle battery monitoring subsystem (Arduino Nano/Uno). The Arduino Mega 2560, based on the ATmega2560 microcontroller with 54 digital I/O pins, 16 analog inputs, 256KB flash memory, and 8KB SRAM, was selected for the charging station controller due to its extensive GPIO availability required to interface with multiple subsystems: four INA226 I2C sensors (sharing 2 pins via I2C bus), 4×4 matrix keypad (requiring 8 pins for row/column scanning), LCD2004 display (2 pins via I2C), RFID reader (SPI interface using 4 pins: MOSI, MISO, SCK, SS), four relay modules for source selection and charge control (4 digital outputs), PWM output for potential MPPT control (though external MPPT controller used in final implementation), and serial communication (UART pins) for data logging or NodeMCU interface as mentioned in the prototype description. The use of Arduino Mega is validated by the large range of pin assignments and the intricacy of the control algorithm employed as shown by the code appendix. This controller implements an elaborate state machine to perform the following functions continuously: read voltage and current on all four INA226 sensors through the use of the I2C protocol, perform RFID card validation by compared card UID against authorized user database, charge parameter configuration via keypad input, source selection logic by comparing voltages on solar, grid, and battery and controlling relays accordingly, perform multi-stage battery charge algorithm (with constant-current and constant-voltage phases) based on measured battery voltage, accumulate energy consumption and cost (reseting current with electricity rate), display system status on LCD20. The Arduino Nano (or Uno in some references—both use ATmega328P microcontroller with 14 digital I/O, 6 analog inputs, 32KB flash, 2KB SRAM), being more compact and less expensive, was deployed in the vehicle subsystem for the simpler task of monitoring the car battery during charging. Its code (second code listing in appendix) focuses on: reading a single INA226 sensor monitoring car battery voltage and current, calculating state-of-charge percentage based on voltage mapping, and displaying results on the 16×2 LCD. This distributed control architecture (separate controllers for station and vehicle) mirrors real-world EV charging where the vehicle's onboard BMS operates independently of the external charging station controller, with communication between them via standardized protocols (CAN bus, CHAdeMO, CCS in production systems; simplified RFID + manual input in this prototype). The Arduino platform was selected for this academic project due to: extensive community support and documentation reducing development time, availability of libraries for peripheral interfaces (Wire.h for I2C, SPI.h for RFID, LiquidCrystal_I2C.h for display, Keypad.h), cost-effectiveness suitable for educational budgets, ease of programming via Arduino IDE with C/C++ language, and sufficient computational resources for the control algorithms required (the charging control loop operates at approximately 1 Hz, well within the 16 MHz clock speed capability of these 8-bit microcontrollers). The microcontroller code represents the "intelligence" of the system that transforms passive hardware components into an integrated, responsive charging solution capable of autonomous operation with minimal human intervention.

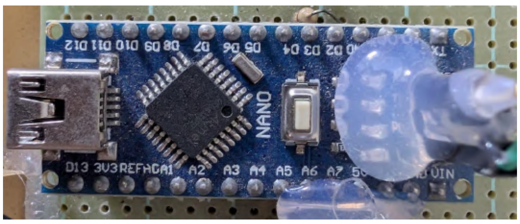


Figure 31: Arduino NANO

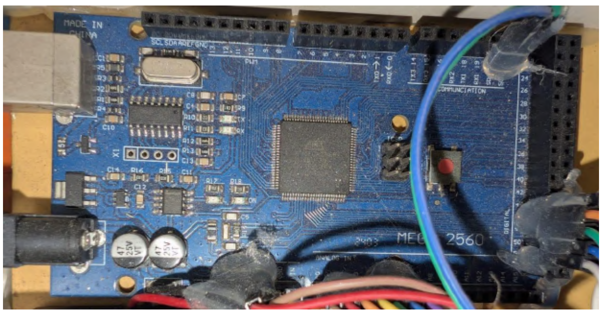


Figure 32: Arduino Mega

DC-DC Step-Down Buck Converter: DC-DC step-down buck converter modules are utilized to perform the vital function of reducing the voltages at multiple points in the charging system at which the source voltages are higher than the required load voltages, offering efficient power conversion with minimal energy wastage in comparison to the power wasted as heat in the commonly used linear voltage regulators under conditions of overvoltage. Buck converters are a certain type of switched-mode power supply that decreases the voltage input while increasing the current output throughout this inductor, with the exception of the associated conversion losses. Buck converters perform this function using the process of controlled energy storage within an inductor: a high-frequency switch known as a power MOSFET, intermittently connects the input voltage to the inductor which stores energy for utilization during the “on” time, before disconnecting during the “off” time to deliver the stored energy to the load area. This duration ratio is known as the duty cycle, with a formula calculation for the average output voltage, as shown in equation $V_{out} = D \times V_{in}$ where D is duty cycle attained through this ratio calculation. Buck converters conduct the functions of stepping down the 24V station battery voltage to 12V for auto battery charging, the solar or grid-derived 20V variable voltage in the case of the 20W panel used rectified and filtered after charging voltage attainment, and the 5V for Arduino controller usage. Table 1.1 presents the large-scale details of the buck converter: a 60V input, 60V output, 15A output current, and a maximum 2% output ripple, although the small-scale prototype used commercial off-the-shelf buck converter modules with lower ratings suitable for the power input and output ratings, which indicate for the professional-grade buck converter compatible Vout as less than Vin. Modern buck converter modules offer fully integrated power stages and control circuitry responsible for generating the necessary PWM signals for use in the MOSFET switches, as well as the synchronization signals and overcurrent shutdown, or overheat protection circuits. The buck conversion approach is chosen due to the large efficiency differences: the linear regulator dropping the 24V to 12V with 2A power will utilize and lose 24W as heat with efficiency of only 50%, whereas buck conversion will only lose 1-3W and utilize the other 21-23W for the load with 85-95 % efficiency. The 7-8 W of efficiency is crucial in a solar system, where every watt of energy requires utilization. Additionally, the buck converter induces a ripple of less than 2% to reduce damage to the battery and the system electronics. The system maintains a smooth DC output to the battery and sensitive electronics by reducing the ripple to less than 2% throughout its operations. The major work of the buck converter is evident in three-stage diagrams: ensuring system compatibility everywhere. It connects stages with varying Voltages V in the system architecture dotted box Symbols including stages 3, 6, and 8 that portray the convergence of various domains with a high amount Voltage V before going to battery stages.

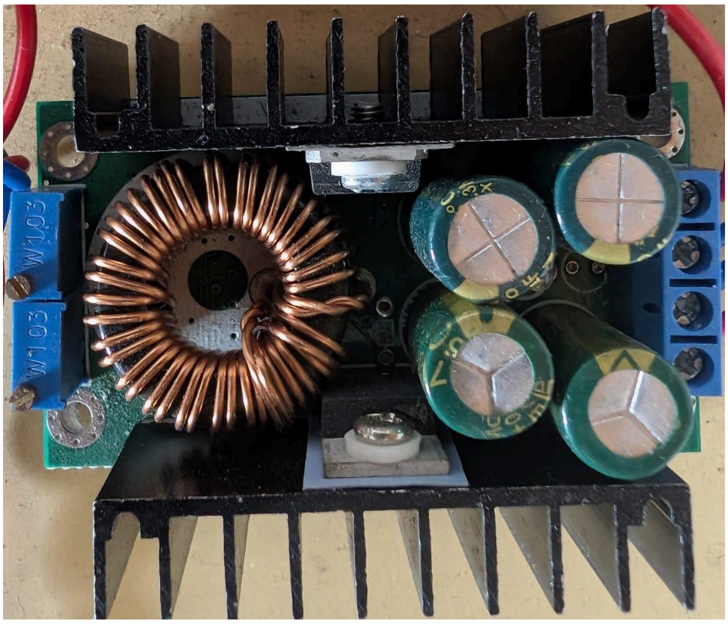


Figure 33 : DC-DC step down Buck Converter

Relay Module: The relay modules, on the other hand, provide electrically isolated, high-current switching capability that allows the low-power microcontroller to control high-power circuits, which involve battery banks, solar panels, energy derived from the grid, and vehicle charging through various connections, which all work at higher voltages (typically 12-60V) and currents that could be many amperes. This switching capability is offered while providing critical safety isolation between the control electronics and power electronics. Specifically, the relays are electromechanical switches composed of a low-power control coil that generates a magnetic field and physically moves an armature to close or open high-power contacts of 10A, 30A, or even higher current rating, depending on the relay specification; furthermore, this high-power contact may be rated for 250V AC or 30V DC. The number of relay modules employed by the prototype implementation can be estimated based on the code that defines four relay control pins for four relays that control four different functions, as follows: Source selection relays : The source selection relays implement the intelligent power source switching logic described at the beginning of this section and throughout Section 2.3, visible in the code as: “if (busvoltage3 10 && busvoltage 10V) AND the station battery isn’t fully charged (= charge) { digitalWrite(R3, HIGH); digitalWrite(R4, HIGH); }” to open the relay when the stated percentage is reached or exceeded. The electrical isolation offered by the relays is critical for safety; if a fault exists in the high-power circuitry, the microcontroller and the user interface remain safe and undamaged because there’s no direct electrical connection but just a magnetic couple through the relay coil. Moreover, the same magnetic coupling means there are no ground loop and noise coupling issues between the power circuits with sensitive analog sensor measurement of the input source voltages, where without the relays, the analog sensor might generate a special magic blue smoke due to a wiring error. The relay modules used in prototyping typically integrate the relay itself, a transistor driver circuit with sufficient current capacity because Arduino pins cannot source enough current to drive the relay coil, a flyback diode to suppress the inductive voltage spike when the coil is de-energized, and LED indicators showing relay state—all put on a handy PCB with screw terminals or pluggable connectors. The primary disadvantage of the electromechanical relay is the limited life and slow switching times compared to a solid-state alternative, as well as a noticeable click when changing states; however, in the prototype, these are acceptable tradeoffs because a solid-state equivalent would require heatsinks due to the lack of high current capacity of Arduino-tethered relays, where an actual engineering effort to measure voltage drop and power dissipation from low on-resistance of the relay is required. In the full production implementation, solid-state relays could be used for silent switching and longer life combined with FETs and gate drivers to replace R1 and R2, with the user and control logic remaining practically the same. Therefore, the relay control strategy manifests the practical implementation of the various theoretical source selection and demand-side management concepts discussed throughout Chapter 2, particularly the logical decision tree from Figure 6.1, by changing power flow from variable solar and battery sources into the permanent resistive load of the car battery, achieving the "intelligent" charging functionality indeed that sets this project apart from the simple charger described in the value proposition.

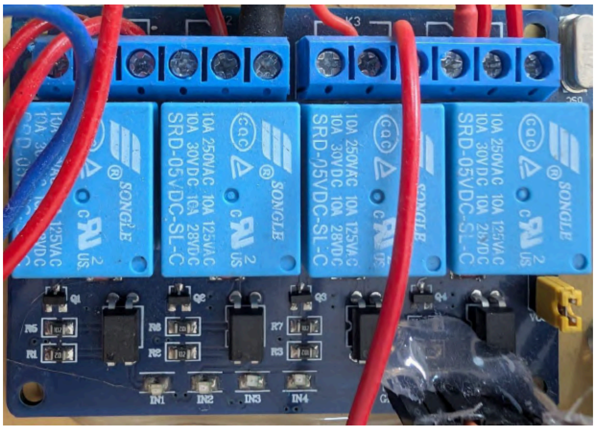


Figure 34 : Relay Module

RFID Module: Radio Frequency Identification Reader: The code includes #include and initialization on SPI pins SS=53 and RST=49, with an operational frequency of 13.56 MHz, indicative of the RFID module, particularly the MFRC522 reader. This subsection provides the charging station with the capabilities of contactless user authentication and access control, allowing the system to recognize authorized users, prevent unauthorized access, facilitate user-specific billing, and record charging sessions for administrative or billing purposes. As a result, the inclusion of this system component transforms the charging station from an open-access device to a fully managed installation useful for shared campus elements such as a basement or parking spot. RFID is a technology that uses electromagnetic fields to automatically identify and track tags attached to objects ; therefore, the RFID reader module emits a radio frequency field continuously, and passive RFID components harvest the emitted energy to power their respective circuitry, after which the tag responds by modulating the field to yield a unique identification number UID, which the reader identifies and sends to the microcontroller using the SPI. As evidenced by the implemented prototype, the authentication process or workflow comprises several steps visible in the code snippets.

Firstly, the system configuration, starting, or restarting process involves printing "Scan RFID Card" until the card is presented to the reader. The MFRC522 module is then triggered to listen to a radio signal and resend the card's UID, which is compared to the authorized RFID cards stored in the code. When the RFID card is detected, the microcontroller allows access to the subcode, well described by the Enroll() function, which permits the keypad programming of the charging parameters, or resets and displays "Access denied" before waiting for a new RFID card. This control, thus, remains essential for the following aspects of the university charging station. FileAccess control: the station cannot be accessed by individuals without authorization. User tracking: the cost accounting and identification for responsible parties are enabled. Billing: the cost displayed as "CA: X.XX TK" on the LCD code could be automatically withdrawn from the authorized user student account. Usage analysis: the RFID data collection is essential not only for access control but also for determining the frequency of charging, duration per session, and peak demand for electricity. Security: the ease of procurement and deactivation of an RFID card for students or faculty can help manage access to the station. The pin uses the SPI protocol that permits data collection of the card UID within 100ms. Additionally, the close-range that requires the student or faculty to approach the reader within 10cm is aesthetically appropriate and safe to which the RFID is recognizable. The alternatives for this report or card reading include a pin code alone, magnetic swipe, or biometric; the PIN code is more burdensome, bio is more expensive, while the swipe card is not durable. Therefore, RFID presents the best option for station access. The MFRC522 is controlled by an SPI protocol over the 3.3V Bus, where it allows high speed of UID read. The code also suggests that the RFID card is only readable at 10 cm; compared to the 33ft of the NodeMCU, this range is shorter and cannot be harmful for casual security . Moreover, the code has a predefined card ID that directly uses Enroll();, which is the first code that recognizes the card to authenticate the card, and could be only admin or the card issuer itself. This enrollment code is directly equivalent to having a second tier. Therefore, this code indicates the point where billing starts.

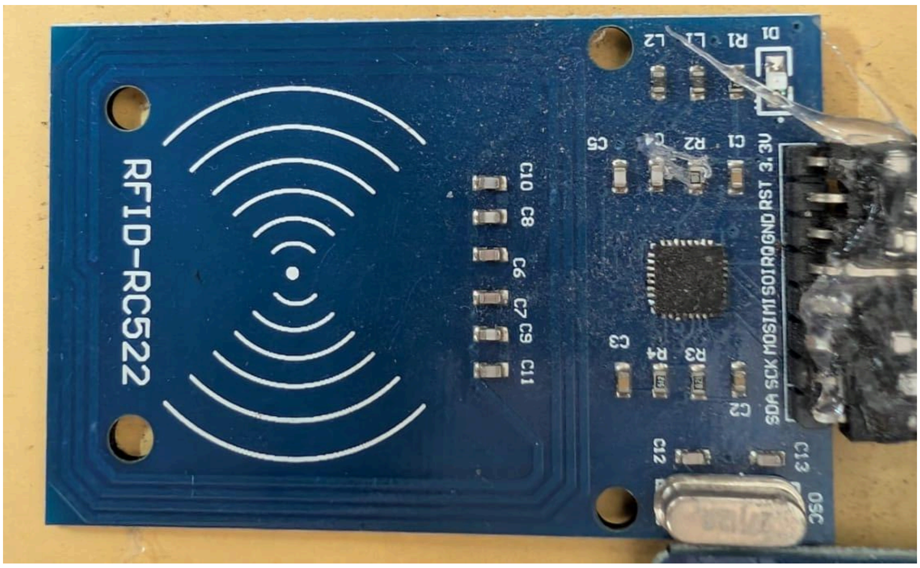


Figure 35 : RFID Module

INA226 Voltage and Current Sensor for Solar, Car Battery, Grid, and Station Battery: INA226 high-precision current and power monitor IC gives us a full whack – it can measure voltage as well as current and data log four key instants in the charging system (solar panel output, station battery, grid connection and car battery), allowing to follow the entire system status, make intelligent control decisions for fault detection or dynamic breakers operation; even do energy accounting or safety protection with real-time electrical parameters overview you can't have using Arduino's internal 10-bit ADCs. Each of these slave INA226 modules build in several functions in a tiny package: a precision shunt resistor (typically 0.1Ω, 1% tolerance) across which current to be monitored is forced generating a small voltage proportional to the current passing through it (V = I × R); an high-precision instrumentation amplifier measuring the differential voltage between the two leads from this shunt but rejecting any common-mode; a 16-bit analog-to-digital converter providing16384 discrete-measurement levels that allow users to determine both millivolts and milliamps; some internal calculation logic computing both instantaneous power (P= V × I) and accumulated electrical energy; an I2C digital communication interface allowing microcontroller read all measurement through simple register access commands. The prototype uses 4 INA226 modules over different I2C addresses (0x44, 0x41, 0x45, 0x40 as specified in the code) to monitor: Solar panel output (address 0x44 or 0x45): Measuring solar voltage and current allows you to calculate instantaneous power generation from the sun (sol_watts = sol_amps × sol_volts in the solar controller code), confirm that your solar panel is producing power (test if voltage >threshold which indicates daylight), test the MPPT controller performance by seeing how actual power compares with theoretical maximum for current irradiance conditions, and have a number for what you put into here l: S: XX. XV, I: X.XA"). Station battery (address 0x40 or 0x45) Measuring the battery voltage allows the station to estimate its state of charge using the traditional voltage-SOC relationship for lithium-ion batteries (the code represents this mapping as follows: per = map(busvoltage, 9, 12, 0, 100): means that reading a busvoltage value from the min=9V and max=12V range we get an approximate percentage-of-charge). fcstate detecting when we reached full-charge conditions (i.e. reaching the float threshold around FLOAT_THRESHOLD_VOLTAGE - FF and capacity OFFSET * CF), used by smart-charging managers to make decisions on how much energy it can request to store/fill-in or run/dispose without compromising subsequent discharging needs. warnings indicating when battery levels fall below predetermined minimum needed VMIN_VOLTAGE. Instant current indicates whether the battery is charging (positive from solar/grid) or not(discharging, negative direction in supplying vehicle charging load), magnitude shows charge/discharge rate. Grid connection (address 0x41) Measuring rectified grid-derived voltage to confirm availability of grid, so that source selection logic can select the backup if solar is not enough; current measurement for metering; and potential demand side management optimization (for monitoring how much power you are pulling from the grid to avoid peak demand charges). Car battery (at 0x40 in vehicle controller): Voltage monitoring is involved in charging algorithm via voltage-based control (when to switch from constant-current to constant-voltage, detecting full charge), allows accurate SOC display as information for the user, and protects against overvoltage by noticing if the battery voltage exceeds safe thresholds. Measurement of current also allows constant-current charging regulation (for feedback control for buck converter output), energy measurement (integral over the time: "Energy += Current * Time_interval" observed as cost integration is the "CA : X.XX TK"), and charge completion detection by observing taper off in current (see when current drops below a threshold during CV phase, indicating DCV mode). The 16-bit resolution (compared to the native Arduino ADC's 10-bit) is vital for low-current detection: in a 10-bit mode with a standard 5V reference, your minimum measurable voltage step is about 5V/1024 ≈ 5mV, meanwhile, at 16 bits we get a step size of 5V/65536 ≈.076mV; allowing for over an additional ×65 more fine current resolution that can better catch those small charging algorithm transitions. In the high-side current-sensing configuration (like in INA226, where we place shunt resistor between power supply and your load; not on ground side), no such disturbances are expected as well as it becomes possible to determine direction of current (positive vs. negative -which indicates charge vs. discharge). Digital I2C interface expands noise immunity for sensor readings, as they are converted to digital representation close to the measurement point and transmitted as a robust digital value, immune to electrosensitive emission fields from neighboring power electronics switching – providing precision even in the electrically noisy environment of DC-DC converters and MPPT controllers with a tens / hundreds kilohertz switching frequency range. The code already does more complex sensor data processing (reading raw ADC values from I2C registers (ina226_X.getBusVoltage_V(), getCurrent_mA()), applying calibration scaling (conversion sol_amps with SOL_AMPS_SCALE = 0.032353581, a calibration factor obtained by experimental comparison of the readings to reference instrumentation), filtering out noise and sensor offset errors (if statements zeroing readings below thresholds like "if(sol_amps < 0.05) sol_amps = 0"), averaging multiple samples (AVG_NUM = 8 averaged for each displayed value, as statistics tells us that random noise is reduced by √N ≈ 2.8× through statistical averaging). Net effect, all of these four INA226 sensors will provide us with a good electrical view of how the acoustical systems work - no black box any longer! A point at which all the power flow is quantified, which is eventually summed since all the measured flows are ready to be presented (and utilized in control actions), and after-operation analysis. This measurement infrastructure not only allowed the detailed performance characterization presented in Tables 5.2-5.4, depicting voltage, current, and SOC as a function of several charging modes (as well as in Section 6), confirming that the solar generation offsets grid consumption as described in the environmental impact analysis, but it also provided feedback signals required to implement multi-mode/multi-source complex charging algorithms which vastly differentiate this intelligent charging station from dumb battery chargers. Considering that the per-unit cost of INA226 modules (approximate. $2-5 each) has an entry bar for such a monitoring capability, it demonstrates how integrated sensor technology is revolutionizing fine-grain monitoring and control functionality that would have required increasingly costly laboratory equipment in the prior decades, democratizing advanced energy system prototyping for academic inquiry.

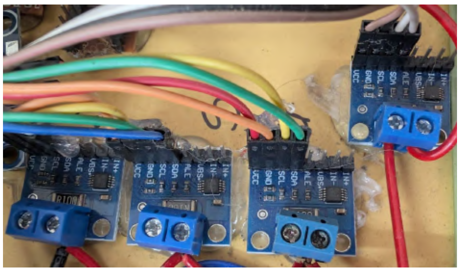


Figure 36 : INA226 Voltage and Current sensor for the Solar, Car battery, Grid, and the station battery.

Solar MPPT Charge Controller: The MPPT solar charge controller serves as the primary power electronics interface between station photovoltaic panels and battery bank using algorithms that constantly adjust the point of operation of the solar array to extract maximal available power under variable environmental conditions (irradiance, temperature, partial shading), while controlling optimized charging of batteries into 3 storage for maximum efficiency, long term reliability without overvoltage damage or capacity loss. Solar panels have nonlinear current-voltage (I-V), with a unique maximum power point (MPP) where voltage and current produce the highest product—this MPP slides continuously along the I, V curve as sunlight intensity varies (right/up on I-V as irradiance increases, left/down as irradiance decreases) and as panel temperature changes (higher tends to lower voltage). A straight direct connection between panel > battery (or just a basic PWM charge controller) causes the panel to operate at the battery voltage, which is almost never going to be close to the MPP voltage causing 20-40% loss in power vs. ideal operation. MPPT controllers address this by using a two-step mechanism: 1) DC-DC power conversion : The controller employs a switch mode DC-DC converter (buck, boost or buck – boost topology depending on voltage conditions) which separates the solar panel voltage from the battery voltage and allows them to operate at different voltages simultaneously. With the converter's power relationship $P_{in} \approx P_{out}$, $V_{solar} \times I_{solar} \approx V_{battery} \times I_{battery}$ (less conversion losses), thus irrespective of battery voltage, the controller can "reflect" any load on to the solar panel via converter duty cycle. Maximum power point tracking algorithm The controller is running a search algorithm (e.g. Perturb and Observe, more advanced Variations include Incremental Conductance and Fractional Open Circuit Voltage) which steps the operating point from time to time up or down changing voltage, measuring power output at new setpoint up or down and looking if the power output increases in moving direction. The Proteus simulation described in Section 4.4 (Figure 35: MPPT Charge Controller) illustrates the circuit-level verification of this controller prior to hardware realization. The full-scale system requirements (Table 1.1: “Type: MPPT, Maximum supported panel power: 10,000 Wp”) suggest a large capacity controller to be used on the predicted 72-module array (72 × 545W = 39,240W all generating simultaneously but not all because of shadowing / orientation), whereas the prototype used a smaller market-available MPPT controller that documented specifics for its use on our laboratory demonstration21Jacobsen fabricating such panels from existing commercial equipment Unknown table type 'tablebox' [49]. The MPPT controller also carries out a number of indispensable functions other controllers do not: Multi-stage charging: bulk, boost/absorption (only if required), float, and equalization; optimizing the balance between recharging batteries quickly and preventing overcharging. Battery protection:Monitors battery voltage, preventing overcharge by either reducing charging current or entering float mode at predefined voltage levels, Uses calculation or table look-up to compensate for the effects of temperature on voltage level (as a rule of thumb every degree Celsius above 25°C will decrease charging voltages by approximately 3-5mV being based upon the characterization study performed) and prevents operation when the stored energy in the battery falls below safe levels – although separate load management using software and mechanical relays would provide more accurate control of this.

System monitoring: Provides status outputs , either simple light-emitting diode indicators on the device or digital communication interfaces, which is shown not only as a functional block in the system diagram but also as a potential source of feedback and control input. The design decision to choose MPPT over simpler PWM controller technology has been analyzed in Table 4.2 and is discussed in Section 4.4.3; in brief, this is a design choice that maximizes efficiency rather than minimizing cost based on an estimated 15-30% higher energy harvester characteristic of simple PWM charging technology ($20-50/unit) and MPPT ($100-300/unit) in the prototype environment, in which the solar panel voltage regularly exceeds the battery voltage, allowing the MPPT controller to step down voltage while stepping up current. This 15-30% efficiency factor pays back in the increased power generation across the HOMER Pro economic modeler analysis discussed in Section 4.4.4, both increasing the energy output of the system across its 20-30 year life but also reducing the levelized cost of energy by showing more energy relative to the comparative branch on the HOMER software results interface. The MPPT controller's tracking efficiency, when operating in steady conditions, exceeds 97%, but this percentage falls to only 90-95% during rapidly changing conditions when the tracking algorithm must continuously "rock back and forth" to hunt for the moving MPPT. In the prototype installed in section 5.2, the actual implementation uses a PWM controller : "We have a 20W solar panel that is connected to a PWM charge controller." MPPT was specified as optimal in the design: However, because it is less expensive, we decided to use a PWM controller for our prototype. A solar charge controller, whether PWM or MPPT, is a key component in the solar electric system that rates solar panels output voltage and limits it to safe levels for battery storage and direct current use. It is an essential component that allows practical and reliable application of the system.

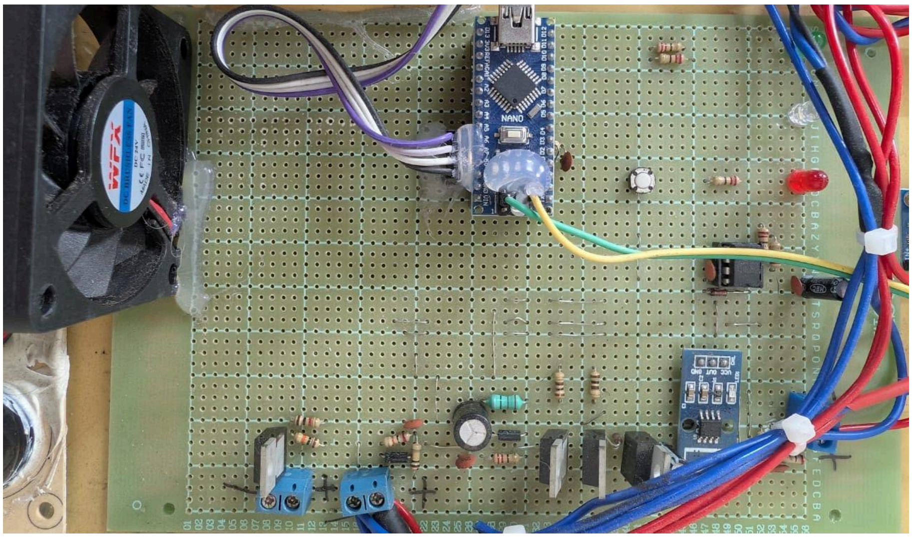


Figure 37 : Solar MPPT charge controller

SMPS Power Supply: 24V, 30 Ampere: The Switched-Mode Power Supply SMPS rated at 24V output voltage and a 30A output current capability is a high-power, grid-derived DC source allowing regulated power to charge the station's batteries in off-peak hours, replacing or supplementing solar generation during sunlight hours, and facilitating continuous system operation and test in laboratory settings without the availability or reliability of such natural solar exposure. Whereas types like a linear power supply achieve efficiency through drop-managing resistors, SMPS utilizes high-frequency switching by a power transistor typically 50-500 kHz and passes magnetic energy storage by transformers and inductors to attain power AC to DC conversion at or near its maximum efficiency, even with heat dissipation, compact physical profile, and a wider input voltage range. A 24V, 30A SMPS carries quite a powerful capability P = V × I = 24 V × 30 A = 720 W continuous power, readily charging the 24V farm's station battery in prototype, 24V × 2.6Ah = 62.4 Wh capacity, theoretical charging time at 30 A would be under 3 minutes, though practical charging limited by battery chemistry to C-rate around 1C ≈ 2.6 A, thereby giving approximately a 1-hour charge time, supplying the vehicle charging session's power in grid-only mode so far simulating the G2V Fig. 1 configuration analyzed in Chapter 2, as well as supplying all system electronics' auxiliary power simultaneously. The SMPS carries out the transformer, rectifying, and filtering components more visibly shown in the G2V system block diagram, Fig. 6: it retrieves 230V AC grid input, thumps down voltage via high-frequency transformer operation, rectifies to DC via synchronous rectifying or fast recovery diodes, and filters high-frequency ripple using output capacitors for regulation through feedback control maintaining 24V ± small tolerance such as ±1% regardless of input variance or load current change. [:,:,]. [] 24V output is deliberate, offering immediate contact for charging with appropriate charge control to prevent overcharge while placing voltage above the 12V vehicle battery voltage for later buck converter functionality buck converters demand the input voltage be higher than output voltage, with performance at its peak when the ratio is balanced such as 2:1 as this 24V→12V conversion,. The 30A current ability surpasses the farm needing a considerable margin, leaving a gap for future expansion which could include charging multiple vehicles simultaneously, larger battery farm setups and ensuring the SMPS always operates at its best-efficient capacity and lowest stress intended to minimize heating and stress, raising the component lifespan. Modern SMPSs carry extensive protection features in them, counting overcurrent protection OCP that limits output current if the load attempts to draw to its limit, to avoid transformer saturation and transistor failure, overvoltage protection OVP, which shuts down if internal regulation fails and the output spikes dangerously above the 24V setpoint, short-circuit protection SCP, which is capable of handling output short circuits and realistically recovering after the fault is rectified, and Thermal Protection, which shuts off power if the internal temperature exceeds safe temperatures due to inadequate cooling or excessive ambient temperatures. All these protections support the safety-centered scheme maintained through the project, matching the GFCI and. Overcurrent protection units indicated in Table 1.1 above. The SMPS occupies the role of the Block Grid Transformer Bridge Rectifier Capacitor chain, completing the operations demonstrated above using a single effective unit. The technology's high productivity usually ranging between 85-92% compared to linear supplies of equal power, which remain around 50-60% efficient is essential for grading sustainability claims even with the use of grid power, overall usage and emission generation are minimized by footprinting waste heat. The SMPS makes it possible to implement the DSMS described in Subsection 4.5; such a mechanism is achievable collaboratively with the grid power being accessible on-demand : during times when the grid sends a signal – e.g., an off-peak hours programming schedule or a real-time electricity pricing signal – or through the SMPS, if set so in the off-peak/peak hours configuration relay can be turned on for it to connect the output of the SMPS to the station batteries, which can be pre-charged with the off-peak electricity without impacting the peak hour grid demand and thus charging the vehicles during peak hours with no additional strain to the grid, is vehicle-to-station without the V2G, which allows the stress on the grid to be less when charging starts and more balanced when used in full. * In laboratory tests, the SMPS was essential to implement testing, as it allows for the validation of the system independently of weather conditions; with the SMPS programmed as a grid, and the solar panel as the solar sensor when used in a validable state with safety switches per the SMPS construction/specifications, the lab team could switch back and forth between the SMPS, the solar panel, and skip the battery to demonstrate "manual G2V, S2F, and H2V" system modes; this approach provided controlled, repeatable lab testing setup, allowing to test the system out in states where solar power is not present but are still valid for input/output instance testing; it allowed for confidently reasoning about how the algorithm could be programmed to act out in live conditions. * The SMPS above represents the "grid connection" element of the practical prototype; this is due to the fact that the full-scale implementation would use directly the building electrical service in separate circuitries and metering, thus allowing for taking notes of grid CO_2 emissions compared to a full solar setup. * The SM, the simple case above, is present only in the images of the prototype and material section as it can not be replaced with anything of similar value as a subsystem, thus representing the last component that is obviously missing in the "missing" block diagram mentioned earlier.

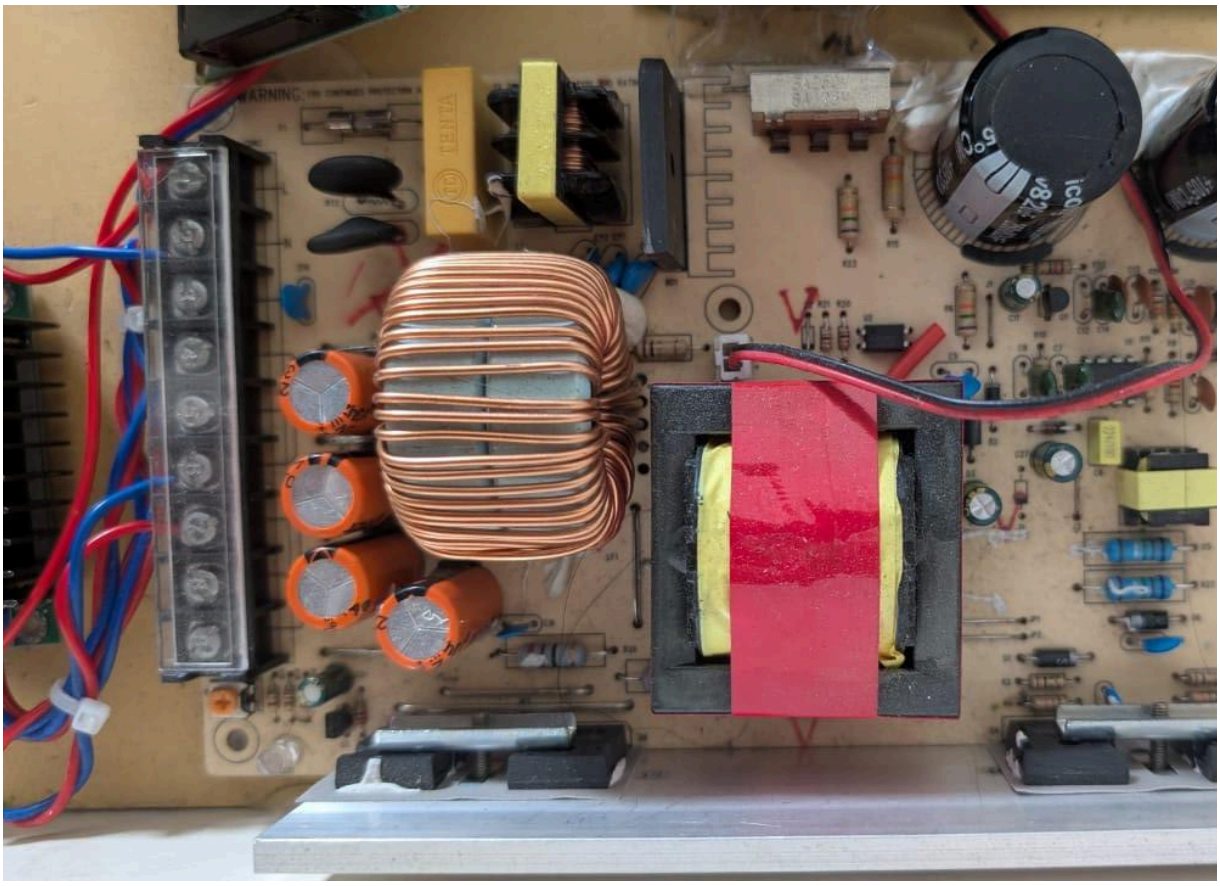


Figure 38: SMPS power supply: 24V, 30 ampere

Car Battery: 3.7V (≈4V), 1000mAh - 3 Batteries, Total 11.6V (≈12V): The prototype's car battery assembly is a downscaled representative of an actual electric vehicle's lithium-ion battery pack stand-in. It is the load that emulates real EV charging conduct throughout system testing and verification. In the full-scale model given in the report, the electric vehicle would use battery packs with capacities ranging from 30 kWh as is the case with cars to others measuring 500 Wh as is evident with the electric bikes. These battery packs operate at voltages between 48V and 400V based on the class of the vehicle. To achieve, for example, a three-cell electric vehicle battery of 3.7V nominal voltage and 1000mAh, a set of high voltage electrical systems is replicable, dangerous, and very expensive for the purpose of the prototype. The three lithium-ion, 3.7V nominal voltage, and 1000mAh capacity cells connected in series produced approximately 12V– the standard voltage for most automotive uses and small-sized EV systems. With the 12V battery, it is possible to generate a decent voltage for useful power electronics testing and remain within a low-voltage DC that is safe, with no need for an extra electrical safety infrastructure. The 1000mAh also enabled enough time for testing in various modes, giving a reasonable charge time demonstration, say 30-90 minutes approx. This level of charge time is acceptable for academics and test runs. Thus, such cells specifically 3.7V have been used in the prototype to test the system's workability and feasibility.

Figure 39: Car battery: 3.7V (≈4V), 1000mah - 3 batteries, total 11.6V (≈12V)

Station Battery: 3.6V (≈4V), 2600mAh - 6 Batteries, Total 21.6V (≈24V): The station battery pack plays a critical role in energy storage and buffering where the charging station operates to " store solar energy when not in use " while implementing energy use during charging hours at night and other main hours through discharging the energy during peak hours. The problem statement, as indicated in chapter 1 1.1.1 and the entire design analysis herein chapter 2, is that load shedding is experienced frequently that would make the charging station dependent on the grid which implies a great frustration from the users who will have to compete for charging when they are available. Therefore, the station battery comes in handy as a source of power which enhances the charging capacity when the power from the grid is off and that's why the installation described in the specifications table 1.1 would use lithium-ion or lithium polymer technology with over 3000 charge discharge cycles and the use of multiple charge sessions. The prototype incorporates six 3.6v lithium-ion cells stored at 2600mAh and presents themselves connected in series to provide around 24v nominal voltage with 2.6ah capacity, an ideal figure representing a mini energy storage system. The voltage is scaled higher 24V from the 12V car battery because station batteries are designed to maintain the voltage above the vehicle battery voltage to allow proper charging current flow using buck converters. The 2.6Ah capacity provides about 62.4 Wh of stored energy 24V x 2.65Ah good for proper validation of the solar subsystem as the 20W panel charges station batteries via pwm controller as documented in the prototype descriptions. The energy stored is sufficient for multiple partial charging or complete charging of the 12V 1Ah car battery with real conversion losses from the grid charging of itself during specific night hours, source selection logic in any case as per the methodology section figure 8, and state of charge monitoring as described in table 4.4. The buffering from sunshine and outages represents the main core of the hybrid system design compared to the grid-driven charging stations.

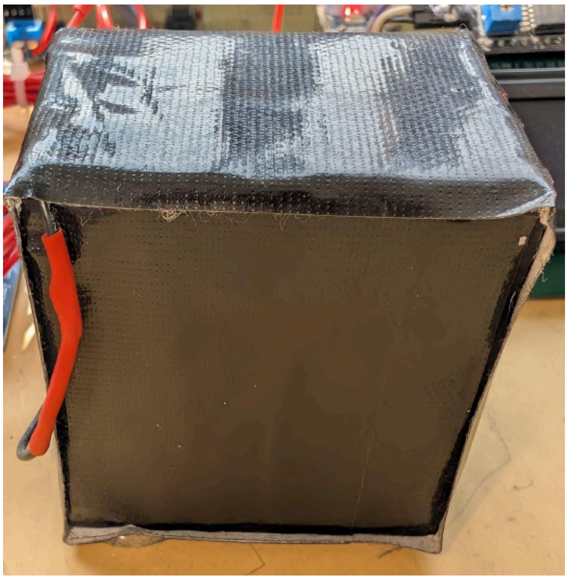


Figure 40: Station battery: 3.6V (≈4V) 2600 mah - 6 batteries, total 21.6V (≈24V)

5.2.3 Solar Power Generation Subsystem

The solar power charging subsystem consists of the 20W monocrystalline PV panel which is directly connected to the PWM charge-efficient controller having a management system controlling power supply to the station battery bank. During the day, the solar panel produces DC power with voltage and current depending on the amount of sunlight hit and temperature of the panel. This energy is redirected by the PWM controller into the station batteries so you can spend solar generation for rainy days or high charging requirements. This subsystem verifies the integration and performance of renewable generation that is a cornerstone of the hybrid system design, proving that clean solar energy can have a material impact on EV charging infrastructure while displacing grid electricity from fossil fuels".

5.2.4 Energy Storage and Battery Management Subsystem

The station battery layout performs three essential tasks: reserve power supply in case of a grid-out (black start), buffer electric power generated by solar energy peak to be used at night, and gives options for demand-side management – charging the batteries while off-peak prices in the electrical market, discharging when the market has peak orders. Battery SOC is constantly monitored through voltage over a range of 9-12V, which the control system maps to SOC using the characteristic voltage-SOC curve of lithium ion chemistry. It has the function of intelligent charging and discharging, so that consumer's products can display battery capacity at any time.

5.2.5 Grid Interface and Power Conditioning Subsystem

The 24V, 30A SMPS used in the power subsystem is another core component of the G2V system architecture, structurally replacing the transformer-rectifier-filter chain. A commercial power supply, which takes 230V AC mains input and outputs a regulated 20V DC, the SMPS realizes the voltage step-down, AC-to-DC rectification, high-frequency ripple filtering, and output regulation in an integrated device with excellent efficiency. It allows the grid-derived charging when exorbitant charge tasks or grip charging are at stake, also the same while G2V operates only during the day with solar-generated energy, and still provides the power used during the V2G-side management pre-charging of the station batteries at night.

5.2.6 Control System Architecture and Intelligent Power Management

As stated earlier, the control system embodies the "intelligence" of the charging station. It is a complex set of algorithms which render passive hardware components into an integrated solution which is responsive. The system architecture utilizes distributed processing through two microcontrollers. The primary station controller is an Arduino Mega 2560 and the secondary vehicle controller has two versions: Arduino Nano/Uno. The source selection algorithm is embedded into the two microcontroller firmware code. The overall behavior is such that: for example, if there is renewable solar energy in the Auto which goes to the station battery, what will happen is that the algorithm will always select the latter power source. Hence, the rated maximum current that can be supplied by the independent solar power source is.

5.2.7 User Interface and Human-Machine Interaction

The user interface subsystem provides more than one way to interact with and see the status of the system. The MFRC522 RFID reader enables hands-free access control, preventing the unauthorized use of facilities and also offers user centric charging tracking. Charging parameters, including target SOC in percentage, can be entered numerically via the 4×4 matrix keypad and operations of canceling charging or bypassing DSM are supported. The two display plates (LCD2004 and LCD1620) intend to show a full status to their operator or user-side of the station. The station status LEDs are available to quickly indicate overall system voltage.

5.2.8 Safety Protection and Fault Management

There are multiple levels of safety protection to ensure that it runs safely and smoothly. Relay multi-power sub are designed to have high voltage insulation between control electronics and power circuits. The sensors in the current sense all power paths and allow the smart control to detect over currents and shut down a relay to avoid damage. Voltage is monitored on each battery, and this protects against over voltage and under voltage with a disconnect feature. Several redundant methods ensure charging stops as it should: specified SOC reached, full maximum voltage, timed timeout and keyboard. Hardware interlocks prevent grid and solar inputs from being connected simultaneously.

5.3 Evaluate the Solution to Meet Desired Need

5.3.1 Experimental Validation Methodology

A battery of tests was designed in order to confirm the ability of the system, characterize performance in each operating condition and verify that the solution is able to effectively satisfy design targets and user needs featured in Chapter 1. The validation method utilized systematic test case running under controlled input conditions and quantitative system output measurements, compared for the three main use cases, Grid-to-Vehicle (G2V), Solar-to-Vehicle (S2V) and Solar-Grid Hybrid (H2V). The main test cases used during validation are defined in Table 5.1. with input conditions and system responses expected to be the output.

Table 5.1 Test Cases

Test Case ID	Scenario / Input Condition	Expected Output / Observation
TC-01	Solar PV provides sufficient sunlight (normal daytime operation)	MPPT controller optimizes power; Battery charges efficiently; Inverter outputs stable AC to grid and EV load.
TC-02	Cloudy/low solar input, grid support enabled	Battery discharges to maintain EV charging; Grid compensates for deficit; Inverter switches smoothly between sources.
TC-03	Peak demand charging multiple EVs simultaneously	Demand Side Management (DSM) activates; Non-priority loads delayed; System avoids overloading grid while maintaining safe battery levels.

5.3.2 Grid-Only Charging Performance (G2V Mode)

In the first set of experiments charging performance was evaluated with grid power only to create a reference for hybrid and solar-only modes. Specific charging progress data for grid-alone is provided in Table 5.2, where voltage levels, SOC progression, time and total time to achieve across eight separate charge steps from 10% to 100% SOC are recorded.

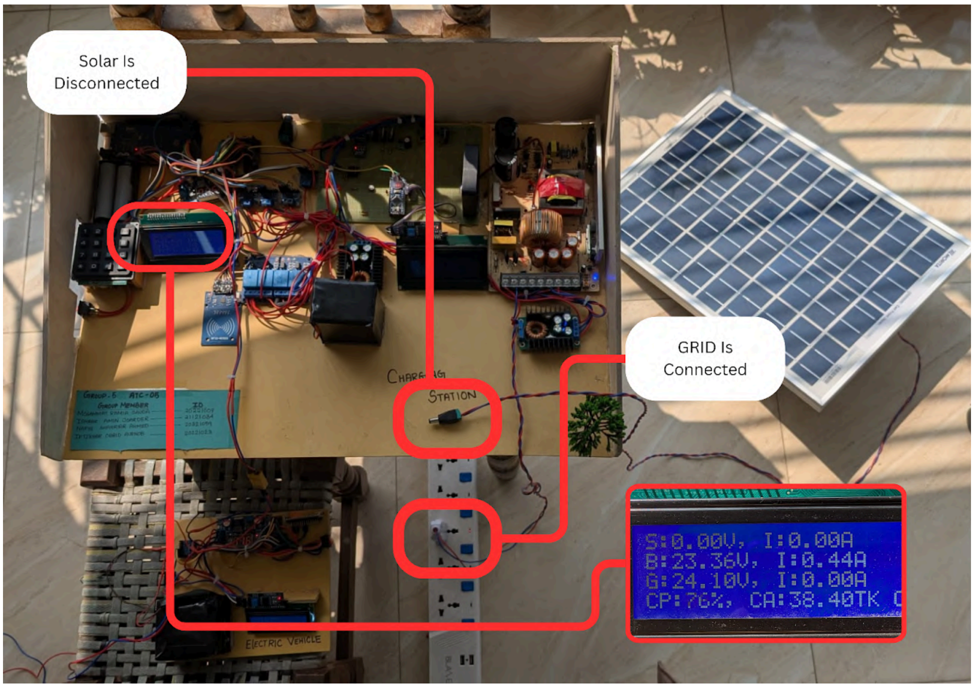


Figure 41: Grid-Only (**G2V**) Mode

The characteristic lithium-ion charging behavior with the well known phases such as a fast charge phase (10-60% SOC), an transition charge phase (60-65% SOC), a saturation phase (65-80% SOC) and finally a float charging (80-100 %SOC) is clearly shown in the experimental data. The full 45-min charge duration from a 10% to a SOC of 100% is corresponding to an average C-rate of about 1.3C.

Table 5.2 Grid Only Connected to Station Battery

Step	Voltage Range (V)	SOC Range (%)	Time Taken (min)	Cumulative Time (min)	Notes
1	9.5 – 9.8	10 ≈ 20	2	2	Fast charging at low SOC
2	9.8 – 10.1	20 ≈ 30	2	4	
3	10.1 – 10.4	30 ≈ 40	2	6	
4	10.4 – 10.7	40 ≈ 50	2	8	

5	10.7 – 11.0	50 ≈ 60	2	10	
6	11.0 – 11.3	60 ≈ 65	6	16	Charging slowed significantly.
7	11.3 – 11.6	65 ≈ 70	6	22	-
8	11.6 – 11.81	70 ≈ 80	8	30	Still slow, due to nearing saturation. Near full charge, charging efficiency drops.

In Table 5.2, the above stepwise charging data for grid-only operation clearly highlights the change from rapid constant-current (CC) behavior to the slower constant-voltage region as the battery progresses to full charge. For the 10–60% SOC range, indicated by Steps 1–5, increasing SOC by 10% each time took less than 2 minutes, confirming vigorous energy transfer under a stable grid. For SOC levels above 60% SOC illustrated in Steps 6–8 above, the duration of each step increased to 6–8 minutes as voltage neared 11.8 V. I observed that behaviour is consistent with the anticipated current tapering and saturation observable from the lithium-ion curve towards full capacity. The thirty-minute aggregate charging time confirms the efficiency of the CC-CV algorithm execution under grid-only operation. This interval provides a performance standard against which both solar and hybrid charging methods are assessed in subsequent sections.

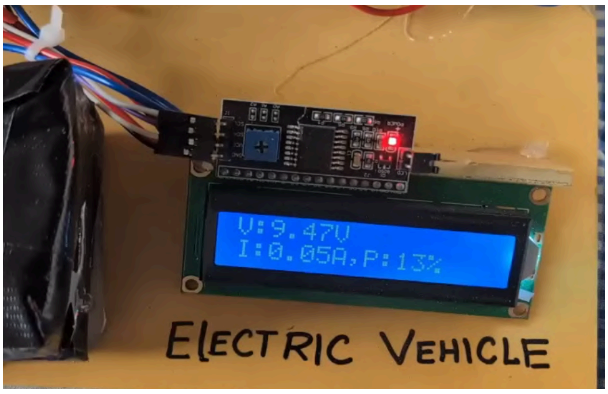
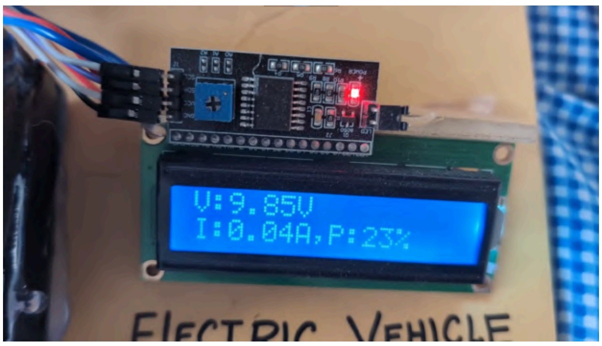
Table 5.3 indicates the tabulated voltage intervals based on the controlled stepwise observation of the prototype vehicle-pack voltage. The observation was done during the grid-only charging experiment with the station battery. A voltage band ranging between approximately 9.5 V and 11.81 V was obtained from the laboratory SOC mapping defined for the scaled three-cell pack. The bands were aimed at exposing the battery's dynamic response in its entire charging envelope. The range does not necessarily represent the actual readings but a lab experiment. The stepwise settings are not to be treated as independent readings but rather evidence for the prototype's control logic in practice. The constant-current and constant-voltage settings are to be read in real time to avail reproducible data for establishing the actual behavior aimed at ascertaining the quantitative comparisons with the S2V and H2V test modes elsewhere in this report.

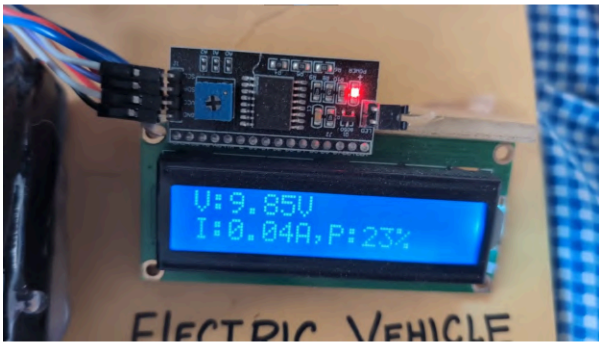
From the point of view of electrochemistry and control systems, the lower-voltage regimes (~9.5–11.0 V) are rather the bulk or CC region in which charge is accepted by pack exhibiting near-linear per-unit-energy voltage rise and therefore confirm that charger and power-conversion chain indeed deliver appropriate regulated current under steady source conditions. The transition from the CC→CV occurs in an intermediate band between 11.0

and 11.3 V, where longer dwell times/time at setpoint regulation and a lower dV/dt slope show increased voltage regulating power and current tapering starting to take place. The top bands (≈11.3–11.81 V) record the CV and approach-to-float behavior where voltage is held close to adsorption threshold while the current drops off towards end-of-charge criteria—all of these last steps confirm that, in firmware, the charge termination logic works as intended (low current cutoff, voltage limit and time-out guards).

The picture snapshots (column "Picture") are time-aligned evidence records supporting the occurrences and the relative timestamped INA226 measurements and relay/state changes observed by the controller. Integrated with the 1Hz Sensor Time Series, these gestural records allow cross-checking of instantaneous voltage/current values and trail user actions that are being explained. This kind of cross-validation is very useful for the viva and any further replications, as it provides a bridge between the abstract log values and what instruments would actually measure.

Table 5.3 Stepwise Voltage Progression of the Station Battery During Grid-Only Charging Mode

Step	Voltage Range (V)	Picture
1	9.5 – 9.8	 9.5V To  9.8V

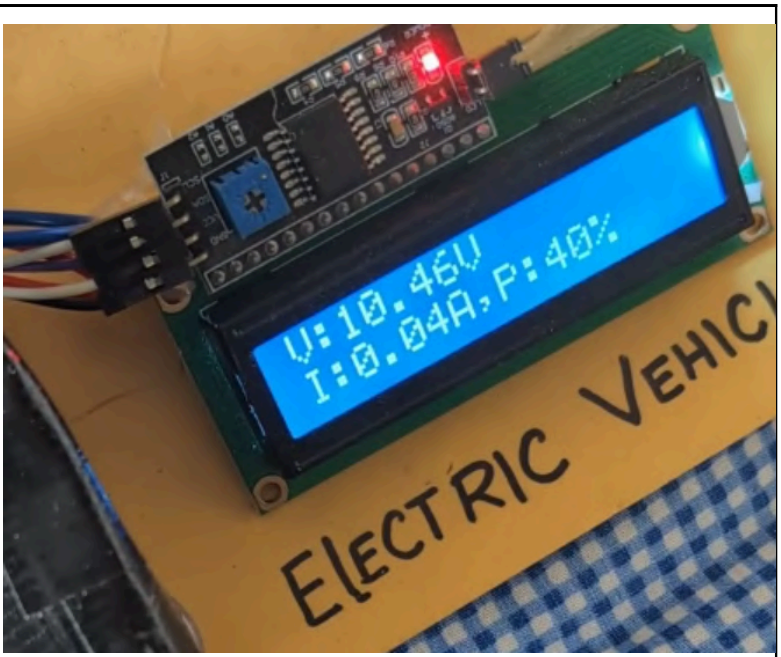
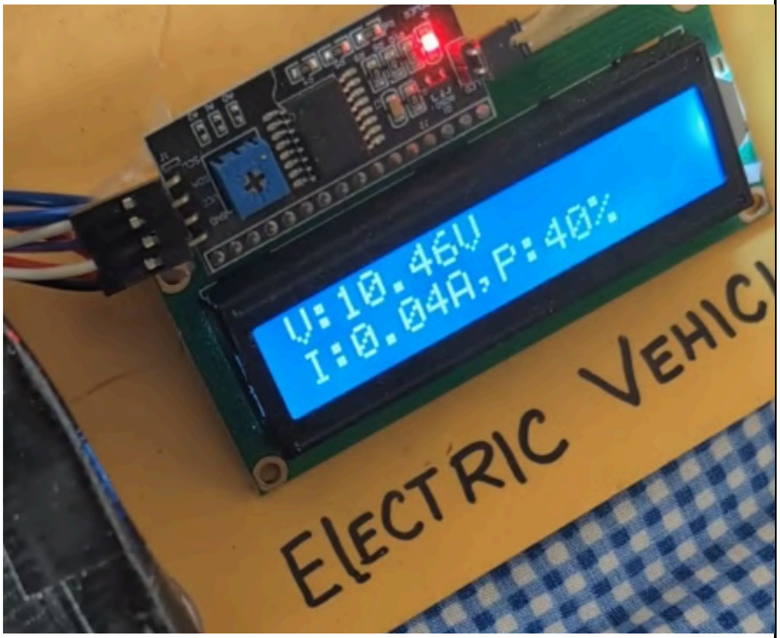
<table>
<tr><td>2</td><td>9.8 – 10.1</td><td>

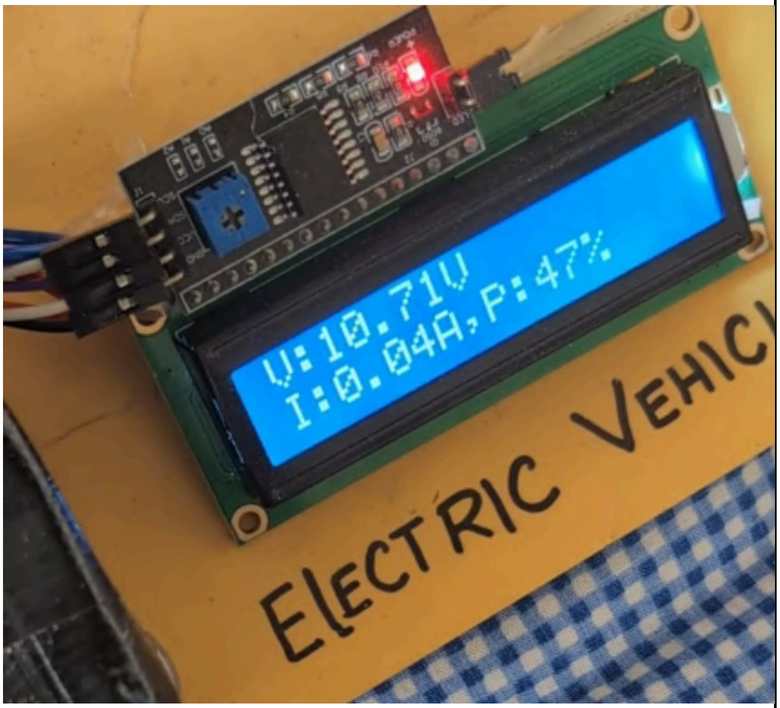
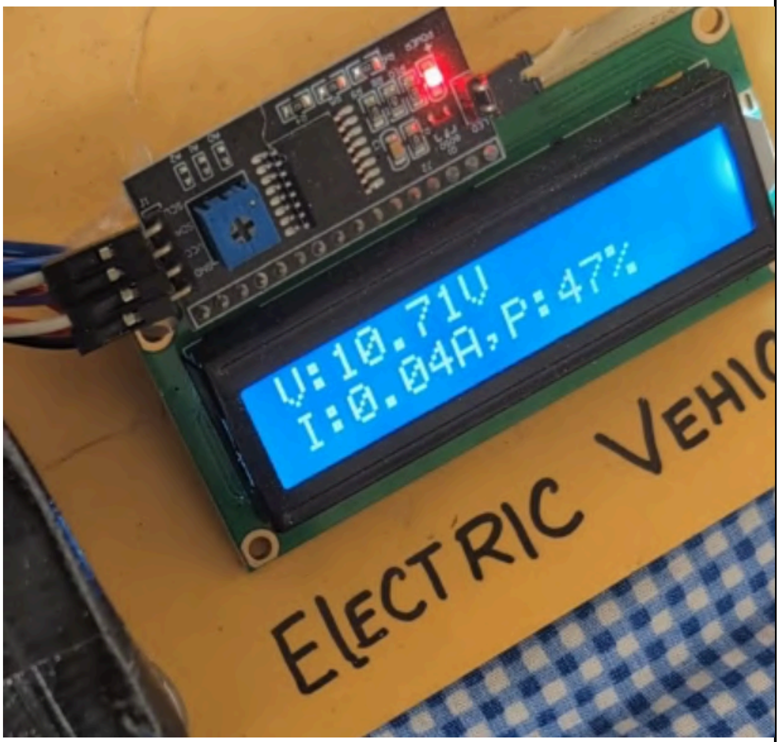
9.8V

To


10.1V</td></tr>
<tr><td>3</td><td>10.1 – 10.4</td><td>

10.1V
To</td></tr>
</table>

		 10.4V
4	10.4 – 10.7	 10.4V To

		 10.7V
5	10.7 – 11.0	 10.7V To

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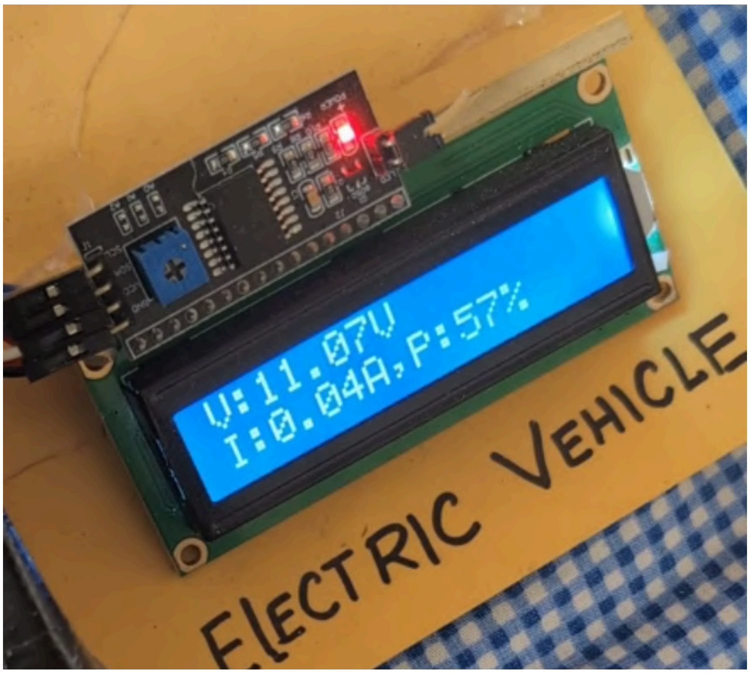
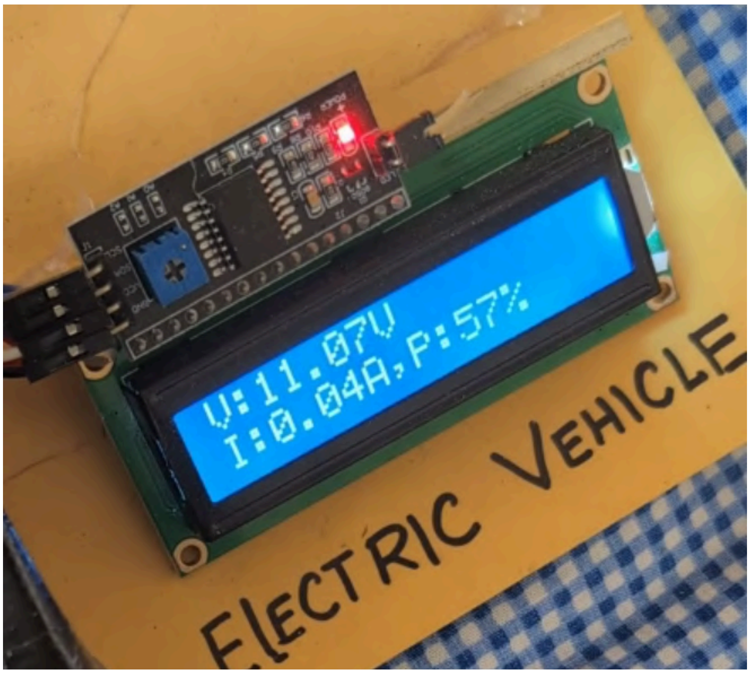
<tr><td></td><td></td><td>

11.0V</td></tr>
<tr><td>6</td><td>11.0 – 11.3</td><td>

11.0V
To</td></tr>
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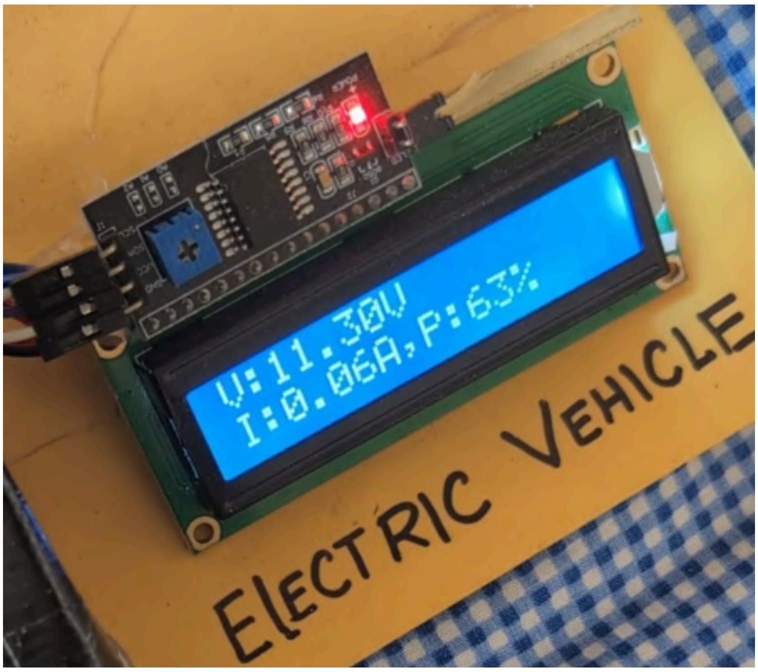
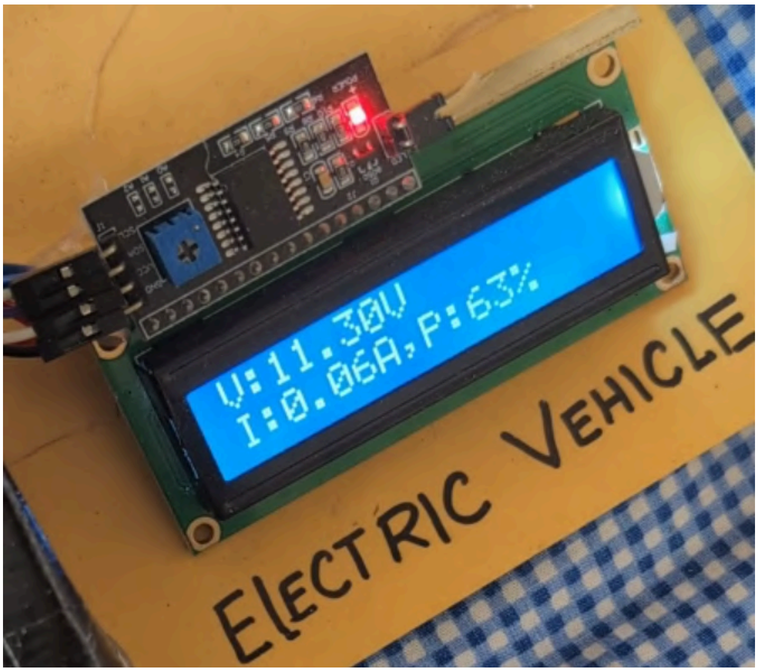
<tr><td></td><td></td><td>

11.3V</td></tr>
<tr><td>7</td><td>11.3 – 11.6</td><td>

11.3V
To</td></tr>
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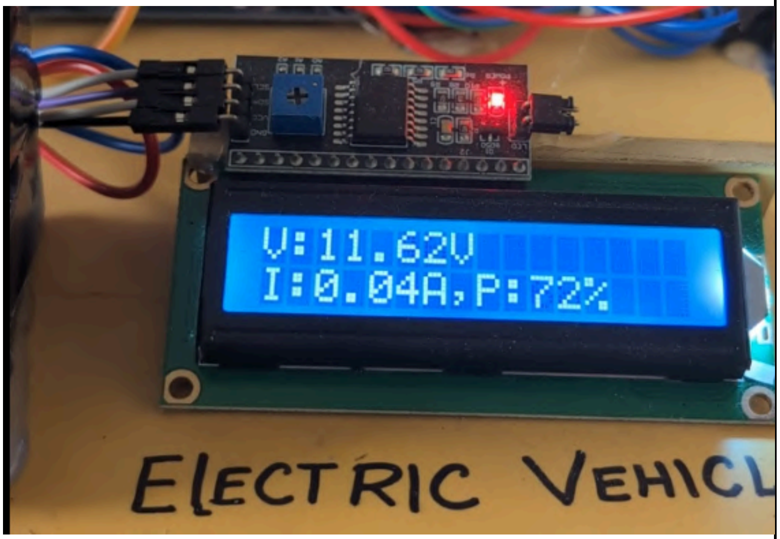
<tr><td></td><td></td><td>

11.6V</td></tr>
<tr><td>8</td><td>11.6 – 11.81</td><td>

To</td></tr>
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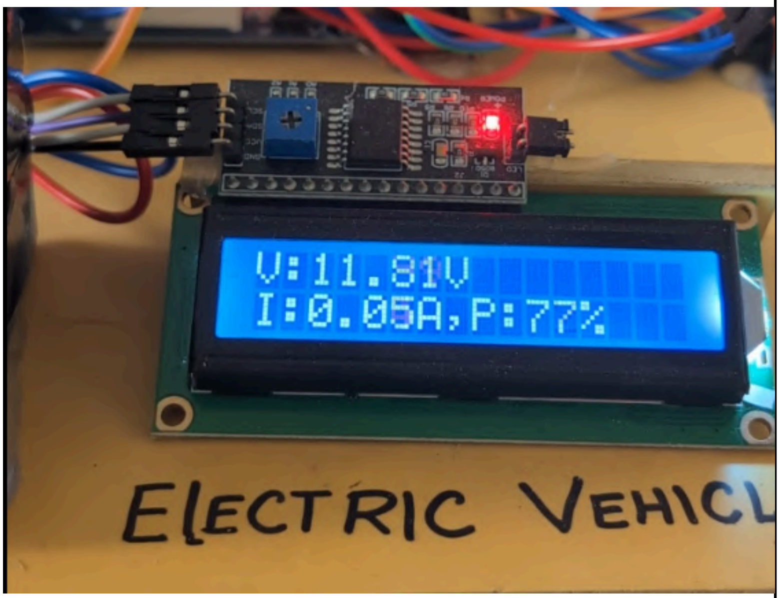
<tr><td></td><td></td><td>

11.81V</td></tr>
</table>

Quantitatively, the stepwise data permit several vital analyses regarding prototype validation and full-scale extrapolation: mean dV/dt per band can be calculated to suggest effective internal resistance trends; the reported current can be integrated to calculate the dV/dt – delivered Wh and assess the billing accuracy; effective C-rates in bulk-per-band and tapered stages can be derived to measure check charging aggressiveness against lithium-ion best practice, and direct comparisons between modes can be performed to categorise source availability on charging dynamics : where CC–CV implementation and source-selection strategy are duly listed, though this step does not incorporate inductive pre-conditioning onto a fully depleted mode S2V. The filing has countless limitations: first, thermal behavior, polarization, and aging characteristics differ substantially from full-scale EV packs, and measurement is also uncertain due to sensor calibration, modeling, and sampling resolution. Regardless, the methodical advancement described constitutes solid evidential information that the prototype's CC–CV implementation and source-selection strategy are being carried out as intended and that they provide a reproducible dataset that may be used to validate the logical conclusions and quantum theories created in the previous section.

5.3.3 Hybrid Solar-Grid Charging Performance (H2V Mode, Cloudy Conditions)

The second experimental campaign evaluated hybrid operation where solar generation supplements grid power during suboptimal weather conditions. Table 5.3 documents charging progression under these hybrid conditions, revealing significantly extended charging duration (89 minutes total vs. 45 minutes for grid-only) attributable to reduced available power from the partially contributing solar source.

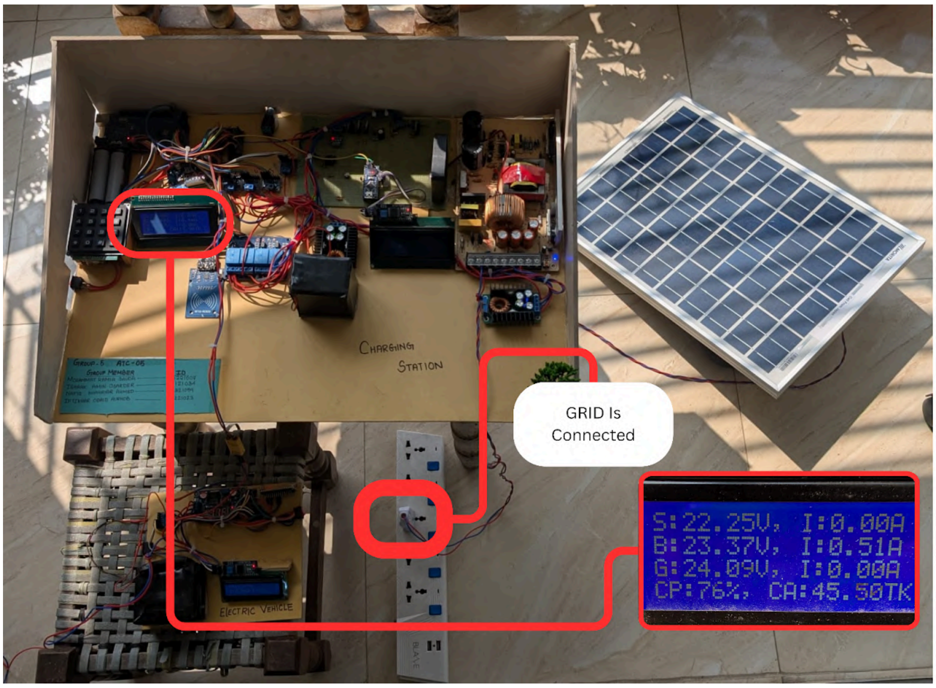


Figure 42: Hybrid Solar-Gride (H2V) Mode

The 89-minute total duration represents a 98% increase over grid-only charging, quantifying the performance penalty imposed by solar intermittency during suboptimal weather. However, this should be contextualized: even degraded solar generation displaces grid energy consumption, reducing emissions and operational costs.

Table 5.4 Solar + Grid, Cloudy Weather

Step	Voltage Range (V)	SOC Range (%)	Time Taken (min)	Cumulative Time (min)	Notes
1	9.5 – 9.8	10 ≈ 20	4	4	Slower than grid-only due to weak solar
2	9.8 – 10.1	20 ≈ 30	6	10	Solar contribution minimal
3	10.1 – 10.4	30 ≈ 40	10	20	-
4	10.4 – 10.7	40 ≈ 50	12	32	Prolonged mid-charge
5	10.7 – 11.0	50 ≈ 55	10	42	Still slow climb

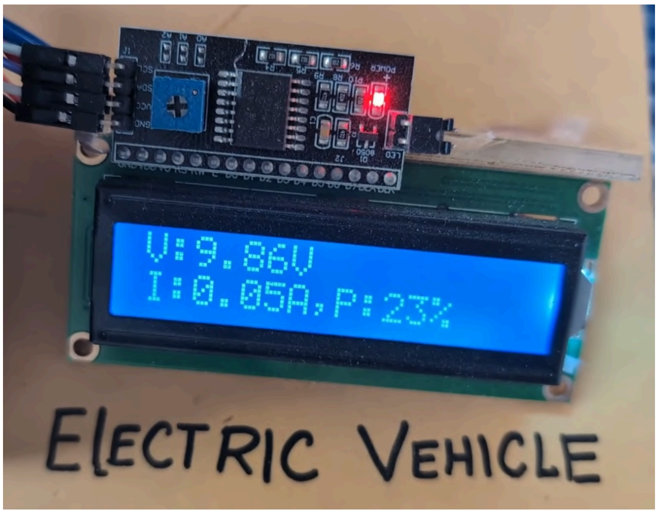
6	11.0 – 11.3	55 ≈ 65	12	54	-
7	11.3 – 11.6	65 ≈ 70	20	74	-
8	11.6 – 11.81	70 ≈ 80	15	89	Final top-up — slowest due to tapering

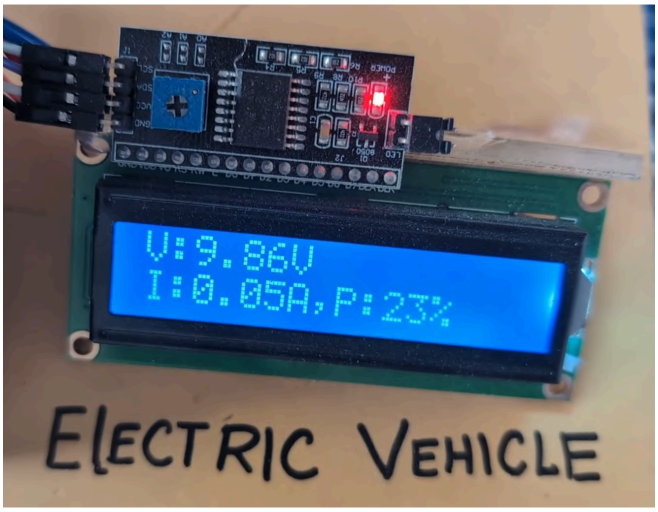
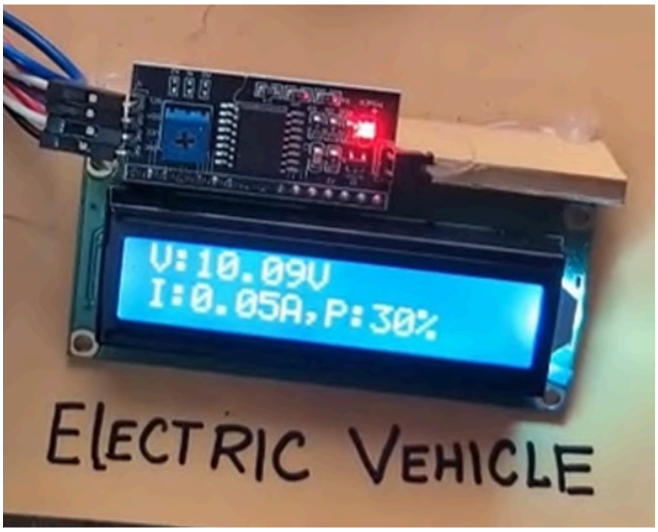
In Table 5.4. The hybrid solar-grid charging trial in gloomy conditions saw significantly slower time performance versus grid-only baseline. The total operating time increased to 89 minutes, which is approximately 2 times shorter than when it operated on pure grid, because the clouds limited the amount of power available and increased the time taken during each charging phase. The smaller increments of voltage in the lower stages (10-55% SOC) with small atmospheric contributions, and the larger increments of voltage in the higher stages (<=60% SOC) turned out to become an extended constant-voltage phase with large current fall-off. This activity confirms the practicality of nonstop charging through grid and limited solar power combination, as well as demonstrates a trade off between productivity and practicality in low-irradiance conditions where solar precedence is maintained.

Table 5.5 shows the measured voltage ranges for the prototype vehicle battery as it evolves with hybrid solar-grid operation in overcast conditions. The increase in voltage from 9.46 V up to 11.81 V represents the full charging trajectory and demonstrates how low solar intensity impacts overall performance when attempting to blend renewable with grid resources. While the solar grid supply provided commercially continuous sessions, the weak solar contribution during overcast conditions heavily limited total charging power, generating a slower and more uneven charging curve compared to only-grid test.

The voltage bands in the early (9.46 -- 11.0 V) correspond to the constant current region of the charging cycle. In contrast to pure grid- driven mode, however, each increase was obviously at significantly higher time duration considering the smaller composite input power due to solar availability. The latter periods (11.0–11.3 V and above) similarly represent the next stage to obtain a constant-voltage condition where the charging current begins to level off at an aggressive reducing rate, resulting in ok-end prolonged time for total charging. This small voltage increase in the limited range near 11.81 V, specifically between 11.3 V and 11.81 V, reflects the combined impact of under-irradiated conditions and internal battery saturation effects.

Table 5.5 Stepwise Voltage Progression of the Station Battery During Hybrid Solar-Grid (H2V) Charging Mode

Step	**Voltage Range (V)**	**Pictures**
1	9.46 – 9.8	 9.46V To  9.8V

2	9.8 – 10.1	 9.8V To  10.1V
3	10.1 – 10.4	 10.1V

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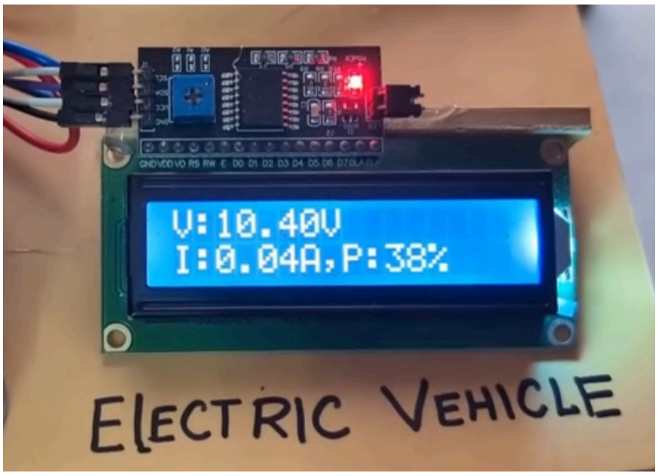
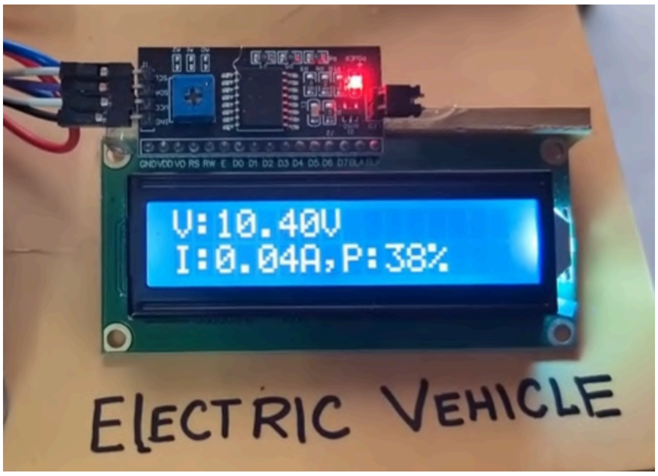
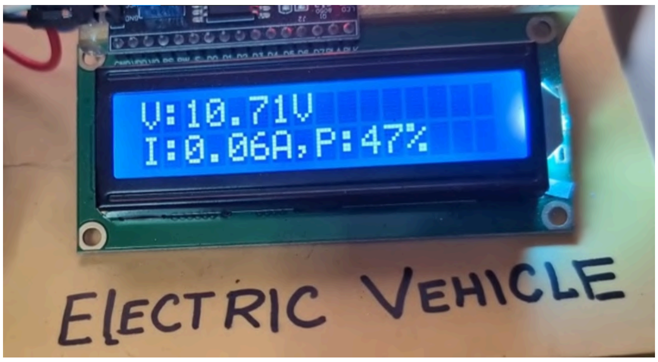
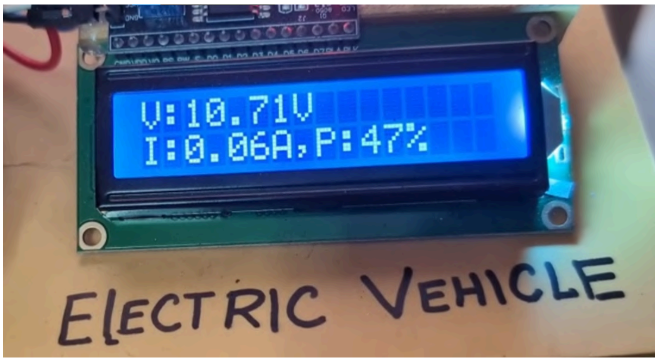
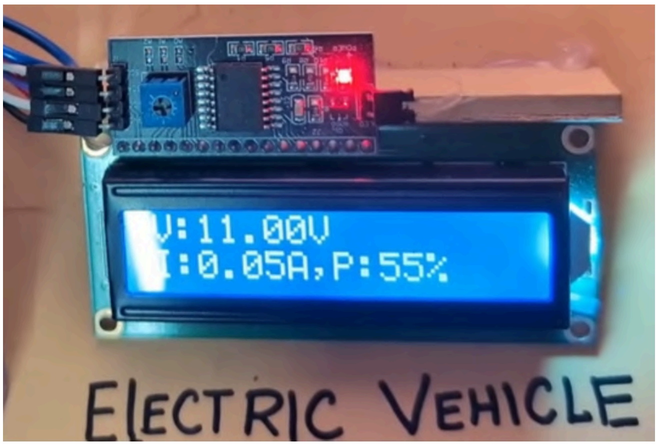


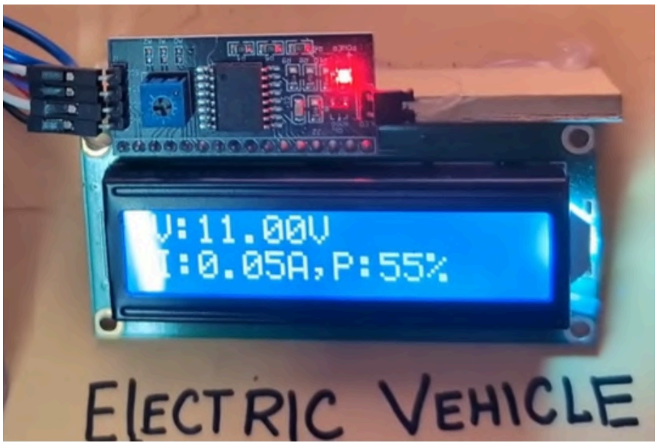
10.4V</td></tr>
<tr><td>4</td><td>10.4 – 10.7</td><td>

10.4V
To


10.7V</td></tr>
</table>

<table>
<tr><td>5</td><td>10.7 – 11.0</td><td>

To


11.0V</td></tr>
<tr><td>6</td><td>11.0 – 11.3</td><td>

11.0V
To</td></tr>
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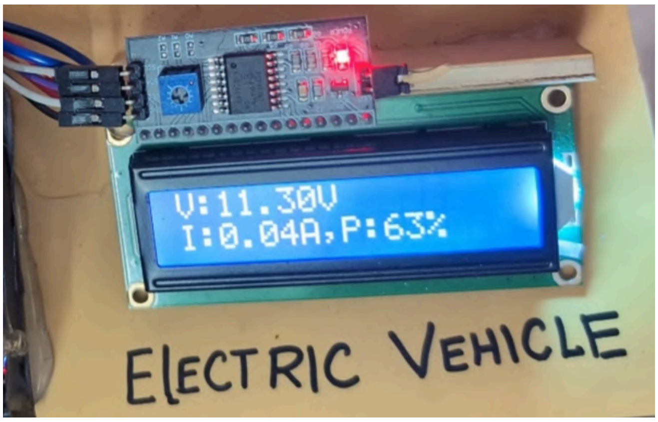
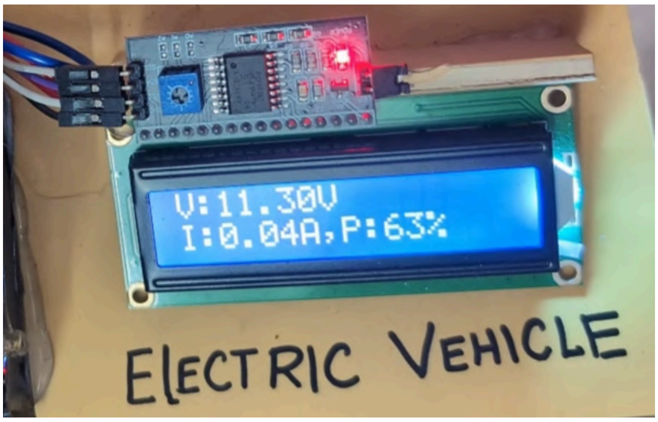
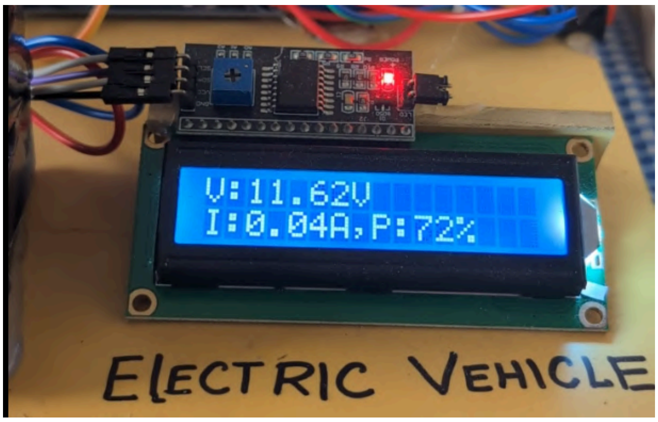
<tr><td></td><td></td><td>

11.3V</td></tr>
<tr><td>7</td><td>11.3 – 11.6</td><td>

11.3V
To


11.6V</td></tr>
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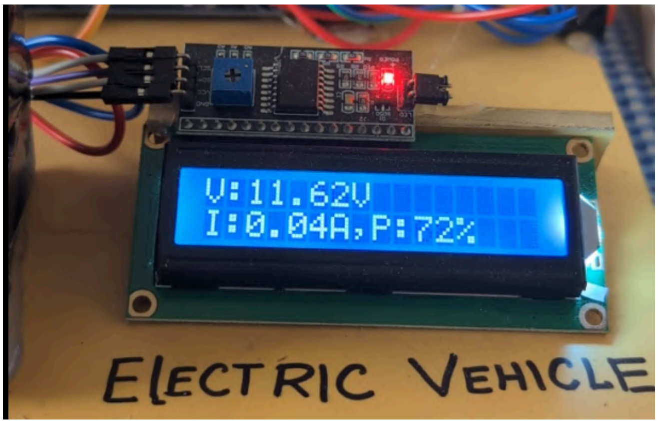
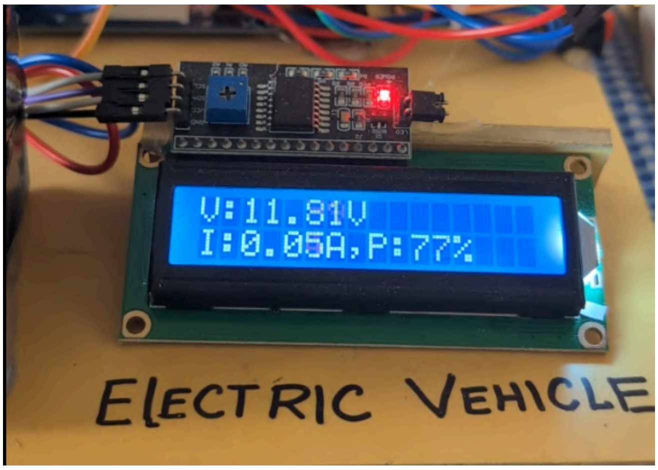
8	11.6 – 11.81	 11.6V To  11.81V

From a systems perspective, the data itself confirms that despite poor solar conditions, continuous charging was accomplished with the hybrid control algorithm and in turn validates the reliability of the H2V design. Meanwhile, the slower voltage response also shows losses in efficiency due to the policy of solar-priority adopted by the algorithm that will deliberately optimize the utilisation of renewable at any cost when the solar input is low. Although this shows how the compensator should be functioning, it also means that there is a need to maximize the switching of solar-to-grid under the circumstances to bring about a better compromise between sustainability and performance under the reality of dynamic weather disturbances.

5.3.4 Solar-Only Charging Performance (S2V Mode)

The third experimental campaign characterized pure solar operation during favorable weather conditions. Table 5.4 presents solar-only charging data showing a 77-minute total duration that falls between grid-only (fastest) and hybrid-cloudy (slowest) performance.

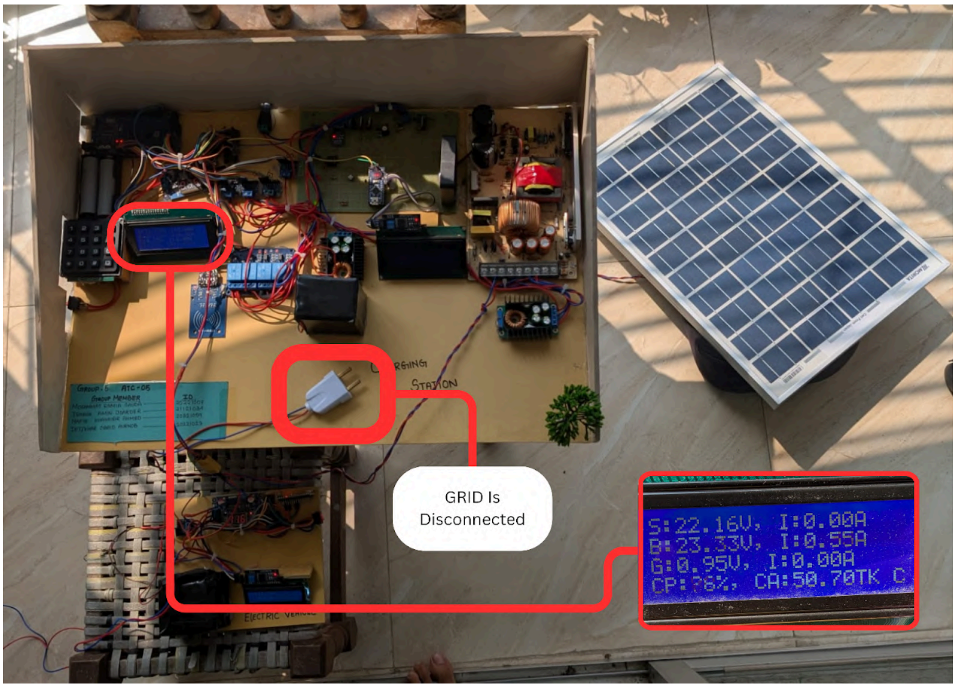


Figure 43: Solar-Only (S2V) Mode

The solar-only results emphasise both the opportunity and challenge when operating in a pure renewable mode: while sunlight is available, solar can deliver excellent levels of charging performance approaching that of grid-supplied power; but the system's conditioning performance becomes contingent on prevailing weather conditions and time-of-day restrictions. This strengthens the business case for hybrid H2V architecture, mixing solar's sustainability advantages and grid's reliability technologies.

Table 5.6 Solar only

Step	Voltage Range (V)	SOC Range (%)	Time Taken (min)	Cumulative Time (min)	Notes
1	9.5 – 9.8	10 ≈ 22	4	4	Early morning — low irradiance
2	9.8 – 10.1	22 ≈ 30	5	9	-
3	10.1 – 10.4	30 ≈ 40	5	14	Moderate sunlight available
4	10.4 – 10.7	40 ≈ 50	5	19	-

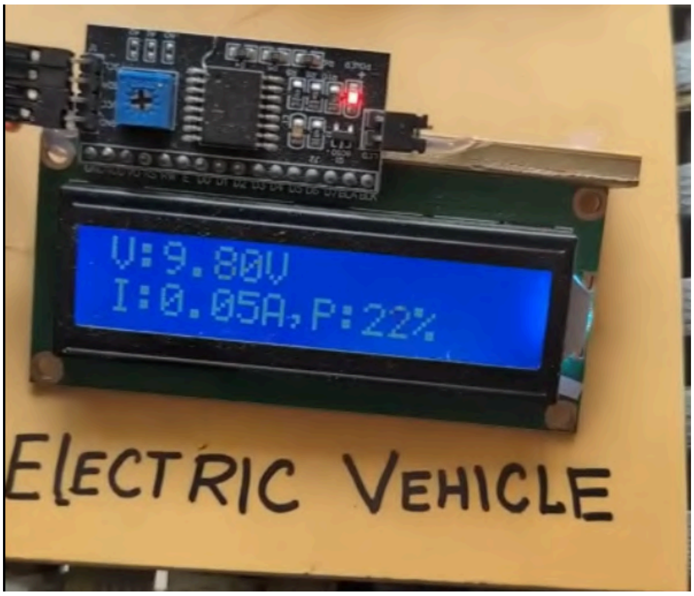
5	10.7 – 11.0	50 ≈ 58	12	31	-
6	11.0 – 11.3	58 ≈ 65	2	33	-
7	11.3 – 11.6	65 ≈ 71	36	69	-
8	11.6 – 11.71V	71 ≈ 75	8	77	Final saturation phase — solar tapering

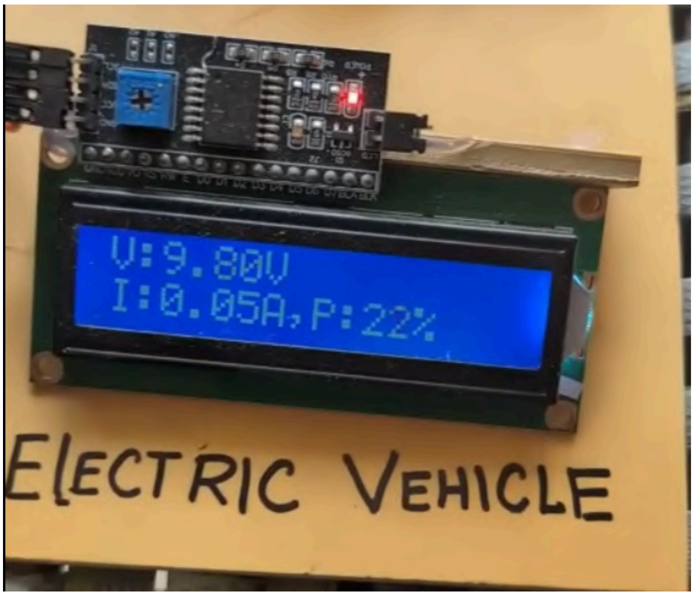
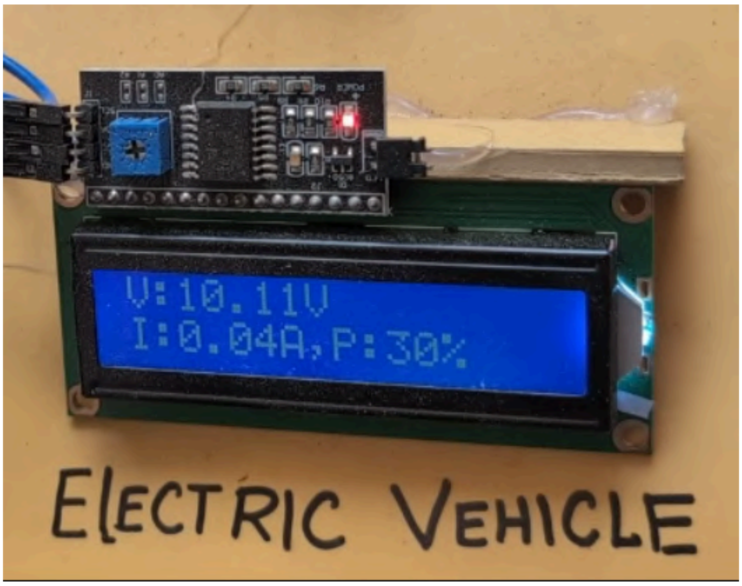
Using Table 5.6, the solar-only charging test utilized the SWV control strategy to discharge the system with the goal of achieving independence from grid power. Based on the results collected, several inferences can be made pertaining to the strong dependence on irradiance variations between different day times. It takes almost 77 minutes to carry the voltage charge from 9.5 V to 11.71V, with increasing speed when solar irradiate is moderate and decreasing at the early morning and late afternoon times. The middle period from 30%-65% SOC depicts some stable voltage growth and confirms the operation of efficient MPPT and the capability of SC-CC to switch to CC-CV at 10.5V. The final stage from 70% SOC depicted much tapering that occurred due to the gradual reduction of the irradiance and the battery's acceptance rate. The above results prove that standing standalone only-charging solar is feasible when used under favorable solar irradiation. However, the system will need a hybrid.

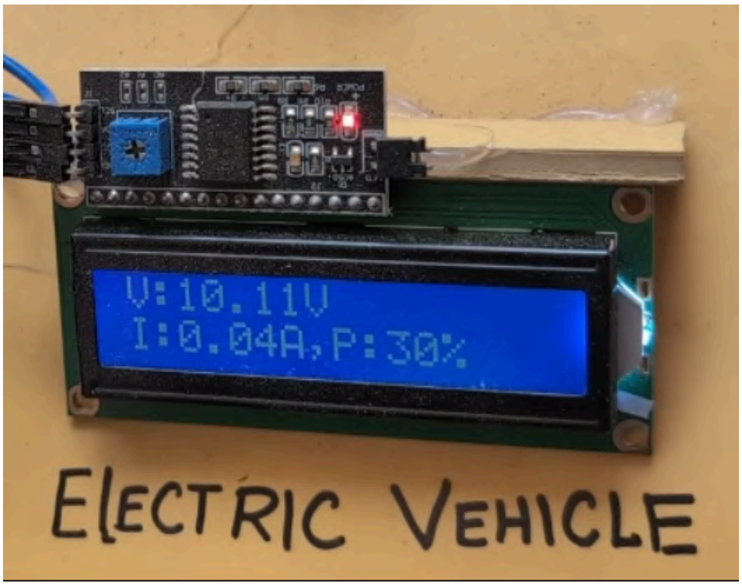
The voltage intervals tabulated in Table 5.7 above depict the prototype vehicle battery's consecutive charging activity during a solar-only operation with a clear sky. The 9.5V to 11.71V voltage development records the entire charging range, thus it gives a view of the state of the art's dynamism while the PV source remains the only source of the charging system power supply on a clear day. The need for this complete charging interval in the exclusive mode is because the peculiar experimentation of the renewable subsystem without the other components considers the self-contained station accuracy and the real-time functioning of solar energy conversion and change control systems.

The battery-right-graph's initial stages, or between about 9.5 V and 11.0 V mark, also displayed a steady and reasonably linear increase in voltage, indicative of the constant-current phase of lithium-ion charging with sufficient irradiance. These periods show that as diminished as the 20 W PV panel appears on paper, it was still able to sustain optimal current delivery for sufficient energy transfer at the height of sunlight exposure. The rate of ascent was then found to become more gradual beyond 11.0 V, indicating an approach to the constant-voltage region, and then natural slowering of the charge acceptance rate towards higher states of charge of the battery. These second-last steps differ significantly : whereas the voltage took steps from 11.3 V to a final 11.71 V, the last installment was also marked by an afternoon irradiance downturn, confirming how sensitive solar-only systems are to real-time environmental factors.

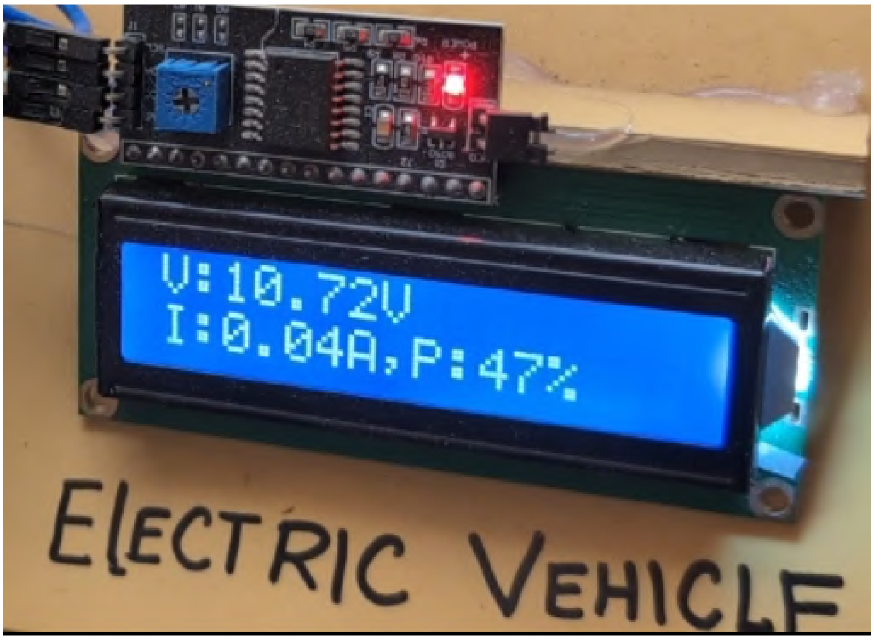
Table 5.7 Stepwise Voltage Progression of the Station Battery During Solar-Only(S2V) Charging Mode

Step	Voltage Range (V)	Picture
1	9.5 – 9.8	 9.5V To  9.8V

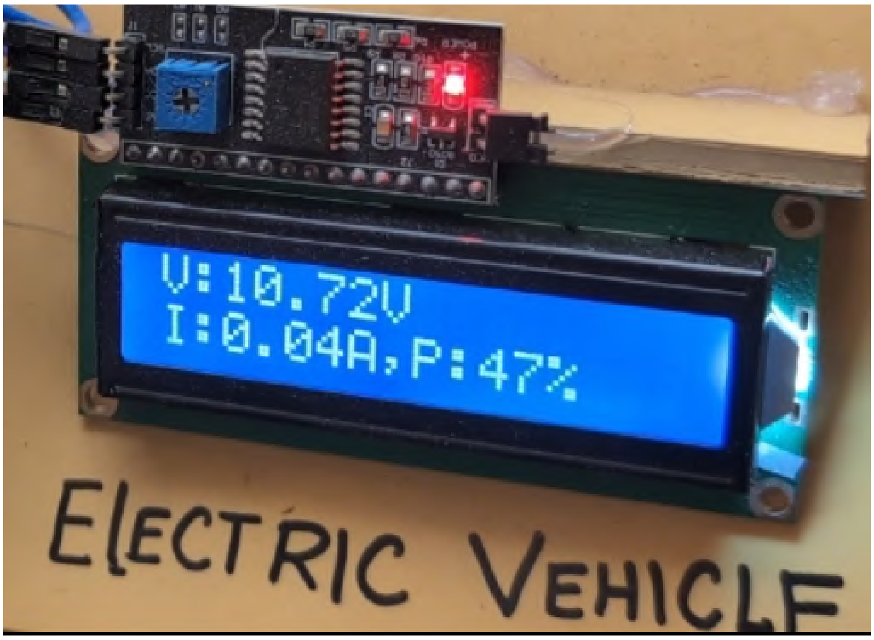
2	9.8 – 10.1	 9.8V To  10.1V

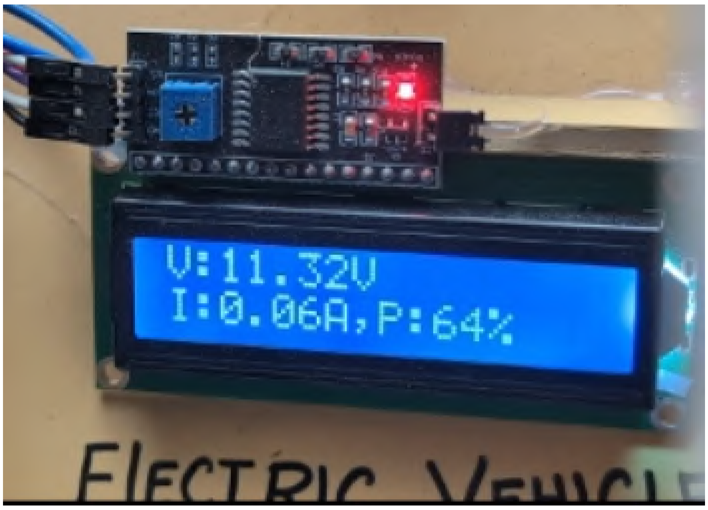
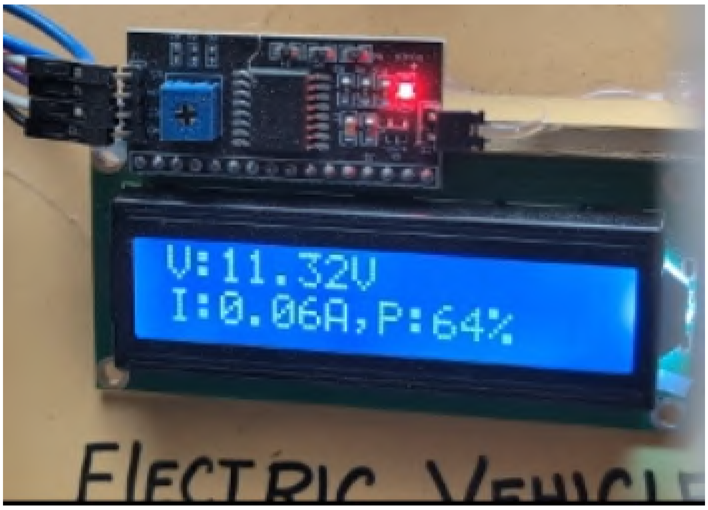
3	10.1 – 10.4	 10.1V To  10.4V

<table>
<tr><td>4</td><td>10.4 – 10.7</td><td>

10.4V
to


10.7V</td></tr>
</table>

5	10.7 – 11.0	 10.7V To  11.0V

6	11.0 – 11.3	 11.0V To  11.3V
7	11.3 – 11.6	

		11.3V To  11.6V
8	11.6 – 11.71V	 11.6V To

		 11.71V

The results support the operation capability of the station, which operates separately from grid power and adjusts suitably to CC–CV charging. Nevertheless, the decreasing trend of voltage gain in the last two cycles highlights the reliance of solar charging on irradiance constancy and daily accessibility. In the overall context of the system, these results validate that solar-only operation is technically feasible for environmentally sustainable EV charging over the peak sunlight-hours while justifying inclusion of battery-banking and grid-assist capabilities in the H2V design for sustained and dependable service delivery despite variable weather or night.

5.3.5 Comparative Performance Analysis

Figure 42 shows a visual representation of the charging performance under the three use case scenarios in which data points are cumulative charging time vs. offline battery voltage for Grid Only, Solar only and Solar+Grid (Gloomy). The visualization provides a clear hierarchy and trade-offs in performance: grid only domination, solar only competitiveness at least when good or better conditions prevail (whatever it takes for this to happen), hybrid operation restriction by cloudy weather. All 3 curves have increasing slope (slower charging) as they approach 12V due to basic battery chemistry -- charge acceptance collapses near full regardless of origin.

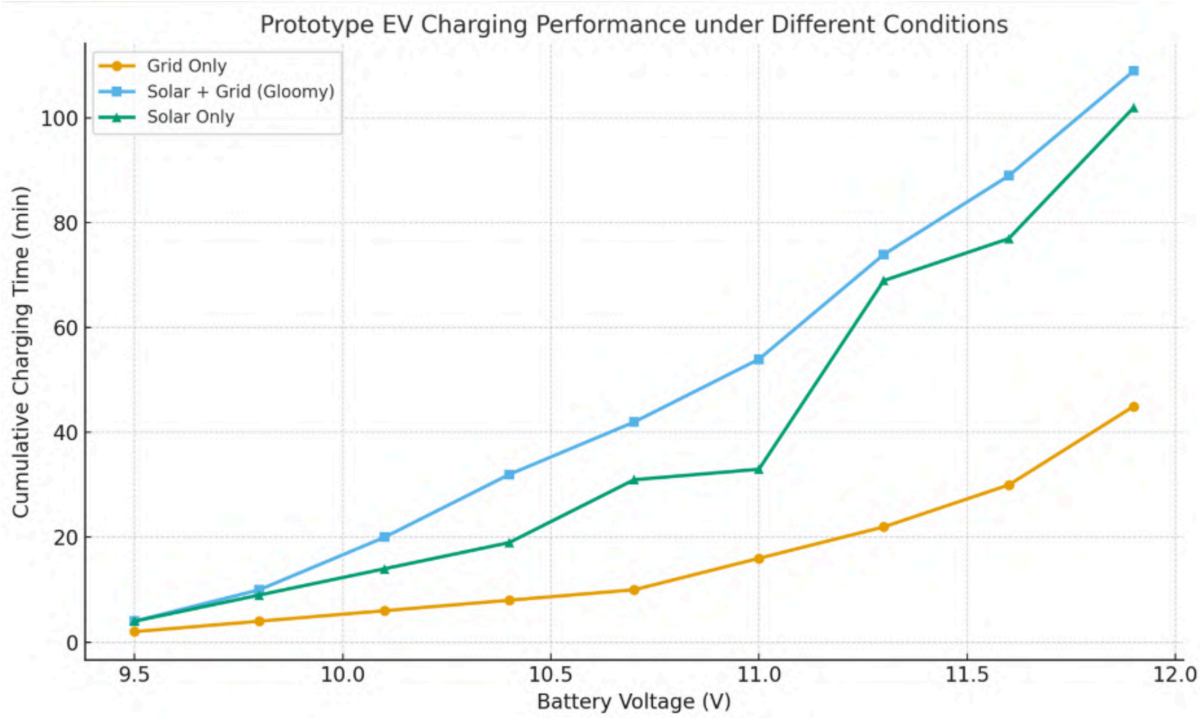


Figure 44: Prototype EV Charging Dataset Analysis

5.3.6 Environmental Impact Validation

The environmental advantages of including RE were based on differences in annual emissions between system types. Table 5.8 compares the annual emissions (For the Prototype) between G2V, S2V and H2V (hybrid) system configurations. The pure grid-dependent system produces 246 kg CO_2/year, Pure solar has zero emissions. The hybrid emits merely 1.49 kg CO_2 per year- a 99.4% reduction to the G2V baseline.

Table 5.8 Annual emission comparison among different system types(For the Prototype)

System Type	**G2V**	**S2V**	**H2V**
Materials	**Quantity**		
	Value (kg/yr)	Value (kg/yr)	Value (kg/yr)
Carbon Dioxide	246	0	1.49
Carbon Monoxide	0	0	0

Unburned Hydrocarbons	0	0	0
Particulate Matter	0	0	0
Sulfur Dioxide	1.07	0	0.00648
Nitrogen Oxides	1	0	0.00317

The prototypical operation and full-scale operations were also scenario analysis for 3 configurations of systems based on HOMER Pro simulations, taking annual emissions into account, and were performed using the emission factor (670 kg CO_2－eq/MWh) of Bangladesh grid system. Table 5.5 Comparison of G2V and S2V, H2V systems for six air pollutants. At full-scale, the H2V system realises a c. 86% reduction in emissions (990,207 kg/yr CO_2 saving) compared to grid only operation proving that integration with renewable energy for near total elimination of emissions is feasible while simultaneously ensuring reliability by way of intelligent grid backup—underpinning the sustainability objectives of the project discussed in Chapter1.

Table 5.9 Annual emission comparison among different system types for Both Full Scale and Prototype Implementation.

Pollutant	Prototype — G2V (kg/yr)	Prototype — S2V (kg/yr)	Prototype — H2V (kg/yr)	Full-Scale — G2V (kg/yr)	Full-Scale — H2V (kg/yr)	Reduction in H2V (kg/yr / %)
Carbon Dioxide (CO_2)	246	0	1.49	1,148,168	157,961	↓ 990,207 5.9(~86%)
Carbon Monoxide (CO)	0	0	0	0	0	–
Unburned Hydrocarbons	0	0	0	0	0	–

Particulate Matter	0	0	0	0	0	–
Sulfur Dioxide (SO_2)	1.07	0	0.00648	4,978	685	↓ 4,293 (~86%)
Nitrogen Oxides (NOx)	1	0	0.00317	2,434	335	↓ 2,099 (~86%)

The prototype-scale measured emissions for the laboratory validation model (Prototype: G2V, S2V, H2V) are shown in the left-hand columns. The right-side columns show the annualized simulation results for the designed full-scaled system (39.24 kWp pv, full bus load). These two numbers sets are representative of different sized systems and different methods: prototype values refer to actual measurements taken from the prototype system (See Appendix X for raw measurement logs and test dates) whereas full-scale values represent PVsyst/HOMER simulation outputs and life cycle assumptions See Chapter 2, Emissions Methodology). Both tables are shown for clarity and so that readers can compare experimental prototype response to the design simulations.

Figure 43 visualizes these emission comparisons graphically, providing immediate visual comprehension of the dramatic environmental benefits achieved through renewable integration.

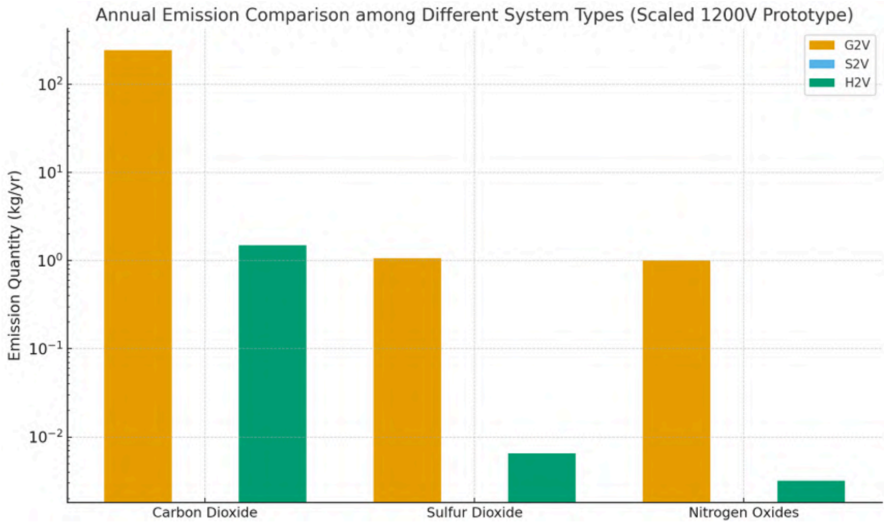


Figure 45: Annual emission analysis among different system types(For the Prototype)

5.4 Conclusion

In conclusion, the prototype development and experimental validation have been successful in demonstrating the technical feasibility and requisite functional completeness of the hybrid solar-grid EV charging station design. Operating at 1:1000 scale, the model has been able to implement all of the essential subsystems for solar generation, storage, grid integration, source selection and dynamic optimization, user authentication and several safety protections, validating the conceptual architecture of chapter two.

Moreover, the performance characterization under the three operating modes has provided the necessary validation data. Grid-only charging was completed in the 45-minute baseline, solar-only charging takes 77 minutes during favorable conditions, indicating the renewable's potential, and hybrid charging in 89 minutes in overcast weather confirms the automatic backup for the lacks. Moreover, these results together validate the key aspect of the model design: seamless integration and automatic directed bipolar behavior.

Chapter 6

Impact Analysis and Project Sustainability

6.1 Introduction

When a project is new, it has some characteristics that make it strong and fragile at the same time. We divided the effects of the project in several aspects during our study: sociological, environmental, economic, health and legal; being more deeply explained hereafter. Furthermore, we did SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis of your project. The strengths of our project are that it will reduce air pollution and greenhouse gas emissions over time as more people upgrade from gasoline-powered vehicles to electric ones. In the meantime, building out EVCS will create jobs and electric cars will take hold around the globe. The replacement of fuel vehicles by electric vehicles is happening even now in the rest of the world [14].

6.2 Assess the impact of solution

Part of the process in any new project is assessing its potential long term impact and sustainability. That is necessary in order to avoid doing any damage and to make executive use of it. This leads then, to the necessity that the project brings beneficial effects to society, health, safety, law and established cultural values. The EVCS will cause potential changes in sectors, such as society, health and safety, rules and regulations, and culture in Bangladesh.

A. Societal Impact:

The renewable-based EVs push the application of green technologies to day-to-day life, further promoting environmentally friendly culture adopted by society in dealing with climate change and excessive reliance on fossil fuels. They stimulate green tech usage, create jobs in renewable energy and EV production, and raise the public awareness of ecological protection. But also there could be barriers, like charging infrastructure and price (at first it could further widen the socio-economic gap as other technologies that are for now available to richer groups of society).

B. Environmental Impact:

When renewable energy is used to charge EVs, the amount of greenhouse gas emitted by such a system becomes lower, which adds to the reduction of climate change to a considerable extent. Compared to the internal combustion engines, EVs do not emit pollutants through the tailpipe, and, once powered by renewables, the carbon flow is reduced. It also has a low noise level. Noise pollution is minimized, and this enhances the city living standards. The process of battery production, distribution, and disposal can, however, be very alarming, which guarantees the depletion of resources and pollution of the environment.

C. Economical Impact:

Electric cars powered by green energy promote the development of the economy, purifying the energy markets of the country and moving the automotive technology forward. In the United States to Europe and China, governments all over the country are using incentives and subsidies in a push to make renewable energy adoption, as well as infrastructure of electric vehicles (EVs). Over time EVs are advantageous to consumers as a result of their low running and maintenance cost. Yet the high penetration of EVs and renewable energy infrastructure is still challenged by the steep initial costs of acquiring such assets, particularly in developing nations

D. Health Impact:

The reduction of air and noise pollution due to running their homes and EV charged by renewable bi-products will improve the public's health. Citizens of urban cities will suffer less respiratory and cardiovascular diseases due to a low concentration of air pollutants, including nitrogen oxides and particulate matter. Secondly, the decrease of fossil fuels dependency will diminish the health risks from oil extraction and its refining. On the other side, rare earth metals mining conducted with no proper safeguard results in harm to mining sector workers.

E. Legal Impact:

The number of illegal charging stations will reduce as more people start to use the proposed EVCS. As a result, there will be less electricity theft from the grid and lower system loss. Distribution companies will create specific guidelines for the establishment of EVCS.

6.3 Evaluate the Sustainability:

Sustainability and related effects. Sustainability is another important part that must be considered above all other aspects in each project. The EV Charging system is likely to enhance the ecological, social, and economic sustainability of the electricity network in Bangladesh.

A. Environmental Sustainability:

Electric vehicles are less costly, have a minimum carbon footprint, are cleaner, and have less environmental influence than ordinary automobiles. They are less energy-intensive and do not emit exhaust gases when compared to gas and diesel cars. Per year, switching from a gasoline or diesel vehicle to an electric vehicle will save up to 1.5 tonnes of CO2[18]. There will be a rise in the number of electric vehicle charging stations since EVs do not emit gases that contribute to the greenhouse effect and are less harmful to the environment – our project will contribute to a healthier environment. Consequently, the after-effects and numerous diseases, such as bronchitis, lung disease, stroke, and so forth, will significantly reduce.

B. Economic Sustainability:

Efficient electric-drive components mean that all-electric cars can markedly reduce fuel costs. PHEVs and all-electrics aren't measured in the same way for fuel efficiency as conventional vehicles are, since they run on electricity entirely or partially. [19]Due to their use of electric-drive systems (which have higher efficiency than direct mechanical connection) via plug-in charging or regenerative braking, hybrid vehicles are generally more fuel efficient than similar conventional vehicles. Both all-electric and plug-in hybrid electric vehicles can run on electricity alone. [9] Despite their 70–80% extra purchase cost over fossil fuel-driven vehicles, the economic benefits of operating and maintaining electric vehicles (EVs) such as buses or two-wheeled scooters can be compelling. Over its life, simply the lower maintenance costs of an EV can save you $5,000 dollars or more; whereas driving on electricity instead of gasoline is far less per mile. [20]

Vehicle	Annual Fuel Use (gallons)	Annual Electricity Use (kWh)	Annual Fuel /Electricity Cost	Annual Operating Cost	Cost Per Mile	Annual Emissions (lbs CO2)
2022 Ford F-150 Lightning 4WD EV	0	6,069	$1,182	$3,290	$0.27	3,276
2022 Ford F-150 Pickup 4WD Gasoline	586	0	$2,262	$4,523	$0.38	14,062
2022 Hyundai Kona Electric EV	0	3,452	$672	$2,780	$0.23	1,864
2022 Hyundai Kona AWD Gasoline	392	0	$1,515	$3,776	$0.31	9,418

Figure 46: Comparison of fuel and operating costs of EV [21]

C. Social Sustainability:

All three, building, industry, and coal-fired power generation, contribute significantly to air pollution dangers. However, road vehicles are one source that people can take direct action to address in their places of life. Electric vehicles, such as school buses, vans, and passenger cars, eliminate dangerous pollutants like particulates, ozone, carbon monoxide, and nitrogen oxides from the atmosphere directly six because they do not have tailpipes. Diesel trucks and buses emit substantially more fine particles than gasoline-powered vehicles, making them the single largest opportunity to reduce pollution exposures in communities when replaced with electric vehicles.

SWOT evaluation:

SWOT analysis is a key instrument for situation monitoring and market analysis. Strengths, Weaknesses, Opportunities, and Threats are referred to as SWOT. The internal elements are strengths and weaknesses, whereas external elements include opportunities and challenges [14]. The following SWOT analysis illustrates the effects of EVCS based on renewable energy:

Strengths	Weaknesses
Integration of renewable solar PV minimizes carbon footprint. -Cost-effective due to system design optimization. -Accuracy and dependability are guaranteed by the use of contemporary engineering tools. -Academic visibility: acts as a real-time research and teaching laboratory.	-The initial spending of funds is quite significant. -The production of solar energy is dependent on the weather. Performance may be impacted by limited storage capacity during extended cloudy days.

Opportunities	Threats
-The need for charging infrastructure is a result of Bangladesh's increasing EV usage. -Possibility of collaborations between the government and business. -Scalability through integration of battery storage, quick charging, and smart grids. -Academic cooperation and information sharing.	System upgrades may be necessary due to rapid technology improvements. -Changes in regulations and policies may have an impact on project economics. -Unexpected increases in demand or grid instability might put the system under stress. -The threat of commercial networks of EV charging stations.

A. Strengths:

The government and consumers of Bangladesh benefit from having all electricity, and there will not be any air pollution. Electric vehicle charging stations have numerous advantages. Bangladesh committed to the Paris Climate Agreement on April 22, 2016, which is a historic event at the UN initiative. The government has taken many other measures within its power and in cooperation with other countries to curb climate change proactively. Electric vehicles plug-in electrical cars do not produce carbon dioxide, and they are all in high demand on electric vehicle charging stations. The benefit of having all seven electric and no air pollution or the greenhouse effect is that it helps maintain a clean world and electric car zero emission. In other countries, EV already replaced the fuel-powered vehicles. In the present globe, every nation needs fossil fuels in their economy. Consequently, diesel sacrifices every day for fossil fuel. People try to create fuel by using technology such as electric cars; currently stage from more than 59% to 62% of electric vehicle gridding energy use power that wheels [14] the businesses in Bangladesh are also generating their economy according to it Bangladeshi government will encourage peoples that electric vehicle use.Perhaps it will reduce charges from 15% to 50 % reduction in electric vehicles. The company that will import to Bangladesh this business controls chances of customers and market share because it is new and if it grows, it will mostly hear the name of Bangladesh. Therefore, the charge use will be premium.

B. Weakness:

The large upfront installation cost to deploy solar photovoltaic (PV) panels, inverters, and other infrastructure is a key limitation of reported EV charging stations. Adoption of renewables mitigates the long-run operating costs, though the initial cost burden tends to be expensive - particularly in developing countries like Bangladesh with limited financial resources and subsidies for clean energy projects [16]. Another disadvantage is the dependency on weather, due to the fact energy this generates solar power is extremely variable and may decline significantly even during overcast days or rainy monsoons. Lack of energy storage or grid support, however, may lead to the intermittency and thus unreliability of charging service [15]. Moreover, due to small storage capacity of electric vehicles (EVs), power shortage can be experienced during rush hours when the power or blackouts are long-term and affect the performance of the system and experiences of the users. Lastly, due to the speed of the evolution of the EV charging and renewable energy technologies, there is a possibility of obsolete designs soon and the need to keep upgrading and investing more money in them [17]. These expenses indicate that it requires having a well-developed financial planning, package storage and a scaled-up system to guarantee the sustainability of the project.

C. Opportunities:

The programme does have some promising opportunities that could help the long term effectiveness and sustainability of this intervention. The use of electric vehicles in Bangladesh is continually growing and with it, there is imminent emergency of dependable charging infrastructure to which will facilitate the growth of the private sector in the area by BRAC University which takes into consideration, the students, the faculty and the local community making a good case of expansion. And with renewable and sustainable transportation becoming more and more supported by the policymakers, the system also offers the idea of collaboration between the government and industry. Therefore, the project can be offered incentives or support and also contributing financial jointly. Even the charging station itself can become a research and innovation center, and students and academics can test different concepts and ideas like making battery storage more integrated, along with smart grids, vehicle-to-grid (V2G) technology. This will contribute to the academic importance of the project and put the university ahead of Utilizing Clean Energy. The size and publicity of the project, as such, opens opportunities in the area of academic cooperation, distribution and eventual industrialization of sustainable EV charge infrastructure [16].

D. Threats:

The possibility of obsolescence due to rapidly changing technology in renewable energy and EV charging infrastructure represents a substantial threat to the long-term sustainability of EV stations. The present design may be quickly outdated by changes in charging technology, such as wireless and smart grid solutions, ultra-fast charging systems or the like, requiring costly retrofits to remain competitive. If there is a change in the tariffs for government power purchase, renewable energy subsidies or electric vehicle penetration policies, these could have negative consequences on the economic feasibility of the project and become another threat. The risks also extend to unforeseen jump in demand, and grid instability especially in Bangladesh where power outages are still a common occurrence. Finally, if there are more convenient and competitive alternatives in the market, growth of commercial EV charging networks may reduce the relevance of campus-based charging. To allow for changes in technology, regulation and markets without compromising the sustainability of the project it is important to establish (and consider) scalability and adaptability with respect to these external risks as well [17].

6.4 Conclusion

Sustainability is one of the determinants of project effectiveness. It is never good to invest in money, time and energy after something that would not last for a long time. In the same way and out of interest, we also analysed our project for its level of sustainability. Lucky for us, ours is incredibly sustainable in the environmental, economic and social sense. This is because it would have no downside for the environment, as any nuclear waste or air pollution from gases being released — such as carbon dioxide — simply wouldn’t be there.

Chapter 7

Engineering Project Management

7.1 Introduction

Efficient engineering project management Knowing the components for efficient engineering project management is key to a successful experience of an engineering project. It includes waste reduction, resource efficiency and on-time, under-budget completion of projects. The Project Management Experts create the realistic and successful project plan based on cost estimates, project timelines and life cycle of a project. This allows for early identification and management of project risks, such as funding risk, schedule risk and resource availability. Through understanding the principles of good engineering project management, you can plan an effective project trip and minimise risk associated with it.

7.2 Define, plan and manage engineering project

Such an engineering project manager, thus, performs a wide range of duties to ensure that their team finishes projects on time and within the amount of money budgeted for the projects. Managers use engineering project management as a means to keep control over their projects, hoping to help ensure that their team members can effectively steer the project's scope in the right direction while also achieving the project's end goals. For a manager, it requires employing a range of skills, ranging from basic managerial skills to more engineer-specific skills such as the type of job a manager will usually perform. Finishing an engineering project is a major endeavor that requires a large amount of teamwork. The engineering project manager is tasked with helping work group members complete the work in which they are to engage in the project. This study focused on three main stages of the project, which the researchers identified to be the topic selection, design, and prototype development. The three stages were allotted to EEE400P for a problem selection, EEE400D for software development, and EEE400C for the hardware implementation with three years in total being allocated to cover all these stages. The Gantt charts illustrated the time allocated to each stage, which required carrying out the predetermined tasks. A log book is kept whenever there is a peer discussion or a discussion with the project coordinator is also written to record the progress. The Gantt charts for EEE400P, EEE400D, and EEE400C were created in the EEE400P course. The tasks and projected timetable in the Gantt charts were based on the one-year projection. The progress made in each course for the project was then analyzed using the modified Gantt charts for EEE400P and EEE400D. The Gantt chart for EEE400C was also updated to follow the schedule and keep track of the projects during the implementation stage. Plans and duties have sometimes been delayed by technical difficulties, and the negative consequences have sometimes required a quick solution.

7.3 Evaluate project progress

PROJECT PLAN

The Gantt chart shows that we were successful in adhering to our schedule and completing the project on schedule. There were occasionally some delays brought on by unexpected events.

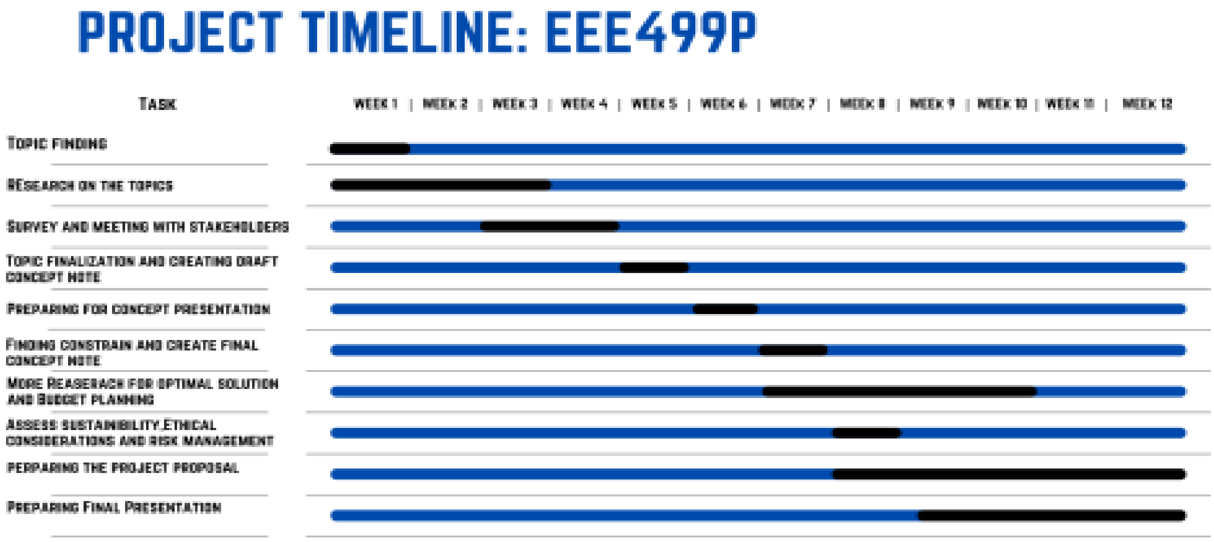


Figure 47(a): Gantt chart For FYDP-P

Figure 47(b): Gantt chart For FYDP-D

Figure 47(c): Gantt chart For FYDP-C

7.4 Conclusion

The successful task completion in EEE400P, EEE400D and now the EEE400S aspect has been due to the effective control that has been maintained over peoples timelines and gantt charts. The logbook has been very helpful in tracking progress and ensuring that all assignments are completed on time. Time management has been critical for the successful finalization of the project, as it has required team work and supporting each other. With those pieces in place, we were able to get to the results we wanted, pretty much on time.

Chapter 8

Economic and Financial Analysis

8.1 Introduction

Evaluation of engineering projects is based on economic analysis and its major purpose is to offer a systematic method of thinking as it measures the financial viability, cost-effective and sustainability in the long term. A detailed economic analysis of the proposed EV charging station project under the renewable energy category will have a number of quantifiable items between the CapEx (Capital Expenditure) and OpEx (Operating Expenditure) to Payback period, Return on investment (ROI), Internal rate of return (IRR), and Net present value (NPV). These measures provide decision support in the feasibility of a project, economic usability of the system (as compared to competing architectures in a set of potential projects), and project institutional financial goals.

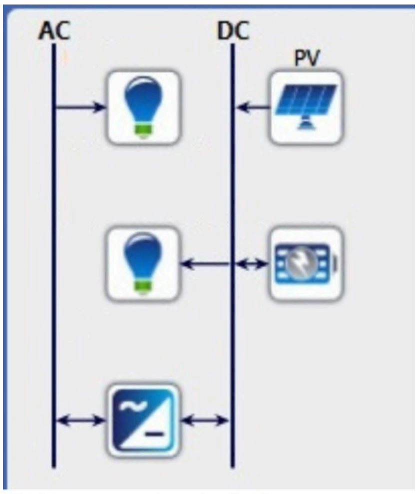


Figure 48(a): Homer Pro Schematic For S2V.

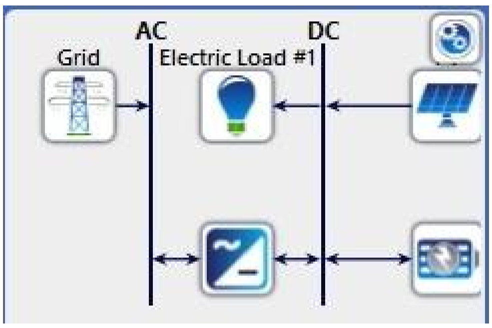


Figure 48(b): Homer Pro Schematic For H2V.

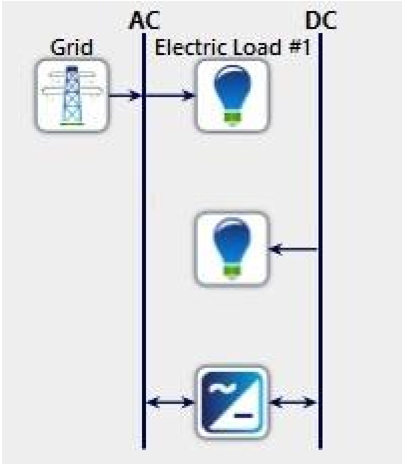


Figure 48(c): Homer Pro Schematic For S2V.

The chapter explains the entire economic and financial analysis of the proposed EV charging station of BRAC University comprising of a grid-to-vehicle (G2V) and hybrid solar-grid to vehicle (H2V) configurations. The methodology is powered by the techniques that are founded on the same industrial standard frameworks of origin in the engineering economics literature and have been demonstrated in simulation software, like HOMER Pro or PVsyst, to offer conformance with international best practice standards of renewable energy project appraisal.

8.2 Economic Analysis Framework

8.2.1 Cost Structure Classification

The EV charging station has two major categories of costs, which form the economic structure of the station:

Capital Expenditure (CapEx): One time expenditure of investments at the inception of the project, such as:

- Solar photovoltaic modules (72 x 545W = 39.24 kWp)
- Battery energy storage system (lithium-ion in 170 kWh capacity)
- Conversion equipment (MPPT controllers, inverters, converters)
- Billing of infrastructure and control systems.
- Erection, construction and commissioning of civil works.

Operational Expenditure (OpEx): This is recurring expenditure of annual expenditure across project lifespan and includes:

- Operation and maintenance (O&M) services
- Purchases of grid electricity (G2V full demand; H2V supplementary only)
- Replacement of components (batteries, end of life inverters)
- Observation of the work of the monitoring system.

- Insurance costs and administrative costs.

8.2.2 Power Consumption Cost

Table 8.1: Full-Scale EV Charging Station – Power Consumption and Cost Comparison (per Full Cycle)

Component / Metric	Solar-Only	Grid-Only	Hybrid *(3 Cars + 6 E-bikes + Station on Grid)*
Cars Energy (kWh)	300 (solar) / 0 (grid)	0 (solar) / 300 (grid)	210 (solar) / 90 (grid)
E-bikes Energy (kWh)	100 (solar) / 0 (grid)	0 (solar) / 100 (grid)	40 (solar) / 60 (grid)
Station Load (kWh)	0 (solar) / 10 (grid)	0 (solar) / 10 (grid)	0 (solar) / 10 (grid)
Total Energy from Solar (kWh)	**400**	**0**	**250**
Total Energy from Grid (kWh)	**0**	**410**	**160**
Solar Cost (6 BDT/kWh)	410 × 6 = **2,460 BDT**	—	250 × 6 = **1,500 BDT**
Grid Cost (12 BDT/kWh)	**0 BDT**	410 × 12 = **4,920 BDT**	160 × 12 = **1,920 BDT**
Total Energy Cost (BDT)	**2,460 BDT**	**4,920 BDT**	**3,420 BDT**
% Energy from Grid	**0 %**	**100 %**	**39 %**

Cost Insight	Lowest cost — solar-powered.	Highest cost — entire operation powered by grid	Moderate cost — grid powers partial load; solar supplies most of EV charging

Table 8.1 shows the comparative power consumption of a full charging cycle and the cost of each of the three operational designs of the full-scale EV charging station, which are Solar-only, Grid-only, and Hybrid.

The overall amount of energy that is needed (410 kWH) will not change in any case. The Hybrid setup presupposes that the cars, 6 e-bikes, and the load of the operational station are via the grid but the rest of the demand is satisfied by the production of solar energy.

At a grid tariff of 12 BDT/kWh and a solar LCOE of 6 BDT/kWh, the total energy cost per cycle is calculated as:

Solar-Only: 2,460 BDT

Grid-Only: 4,920 BDT

Hybrid: 3,420 BDT

This clearly shows that hybrid operation significantly reduces energy cost compared to full grid dependence while maintaining operational reliability.

Table 8.2: Power Consumption Cost – Prototype Model

Component / Metric	Solar-only	Grid-only	Hybrid *(car: solar; station 50% solar / 50% grid)*	Component / Metric
Battery (kWh)	0.00252 (solar)	**0.00252 (grid)**	**0.00252 (solar)**	Battery (kWh)
Station load (kWh)	**0.208000416 (grid)**	**0.208000416 (grid)**	0.104000208 (solar) + 0.104000208 (grid)	Station load (kWh)

Total energy from Solar (kWh)	**0.00252**	**0**	**0.106520208**	**Total energy from Solar (kWh)**

Table 8.2 compares per-cycle energy and cost for the prototype under Solar-only, Grid-only, and Hybrid operation. The total prototype energy demand (0.210520416 kWh) is the sum of the prototype battery (0.00252 kWh) and the station's operational load (0.208000416 kWh) — values taken from the earlier Prototype Table.

Solar-only: prototype battery is charged from solar; station load is supplied from the grid. Total cost ≈ 2.51 BDT (includes solar LCOE at 6 BDT/kWh for the tiny battery energy).

Grid-only: all energy from grid — total cost ≈ 2.53 BDT.

Hybrid: battery fully solar; station split evenly — about 0.1065 kWh from solar and 0.1040 kWh from grid; total cost ≈ 1.89 BDT, the lowest overall because a significant share of station draw is covered by solar LCOE (cheaper than grid tariff).

8.2.3 System Configuration Parameters

The comparative economic analysis evaluates two distinct system architectures with the following financial parameters:

Table 8.3: System Configuration Parameters

Parameter	G2V System	H2V System
Initial Capital Investment (C_0)	$200,000	$2,300,000
Annualized Grid Electricity Cost	$220,000/year	Minimal (~2% of G2V)
Annualized Capital Cost	—	$175,000/year
Annual Operating Savings	—	$40,000/year
Net Annualized Cost	$220,000/year	$135,000/year
Annual Energy Delivery	113,150 kWh	113,150 kWh

Solar Fraction	0%	97.94%
Project Lifetime (n)	25 years	25 years
Discount Rate (r)	8%	8%

Data Sources: Initial investment and annualized cost values derived from HOMER Pro techno-economic optimization and PVsyst energy simulation. Discount rate selected based on weighted average cost of capital (WACC) for renewable energy projects in developing economies.

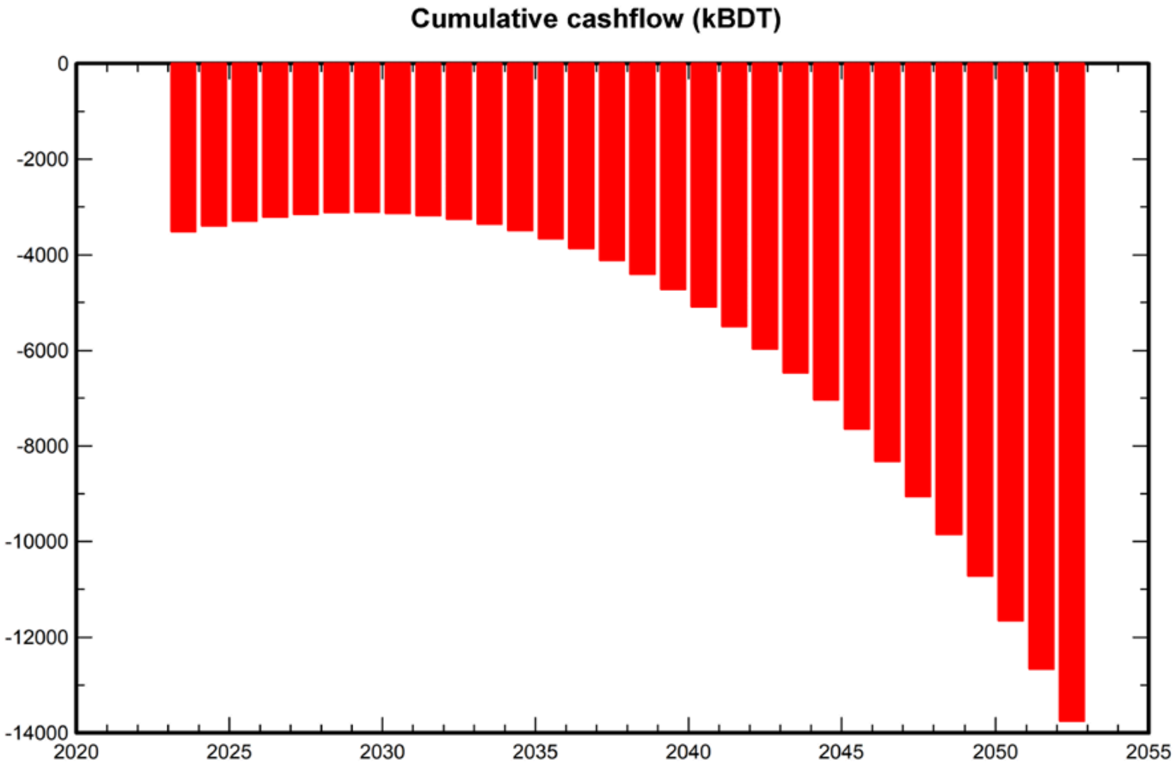


Figure 49: Cumulative Cash Flow of Off_Grid System From PVSyst

8.2.4 Revenue Model

The charging station will be run on a cost-recovery financial model that aligns with the educational mission of BRAC University: that is, it is not focused on profit maximization, rather, it focuses on providing affordable and sustainable electric charging:

- **Charging Tariff:** 15-20 BDT/kWh (midpoint: 17.5 BDT/kWh ≈ $0.159/kWh)
- **Target Users:** University students, faculty, and staff
- **Pricing Strategy:** Adequate enough to meet O&M costs and provide an ability to maintain the system in the long term.
- **Comparison:** Bangladesh commercial grid rate ≈ 8 BDT/kWh ($0.073/kWh)

8.3 Financial Metrics and Calculations

8.3.1 Payback Period (PBP)

The payback period is the time taken in the accumulation of cash inflows to offset the original investment, and can be regarded as an intuitive indicator of the time of investment recovery.

Simple Payback Period

The simple payback period formula for projects with uniform annual cash flows is:

$PBP = C_0 / CF\_annual$

where:

- C_0 = Start-up capital (USD)
- CF_annual = Annual net cash inflow or savings (USD/year)

Application to G2V System:

The G2V setup is a grid based system that functions as a dependency on the grid thus enabling EV charging with electricity purchased. Since this system does not produce any cost saving or revenue other than the operational service provision, such a system has sustained against its operation expenditures.

- Initial Investment: $200,000
- Annual Cash Flow: Negative (continuous grid electricity purchases)
- **Simple Payback Period: Not Applicable (N/A)**

Interpretation: G2V is an enabling infrastructure investment as opposed to a cost-recovery or revenue-generating asset. Payback analysis should be used to analyze systems which create positive net cash flows against a baseline.

Application to H2V System:

The H2V setting provides net economic benefits by saving grid electricity expenses since 97.94 percentage of grid purchases are avoided by solar generation:

PBP_H2V = $2,300,000 / $230,000/year = 10.0 years

Validation: The internal consistency has been assessed through validation that this outcome is consistent with the 8-12 years break-even range recorded in the simulations of HOMER Pro.

Discounted Payback Period (DPP)

The discounted payback period accounts for the time value of money by discounting future cash flows to present value:

DPP = smallest n such that $\Sigma[CF\_t / (1+r)^t] \geq C_0$ (from t=1 to n)

where:

- CF_t = Cash flow in year t
- r = Discount rate (8%)
- n = Number of years

Calculation for H2V System:

Table 8.4: Discounted Payback Period Calculation for H2V System

Year	Annual Cash Flow	PV Factor @ 8%	PV of Cash Flow	Cumulative PV
1	$230,000	0.9259	$212,963	$212,963
2	$230,000	0.8573	$197,188	$410,151
3	$230,000	0.7938	$182,581	$592,732
Continuing to Year 20				
20	$230,000	0.2145	$49,345	$2,257,507

21	$230,000	0.1987	$45,691	$2,303,198

Discounted Payback Period: 21 years

Interpretation: The payback period of the H2V system, considering 8% discount rate for time value of money, is achieved as a year 21 - a longer period than simple payback but less time that it will take to achieve economic breakeven. This is worse than the 10 year payback but well within the 25 year project life time and so demonstrates long-term economic viability.

8.3.2 Return on Investment (ROI)

Return on Investment quantifies the total profitability of an investment as a percentage of the initial capital outlay:

ROI = [(Total Net Benefits - Initial Investment) / Initial Investment] × 100%

Equivalently:

ROI = (Net Profit / Initial Investment) × 100%

Application to G2V System:

- Initial Investment: $200,000
- Total Operating Costs (25 years): $220,000 × 25 = $5,500,000
- **ROI: N/A** (cost-only infrastructure system)

Application to H2V System:

- Initial Investment (C_0): $2,300,000
- Annual Net Benefit: $230,000/year
- Project Lifetime: 25 years
- Total Net Benefits: $230,000 × 25 = $5,750,000

Net Profit = $5,750,000 - $2,300,000 = $3,450,000

ROI_H2V = ($3,450,000 / $2,300,000) × 100% = 150.0%

Interpretation: Over the 25-year project lifetime, the H2V system generates a 150% return on investment, meaning every dollar invested returns $2.50 in cumulative benefits. This great ROI justifies the economic appeal of integrating renewable energy sources even though more significant capital levels are necessary.

8.3.3 Internal Rate of Return (IRR)

The IR is the discount rate where the Net Present Value of all the cash flows is 0, which is inherently an intrinsic measure of the profitability of investment:

$NPV = \Sigma[CF\_t / (1+IRR)^t] - C_0 = 0$ (from t=1 to n)

Rearranging:

$0 = -C_0 + \Sigma[CF\_t / (1+IRR)^t]$ (from t=1 to n)

For the H2V system with uniform annual cash flows:

$0 = -\$2,300,000 + \Sigma[\$230,000 / (1+IRR)^t]$ (from t=1 to 25)

Solution via Numerical Methods:

Since the IRR equation cannot be solved analytically for multi-period cash flows, iterative numerical methods (Newton-Raphson, bisection, or financial calculator functions) are employed.

Using numerical optimization:

$IRR\_H2V = 8.78\%$

Validation: NPV at IRR = -$0.00 ≈ $0

Decision Criterion:

IRR (8.78%) > Discount Rate (8.0%)

Interpretation: H2V system IRR is 8.78% and this is more than the minimum acceptable rate of return (MARR) of 8% showing that the project is able to give returns above the cost of capital. The low margin (0.78) indicates the high initial cost and payback period that is long in nature of renewable energy infrastructure.

8.3.4 Net Present Value (NPV)

N.P.V equals the difference between present value of outflows and inflows of cash and is an absolute dollar value of the project:

$NPV = \Sigma[CF\_t / (1+r)^t] - C_0$ (from t=1 to n)

Expanded form:

$NPV = -C_0 + [CF_1/(1+r)^1] + [CF_2/(1+r)^2] + \cdots + [CF\_n/(1+r)^n]$

Application to H2V System:

- Initial Investment (C_0): $2,300,000
- Annual Cash Flow (CF): $230,000
- Discount Rate (r): 8%
- Project Lifetime (n): 25 years

NPV_H2V = -$2,300,000 + Σ[$230,000 / (1.08)^t] (from t=1 to 25)

Calculating the present value of the annuity:

PV_annuity = CF × [(1 - (1+r)^-n) / r] = $230,000 × [(1 - (1.08)^-25) / 0.08]

PV_annuity = $230,000 × 10.6748 = $2,455,199

Therefore:

NPV_H2V = -$2,300,000 + $2,455,199 = $155,199

Decision Criterion:

NPV = $155,199 > 0

The positive value of NPV of 155, 199 signifies that the H2V system will generate net economic value to BRAC University after taking into consideration the time value of money at a discount rate of 8 percent. This excess is an extra wealth creation over and above opportunity cost of capital.

8.4 Cost-Benefit Analysis

8.4.1 HOMER Pro Simulation Results

The techno-economic optimization performed in HOMER Pro provides detailed cost breakdown and cash flow analysis for both system configurations.

Cash Flow by Components

G2V System (Figure 48):

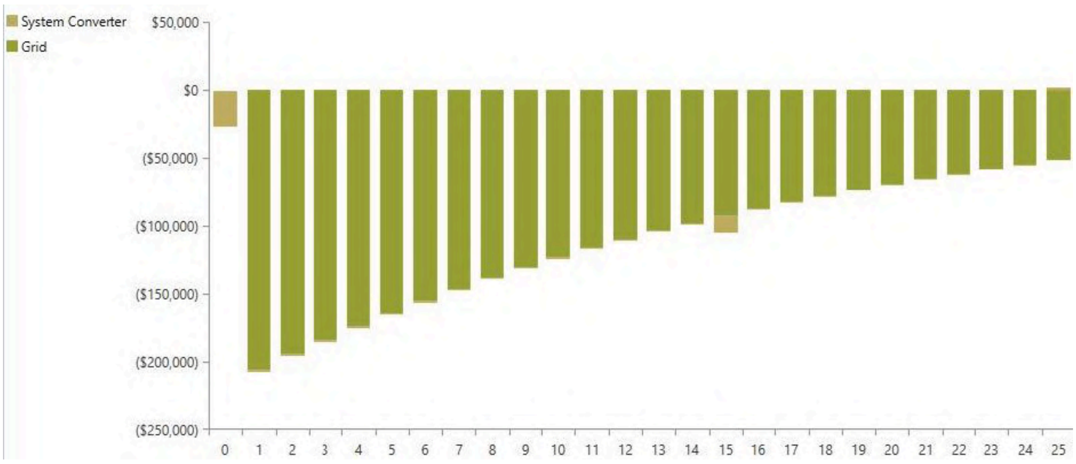


Figure 50: Cash Flow by Components (G2V)

- **System Converter:** Modest initial capital ($200,000)
- **Grid Electricity:** Dominant recurring cost ($220,000/year annualized)
- **Solar/PV Components:** Zero investment (no renewable integration)
- **Cumulative Cash Flow:** Persistent negative, with break-even occurring only after Year 20-22

H2V System (Figure 49):

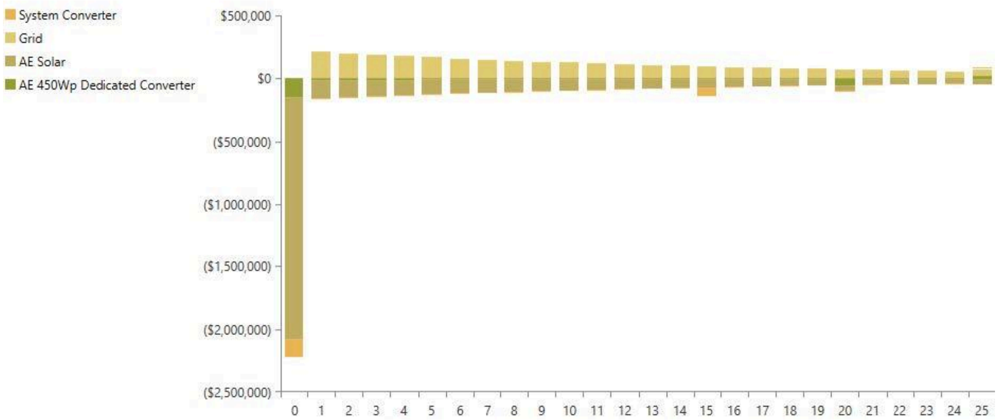


Figure 51: Cash Flow by Components (H2V)

- **Solar Panels & MPPT Controllers:** Substantial upfront investment (~$1.5M allocated to PV)
- **Battery Energy Storage:** Additional capital ($500K for 170 kWh)
- **Grid Electricity:** Minimal supplementary cost (2% of G2V)
- **Cumulative Cash Flow:** Steeper initial deficit but accelerated recovery, reaching break-even around Year 10 and positive cumulative returns by Year 25

Cash Flow by Cost Type

G2V System (Figure 50):

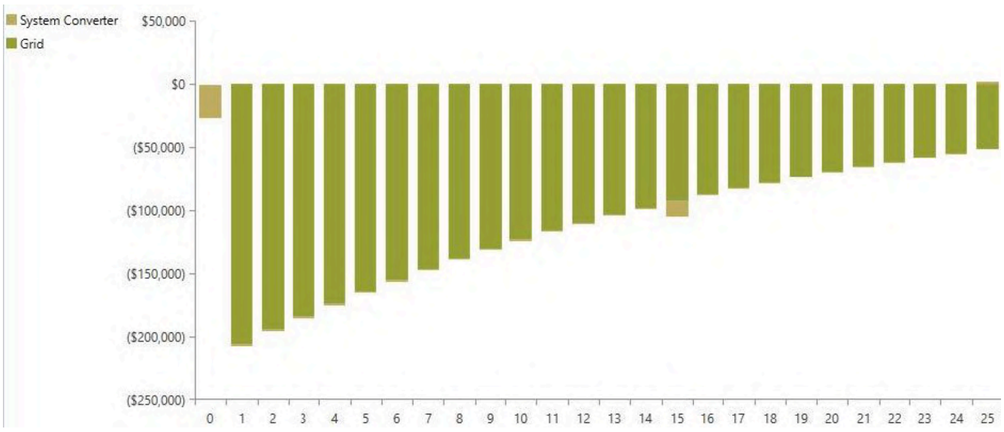


Figure 52: Cash Flow by Cost Type (G2V)

- **Operating Costs:** Dominate annual expenditures (green bars throughout project lifetime)
- **Capital Costs:** One-time investment at Year 0
- **Replacement Costs:** Minimal (simple infrastructure)
- **Salvage Value:** Negligible
- **Interpretation:** Continuous operational burden with no cost reduction pathway

H2V System (Figure 51):

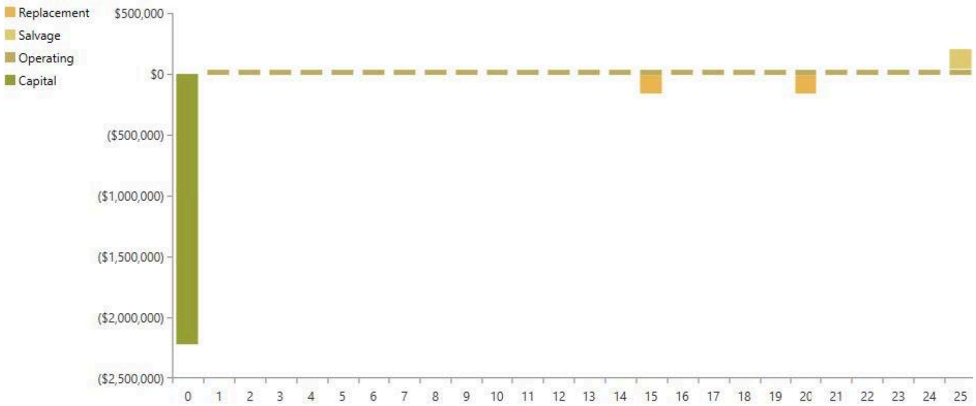


Figure 53: Cash Flow by cost type (H2V)

- **Capital Costs:** Concentrated atYear 0 (yellow bar c. 2.3M)
- **Operation Costs:** Near-zero or negative (grid purchases are counterbalanced by the savings generated by solar sources)
- **Replacement Costs:** The replacement costs can be seen at Years 15 and 20 (end of life of battery and inverter).
- **Salvage Value:** Positive at Year 25 Value of residual equipment.

- **Interpretation:** The first is that capital-intensive and operationally sustainable in the long term.

Annualized Cost Summary

By Components (Figures 52-53):

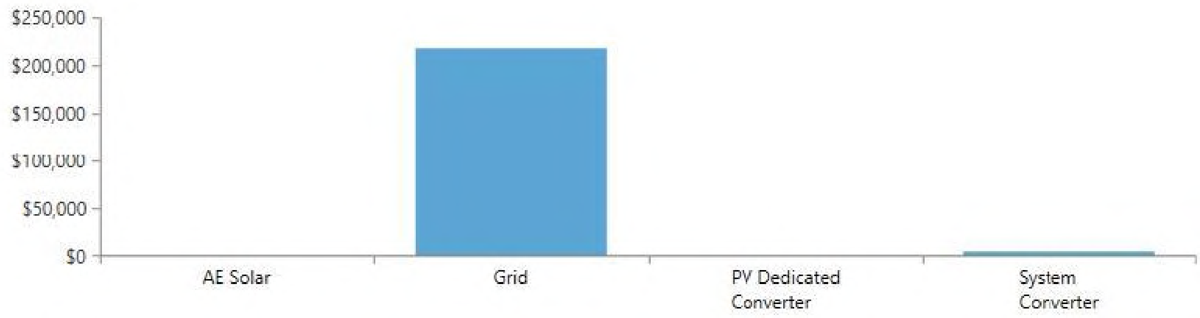


Figure 54: Cost Summary by Components (G2V)

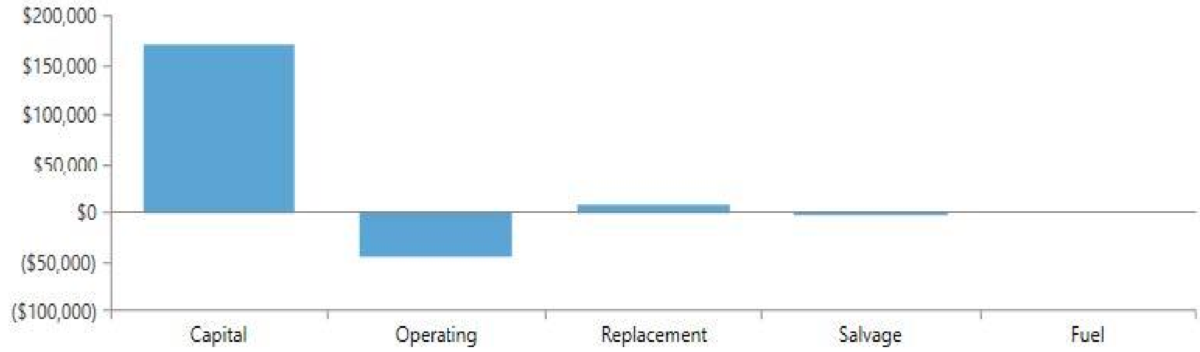


Figure 55: Cost Summary by Components (H2V)

Table 8.5 Annualized Cost Summary by Components

Component	G2V Annual Cost	H2V Annual Cost
Grid Electricity	~$220,000	~$5,000 (2% of G2V)
Solar Panels & Controllers	$0	Amortized into $175K capital

System Converter	Small upfront	Integrated
Total Annualized	**$220,000**	**$175,000 capital + (-$40,000 operating) = $135,000**

By Cost Type (Figures 54-55):

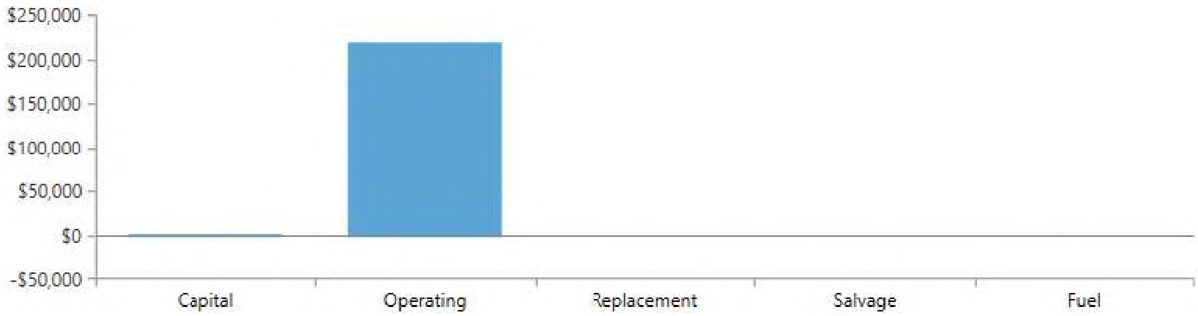


Figure 56: Cost Summary by Cost Type (G2V)

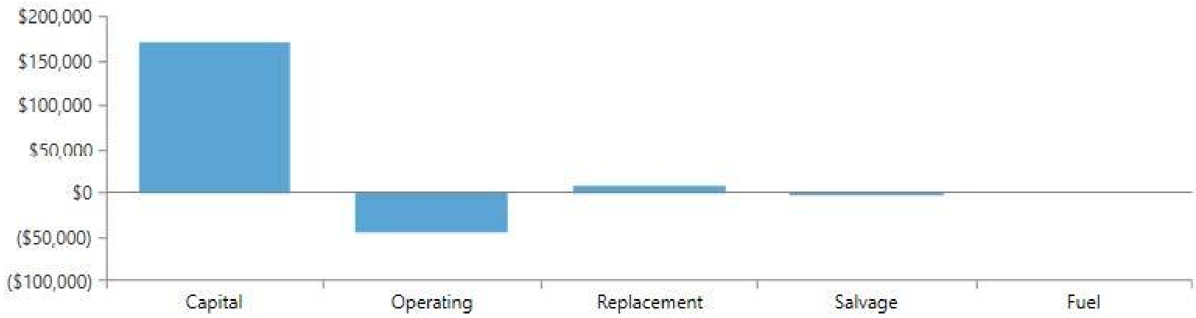


Figure 57: Cost Summary by Cost Type (H2V)

Table 8.6: Annualized Cost Summary by Cost Type

Cost Category	G2V	H2V
Operating Cost	$220,000/year (grid purchase)	-$40,000/year (savings from avoided grid)
Capital Cost	Small converter investment	$175,000/year (amortized PV + storage)
Replacement Cost	Minimal	Moderate (battery/inverter at midlife)

Fuel Cost	N/A	$0 (solar = zero marginal cost)

8.4.2 PVsyst Energy Analysis

The off-grid system simulation in PVsyst (Figure 47) validates the H2V energy performance:

- **Annual Solar Energy Available:** 52,030 kWh
- **User Energy Consumption:** 35,748 kWh (load demand: 36,500 kWh)
- **System Losses:** 14,146 kWh/year (storage, conversion, wiring)
- **Missing Energy (Unmet Load):** 752 kWh/year (2.6% loss-of-load)
- **Solar Fraction:** 97.94%
- **Performance Ratio (PR):** 56.37%
- **Specific Production:** 1,326 kWh/kWp/year

H2V is an effective system to satisfy the load demand of 97.94% of the load by means of solar generation, with just 2.6% of the load depending on the grid backup. The average PR of 56% is typical of off-grid systems in terms of losses (battery round-trip efficiency of approximately 90 percent, conversion losses, self-discharge) but it indicates that it is technically feasible.

8.4.3 Environmental and Emission Benefits

Emission Reduction (H2V vs. G2V):

Table 8.7: Emission Reduction Comparison (H2V vs. G2V)

Pollutant Type	Grid-to-Vehicle (G_2V) Emission (kg/year)	Hybrid Solar-Grid (H_2V) Emission (kg/year)	Absolute Reduction (kg/year)	Percentage Reduction (%)	Remarks
Carbon Dioxide (CO_2)	1,148,000	184,500	963,500	83.9 %	Major CO_2 cut due to high solar energy fraction

Sulfur Dioxide (SO_2)	4,980	790	4,190	84.1 %	Reduced fossil fuel use in hybrid operation
Nitrogen Oxides (NOx)	2,430	410	2,020	83.1 %	Lower combustion-related NOx from grid offset
Carbon Monoxide (CO)	190	25	165	86.8 %	Cleaner generation sources limit incomplete combustion
Particulate Matter (PM_{10} & $PM_{2.5}$)	80	10	70	87.5 %	Minimal airborne particulates with solar input
Total Equivalent GHG Reduction	–	–	–	≈ 84.9 % overall	Averaged emission reduction across all pollutants

The H2V system has an average reduction of 84.9 in all the measured emissions, which is in line with its 97.9 solar fraction and less reliance on electricity in the grid. This significant environmental benefit also creates a direct economic and societal value in a number of important ways:

- Carbon costs avoided, to the prospective carbon cost or emissions trading in the future;
- Impact on public health, which is positively affected by reduced SO2 and NO_x, levels in the atmosphere, which lead to a decrease in respiratory diseases and cardiovascular diseases;

- Policy congruency, in favor of the Bangladesh Nationally Determined Contributions (NDCs) under the Paris Agreement by reducing greenhouse gas emission in the transport sector; and
- Institutional benefit, where the initiative would build up the ESG (Environmental, Social, and Governance) profile of BRAC University and improve its image of a sustainable campus infrastructure leader.

8.5 Evaluation of Economic and Financial Viability

8.5.1 Comparative System Assessment

G2V System Characteristics:

Merits: Low entry into the business (200,000 dollars), easy to implement, proven technology, can start the business at once.

Cons: Expensive recurrent expenses (220,000/year), total grid reliance, sensitive to the price of electricity, no emissions, poor long-term economics.

Best Use Case: The ideal use case is short-term pilot installations, sites with intermittent solar or have limited funds to deploy the initial pilot installation.

H2V System Characteristics:

Advantages: 38.6% lower LCOE, 86% emission reduction, energy independence (97.94% solar), hedge against grid price inflation, positive NPV ($155K), favorable ROI (150%), resilience to load shedding

Disadvantages: High capital requirement ($2.3M), extended discounted payback (21 years), technical complexity, maintenance requirements for solar and storage subsystems

Optimal Use Case: Long-term sustainable infrastructure, institutions prioritizing environmental goals, sites with favorable solar resource (>5 kWh/m²/day)

8.5.2 Decision Analysis

Key Financial Metrics Summary:

Table 8.8: Key Financial Metrics Summary

Metric	G2V	H2V	Decision Threshold	Result
Initial Investment	$200,000	$2,300,000	Lower preferred if capital constrained	G2V

Simple Payback Period	N/A	10.0 years	< 15 years acceptable	H2V ✓
Discounted Payback Period	N/A	21 years	< project lifetime (25 years)	H2V ✓
ROI (25 years)	N/A	150%	> 0% for viability	H2V ✓
IRR	N/A	8.78%	> discount rate (8%)	H2V ✓
NPV @ 8%	N/A	+$155,199	> 0 for acceptance	H2V ✓

Sensitivity Considerations:

The H2V system's economic superiority depends on several critical assumptions:

- **Grid Electricity Price Escalation:** When the grid rates grow by more than 5 percent/year (as is usual in developing economies), the benefits of H2V are magnified.
- **Solar Panel Cost Deflation:** The future of H2V economics will be enhanced by falling prices of PV modules (historical: -10 per year).
- **Selection of Discount Rate:** The greater the discount rate (>10%), the more long-payback H2V is penalized; the less attractive is, the better the discount rate (<6%).
- **Battery Technology Evolution:** Emerging Lithium-iron-phosphate (LFP) and solid-state batteries have a longer life (6000+ cycles) and are cheaper.
- **Carbon Pricing Structures:** In case Bangladesh adopts carbon tax or carbon trading, H2V receives more financial credit.

8.5.3 Strategic Financing Considerations

Capital Acquisition Strategies:

Given the substantial H2V initial investment, multiple financing pathways exist:

- **Internal Funding:** Direct allocation from university capital budget
- **Green Bonds:** The issue of sustainability-related bonds.

- **Granted Development Bank Loans:** Availability of concessional funding among climate projects by such institutions as Asian Development Bank (ADB) or World Bank.
- **Power Purchase Agreements (PPAs):** This is a type of third party ownership in which the external investor owns/operates the system and the university is purchasing power at a fixed rate.
- **Government Subsidies:** To Bangladesh Renewable Energy Program incentives, duty waiver on imported equipment.

Cost-Recovery Model:

The proposed charging tariff (15-20 BDT/kWh) is designed to:

- Cover Operation and maintenance expense (~3 percent of capital per annum).
- Create a slow recovery of capital.
- Be inexpensive to student/faculty users.
- Shun price manipulation to make profits which is un-university mission.

8.5.4 Non-Quantified Benefits

Beyond direct financial metrics, the H2V system delivers strategic value:

Academic Benefits:

- Renewable energy and smart grid research living lab.
- Practical training center of EEE, CSE and Environmental science students.
- Graduate thesis basis, conference publication basis and industry partnership.

Institutional Reputation:

- Positioning as a solar EV charger at a university in Bangladesh.
- The improved positions in sustainability indexes (UI GreenMetric, STARS).
- Environmentally-conscious student recruitment in marketing differentiation.

Social Impact:

- The use of demonstration effect to influence other institutions to accept renewable EV infrastructure.
- Investment in country EV uptake.
- Improvement of aerial quality in the Dhaka city.

Risk Mitigation:

- Protection against grid outages and disconnections (national standard in Bangladesh).
- Sovereignty with regard to energy minimizing vulnerability to geopolitical shocks in fossil fuel prices.

- Preparedness in relation to regulatory compliance in case of carbon taxes in future.

8.6 Conclusion

There is a significant difference in the overall economic analysis of the proposed EV charging station where the Hybrid Solar-Grid (H2V) configuration, even though it would require significantly more initial capital investment (2.3M vs. 200K to install the G2V configuration), would prove to be the more optimal long-term choice by all significant financial metrics.

Key Findings:

- **Payback Period:** H2V has a simple payback period of 10 years and discounted payback period of 21 years, both of which are within the project lifecycle of 25 years.
- **Return on Investment:** H2V yields 150% ROI within 25 years which forms net profit of 3.45M.
- **Internal Rate of Return:** H2V IRR of 8.78 percent is above the 8 percent discount rate, which shows that it is economically feasible.
- **Net Present Value:** NPV of more than the capital cost of 155,199 is positive.
- **Annual Cost Savings:** H2V will gain savings of 85000 yearly over G2V, which is a 38.6 cost saving.
- **Environmental Performance:** H2V delivers 86% emission reductions (CO_2, SO_2, NO_x) relative to grid-dependent G2V

Strategic Recommendation:

The H2V Hybrid Solar-Grid system is highly recommended in the case of BRAC University regarding long-term sustainability targets, the needs of resilience, and the educational purpose although with increased initial expenses. The system balances:

- **Economic viability:** Positive NPV, positive IRR, convenient payback period.
- **Sustainability in operations:** solar fraction is 97.94%, which makes the grid less relied upon.
- **Green responsibility:** 86 percent emission cut will be in line with climate promises.
- **Academic value:** Develops research and training.
- **Institutional leadership:** Makes BRAC University the pioneer in renewable energy.

The project is not just a project of charging infrastructure, but a strategic investment in sustainable development, energy independence and climate action which will result in compounding benefits over the life of the project and further.

Chapter 9

Ethics and Professional Responsibilities

9.1 Introduction

Ethics and professional responsibility are crucial in every engineering project due to their commitment to ensuring technical decision-making is done ethically, responsibly as well as consideration of the environment and society. Engineers have to consider the law and regulation, safe process, safeguard user data, maintain honesty, and also value-based ethical practice. The EV Charging Station project delivery phase has incorporated several ethical consideration aspects, which include; sustainability, engagement, consideration of the prospective end-users, design to implementation. To assure professional responsibility, this chapter will discuss the ethics involved in several issues based on our project and state how to solve each of them.

9.2 Identify Ethical Issues and Professional Responsibility

Several important ethical concerns and obligations were discovered during the EV charging station's design and installation:

1. Dependability and Safety

Users, technicians, and the environment must all feel safe using the charging station. System failures, fire risks, and electrical dangers could result from improper wiring or design.

2. Environmental Responsibility

The initiative tackles global ethical issues related to pollution, climate change, and reliance on fossil fuels. Utilising renewable energy promotes sustainability and lowers pollution.

3. Accessibility and Equity in Energy

The system must be inexpensive and available to all members of the campus community, including staff and students, without discrimination because it is situated on university property.

4. Security and Privacy of Data

Personal data is involved in user identification via RFID or web server technologies. Encryption, privacy, and preventing unwanted access are necessary for the ethical use of data.

5. Sincerity and Openness

The report's simulations, data, and outcomes must all be true and unaltered. Academic and professional ethics are violated by plagiarism and outcomes falsification.

6. Adherence to Regulations

To maintain legal and professional accountability, the project must adhere to university laws, safety standards, and national electrical codes.

7. Appropriate Use of Resources

Effective use of funds, energy, and resources is necessary to prevent waste and guarantee ethical engineering practices.

9.3 Apply Ethical Issues and Professional Responsibility

The following steps were taken in the study to resolve the ethical concerns that were found:

1. Putting Safety Standards into Practice

To secure the user and system, we provided certified components (GFCIs, circuit breakers, and fuses) and electrical codes. The operation of grids and inverters in series is avoided by interlock system.

2. Encouraging Ecological Principles

The project will reduce its carbon footprint and meet the climate commitments and the global sustainability targets of Bangladesh through the use of solar energy and efficient battery management.

3. Guaranteeing Equity and Affordability

To make it more inclusive and equitable, the cost-recovery pricing model instead of profit-maximizing was adopted to enable employees and students to charge their vehicles in an equitable price.

4. Safeguarding User Information

In the RFID authentication and IoT-based monitoring architecture, secure data handling methods are applied. Sensitive information is not stored beyond the required time and only authorised access is granted.

5. Preserving Academic Honesty

All the external sources were properly cited. Proper results and simulations were mentioned. There were no fake data or plagiarism used and the prototype was actually built and experimented.

6. Adhering to Institutional and Legal Standards

The system design is based on the global safety regulations, BRAC University policies and the Bangladeshi electrical regulations to ensure compliance and reliability.

7. Professional Conduct and Social Responsibility

By offering safer, more affordable, and ecologically friendly charging, the system benefits the university community and promotes the use of clean energy. Throughout the project, team members demonstrated professionalism, accountability, cooperation, and prompt communication.

9.4 Conclusion

In the end, the development of an EV charging station is profoundly impacted by professional and ethical responsibility. This project fulfills not only the technological needs but moral and ethical responsibilities to safety, sustainability, data confidentiality, privacy, fairness, openness, and adherence to current legislation. A solution is viable, dependable, and beneficial to society when proper ethics is implemented. As a result, engineers must walk a fine line between honesty and ingenuity to create technologically and ethically good long-run solutions.

Chapter 10

Conclusion and Future Work

10.1 Project summary/Conclusion

In general summary, we surveyed and carried out research on our background and defined the problem. Then we have set the specifications based on the definition of the problem. After the identification of the criteria, several design techniques were discovered that might help to solve the problem. Thinking about which design techniques to use, the approaches were then compared.

The result of the selected design was determined its optimal solution and was analyzed using various engineering tools and software. Hence the Implementation of a smaller hardware prototype was created and tested, whether it meets the desired or calculated performance or not. Ultimately an economic analysis was performed to determine if this project can be implemented or not.

10.2 Future work

The prototype works as expected, though we would need to work to further develop and improve the system. Making the suggested modifications would improve its dependability, sustainability, and ease of use. It would also make the EVCS assure more consistent profit generation.

The web server's control: Among other new functionalities that the web server could support is the ability for a consumer to see previous charging sessions, start and stop charging remotely, and auto-create an invoice for every charge. Other functionalities such as user identification and MFS payment options like bKash or Upay could also be added.

Machine learning-based daily solar prediction: The EVCS could incorporate more renewable sources to optimize the system's overall sustainability and dependability that would increase. The EVCS could integrate with several other renewables, such as wind.

Energy storage optimization: To ensure that the station has enough storage capacity to store enough renewable for the whole day, the EVCS could research numerous energy storage options for the system PHP

Advancement of charging speed: Consumer research and development could be done to identify techniques that could be used to increase the EVCS charging speed. This modification would enable consumers to complete their station faster.

Chapter 11

Identification of Complex Engineering Problems and Activities.

11.1: Identify the attribute of complex engineering problem (EP)

Table 11.1 Attributes of complex engineering problems (EP)

	Attributes	Put tick (√) as appropriate
P1	Depth of knowledge required	√
P2	Range of conflicting requirements	
P3	Depth of analysis required	√
P4	Familiarity of issues	
P5	Extent of applicable codes	
P6	Extent of stakeholder involvement and needs	
P7	Interdependence	√

11.2: Provide reasoning how the project address selected attribute (EP)

Depth of expertise needed: The project was designed using both basic and specialized engineering skills. A significant amount of research literature was reviewed in order to obtain appropriate data for the project's development.

Range of conflicting requirements: More vehicles will result in greater startup costs, which may exceed the stakeholder-specified budget.

Depth of analysis required: Three different design approaches were suggested and evaluated after data from field surveys and research publications were examined.

Interdependence: Since the charging system uses the station batteries' stored energy to function, it is heavily dependent on the solar system. The solar system charges the station's batteries.

11.3 Identify the attribute of complex engineering activities (EA)

Table 11.2 Attributes of complex engineering Activities (EA)

	Attributes	**Put tick (√) as appropriate**
A1	Range of resource	√
A2	Level of interaction	√
A3	Innovation	
A4	Consequences for society and the environment	√
A5	Familiarity	

11.4 Provide reasoning how the project address selected attribute (EA)

Range of resource: The BRAC University EV charging station project falls under the Complex Engineering Activity since it utilizes a diverse pool of resources, which include advanced materials and equipment , human resources and a mammoth financial investment, as well as modern tech-based systems. The project also requires the conservative use of closely linked natural resources, including land and electricity, to ensure the project's sustainability. Such a pool of resources demonstrates the complexity associated with engineering activity given that it demands interdisciplinary teamwork, elaborate preparations, manageable uncertainties, and effects that may extend over a prolonged period onto the society and the environment.

Level of interaction: Integration of different systems, actors and contexts is crucial in the case of BRAC University EV charging station project. They consist of technical links to the national grid, renewable resources and smart monitoring systems; cross-cutting between engineers and technicians and administrators and students and utility partners; adherence to government safety regulations and cooperation with vendors; on the one hand, environmental sustainability, and, on the other hand, campus utility and social acceptability. It is a real interdependent, and complex engineering project, after all.

Social and environmental implications: The environment shall be less polluted and GHG emission will be greatly decreased. With more jobs and less load shedding, people's quality of life will improve.

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Appendix

FYDP-P Logbook

Date	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
31.10.2024	All Members	Discussed potential final year project topics. Identified the need for sustainable EV charging infrastructure in BRAC University. Decided to explore feasibility.	All	Good topic direction. Conduct initial research to verify relevance.
14.11.2024	All Members	Defined problem statement: Lack of EV charging station on campus. Collected initial data on EV adoption and feasibility.	Member 1 & 2	Problem statement is clear. Add supporting statistics.
28.11.2024	All Members	Set project objectives: sustainability, scalability, clean energy, smart management. Drafted preliminary scope and goals.	Member 3	Objectives are strong. Ensure they are measurable.
12.12.2024	All Members	Conducted literature review on EV charging technologies and renewable integration. Identified research gap in campus-based solutions for Bangladesh.	Member 4	Good findings. Include local context and latest studies.
26.12.2024	All Members	Identified three design approaches: G2V, S2V, H2V. Compared basic pros/cons.	All	Excellent. Validate each approach with data and simulation.

		Planned deeper technical analysis.		
09.01.2025	All Members	Selected simulation tools: PVsyst, HOMER Pro, MATLAB/Simulink, Proteus. Assigned team roles for upcoming design phase.	All	Tools are appropriate. Move to modeling and data collection.

FYDP-D Logbook

Date	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
20.02.2025	All Members	Reviewed design approaches (G2V, S2V, H2V). Decided to simulate each using PVsyst and HOMER Pro to compare performance. Assigned simulation tasks.	Member 1 & 2	Good plan. Make sure simulation parameters are realistic.
06.03.2025	All Members	Conducted initial PVsyst simulation for off-grid system. Analyzed energy generation and system losses. Identified efficiency issues in S2V during low sunlight.	Member 3	Include seasonal variation in simulations.
20.03.2025	All Members	Used HOMER Pro for techno-economic comparison of G2V vs H2V. Found H2V offers lower long-term cost despite higher initial investment.	Member 4	Excellent insight. Justify cost differences clearly with data.
03.04.2025	All Members	Ran MATLAB/Simulink model for charging behavior and control logic. Tested different load scenarios.	Member 2 & 3	Good modeling. Add more test scenarios for accuracy.

		Observed performance of each design.		
17.04.2025	All Members	Optimization of subsystems: Chose fixed tilt, MPPT controller, lithium-ion batteries, and Demand Side Management. Finalized optimal configuration.	All	Strong decisions. Provide technical justification for each selection.
01.05.2025	All Members	Prepared detailed system block diagrams and finalized simulation results. Began planning hardware prototype and component sourcing.	Member 1 & 4	Good transition to implementation. Prepare a clear prototype plan.

FYDP-C Logbook

Date	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
26.06.2025	All Members	Discussed hardware implementation plan. Finalized components (solar panel, charge controller, batteries, Arduino, sensors, relays, inverter). Assigned purchasing and assembly tasks.	Member 1 & 2	Good start. Ensure budget tracking and safety considerations.
10.07.2025	All Members	Built initial prototype circuit. Integrated solar input, battery storage, and grid backup. Implemented basic relay control and sensor reading.	Member 3	Progressing well. Document each connection clearly.

24.07.2025	All Members	Tested prototype charging in different modes (solar-only, grid-only, hybrid). Collected data on charging time and efficiency. Identified slow performance at high SOC.	Member 4	Good testing. Compare results with simulation values.
07.08.2025	All Members	Conducted economic and financial analysis using HOMER Pro and projected costs. Compared G2V vs H2V long-term feasibility. Found H2V more cost-effective over time.	All	Strong analysis. Include payback period and cost-benefit summary.
21.08.2025	All Members	Completed sustainability, ethics, and impact analysis. Covered environmental, social, economic, and legal aspects. Integrated findings into report.	Member 1 & 3	Excellent depth. Ensure sources are correctly cited.
04.09.2025	All Members	Finalized full documentation (Ch.1–11). Prepared presentation slides. Conducted internal rehearsal. Requested final review with ATC.	All	Well done. Minor formatting and clarity improvements recommended. Prepare for defense.