Design of Vehicle to Home and Vehicle to Grid energy systems for Newfoundland Conditions

by

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Abstract

In this fast-changing world, Electric Vehicle (EV) is a giant leap in the world of transportation. In comparison with fossil fuel powered vehicles, EVs are more efficient, silent, emit less pollution while in use and they act as mobile power banks, these makes them a better alternative. This in turn can be used for Vehicle to Home (V2H) and Vehicle to Grid (V2G) operations using IoT as a platform to achieve control and monitoring, Nissan Leaf is considered as the EV in this research. In this research, Mozilla IoT is used as the IoT platform to implement V2H and V2G concepts. The research was divided into four phases. In the first phase, the dynamic modelling of solar energy system with V2H concept is implemented. The second phase involves the dynamic modelling of a solar energy system with V2G concept. The third phase involves the design of an IoT based solar energy system with V2H concept. The fourth phase demonstrates the hardware modelling of the V2H and V2G system using Mozilla IoT. The implemented prototype is executed in eight major modes. The results show that the developed system performs accurately and could serve as a viable option along with interoperability and security for the V2H and V2G implementations.

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List of Abbreviations and Symbols

IoT	Internet of Things
BEopt	Building Energy Optimization
MATLAB	Matrix Laboratory
API	Application Programming Interface
GUI	Graphical User Interface
oAuth	Open Authorization
PV	Photovoltaic
MQTT	Message Queuing Telemetry Transport
V2H	Vehicle to Home
MPPT	Maximum Power Point Tracking
V2G	Vehicle to Grid
V2X	Vehicle to Everything
SOC	State of Charge
V	Voltage
A	Ampere
Ah	Ampere-hour
kW	Kilo-Watt
kWh	Kilo-Watt hour
JWC	Java Web Component
HOMER	Hybrid Optimization Model for Electric Renewables

Chapter 1

Introduction and Literature Review

1.1 Introduction

We are now seeing a rise in interest and development of electric vehicles (EVs) and renewable energy as people become more conscious of the impact that fossil fuels and rising CO_2 output have on our environment, paving the way for EVs and renewable energy development. Furthermore, with the recent drive for a better environment, renewable energy is increasingly being used for power generation. Since 2016 [1], an increasing number of nations throughout the world have pledged to uphold the Paris Agreement, whose principal objective is to reduce greenhouse gas emissions. Power plants powered by renewable sources such as solar, wind, hydro, and others are projected to surpass conventional power plants powered by fossil fuels, since renewable energy is a major element in achieving the following goal.

Electric vehicles (EVs) will eventually replace fuel and hybrid-powered cars, resulting in a completely electrified ground transportation system. The major benefits of electric vehicles produce zero emissions when powered by renewable energy, are more powerful, quiet, and can function as mobile power banks. EVs are also exclusively powered by batteries as their primary source of energy. There are many different types of batteries that might be used to power electric vehicles (EVs), but three chemical types have dominated the industry for the past few decades: lithium-ion, lead acid, and nickel-metal hydride. Lithium-ion batteries are becoming more popular among manufacturers since they are less expensive and have a high specific energy.

V2H stands for Vehicle to Home, and it is a technology that allows users to power their homes using the energy stored in an electric vehicle's battery. Because EVs have huge battery packs, they may act as mobile power banks, pulling electricity out as needed. Similarly, V2G stands for Vehicle to Grid, a system that allows users to send stored energy from their batteries to the grid to balance demand. Hybrid PV systems, as well as newer hybrid PV systems with V2H options and hybrid PV systems with V2H V2G systems, are available in most current systems. Although hydro and wind energy account for a significant portion of the current renewable energy industry, solar photovoltaic systems are the most often employed for residential applications [2] [3].

Figure 1.1 shows Vehicle to Home (V2H) block diagram. The electric vehicle is charged by solar panels on the roof, or whenever the electricity grid tariff is low. And later during peak hours, or during power outages, the EV battery is discharged via V2H charger. Basically, the battery of electric vehicle stores, shares and re-purposes energy when needed.

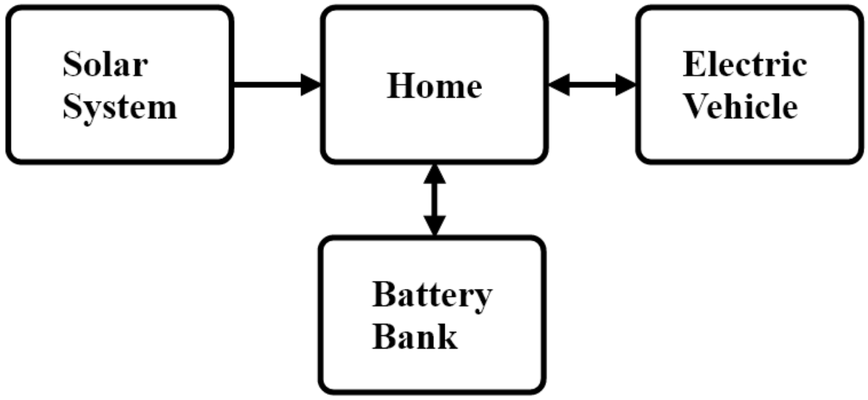

Figure 1.1 - Block diagram of the V2H system.

Figure 1.2 illustrates the block diagram of V2G system, In Vehicle to Grid (V2G), vehicles exchange energy from their traction batteries with the grid in two directions, charging or discharging. The purpose is to stabilize the grid, dampen fluctuations due to various renewable energy such as solar, resolve bottlenecks or make arbitrage on electric prices. The bidirectional exchange with the grid can be through the home's wiring in which parking or garage the car is parked and plugged. It requires a bidirectional charger, with power electronics that can transform, Alternating Current (AC) from the grid into Direct Current (DC) for the battery and vice-versa. It can be either on-board the car or off-board, for example in a wall box.

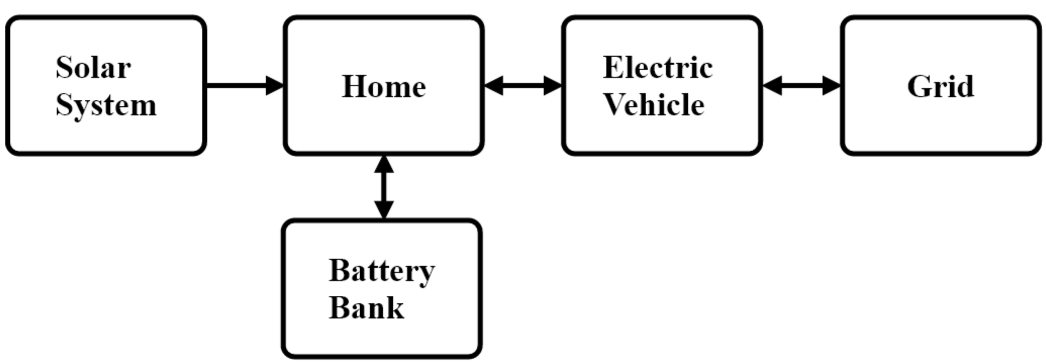

Figure 1.2 - Block diagram of the V2G system.

Instead of being utilized just to reduce greenhouse gas emissions, EVs may also be used to offer V2H and V2G support [4], which would be accomplished through their batteries. Regular or fast chargers might be used to charge EV batteries from power grids or renewables at varied times and locations. The charging procedure could ideally take place in the user's house over the course of a night [5]. The charging process is carried out in this research when there is surplus power available both during the day and at night. When linked to the home for V2H operation, it would use the stored energy to power the house until the other source of power can satisfy the demand. Additionally, when linked to the grid, the energy stored in batteries may be used to provide electricity to the system, therefore balancing demand. This indicates that the electric power grid's energy balance (frequency stabilization) might be aided by electric vehicles.

In a Vehicle to Home (V2H) system as shown in figure 1.1. The PV power is utilized to charge the in-house battery via a charger, and an inverter. For example, let’s assume a house with a solar energy system and V2H system with 120 V and 240V lines, hence the inverter with two outputs of 120V and 240V will be used to convert the stored DC power in the inhouse battery to AC to power the load. In addition, an Electric Vehicle (EV) charger with level 1 and level 2 charging features can be implemented, and a converter to stepdown voltage, which is used for simultaneously charging the inhouse battery and powering the house loads, in case of V2H mode. Current sensors can be used to generate data to implement control of the system.

In a Vehicle to Grid (V2G) system as shown in figure 1.2. In this case, let’s assume a house with a solar energy system along with V2H and V2G system. The PV power is utilized to charge the in-house battery through a charger, and an inverter with two outputs at 120V and 240V is used to convert the stored power in the battery to AC to power the house load. Furthermore, an electric vehicle (EV) charger with level 1 and level 2 charging capabilities is designed, as well as a converter to step down voltage, which is used to charge the in-house battery while simultaneously powering the house loads in V2H mode, and a V2G inverter is used to convert stored power in electric vehicles battery to AC. In addition, current sensors can be utilized to control the system using current measurement data.

From the preceding discussion, it is clear that an efficient system design is required to ensure smooth execution and transition between various modes, such as charging the inhouse battery [4] [5], charging EV batteries, discharging the inhouse battery to meet the home's load demand or charging the electric vehicle, or implementing V2H or V2G concepts [6]. As a result, the Internet of Things (IoT) could be utilized as a platform to control and monitor system execution remotely in real time. Mozilla IoT is utilized as a platform in this thesis to provide real-time remote control and monitoring of the proposed system. Key parameters such as current and voltage are monitored, analyzed, and communicated in real time to Mozilla IoT's WebThings gateway in the proposed system. The system runs in a variety of modes depending on the parameters.

1.2 Background

Solar irradiation is converted to electricity using a semiconductor material in photovoltaic technology. Photovoltaic systems are often constructed in modular style so that future load fluctuations may be accommodated. PV systems can be installed on the ground, on the roof, on the wall. To gather the most energy, the mount can be fixed or a mechanical solar tracker can be used to follow the sun throughout the day. Solar maximum power point tracking can be done on a single axis (following the sun throughout the day) or on dual axis - following the sun at different times of the day (to also adjust the angle of declination for the time of year) [9]. Crystalline silicon solar cells are used in the majority of commercial solar panels. The three most common varieties of solar panels on the market are monocrystalline solar panels, polycrystalline solar panels, and amorphous solar panels [10].

The most significant difference between these panels is their output efficiency. Solar radiation has a 1000 W/m^2 energy capacity, which is typical on the ground on a sunny day, and the output efficiency of a solar panel refers to how much energy the solar panel can create from this solar constant. Monocrystalline materials are now regarded more efficient than polycrystalline and amorphous materials, with polycrystalline and amorphous materials being in last in terms of efficiency. Solar panels are often chosen based on the amount of space or area available for installation. Because of its greater capacity to generate more electricity in a smaller space, monocrystalline is commonly utilized in roof-top installations [11].

Solar, being one of the most important renewable energy sources, has the greatest potential to produce carbon-free energy. For the last few decades, PV systems have been utilized in specialized applications such as off-grid or stand-alone [12] [13] and grid-connected PV systems. Off-grid systems are ideal for distant regions without access to the grid. To minimize overall losses, appliances linked to the stand-alone system might be built for DC sources. Grid-tied solar PV systems, on the other hand, may be synced with the utility grid and excess electricity generated from them can be sent into the main grid via a net-metering system. Grid-tied solar PV systems are now the most prevalent installation option since they can operate as microgrids, supplying excess energy back to the main utility grid. Due to the intermittent nature of renewables, a backup battery is necessary to supply uninterrupted power at periods when there is no or low production.

A standalone hybrid PV system for a home is designed, simulated, and implemented in this study with V2H and V2G options [14], charging and discharging of in-house batteries, level 1 and level 2 charging of Nissan Leaf [15] [16] [17], V2H (discharge of Nissan Leaf) [18], and V2H (discharge of Nissan Leaf) [19]. Nissan Leaf is considered as an electric vehicle (EV) in this study, with battery protection based on the battery's state of charge (SOC), excess power handling with the help of a dump load, nighttime charging in level 1 and level 2 charging of Nissan Leaf [19], and V2G (discharge of Nissan Leaf). When the energy demand of the house loads exceeds the power produced in a Car to Home (V2H) application for a home [20] [21] [22], the stored energy in the electric vehicle is released to match the energy need of the load [23] [24]. The electric car isolates itself from the home in the Vehicle to Grid application and begins reeling power to the grid to balance demand during peak hours [25] [26].

1.2.1 Why is IoT Needed?

The Internet of Things, or IoT, is a network of linked objects that collect and share data about how they are utilized and the environment in which they function. All of this is accomplished through the use of sensors, which are found in every physical device. It may be a cell phone, electrical appliances, barcode sensors, traffic lights, or nearly everything else we encounter in our daily lives. IoT provides a single platform for all of these devices to dump their data, as these sensors continually communicate data about the operating status of the devices. Also, a universal language for all devices to communicate with one another. Data is delivered from multiple sensors to an IoT platform, which then combines the acquired data from numerous sources, does further analytics on the data, and extracts important information as needed. Finally, the data is shared with other devices to improve the user experience, automate processes, and increase efficiency. To put it another way, the Internet of Things (IoT) is a framework in which a network of physical things, such as devices, buildings, and vehicles, are connected with electronics, software, and sensors to give unique identities and the capacity to send data across a network.

The Internet of Things (IoT) makes our lives easier to understand. We can inspect and operate equipment with IoT technologies from anywhere in the world. Depending on the application, it connects numerous processes under one control or multiple controls. In addition, the Internet of Things is built on three essential pillars: sensors, people, and processes, as well as communication. The essential pillars are depicted in Figure 1.3.

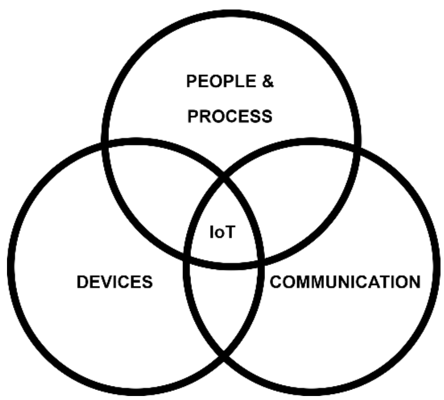

Figure 1.3 - Fundamental Pillars of IoT.

Physical layer, network layer, internet layer, transport layer, and application layer are the five essential layers of IoT. Field level components like as sensors and actuators are included in the physical layer. The physical layer, which comprises of billions of devices, is the base layer. Sensors and actuators connect with a controller, which then passes information from the physical layer to the application layer. Using the ipv4 and ipv6 protocols, the communication layer transfers data from the physical layer to the application layer. The network layer enables addressing and routing capabilities, allowing data packets to travel over multiple networks. Figure 1.4 depicts the network layer, which adds sender and recipient addresses to each box.

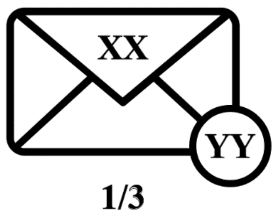

Figure 1.4 - Network Layer.

The transport layer is one of the most important layers which act as a mediator between the network and application layer. It provides the port delivery to the application at the destination computer or application. Transmission Control Protocol (TCP), User Datagram Protocol (UDP) (TCP). If a person receives a package of books in the mail, the transport layer will likely split the books into boxes and number them for sending; figure 1.5 depicts the transport layer.

Figure 1.5 - Transport Layer.

The application layer is the uppermost layer, and it is responsible for presenting the data created by the physical layer and turning it into useful information. Figure 1.6 depicts the multiple layers of IoT, whereas figure 1.7 depicts the interchange of data at multiple levels, with the Smart device serving as the physical layer. With the aid of the Network layer and the internet layer, the data generated by the smart device is sent to the cloud. Finally, the transport layer aids in data transmission to the application layer. IoT is a strong platform, but it has its limitations and vulnerabilities. All of the data collected poses a major privacy and security concern, and several devices interacting causes interoperability challenges.

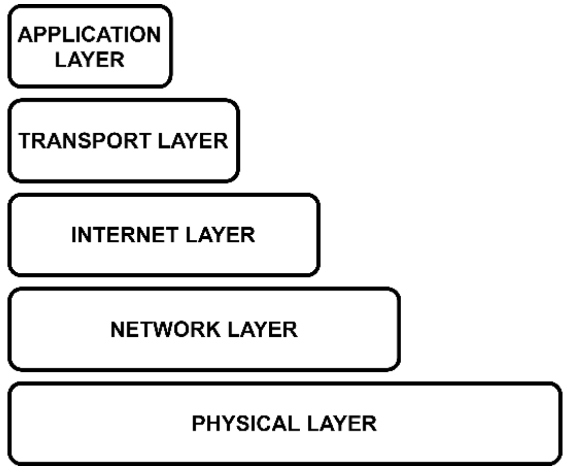

Figure 1.6 - Different layers in IoT

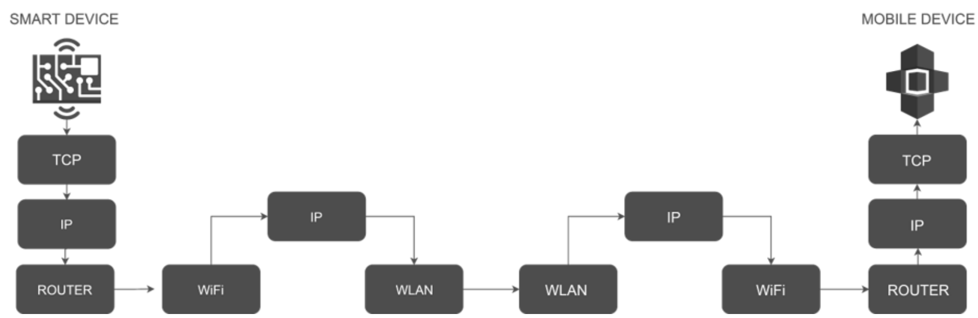

Figure 1.7 - Information exchange between different levels.

1.2.2 Applications of IoT

- Smart Grids
- Smart Transportation
- Smart Homes
- Industry 4.0
- Hospitals – Medical IoT
- Waste Management

1.2.3 What is Mozilla IoT?

Mozilla IoT is a web-based platform for monitoring and controlling devices. Mozilla

IoT is a preferred because of its interoperability, and overall value. The device delivers data to the cloud in most IoT applications, which is subsequently monitored and managed by a dashboard or a mobile app. In this case, however, the entire web of things interoperability is handled locally, with data exchanged with the cloud using a JWT (JSON Web Token) or oAuth framework. In Mozilla IoT, the Web of Things is an online standard that enables communication between smart things and web-based applications. The Mozilla WebThing gateway is a smart Internet of Things gateway that may be used to integrate smart devices in a vendor-neutral way and offer a web interface for monitoring and controlling devices via the internet. By giving URLs (Uniform Resource Locator) to items on the internet, the web of things seeks to build a decentralized internet of things that can be linked, found, and interoperable. Interoperability is also one of the most important characteristics of any internet-facing application [27].

1.2.4 Advantages of IoT

- Improved productivity of staff and reduced human labor.
- Efficient operation management
- Better use of resources and assets
- Cost effective operation.
- Remote control and monitoring.

1.3 Problem Statements/Motivations

Monitoring and control are required to guarantee appropriate operation of renewables and EV-based hybrid, V2H, and V2G systems as the number of renewables and EV-based hybrid, V2H, and V2G systems grows. For seamless execution and transition between multiple modes, such as charging the inhouse battery, charging the EVs battery, discharging the inhouse battery to satisfy the home's load requirement or charging the electric vehicle, or implementing V2H or V2G, an efficient system architecture is required. As a result, the Internet of Things (IoT) enters the scene, where it may be utilized as a platform to manage and monitor system execution remotely in real time. This allows users remote access to the system, as well as important information on efficiency of the system and insights on energy consumption. This allows users remote access to the system, as well as important information on how the system works and insights on energy consumption. This also aids the system's ability to work accurately and seamlessly across multiple modes. As a result, the system's operating costs are reduced and its efficiency is increased.

1.4 Research Objectives

For Newfoundland conditions, this research study proposed an IoT-based system to meet the energy demand of a house with V2H and V2G options

1. To design a PV power system for a selected house in Newfoundland, estimate load data, PV sizing, battery calculation, and size the designed system for the most optimum design.
2. To build a dynamic model of the solar energy system for a house with V2H option in MATLAB/ Simulink and develop a control system to keep the system mode operating on different modes.
3. To build a dynamic model of the solar energy system for a house with V2H and V2G option in MATLAB / Simulink and develop a control system to keep the system operating on different modes.
4. To design an IoT interface for a solar energy system with a Vehicle to Home option for Newfoundland conditions.
5. To design a hardware model for solar energy system for a house in Newfoundland with V2H and V2G option using Mozilla IoT to remotely

monitor and control the execution through various modes.

1.5 Research Contributions/Problem Solutions

The contributions of this research work is to solve the enumerated problems are summarized as follows:

1. For the design and dynamic modelling of a solar energy system with V2H and V2G options, a house in Newfoundland was chosen. To determine the energy requirements, the house was thermally modelled. After determining the energy requirements, the optimal PV sizing, as well as the sizing of energy storage and other components, was determined in order to meet the Section 1.4 Objectives.

2. To ensure data integrity, security, and interoperability, the Mozilla IoT WebThings gateway is installed locally on the Raspberry Pi to ensure data can only be accessible through Mozilla's http tunnelling for data integrity, security, and interoperability, and therefore the system is reliable.

3. Hardware modelling of the proposed system in order to implement multiple modes in order to achieve the objectives outlined in Section 1.4.

1.6 Thesis Organization/Summary

A manuscript style format has been adopted in the preparation of this thesis. A summary of the thesis and each of the chapters is presented as follows:

Chapter 1 includes an introduction and literature review, as well as discussions of the Vehicle to Home (V2H) and Vehicle to Grid (V2G) concepts, PV material selection and standalone PV systems for residential usage, different layers of IoT, fundamental pillars of IoT, and Mozilla IoT. These information formed the basis for this research.

The system design and dynamic modelling of a solar energy system with a Vehicle to Home option for Newfoundland conditions is presented in Chapter 2. This chapter focuses on detailed system sizing of the proposed system with PV and MPPT algorithm to maximize the power output in the simulated system, inhouse battery charging and discharging, Nissan Leaf batteries charging and discharging, simulation of high and load house loads, inverter, charge controller design, and control of the executed system through various modes. The work in this chapter also serves as a part of Objective 1 and 2 in Section 1.4. This chapter is a paper that has been published in the European Journal of Engineering and Technology Research.

Chapter 3 presents dynamic modelling of a solar energy system with Vehicle to Home and Vehicle to Grid option for Newfoundland conditions. This chapter focuses on the detailed system modelling of the proposed system in both V2H and V2G modes, as well as the design of the inverter, buck converter, boost converter, charge controller, PWM generator, Current controller (PI), PLL block, and PV, as well as the implementation of the MPPT algorithm to maximize power output and simulation of high and low loads. The work in this chapter also serves as a part of Objective 3 in Section 1.4. This chapter is a paper that has been published at the European Journal of Electrical Engineering and Computer Science.

The design of an IoT interface for a solar energy system with a Vehicle to Home option for Newfoundland conditions is presented in Chapter 4. BEopt software is used to calculate the annual load profile by thermal modelling the home. HOMER software uses meteorological data for solar irradiance and temperature for the selected site, as well as estimated load data, to optimize system sizing, and an algorithm is designed to run on the cloud with the help of IoT to measure inhouse batteries current, voltage, and state of charge (SOC), loads current and voltage, PV voltage and current, and

Nissan Leaf current and voltage parameters to function in various modes. The work in this chapter also serves as a part of Objective 4 in Section 1.4. This chapter is a paper that has been published at the IEEE Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON).

In Chapter 5, Mozilla IoT is used to implement a solar energy system with Vehicle to Home and Vehicle to Grid options for Newfoundland conditions. The hardware implementation of the proposed system is discussed in this chapter. The experimental arrangement was entirely powered by 12V and was used to demonstrate the Internet of Things, remote control, and monitoring concepts. While the real system uses multiple DC-DC converters and has different voltage levels, Current and voltage sensors, ESP 32, Mozilla IoT, Raspberry Pi, batteries, inverters, and the WebThings gateway are all part of the IoT system. The work in this chapter also serves as a part of Objective 4 stated in Section 1.4. This chapter's work has been submitted to the Jordan Journal of Electrical Engineering and is under revision.

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Co-authorship Statement

I am the principal in all the research papers used in the preparation of this thesis, and my thesis supervisor, Dr. Tariq Iqbal, is the Co-author in all the papers. As the principal author, I carried out most of the research work, performed the literature reviews, carried out the designs, hardware implementations, experimental setups and analysis of the result in the manuscript. I also prepared the original manuscript and subsequently revised each of them based on the feedbacks from the Co-author and peer reviewers throughout the peer-review process. The Co-author, Dr. M. Tariq Iqbal, supervised the entire research work, reviewed and corrected each of the manuscripts, provide research components and contributed research ideas through the research and in the actualization of each of the manuscript.

Chapter 2

Dynamic Modelling of a Solar Energy System with Vehicle to Home option for Newfoundland Conditions*

Preface

A version of this manuscript has been published in the European Journal of Engineering and Technology Research (EJETR). I am the lead author, and I did most of the research, conducted the literature reviews, and designed the system. I also wrote the first draft of the manuscript and then amended it after receiving comments from the co-author and going through the peer review process. Dr. M. Tariq Iqbal, as a co-author, oversaw the study, provided research components, evaluated, and revised the paper, and offered research ideas in the actualization of the manuscript.

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Abstract

This chapter discusses the dynamic modelling of a solar energy system with vehicle to home (V2H) option for Newfoundland condition. A location was chosen (13 Polina Road) in St. John's, Newfoundland, Canada. Using BEopt, Homer and MATLAB software, an optimized system was designed for the chosen site to satisfy the house's energy demand. Furthermore, the concept of V2H is also implemented with aid of smart current sensors installed in the house. When the power provided by the PV panel and the stored energy in the inhouse battery is less than the load's energy demand, the Nissan Leaf's battery used to supply home loads in V2H operation mode. The system operates based on the information generated by the sensors. Detailed system dynamic modelling is also presented along with the simulation results. Eight system control modes are proposed and simulated.

Index Terms: Hybrid power systems, PV, V2H, Renewable energy, dynamic modelling.

2.1 Introduction

Electric vehicles (EVs) are a revolutionary development in the global transportation industry. As compared to fossil fuel powered cars, they have more acceleration and emit no pollution, making them a reliable alternative. Renewable energy resources, such as solar energy systems can help meet the fast-growing energy demand in the fast-changing world. Renewables being variable in nature, there is a need for backup support [1]. Hence the need of battery storage comes into play. The inhouse battery is used to supply uninterrupted power to load when the power produced by PV is not sufficient to meet the loads energy demand [2]. Nissan Leaf (40 kW variant) is considered for the Vehicle to Home (V2H) concept implementation [3][4]. Furthermore, the implemented system, during charging mode has level 1 and level 2 chargers for charging the Nissan Leaf's battery and a converter for simultaneously charging the inhouse battery and powering the load. By default, the designed system uses PV as primary source of power until the produced power is less than the load's energy demand. In this case the inhouse battery is used for powering the loads until it reaches 30% of its State of Charge (SOC). On reaching 30% SOC the system will implement V2H, in this case Nissan leaf's battery will be in discharge mode to meet the load's energy demand [5][6][7].

In this chapter, a system is designed, and its control algorithm is presented to address this issue of implementing Vehicle to Home concept along with hybrid PV system. The system sizing and dynamic modelling was carried out using BEopt, HOMER and MATLAB.

2.2 Site details and calculations

2.2.1 Selected site

A house at 13 Polina Road in St.John's, Newfoundland, Canada was chosen as the research venue. It covers an area of 185.89m2. Figure 2.1 displays a monthly profile of solar radiation and clearness index for the selected site in St.John's, Newfoundland, Canada. The clearness index ranges from 0.20 to 0.30. The solar insolation ranges from 1.28 kW/m2/day to 5.14 kWh/m2/day, with a mean of 3.15 kWh/m2/day.

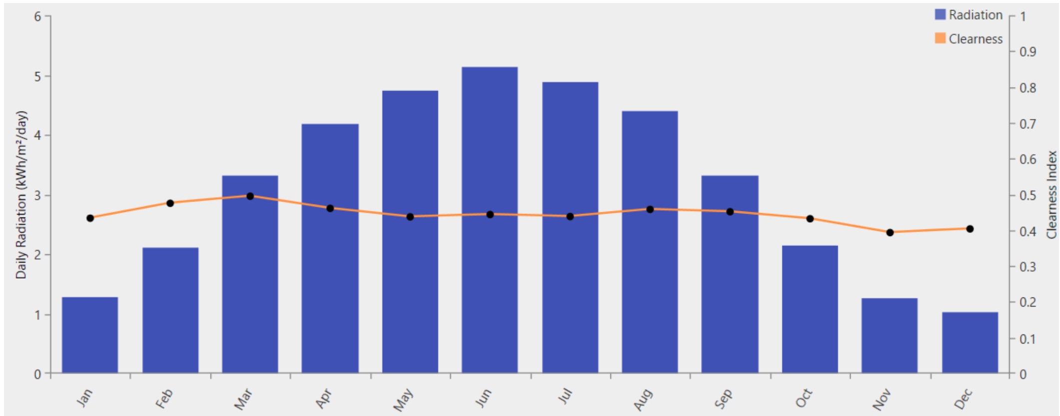

Figure 2.1 - Solar insolation and clearness index of selected site.

2.2.2 Sites Power Requirement from BEopt

BEopt software was used to estimate the annual power requirement for the chosen site. The house's power requirement amounts to around 21111 kWh per year. This includes all the loads in the home, including heaters, boilers, lightning, ventilation, and other considerations such as plugin loads.

2.2.3 Sites Load and Photovoltaic Panel Area Calculation

The site's load requirement comes to 57.8 kWh/day with peak of 11.90 kW. Figure 2.2 illustrates the daily load profile (hourly load data) from HOMER, the hourly energy demand is starting to raise around 6 AM and drops by 9 PM with an all-time high between 6 PM and 7 PM. Figure 2.3 illustrates the seasonal load profile (hourly load data) from HOMER, November to April months is having per hour energy demand compared to May to October months.

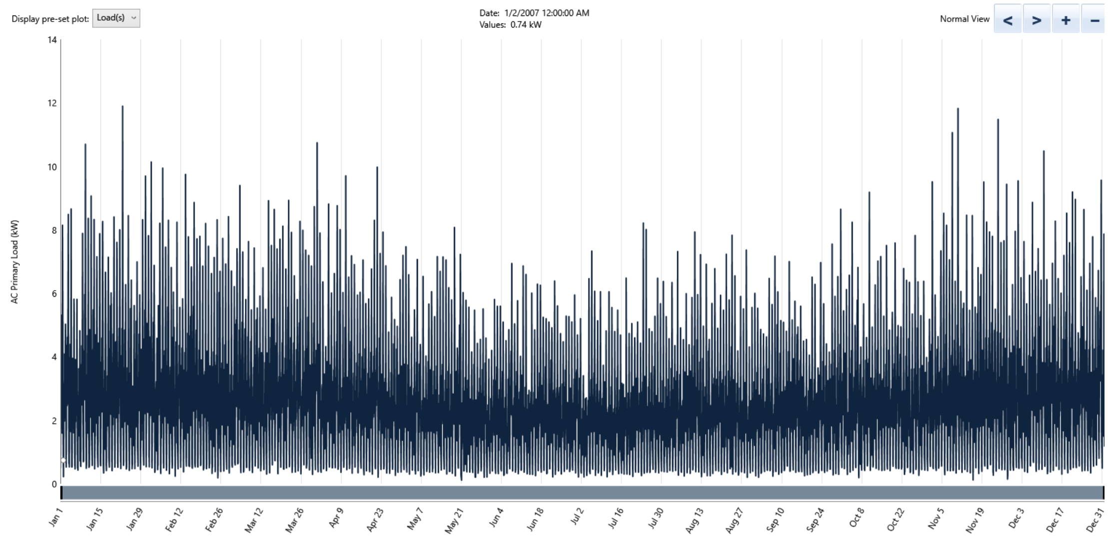

Figure 2.2 - Daily load chart (Hourly load data) from HOMER.

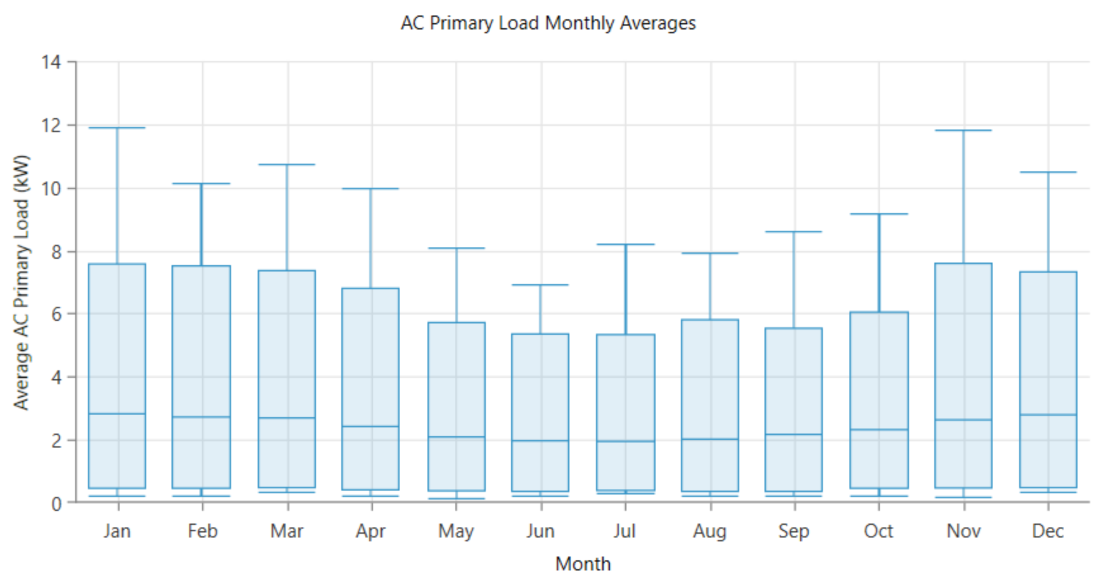

Figure 2.3 - Annual load chart from HOMER.

In St. John's, the average daily sunlight is 1633 hours for 272 days.

Output from BEopt = 21111 $kWh/year$

Per day = 57.8 kWh/day

$$Power\ output\ =\ \frac{energy\ usage\ per\ day}{number\ of\ full\ sun\ hours\ per\ day}$$

$$=\ 12.930\ kW$$

For PV sizing considering derating factor as 0.8

$$=\ \frac{power\ output}{derating}$$

$$=\ 16.1633\ kW$$

$$PV\ size\ array\ =\ \frac{Total\ calculated\ capacity\ of\ PV}{340\ W}$$

For calculated power output

= 38 Modules

For derating factor

= 48 Modules

Area calculation

Area of one Canadian solar CS6U 340 M module is 1.88m^2

For desired power output

$$=\ 38\ x\ 1.88\ =\ 71.44m^2$$

For derating factor

$$=\ 48\ x\ 1.88\ =\ 90.24m^2$$

Available area = 185.89 m^2

Bus voltage = 48 V

For desired power output, number of strings = 20 Strings

Number of panels in each string = 2

Including derating factor the number of strings = 24 Strings.

2.3 System Simulation

Hybrid Optimization of Multiple Energy Resources (HOMER) software was used for system sizing. Figure 2.4 depicts a schematic of the proposed system. The PV panel used is a Canadian Solar CS6U- 340M, the battery is a Trojan SAGM 12 105, the inverter is a 20 kW, 10kW genset which serves only as a backup and has no dynamic implications on the system, Nissan Leaf is added as deferrable load with 9.90 kWh/d with 6.60 kW peak and the home load profile is 57.80 kWh/d with a peak of 11.90 kW.

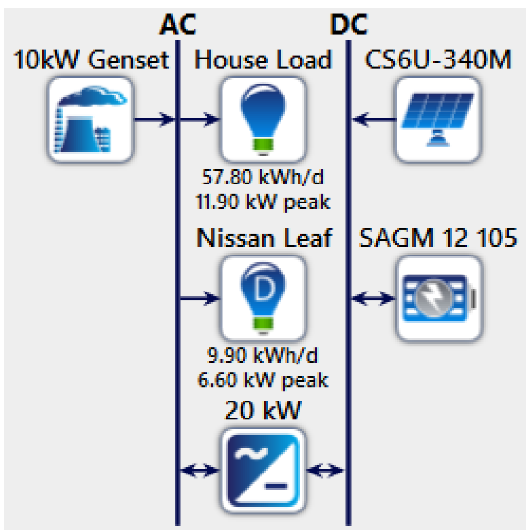

Figure 2.4 Schematic of the proposed system in HOMER.

2.3.1 Photovoltaic Panel

The panel used in this design is the Canadian Solar CS6U 340M, which has a 340 W output and a surface area of 1.8 m^2.

2.3.2 Battery

Trojan SAGM 12 105 battery was chosen for the application. The battery estimate is as follows, with three days of backup. As a result of the calculations, 360 batteries are required without backup. Since the design incorporated a 10 kW backup genset the number of batteries needed dropped to 80 numbers.

Wh/day = $57804\ Wh/day$

3 days = $57804\ x\ 3\ =\ 173413\ Wh$

40% DOD = $173413\ /\ 0.4\ =\ 433532.5\ Wh$

Temp Cons (> 80F) = $433532.5\ x\ 1\ =\ 433532.5\ Wh$

Ah cap of Bt bank = $433532.5\ /\ 48\ =\ 9031.92\ Ah$

Number of Batteries = $(9031.92\ /\ 100)\ 4\ =\ 360\ Nos.$

2.3.3 Nissan Leaf – 40 kW variant

This concept considers a Nissan Leaf with a 40-kW lithium-ion battery pack and a 6.6 kW onboard charger. Another advantage of the Nissan Leaf is that it has a built-in bidirectional converter for charging and discharging (reeling power to home). Nissan Leaf has two modes of operation: charging and discharging. When the Nissan Leaf is discharging or reeling out power. This is used when the PV panels and battery are unable to satisfy the energy demand of the home load [8][9]. The following are presumed when the Nissan Leaf is in charging mode. The home loads are met, and the excess energy produced or stored is used to charge the electric vehicle [10]. Figure 2.5 illustrates the Nissan Leaf 40 kW variant.

Figure 2.5 - Nissan Leaf 40kWh variant.

2.3.4 Inverter

Since the peak load is about 18.50 kW, a 20 kW output power inverter is being considered for the design. The inverter in this case has two outputs: 120 V and 240 V.

2.4 System Dynamic Modelling

Simulink was used to carryout simulation of the proposed architecture. It comprises of PV array, MPPT controller, inhouse battery, boost converters, inverter, level 1 charger, level 2 charger, Nissan Leaf battery. Figure 2.6 illustrates the overall block diagram of the proposed system. The power produced by PV is used for charging the inhouse battery via a charger, inverter with two outputs 120 V and 240 V is implemented to convert the stored power in battery DC to AC to power the load. Furthermore, Nissan Leaf charger with level 1 and level 2 charging feature [11] is implemented, a 10 kW genset is also incorporated which serves only as a backup and has no impact on dynamics of system and a converter is also implemented to stepdown

360 V to 48 V, which is used for simultaneously charging the inhouse battery and powering the house loads [12][13]. Figure 2.7 illustrates the overview of simulated system. The system is simulated for charge and discharge of the inhouse battery, powering the loads using inhouse battery, dual output inverter that gives 120 V and 240 V as output, Nissan Leaf charger with level 1 and level 2 charging, Discharge Nissan Leaf to charge inhouse battery, discharge inhouse battery during night to charge Nissan Leaf and dump load to drain excess power. The implemented system has automatic overrides for state of charge, namely 30% SOC charge ON (inhouse battery) and 40% SOC charge ON (Nissan Leaf battery) for inhouse battery and Nissan Leaf, respectively as shown in figure 2.7. Figure 2.7 illustrates the overview of the simulated system.

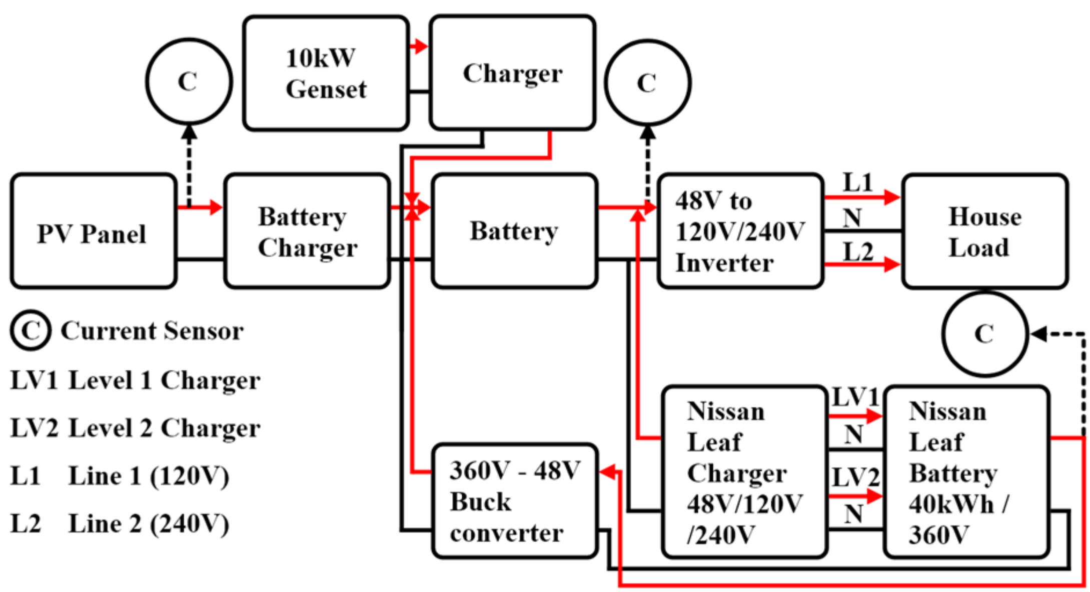

Figure 2.6 - Overall block diagram.

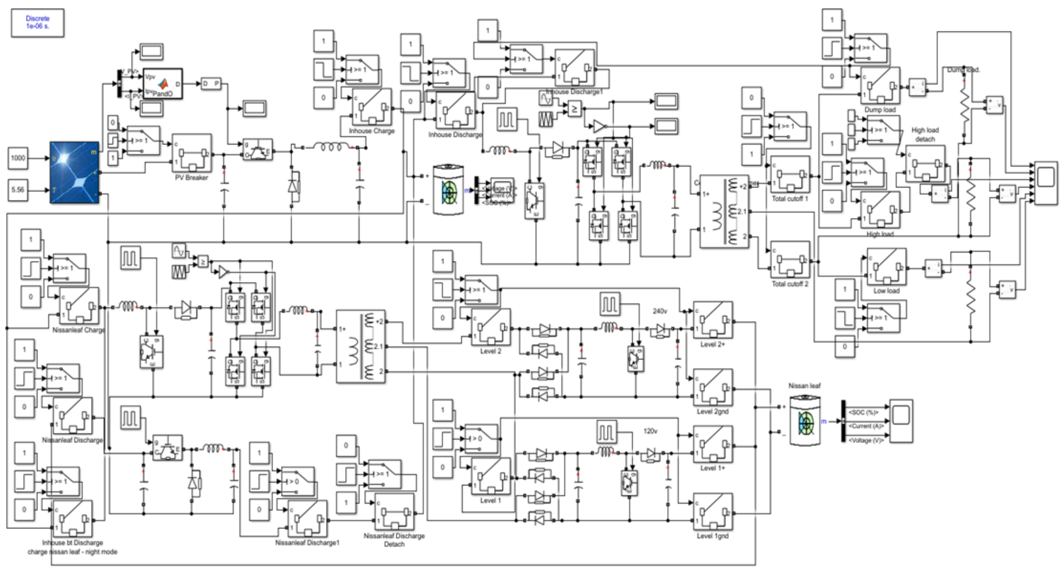

Figure 2.7 - Overview of simulated system.

2.4.1 MPPT Algorithm

Maximum power point tracking (MPPT) is a concept that involves modifying PV impedance depending on varying irradiance to get the most power out of a PV panel. The Perturbation & Observation (P&O) algorithm is used by the MPPT controller in this simulation. The voltage is constantly perturbed in the P&O algorithm, and the inverter service cycle is modified depending on the performance observation. Even when there is a significant decrease or spike in irradiance, this algorithm is the best at tracking the maximum point. Figure 2.8 illustrates the implemented MPPT algorithm - P&O algorithm.

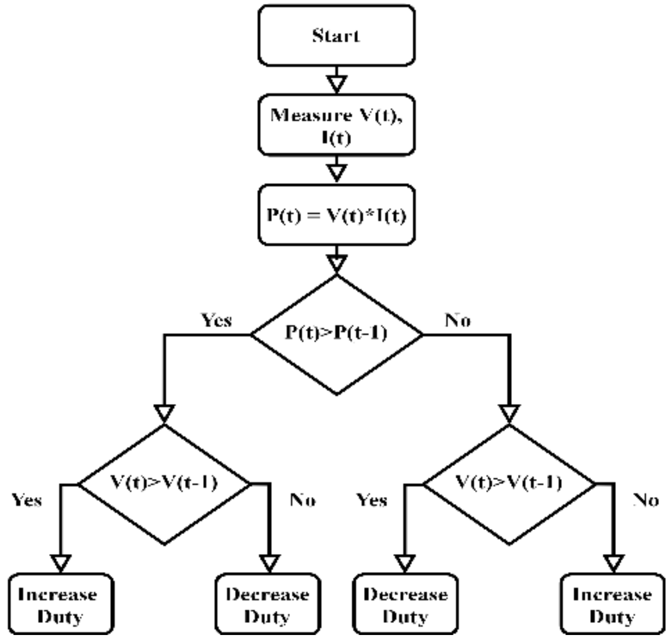

Figure 2.8 - Implemented MPPT Algorithm – P&O Algorithm.

Furthermore, the simulation was carried out incorporating eight modes representing different modes [14] of operation.

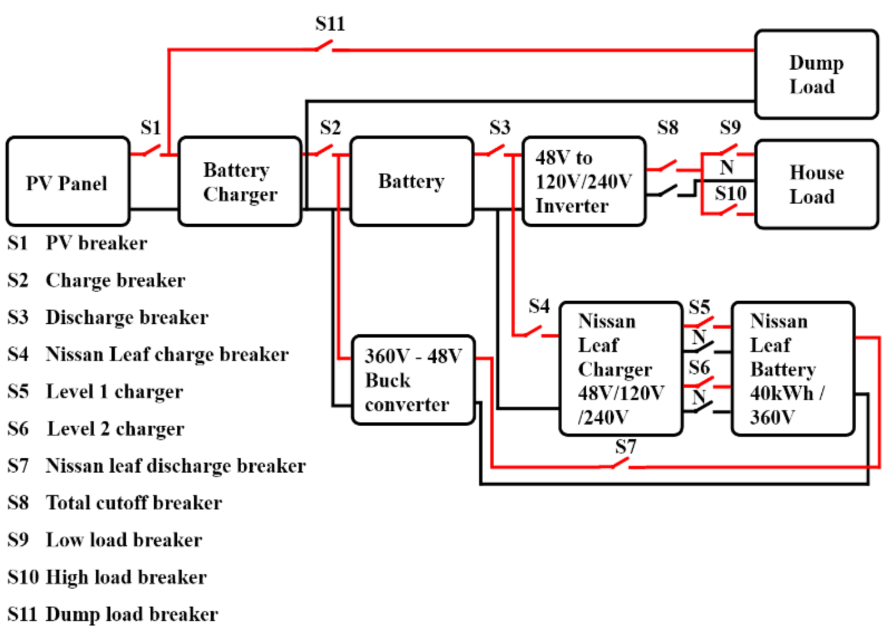

Figure 2.9 - Switching control logic of the system.

TABLE 2.1: Control logic of the proposed system

Modes	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Mode 1	ON	ON	ON	OFF	OFF	OFF	OFF	ON	ON	OFF	OFF
Mode 2	OFF	OFF	ON	OFF	OFF	OFF	OFF	ON	OFF	ON	OFF
Mode 3 (Level 1)	ON	ON	ON	ON	ON	OFF	OFF	ON	ON	OFF	OFF
Mode 3 (Level 2)	ON	ON	ON	ON	OFF	ON	OFF	ON	ON	OFF	OFF
Mode 4	OFF	OFF	OFF	OFF	OFF	OFF	ON	ON	OFF	ON	OFF
Mode 5	-	ON	ON	-	-	-	-	-	-	-	-
Mode 6	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	-	-	OFF
Mode 7	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON
Mode 8 (Level 1)	OFF	OFF	ON	ON	ON	OFF	OFF	ON	ON	OFF	OFF
Mode 8 (Level 2)	OFF	OFF	ON	ON	OFF	ON	OFF	ON	ON	OFF	OFF

2.4.2 Mode 1 – Inhouse battery charging mode

In this mode the output from PV is used for charging the inhouse battery and for powering the loads. In this case the loads energy demand is low. The excess energy is used for charging the battery. Figure 2.9 illustrates switching control logic of the proposed system. From table 2.1, switches S1, S2, S3, S8, S9 turns ON and the switches S4, S5, S6, S7, S10, S11 remains OFF. Figure 2.10 illustrates the charging design executed in MATLAB. From figure 2.10, the duty cycle from the MPPT block is fed into as the gate pulse for the MOSFET in the boost converter circuit. Figure 2.11 and 2.12 illustrates the low load's current and voltage graph. The load has a voltage of 120V and current of 12A.

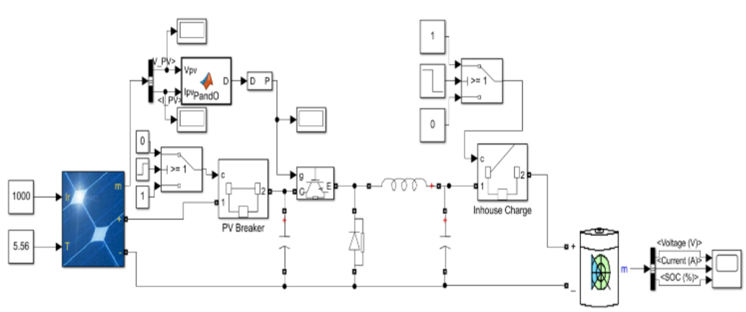

Figure 2.10 – Inhouse battery charging design in MATLAB.

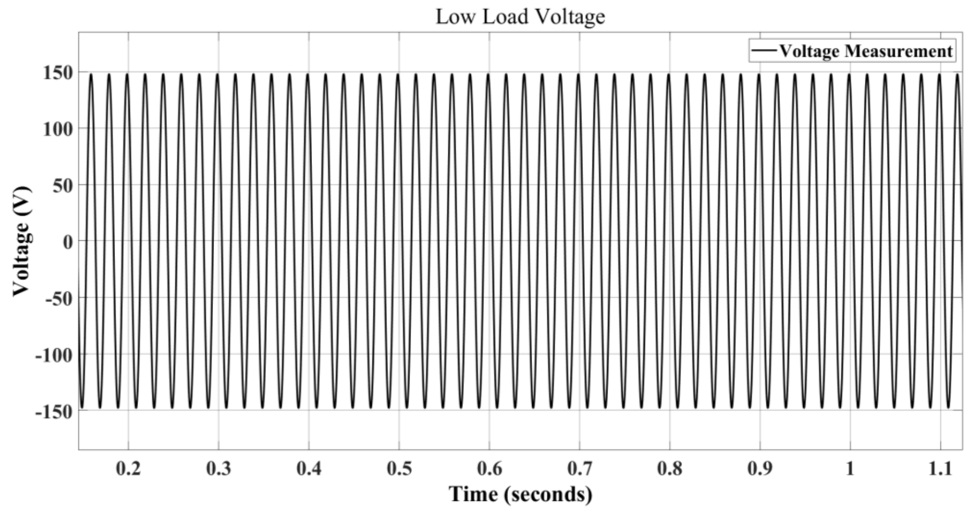

Figure 2.11 – Low load voltage graph.

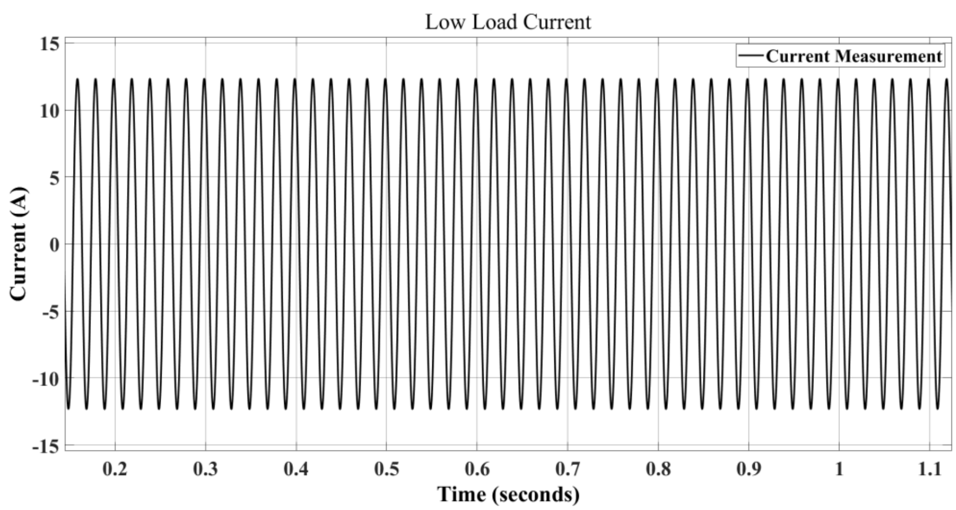

Figure 2.12 – Low load current graph.

2.4.3 Mode 2 – Inhouse battery discharge mode

In this mode the output from PV is low compared to the load's energy demand. In this case the inhouse battery is used to power the load. From figure 2.9 and table 2.1, in Mode 2 switches S3, S8, S10 turns ON and the remaining switches stays OFF. Figure 2.13 illustrates the inhouse battery in discharge mode. Furthermore, a 2-output inverter is incorporated, that give 120 V and 240 V as output. Figures 2.14 and 2.15 illustrate the high loads current and voltage graph. The load in this case has a voltage of 240 V and 27 A.

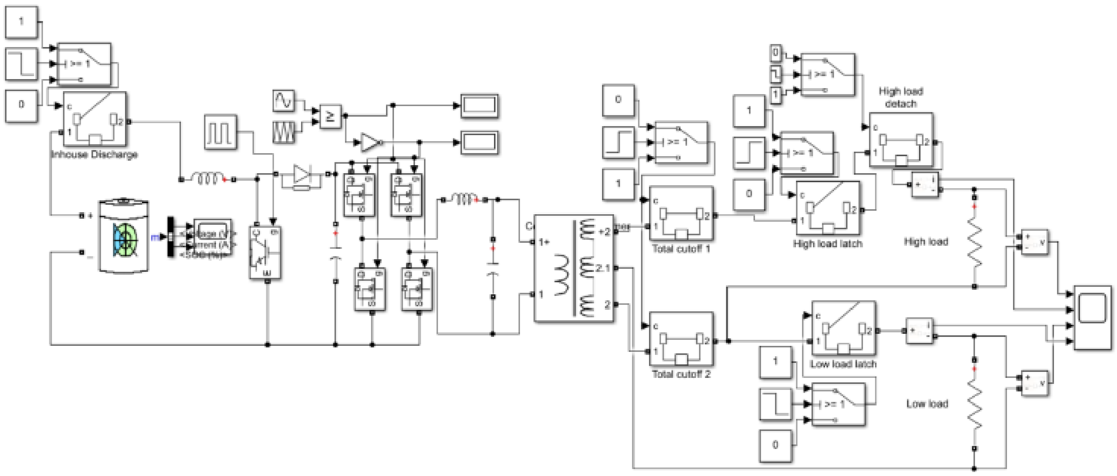

Figure 2.13 - Inhouse battery discharge mode design in MATLAB.

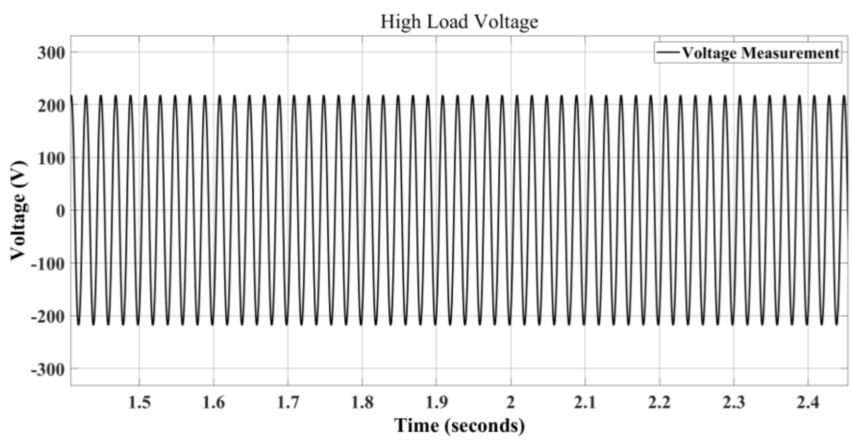

Figure 2.14 - High load voltage graph.

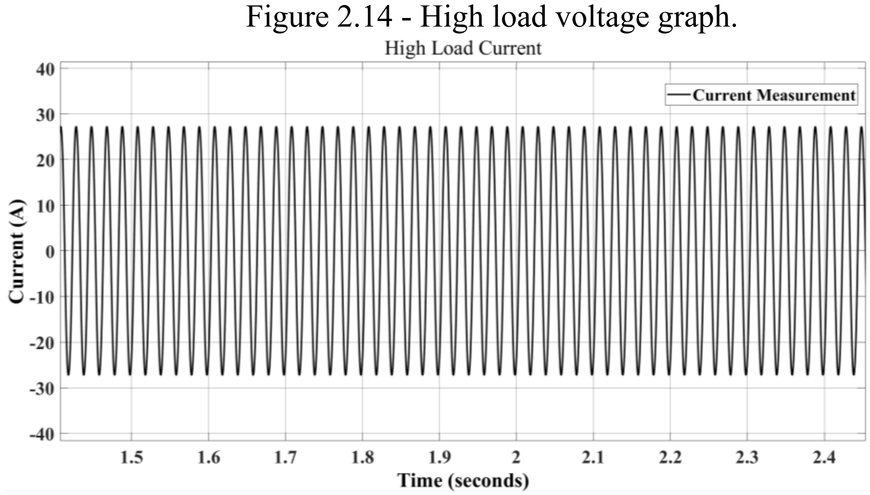

Figure 2.15 - High load current graph.

2.4.4 Mode 3 – Nissan Leaf charge mode

In this mode output from PV is higher than the loads energy demand and the inhouse batteries SOC is greater than 60%, the system will charge Nissan Leaf battery [14]. The implemented charger also comprises of level 1 (120 V, 14 A) and level 2 (240 V, 20 A) charging. Figure 2.16 illustrates the Nissan Leaf's charging mode. An inverter is incorporated to supply power for the level 1 and level 2 chargers. Furthermore, the chargers have incorporated boost converters to boost the voltage to 360 V, charging voltage of Nissan Leaf battery. From figure 2.9 and table 2.1, in mode 3 at level 1 charging, switches S1, S2, S3, S4, S5, S8, S9 turns ON and switches S6, S7, S10, S11 remains OFF. In mode 3 level 2 charging, switches S1, S2, S3, S4, S6, S8, S9 turns ON and switches S5, S7, S10, S11 remains OFF. Figure 2.17 and 2.18 illustrates the charging current graphs for level 1 and level 2 charging, respectively. The SOC of Nissan Leaf battery is illustrated in figure 2.19. The designed system has implemented both level 1 and level 2 charging, the output from level 2 charging can be seen between the time interval of 5 seconds to 10 seconds and the output from level 1 charging can be seen between the time interval of 10 seconds to 15 seconds [15][16].

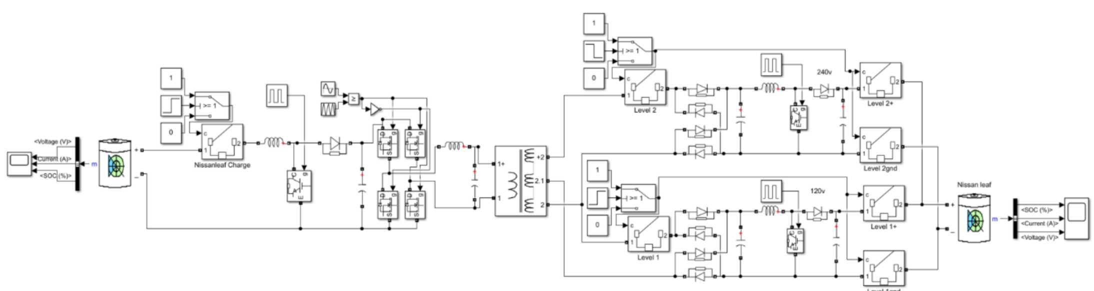

Figure 2.16 - Nissan Leaf charge mode design in MATLAB.

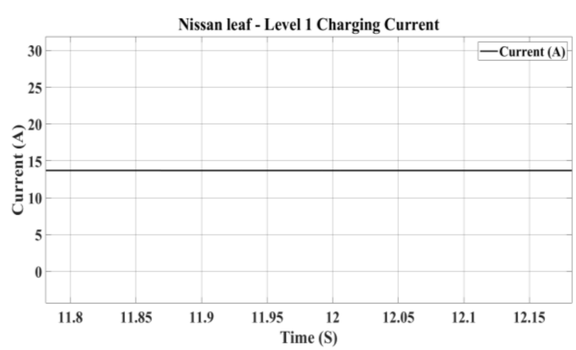

Figure 2.17 - Level 1 charging current graph

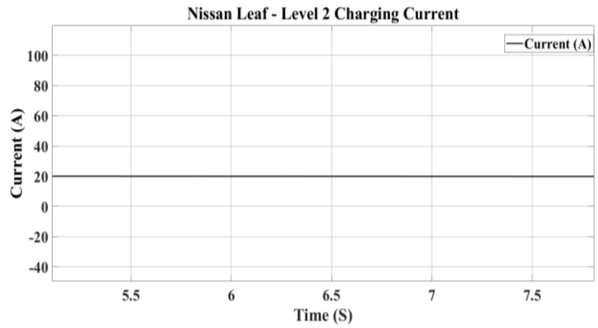

Figure 2.18 - Level 2 charging current graph.

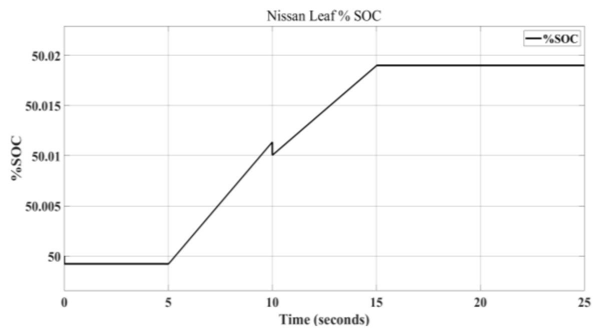

Figure 2.19 - Nissan Leaf's SOC graph

2.4.5 Mode 4 – Nissan Leaf discharge mode.

In this mode output from PV is less than the loads energy demand and the inhouse batteries SOC is less than 30%, in this case Nissan Leaf is reels out the stored power to the house to meet the loads energy demand [17][18]. From figure 2.9 and table 2.1, in mode 4 switches S7, S8, S10 are turned ON and remaining switches stay OFF. Figure 2.20 illustrates the Nissan Leaf's discharge mode. A buck converter is incorporated to convert the high voltage (360 V) from the Nissan Leaf's battery to 48 V to charge the battery and power the load simultaneously [19][20]. Figure 2.21 illustrates the Nissan Leaf's SOC graph. From figure 2.21 the inhouse battery was on discharge cycle between the time intervals of 5 seconds to 15 seconds and then it has started to charge because of Nissan Leaf's discharge mode execution.

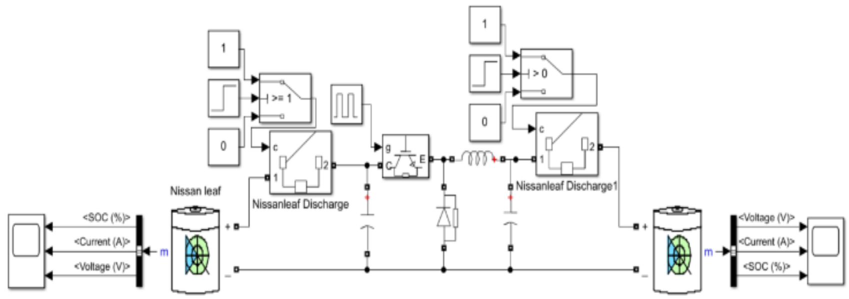

Figure 2.20 - Nissan Leaf's discharge mode design in MATLAB.

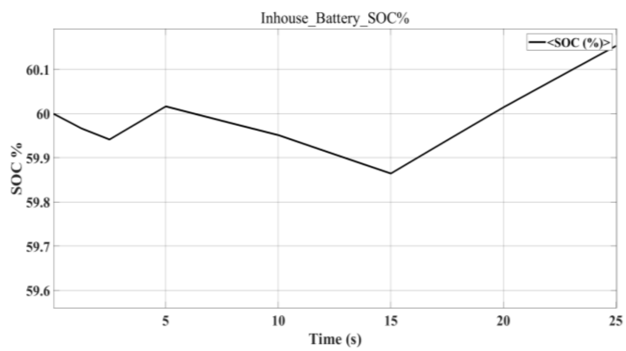

Figure 2.21 - Inhouse batteries SOC graph.

2.4.6 Mode 5 – Inhouse battery protection mode

This mode is incorporated to help in saving the inhouse battery by monitoring the SOC of the battery. When inhouse batteries SOC falls to 30% SOC, the 30% SOC breaker goes HIGH and the 30% SOC charge on breaker goes HIGH to charge the battery. From figure 2.9 and table 2.1, switches S2, S3 turns ON and the remaining switches are OFF.

2.4.7 Mode 6 – System isolation mode

In this mode output from PV is less than the loads energy demand, the inhouse batteries SOC is less than 30% and the Nissan Leaf SOC is less than 40 %, [21] the total cutoff breaker is turned ON. This is executed to isolate the system from the Load so that the system does not fail. From figure 2.9 and table 2.1, in mode 6 switch S2 is turned ON to facilitate further charging of battery when PV starts producing power and switches

S1, S3, S4, S5, S6, S7, S8, S9, S10, S11 remain OFF.

2.4.8 Mode 7 – Excess power handling mode

In this mode the power produced from PV is higher than the loads energy demand, the inhouse battery and Nissan Leaf's battery is charged, a dump load is implemented to dissipate the excess power. From figure 2.9 and table 2.1, in mode 7 switches S1 and S11 are turned ON and the switches S2, S3, S4, S5, S6, S7, S8, S9, S10 remains OFF.

2.4.9 Mode 8 – Nighttime charging mode

In this mode is the power stored in the inhouse battery is used to charge Nissan Leaf's battery at nighttime when the loads energy demand is considerably less and the inhouse batteries SOC is greater than 60% [22]. From figure 2.9 and table 2.1, in Mode 8 level 1 charging, switches S3, S4, S5, S8, S9 is turned ON and the remaining switches S1, S2, S6, S7, S10, S11 stays OFF. Mode 8 level 2 charging mode, switches S3, S4, S6, S8, S9 are turned ON and the switches S1, S2, S5, S7, S10, S11 remains OFF. Figure 2.22 illustrates the nighttime charging mode. From figure 2.22, the designed system has the option to choose between level 1 and level 2 charging even at nighttime charging mode.

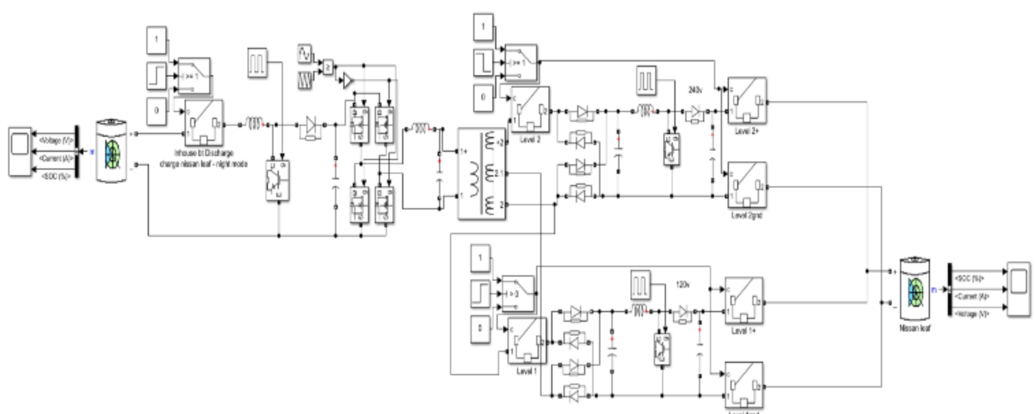

Figure 2.22 - Nighttime charging mode in MATLAB

2.5 Conclusion

Dynamic modelling of solar energy system with vehicle to home option for Newfoundland conditions was successfully designed and simulated. The solar insolation for Newfoundland from figure 3.1 is 3.15 kWh/m^2/day, PV panels considered are 340W modules producing 16.3984 kW implemented in 24 strings with 2 panels in each string. A commercially available inverter of 20 kW capacity was incorporated with 80 Trojan SAGM 12 105 batteries each of 12 V and 100 Ah along with a 10 kW backup genset, Nissan Leaf is implemented as deferrable load with 9.90 kWh/d with 6.60 kW peak. The implemented simulation consists of eight main operating modes i) Inhouse battery charging mode- power produced by PV is used for charging the inhouse battery and for powering the loads simultaneously, ii) inhouse battery discharge mode – The stored power in the inhouse house battery is used to meet the loads energy demand, iii) Nissan Leaf charging mode – The loads energy demand is met and the inhouse battery is charged, the excess power is used for charging Nissan Leaf, iv) Nissan Leaf discharge mode- the loads energy demand is high and the output form PV and inhouse batteries SOC is low [23] Nissan Leaf reels out the stored energy to meet the loads energy demand [24][25], v) inhouse battery protection mode – prevents the inhouse battery from going into degenerative discharge condition, vi) system isolation mode – to prevent the system from failing, vii) excess power handing mode – to handle the excess power produced, viii) nighttime charging mode – To charge Nissan Leaf to get it ready for next day's use. The implemented system has the scalability factor – can be extended to parking lots, multiple houses can be connected to form a microgrid and can power multiple houses or support the grid (V2G). Further this research would be directed towards V2X and V2G concept where vehicles would be used for sharing power to grid, scheduling loads, powering multiple houses, buildings or locality or an entire city and vehicle to vehicle energy transfers

[26][27][28][29][30].

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Chapter 3

Dynamic Modelling of a Solar Energy System with Vehicle to Home and Vehicle to Grid Option for Newfoundland Conditions*

Preface

A version of this manuscript has been published in the European Journal of Electrical Engineering and Computer Science. I am the lead author, and I did most of the research, conducted the literature reviews, and designed the system. I also wrote the first draft of the manuscript and then amended it after receiving comments from the co-author and going through the peer review process. Dr. M. Tariq Iqbal, as a co-author, oversaw the study, provided research components, evaluated, and revised the paper, and offered research ideas in the actualization of the manuscript.

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*This chapter is a version of "Dynamic Modelling of Solar energy System with Vehicle to Homr and vehicle to Grid Option for Newfoundland Conditions", R. Sundararajan and M. T. Iqbal, *EJECE 2021, Vol 5, Issue 3, doi: 10.24018/ejece.2021.5. 3. 329.*

Abstract

The dynamic modelling of a solar energy system with vehicle to home (V2H) and vehicle to grid (V2G) options for Newfoundland conditions is discussed in this chapter. A site (13 Polina Road) was chosen in St. John's, Newfoundland, Canada. An optimized system was built for the chosen site using BEopt, Homer, and MATLAB software's to meet the house's energy demand. Furthermore, smart current sensors installed in the house are used to incorporate the V2H and V2G concepts. The Nissan Leaf's battery is used to supply household loads in V2H operation mode when the power supplied by the PV panel and the storage energy in the inhouse battery is less than the load's energy demand. In V2G mode, the vehicle is only linked to grid. Along with the simulation results, detailed system dynamic modelling is also presented. There are nine different system control modes that are proposed and simulated.

Index Terms: PV, V2H, V2G, Renewable energy, Hybrid power systems.

3.1 Introduction

Electric vehicles (EVs) are the next wave in the global transportation industry. EV's have various advantages, more powerful, emit no pollution and act as mobile power reservoirs. EV's need to be charged, renewable sources of energy, such as solar energy systems, help satisfy the energy demand and also to reduce the carbon footprint [1] Since renewables are inherently variable, backup battery is required. Since EVs act as reservoirs, the concept of Vehicle to Home (V2H) and Vehicle to Grid (V2G) can be implemented [2] [3]. The proposed system implements V2H and V2G concept. The in-house battery acts as backup battery, to supply uninterrupted power the home load's when the power produced by PV is not sufficient to meet the load's energy demand. The Nissan Leaf (40 kW variant) is being considered as EV, for use in the V2H concept. Furthermore, the implemented system has level 1 and level 2 chargers for charging the Nissan Leaf's battery during charging mode, as well as a converter for charging the inhouse battery and powering the load at the same time. Until the produced power is less than the load's energy requirement, the designed system uses PV as the primary source of power. However, if the power produced by PV was less compared to load's energy demand, the inhouse battery is used to power the loads in this situation. When the system reaches 30% SOC, it switches to V2H, which means the Nissan Leaf's battery will be discharged to satisfy the load's energy demand [4]. In V2G mode, the car disconnects from the house and feeds power to the grid [5] [6]

In this chapter, we present a solution that addresses this problem by combining the Vehicle to Home (V2H) and Vehicle to Grid (V2G) principles, as well as a hybrid PV system [7]. For system sizing and dynamic modelling, BEopt, HOMER, and MATLAB were used.

3.2 Site Details

3.2.1 Selected site and solar insolation

The research location was selected as 13 Polina Road in St. John's, Newfoundland, Canada. It has a total area of 185.89m^2. In St. John's, Newfoundland, Canada, Figure 4.1 depicts a monthly solar radiation and clearness index profile for the chosen region. The clearness index varies from 0.20 to 0.30. The average solar insolation is 3.15 $kWh/m^2/day$, with a range of 1.28 $kW/m^2/day$ to 5.14 $kWh/m^2/day$.

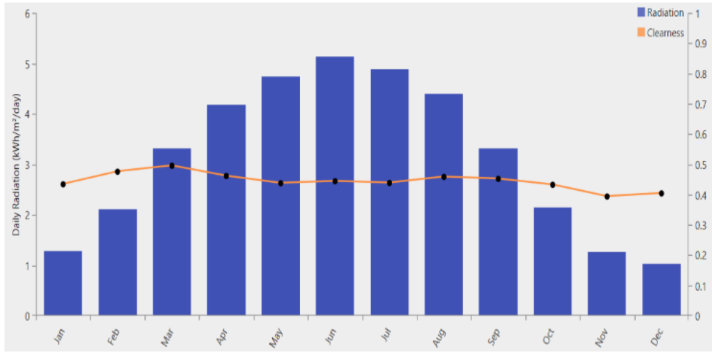

Figure 3.1 - Solar insolation and clearness index of selected site.

3.2.2 Sites Power Requirement from BEopt

The annual power demand for the chosen site was calculated using BE opt tools. The annual power consumption of the house is approximately 21111 kWh. This covers all loads in the building, such as heaters, boilers, lighting, ventilation, and other factors including plugin loads.

3.2.3 Sites Load and Photovoltaic Panel Area Calculation

The daily load requirement for the site is 11.90 kW. The hourly electricity demand rises at 6 a.m. and falls by 9 p.m., with an all-time high between 6 and 7 PM. Figure 3.2 shows the seasonal load profile from HOMER, which shows that the months of November to April have higher per hour energy demand than the months of May to October.

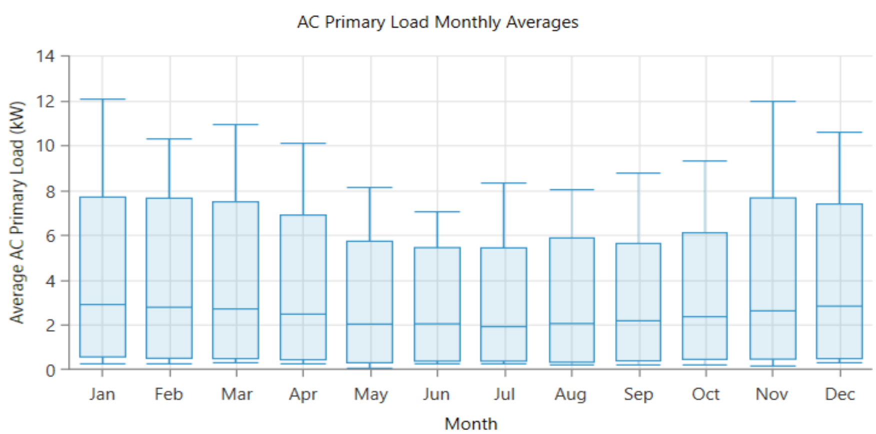

Figure 3.2 - Annual load chart from HOMER.

3.3 System Simulation

The software Hybrid Optimization of Multiple Energy Resources (HOMER) was used to size the system. A schematic of the proposed system is shown in Figure 3.3. The solar panel used was a Canadian Solar CS6U-340M, the battery was a Trojan SAGM 12 105, the inverter was 20 kW, the home load profile was 57.8 kWh/d with a peak of 11.90 kW and a backup, a 10kW genset is installed, which has no effect on the system's dynamics.

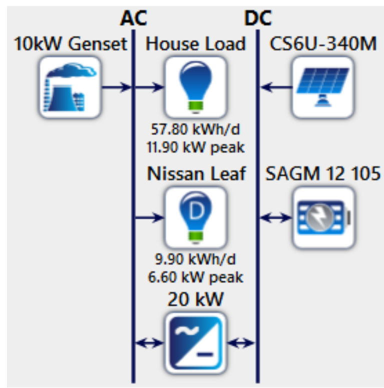

Figure 3.3 – Schematic of proposed system in HOMER.

3.3.1 Photovoltaic Panel

The Canadian Solar CS6U 340M module, with a 340 W output and a 1.8m^2 surface area, was used in this design.

In St. John's, the average daily sunlight is 1633 hours for 272 days.

Output from BEopt = 21111 kWh/year

Per day = 57.8 kWh/day

Power Output=(Energy usage per day)/(Number of full sun hours per day)

Power Output=12.930 kW

For PV sizing considering derating factor as 0.8

= Poweroutput/derating

= 16.1633 kW

PV size array = (Total calculated capacity of PV)/340W

For calculated power output

= 38 Modules

For derating factor

= 48 Modules

Area calculation

Area of one Canadian solar CS6U 340 M module is 1.88m2

For desired power output

= 38 x 1.88

= 71.44m^2

For derating factor

= 48 x 1.88

= 90.24m^2

Available area = 185.89 m^2

Bus voltage = 48 V

For desired power output, number of strings = 20 Strings

Number of panels in each string = 2

3.3.2 Battery

For this application, the Trojan SAGM 12 105 battery was selected. The following is the battery calculation, including three days of backup. The calculations show that 360 batteries are needed without backup. Since the design included a 10 kW backup generator, the number of batteries needed was reduced to 80.

Wh/day= 57804 Wh/day

3 days = 57804 × 3 = 173413 Wh

40% DOD =173413/0.4 = 433532.5 Wh

Temp Cons (> 80F) = 433532.5 × 1= 433532.5 Wh

Ah cap of Bt bank =433532.5/48 = 9031.92 Ah

Number of Batteries = (9031.92/100)×4=360 Nos.

3.3.3 Nissan Leaf – 40 kW variant

Nissan Leaf with a 40-kWh lithium-ion battery pack and a 6.6 kW onboard charger is considered in this concept. A built-in bidirectional converter for charging and discharging is another benefit of the Nissan Leaf (reeling power to home). Charging and discharging are the two modes of operation for the Nissan Leaf. Nissan Leaf is reeling out power or discharging its battery, when the PV panels and battery are unlikely to fulfill the energy demand of the home load, this mode is used [8][9]. When the Nissan Leaf is in charging mode, the following is assumed. The electric vehicle is charged with the excess energy generated or stored after the home loads are met [10].

3.3.4 Inverter

The peak load value is about 19.90 kW and deferrable loads peak value is 6.60 kW, an inverter with a 20 kW output capacity is considered for the design. In this case, the inverter has two outputs: 120 V and 240 V.

3.4 Dynamic Modelling

Simulink was used to simulate the proposed architecture. PV array, MPPT controller, in-house battery, boost converters, inverter, level 1 and level 2 chargers, Nissan Leaf battery and V2G inverter are all included in the simulation. The overall block diagram of the proposed system is shown in Figure 3.4. PV power is used to charge the in-house battery via a charger, and an inverter with two outputs at 120 V and 240 V is used to convert the stored power in the battery to AC to power the house load. Furthermore, a Nissan Leaf charger with level 1 and level 2 charging capabilities [8] is designed, as well as a converter to step down 360 V to 48 V, which is used to charge the in-house battery and simultaneously powering the house loads [9] and a 10 kW genset is incorporated which is used only as a backup and has no impact on dynamics of the system. Overview of simulated system is illustrated in figure 3.5. The system is simulated for charging and discharging the in-house battery, powering loads with the in-house battery, a dual outlet inverter that outputs 120 V and 240 V, a Nissan Leaf charger with level 1 and level 2 charging.

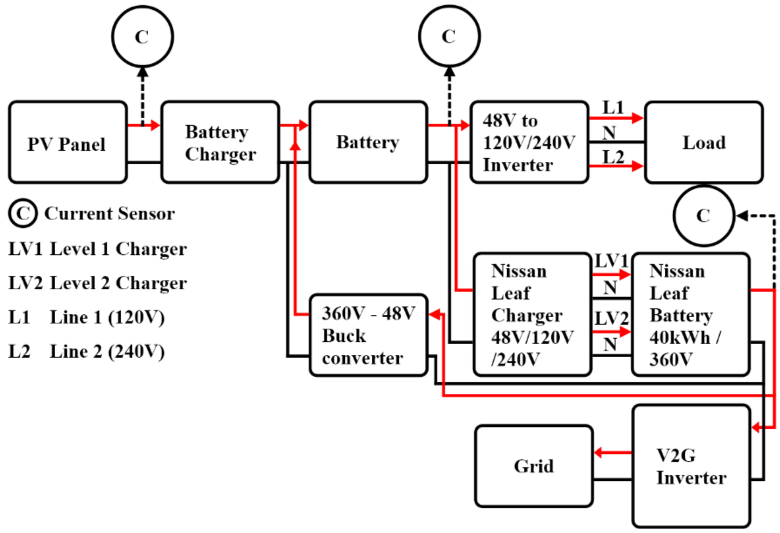

Figure 3.4 – Overall block diagram.

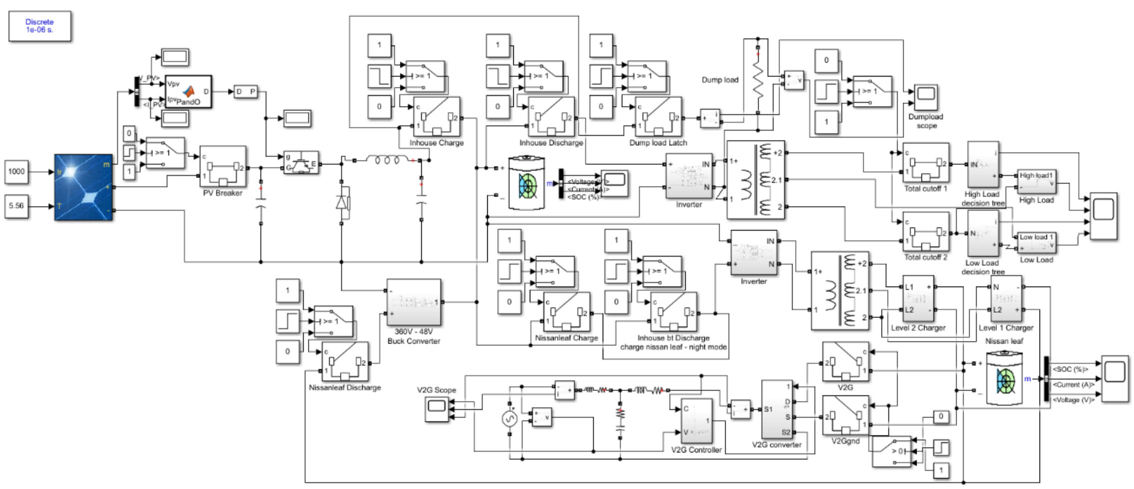

Figure 3.5 - Overview of simulated system in Simulink.

Discharge Nissan Leaf to charge inhouse battery, discharge inhouse battery at night to charge Nissan Leaf, discharge Nissan Leaf to implement V2G mode and a dump load to remove excess power. Automatic state of charge overrides are included in the system, with 30 percent SOC charge ON (inhouse battery) and 40 % SOC charge ON (Nissan Leaf battery) for the inhouse battery and Nissan Leaf, respectively. Figure 3.6 shows the full Simulink simulation block diagram.

3.4.1 MPPT Algorithm

Maximum power point tracking (MPPT) is a concept that entails adjusting PV impedance in response to changing irradiance in order to get the most power out of a PV panel. In this simulation, the MPPT controller employs the Perturbation and Observation (P&O) algorithm. In the P&O algorithm, the voltage is continuously perturbed, and the inverter duty cycle is updated based on the output observation. This algorithm is the best at monitoring the maximum point even though there is a large drop or spike in irradiance.

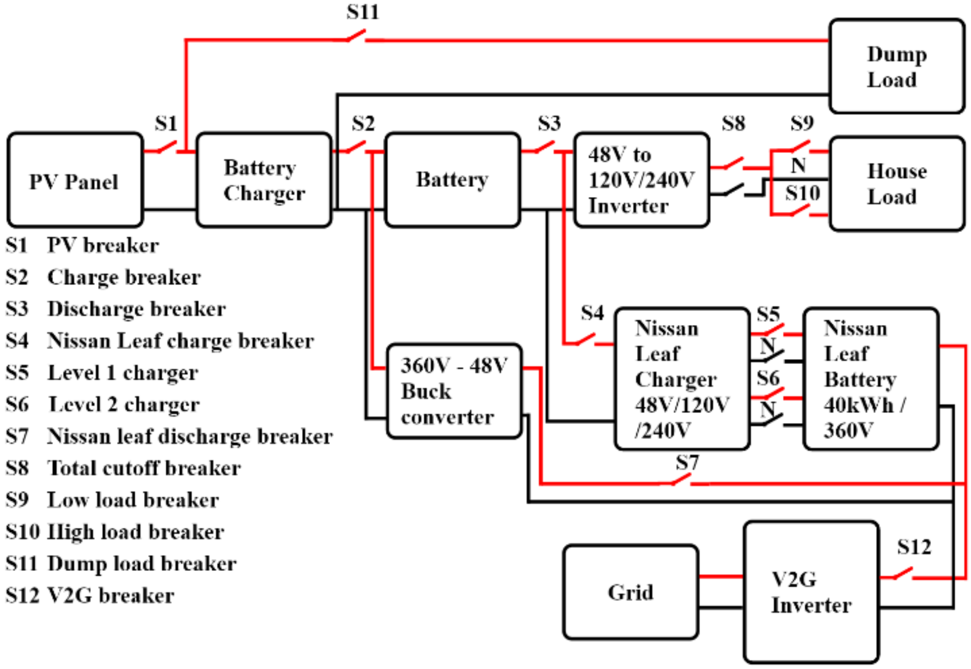

Figure 3.6 - Switching control logic of the system.

Furthermore, the simulation was carried out incorporating eight modes representing different modes [10] of operation. Figure 3.6 illustrates the implemented switching control logic.

Table 3.1: Switch control scheme for the proposed system.

MODES	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Mode 1	ON	ON	ON	OFF	OFF	OFF	OFF	ON	ON	OFF	OFF	OFF
Mode 2	OFF	OFF	ON	OFF	OFF	OFF	OFF	ON	OFF	ON	OFF	OFF
Mode 3 (Level 1)	ON	ON	ON	ON	ON	OFF	OFF	ON	ON	OFF	OFF	OFF
Mode 3 (Level 2)	ON	ON	ON	ON	OFF	ON	OFF	ON	ON	OFF	OFF	OFF
Mode 4	OFF	OFF	OFF	OFF	OFF	OFF	ON	ON	OFF	ON	OFF	OFF
Mode 5	-	ON	ON	-	-	-	-	-	-	-	-	OFF
Mode 6	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	-	-	OFF	OFF
Mode 7	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	OFF
Mode 8 (Level 1)	OFF	OFF	ON	ON	ON	OFF	OFF	ON	ON	OFF	OFF	OFF
Mode 8 (Level 2)	OFF	OFF	ON	ON	OFF	ON	OFF	ON	ON	OFF	OFF	OFF
Mode 9	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON

3.4.2 Mode 1 – Inhouse battery charge mode

The PV output is used to charge the in-house battery and power the loads in this mode. The energy consumption of the loads is minimal in this situation. The extra energy is put to good use by charging the battery. The control logic for charging inhouse battery is depicted in Figure 3.7. Switches S1, S2, S3, S8, S9 are switched ON to implement mode 1 as seen in figure 3.7 and Table 3.1. The current and voltage graphs for the low load are seen in Figures 3.8 and 3.9. The voltage and current of the load are 120V and 12A, respectively.

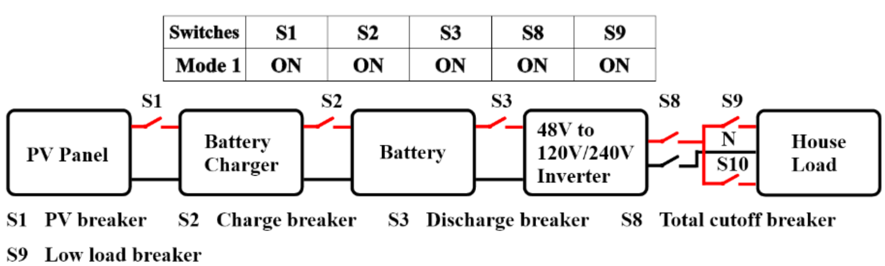

Figure 3.7 Control logic for inhouse battery charging.

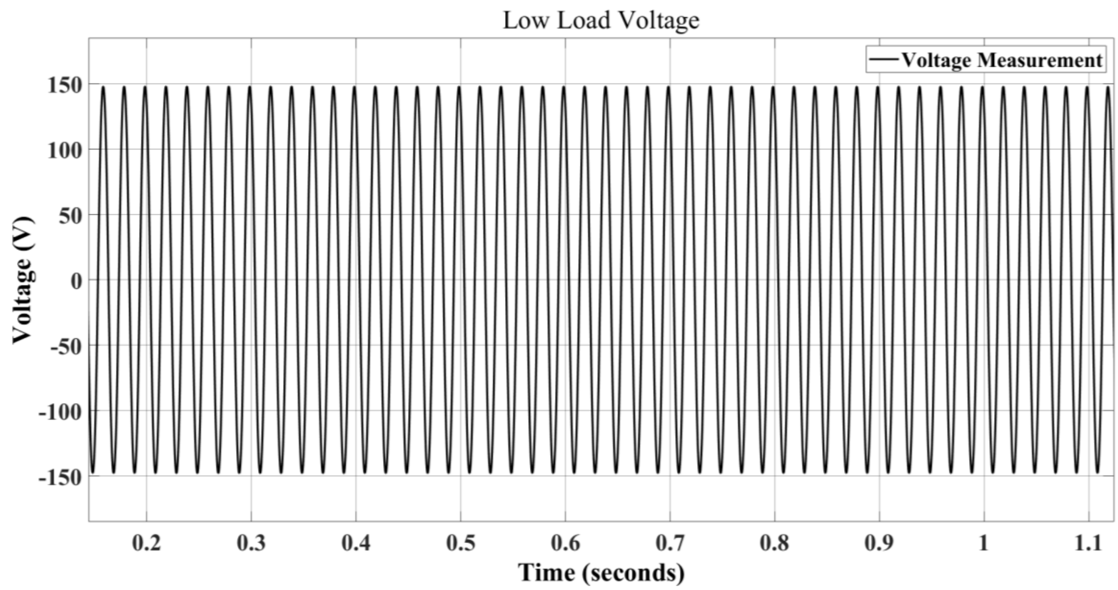

Figure 3.8 - Low load voltage output graph.

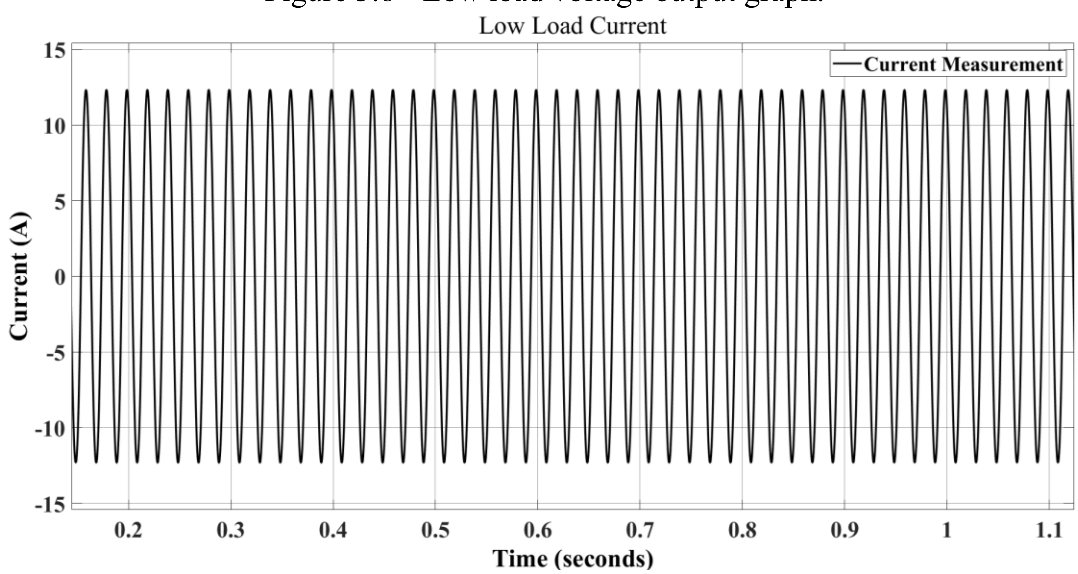

Figure 3.9 - Low load current output graph.

3.4.3 Mode 2 – Inhouse battery discharge mode

PV output is low in this mode relative to the load's energy requirement. The load is powered by the in-house battery in this situation. The control logic for in-house battery in discharge mode is seen in Figure 3.10. A two-output inverter is also used, with output voltages of 120V and 240V. Switches S3, S8, S10 are turned ON to implement mode 2 as seen in figure 3.10 and Table 3.1. The current and voltage graphs for high loads are seen in Figures 3.11 and 3.12. In this case, the load is 240 V and 27 A.

Switches	S3	S8	S10
Mode 2	ON	ON	ON

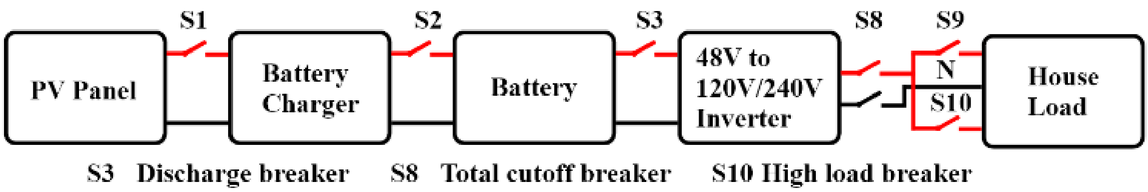

Figure 3.10 - Control logic for Inhouse battery discharge.

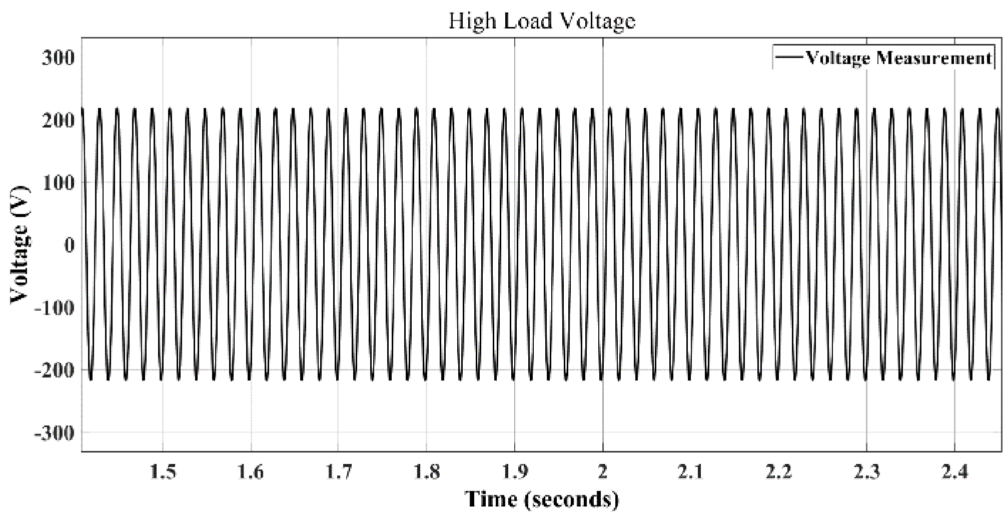

Figure 3.11 – high load voltage graph.

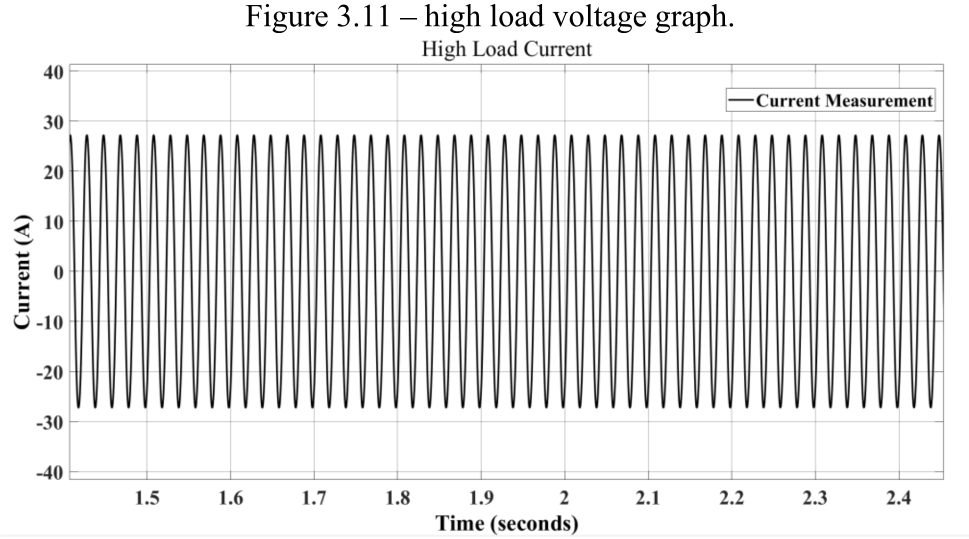

Figure 3.12 – High load current output graph.

3.4.4 Mode 3 – Nissan Leaf charging mode

When the PV output exceeds the load's energy demand and the in-house batteries' SOC exceeds 60%, the device will charge the Nissan Leaf battery [11]. Level 1 (120 V, 14 A) and level 2 (240 V, 20 A) charging are both used in the charger. The control logic for Nissan Leaf at level 1 and level 2 charging modes are depicted in Figure 3.13 and 3.14 respectively. The power for the level 1 and level 2 chargers is supplied by an inverter. Furthermore, boost converters have been integrated into the chargers to increase the voltage to 360 V, which is the charging voltage of the Nissan Leaf battery. Switches S1, S2, S3, S4, S5, S8, S9 are turned ON to implement mode 3 (level 1 charging) as seen in figure 3.13 and Table 3.1. For mode 3 (level 2 charging) switches S1, S2, S3, S4, S6, S8, S9 are turned ON and switches S5, S10, S11 are turned OFF as seen in figure 3.14 and Table 3.1. The charging current graphs for level 1 and level 2 charging are seen in Figures 3.16 and 3.17. Figure 3.18 depicts the state of charge (SOC) of a Nissan Leaf battery. The developed system includes both level 1 and level 2 charging, with the output from level 2 charging is visible between 5 and 10 seconds and the output from level 1 charging is visible between 10 and 15 seconds [12] [13].

Switches	S1	S2	S3	S4	S5	S8	S9
Mode 3 Level 1	ON	ON	ON	ON	ON	ON	ON

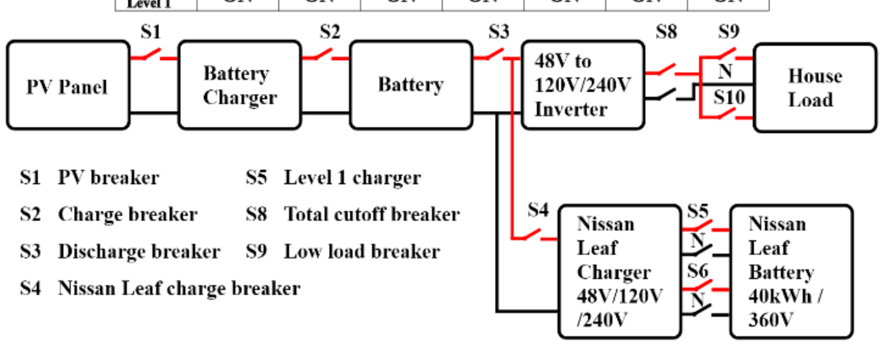

Figure 3.13 - Control logic for Nissan Leaf at level 1 charging mode.

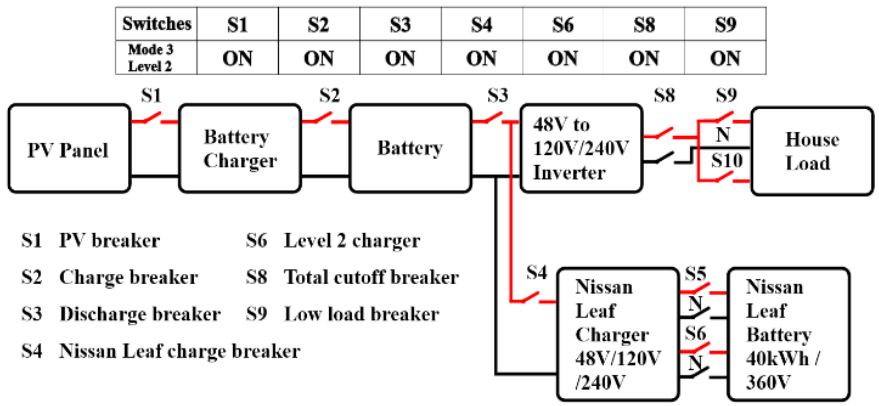

Figure 3.14 - Control logic for Nissan Leaf at level 2 charging mode.

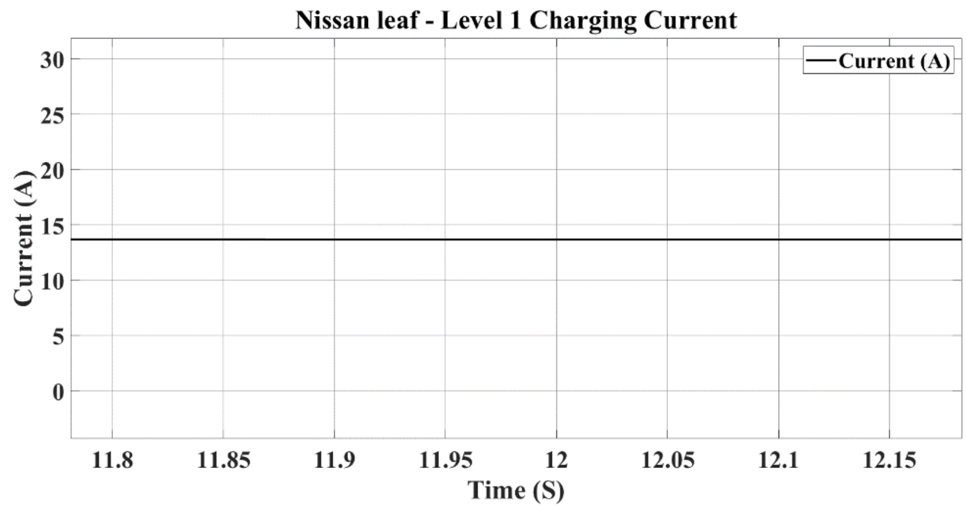

Figure 3.15 - Level 1 charging current output graph.

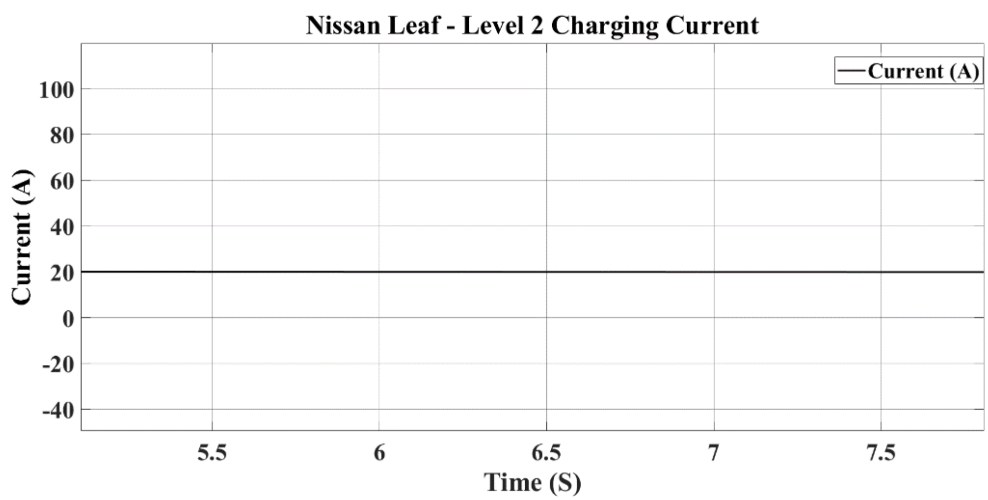

Figure 3.16 - Level 2 charging current output graph.

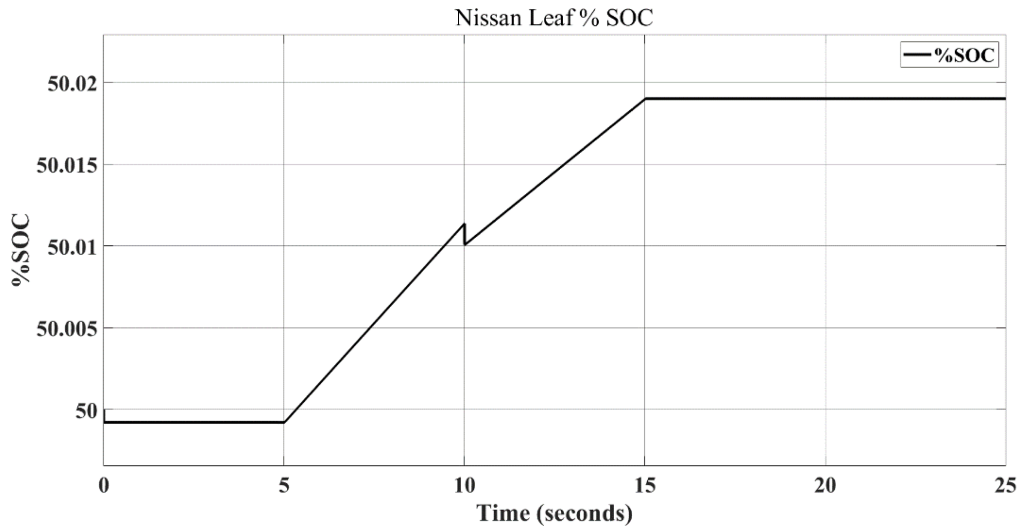

Figure 3.17 - Nissan Leaf's SOC graph

3.4.5 Mode 4 – Nissan Leaf discharging mode

When the PV output is less than the load energy demand and the inhouse batterie SOC is less than 30%, Nissan Leaf reels out the stored energy to the house to satisfy the load energy demand [14] [15]. The control logic for Nissan Leaf in discharge mode is depicted in Figure 3.18. To charge the battery and power the load at the same time, a buck converter is used to reduce the high voltage (360 V) from the Nissan Leaf's battery to 48V [16]. Switches S7, S8, S10 are turned ON to implement mode 4 as seen in figure 3.19 and Table 3.1. The SOC graph for the Nissan Leaf as shown in Figure 3.19. Because of Nissan Leaf's discharge mode execution, the inhouse battery was on a discharge loop between the time intervals of 5 seconds and 15 seconds in Figure 3.19, and then it began to charge.

Switches	S7	S8	S10
Mode 4	ON	ON	ON

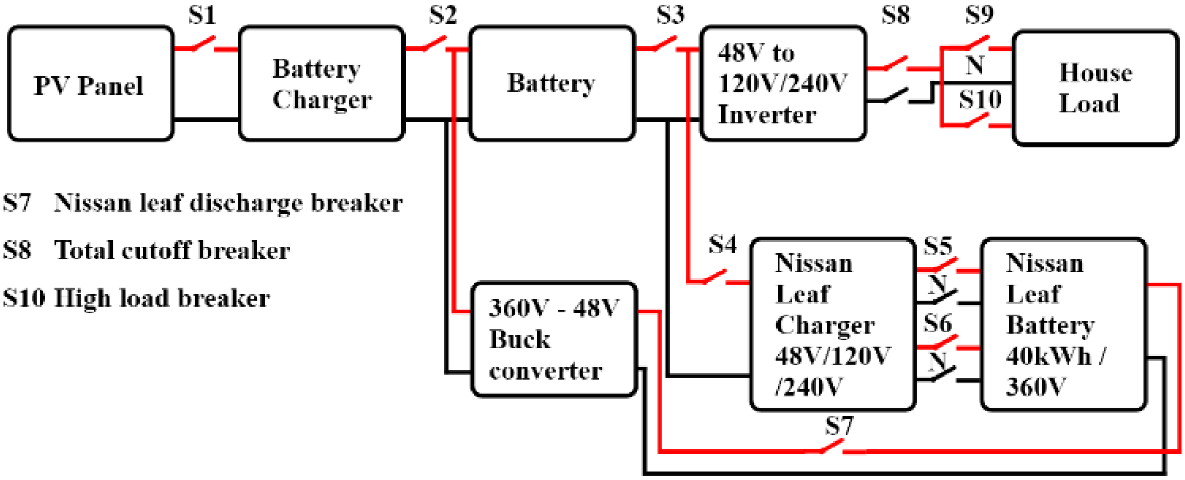

Figure 3.18 - Control logic for Nissan Leaf in discharge mode.

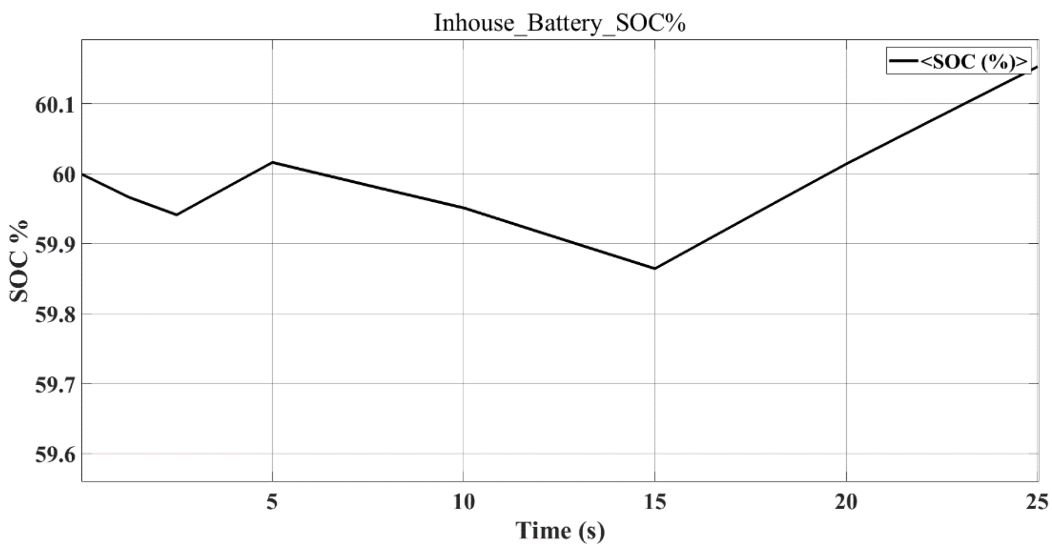

Figure 3.19 – Inhouse batterie's SOC graph

3.4.6 Mode 5 – Inhouse battery protection mode

This mode is included to assist in the saving of the in-house battery by tracking the battery's SOC. When the SOC of in-house batteries drop below 30%, the 30% SOC breaker and the 30% SOC charge on breaker will all go HIGH to charge the battery. Switches S2, S3are switched ON to implement mode 5 as seen in Table 3.1.

3.4.7 Mode 6 – System Isolation mode

The total cutoff breaker is switched on in this mode because the PV output is less than the loads energy demand, the inhouse batteries SOC is less than 30%, and the Nissan Leaf SOC is less than 40%. This is designed to separate the system from the load and prevent it from failing. Switch S2 is switched ON to implement mode 6 as seen in Table 3.1.

3.4.8 Mode 7 – Excess power management mode

When the power produced by PV exceeds the energy demand of the load, the in-house battery and Nissan Leaf's battery are charged, and a dump load is used to dissipate the excess power. The control logic for excess power mode is illustrated in figure 3.20. Switches S1 and S11 are switched ON to implement mode 7 as seen in figure 3.20 and Table 3.1.

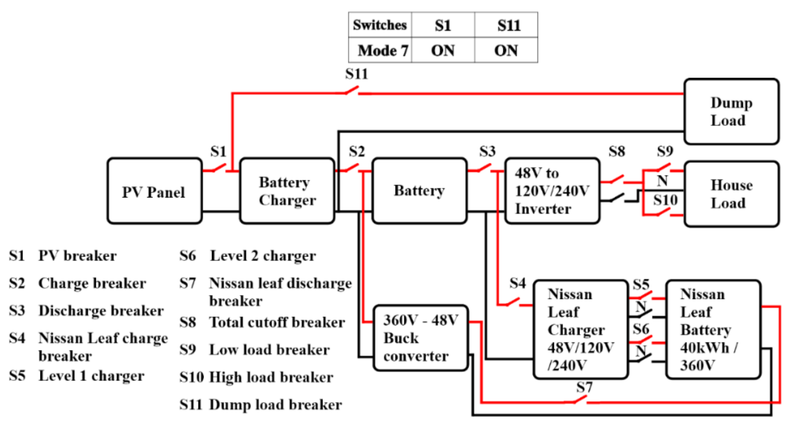

Figure 3.20 - Control logic for excess power mode.

3.4.9 Mode 8 – Nighttime charging mode

The power stored in the inhouse battery is used to charge the Nissan Leaf's battery at night while the loads energy demand is much lower and the inhouse battery's SOC is greater than 60% [17]. The control logic for nighttime level 1 and level 2 charging mode is depicted in figure 3.21 and figure 3.22. Switches S3, S4, S5, S8, S9 are switched ON to implement mode 8 at level 1 charging as seen in figure 3.21 and Table 3.1. In mode 8 level 2 charging switches S3, S4, S6, S8, S9 are switched ON as seen in figure 3.22 and Table 3.1.

Switches	S3	S4	S5	S8	S9
Mode 8 Level 1	ON	ON	ON	ON	ON

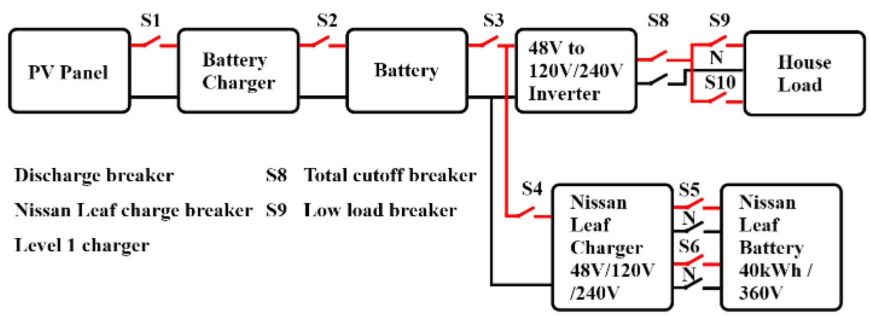

Figure 3.21 - Control logic for nighttime level 1 charging mode.

Switches	S3	S4	S6	S8	S9
Mode 8 Level 2	ON	ON	ON	ON	ON

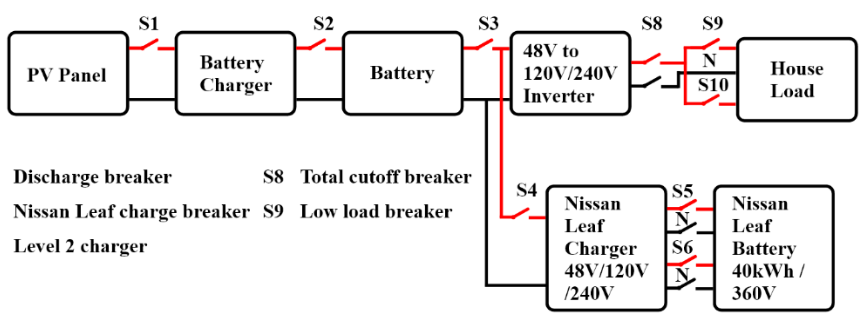

Figure 3.22 - Control logic for nighttime level 2 charging mode

3.4.10 Mode 9 – V2G mode

In this mode the vehicle isolates itself from home and reels power to the grid [18] [19]. Figure 4.23 illustrates the control logic for vehicle to grid (V2G) mode and figure 4.23 illustrates the vehicle to grid mode design in MATLAB. Switch S12 is switched ON to implement mode 9 as seen in figure 4.23 and Table 4.1. The implemented design comprises of PLL block, Current controller (PI) and PWM generator [20]. Figure 4.24 illustrates the implemented PI and PLL controller design. PLL is used to generate a reference signal and the signal is in phase with the actual voltage. The reference signal is used for implementation of current controller in a grid connected inverter. Further the Vgrid voltage is fed to a lowpass filter as shown in equation 1 and figure 4.25. Substituting equation 2 in equation 1 gives the transfer function in equation 3. The magnitude and phase of lowpass filter can be in equation 4. Assuming equation 5, ωc is replaced by ω in equation 6. Further simplification results in equation 7. Adding a second low pass filter as seen in equation 8, the magnitude becomes 1/2 and the angle would be -90 as seen in equation 9. Finally, multiply the output from second low pass filter with 2 to get an output signal (alpha) that is same as input with 90-degree phase shift as seen in figure 4.25.

$$TF = \frac{\omega_c}{s + \omega_c} \tag{4.1}$$

where, ω_c=corner frequency

$$s = j\omega \tag{4.2}$$

$$TF = \frac{\omega_c}{j\omega + \omega_c} \tag{4.3}$$

$$TF = \frac{\omega_c}{\sqrt{\omega^2 + \omega_c{}^2}} < tan^{-1}(\frac{\omega}{\omega_c}) \tag{4.4}$$

$$\omega = \omega_c \tag{4.5}$$

$$TF = \frac{\omega_c}{\sqrt{\omega^2 + \omega_c{}^2}} < tan^{-1}(\frac{\omega}{\omega}) \tag{4.6}$$

$$TF = \frac{1}{\sqrt{2}} < -45 \tag{4.7}$$

$$TF = \frac{1}{\sqrt{2}} \times \frac{1}{\sqrt{2}} < -45 - 45 \qquad (4.8)$$

$$TF = \frac{1}{2} < -90 \qquad (4.9)$$

Further to implement PLL, Vgrid and alpha signals are converter into DQ signals. A control system is set for Q output, the error between Q and Q ref is set as zero and is fed to a PI controller. The output from PI controller gives the angle information which is integrated to get ωt. Output from the Integrator is fed to alpha beta to DQ transformation block. In this case the output from PI controller is aligned with input signal. Hence this value can be used to generate active and reactive current reference signal as seen in figure 4.25 [21] [22].

The generated reference signal is added with grid voltage which generates the reference signal for generation of PWM. A unipolar generation scheme is implemented in the designed system. The reference voltage is compared with the triangular carrier wave and positive and negative references are compared. Output from each comparator is inverted and connected to the gate terminal of each IGBT as seen in figure 4.24. Figure 4.26, 4.27, 4.28 illustrates the grid's voltage graph, grid's current graph and inverter current graph respectively.

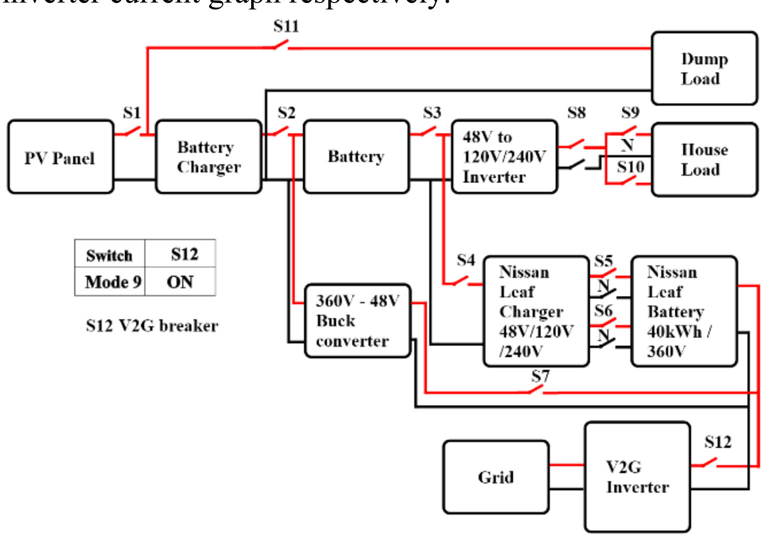

Figure 3.23 - Control logic for vehicle to grid (V2G) mode.

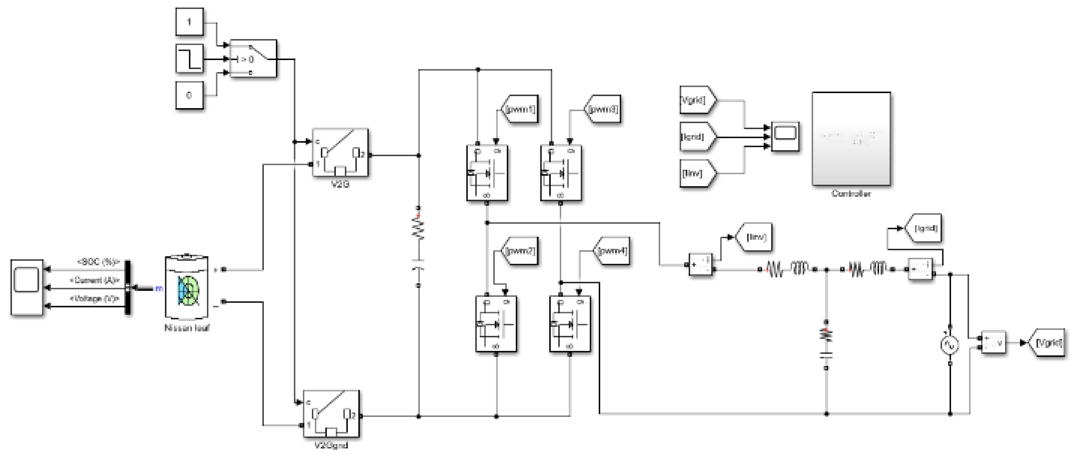

Figure 3.24 - Vehicle to Grid (V2G) mode design in MATLAB.

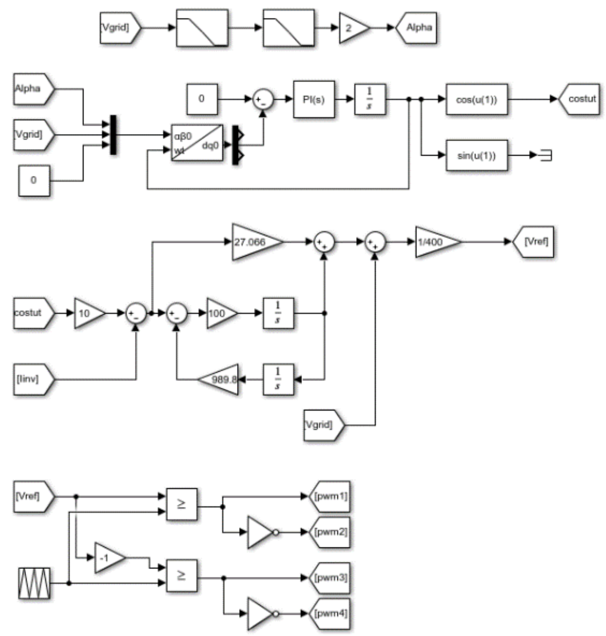

Figure 3.25 - V2G controller – PLL, PI controller.

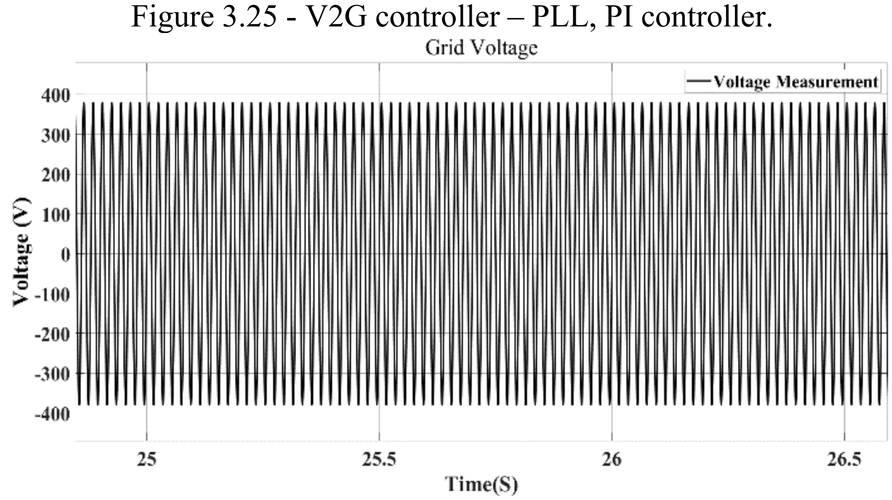

Figure 3.26 - Grid voltage graph – V2G mode.

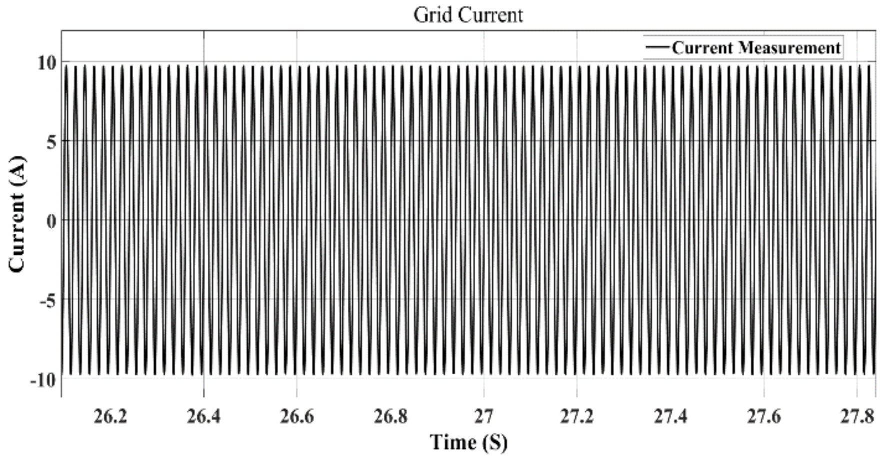

Figure 3.27 - Grid current graph – V2G mode.

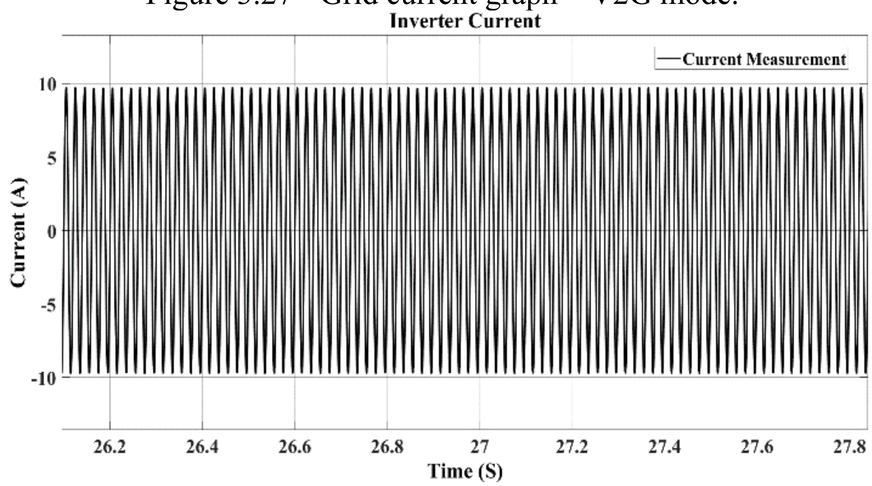

Figure 3.28 - Inverter current graph – V2G mode.

4.5 Conclusions

For Newfoundland conditions, dynamic modelling of a solar energy system with vehicle to home and vehicle to grid options was successfully designed and simulated. The solar insolation for Newfoundland is 3.15 kWh/m^2/day, as seen in Figure 3.1. The PV panels used are 340 W modules that generate 16.3984 kW and are configured in 24 strings, each with two panels. Nissan Leaf is configured as a deferrable load of 9.90 kWh/d and 6.60 kW peak, a 12.5 kW commercially available inverter, 80 Trojan SAGM 12 105 batteries, each rated at 12 V and 100 Ah, a backup genset of 10 kW, and a vehicle to grid (V2G) inverter as seen in figure 7. In the simulation that has been implemented, there are nine main operating modes: i) inhouse battery charging mode – PV power is used to charge the inhouse battery while simultaneously powering the loads; ii) inhouse battery discharge mode – The stored power in the inhouse house battery is used to meet the loads energy demand; iii) Nissan Leaf charging mode – The available power is used to charge the Nissan Leaf after satisfying the load's energy demand and charging the in-house battery; iv) Nissan Leaf discharge mode: the loads have a high energy demand, but the PV and in-house battery SOC is low [23]. Nissan Leaf draws on its accumulated energy to meet the load's energy demand [24]; v) in-house battery protection mode – avoids degenerative discharge of the in-house battery; vi) system isolation mode – prevents system failure; vii) excess power management mode – manages excess power generated; viii) nighttime charging mode – charges Nissan Leaf overnight in preparation for use the next day; ix) V2G mode – power is reeled to the grid. The system is scalable: it can be extended to include parking lots [25], several houses can be joined to form a microgrid [26], and it can control or assist the grid (V2G) [27]. The V2X model, in which vehicles are used to schedule loads [28], power multiple homes, businesses, or an entire city, and transfer power from one vehicle to another [29], will be studied further. [30] [31] [32] [33]

Acknowledgments

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Chapter 4

Design of an IoT interface for solar energy system with Vehicle to Home option for Newfoundland Conditions*

Preface

*A version of this manuscript has been published in the **2020 11th IEEE Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)**. I am the lead author, and I did the most of the research, conducted the literature reviews, and designed the system. I also wrote the first draft of the manuscript and then amended it after receiving comments from the co-author and going through the peer review process. Dr. M. Tariq Iqbal, as a co-author, oversaw the study, provided research components, evaluated, and revised the paper, and offered research ideas in the actualization of the manuscript.*

*This chapter is a version of "Design of an IoT interface for a solar energy system with Vehicle to Home option for Newfoundland Conditions", R. S. Sundararajan and M. T. Iqbal, *2020 11th IEMCON* pp. 0597-0601.

Abstract

This chapter discusses the design of solar energy system in offline mode along with the implementation of Vehicle to Home (V2H) to meet the energy demand of a smart house for Newfoundland condition. A site was selected (13 Polina road) located in St. John's, Newfoundland, Canada. For the chosen site, an optimized system was designed to meet the energy demand of the house using BE opt and Homer software. Further, based on Nissan Leaf (Electric Vehicle), the concept of V2H is implemented with the help of smart current sensors installed in the house that also helps in transmitting the sensor's data to cloud with the help of IoT. Based on the information generated, the system operates either in V2H more or in PV power mode.

Index Terms: PV, V2H, Renewable energy, IoT (Internet of Things), solar energy.

4.1 Introduction

In the fast-changing world, the use of photovoltaic (PV) as power generation and integrating electric vehicles (EV's) has been a welcoming means towards low carbon footprint [1]. However, the PV output is not consistent throughout the day and needs backup support; a battery pack is added to the system to support the system to continue to power the house even when the power produced by PV wasn't sufficient to meet the load demand of the house. When the system starts to lose power, and there is still a high-power demand, V2H concept comes into play to reel power stored in a car battery to support the load demand of the house [2]. The car taken into consideration is Nissan Leaf S plus variant with 62 kW Lithium-ion battery pack. IoT (Internet of Things) plays a crucial role in this system in a handshake with the field level device – smart current sensor. IoT gives sensors the ability to transfer data over the internet. All decisions taken in the system are executed in the cloud with the help of an algorithm. The role of the current sensor is to measure the current that is being used up, being produced, and being stored at this point of time and publish the data to the cloud for the algorithm to act upon. This information comes handy when the algorithm tries to measure the power generated by the PV panel versus the power demand of the home loads versus power stored. In this situation, the data generated and published is used as a reference to make the decision, to use V2H concept. By default, such system operates primarily on power produced by PV until there is a need for the inhouse battery. When the inhouse battery reached 30% of its SOC, implemented V2H concept. In this chapter, we designed a system to address this issue by implementing Vehicle to Home concept along with hybrid PV system using IoT. The sizing of the system was executed with the help of BEopt and Homer.

4.2 Site details and calculations

4.2.1 Selected Site

The site selected for this research was 13 Polina Road which is in St. John's, Newfoundland, Canada. It spans an area of 185.89 m^2.

4.2.2 Site's solar insolation from NERL website

The solar radiation and clearness index for the selected site in St. John's, Newfoundland, Canada can be seen as a monthly profile in figure 2.1. The clearness index is of 0.39 to 0.49 with an average of 0.44, solar insolation varying between 1.28 $kWh/m^2/day$ to 5.14 $kWh/m^2/day$ with an average of 3.15 $kWh/m^2/day$.

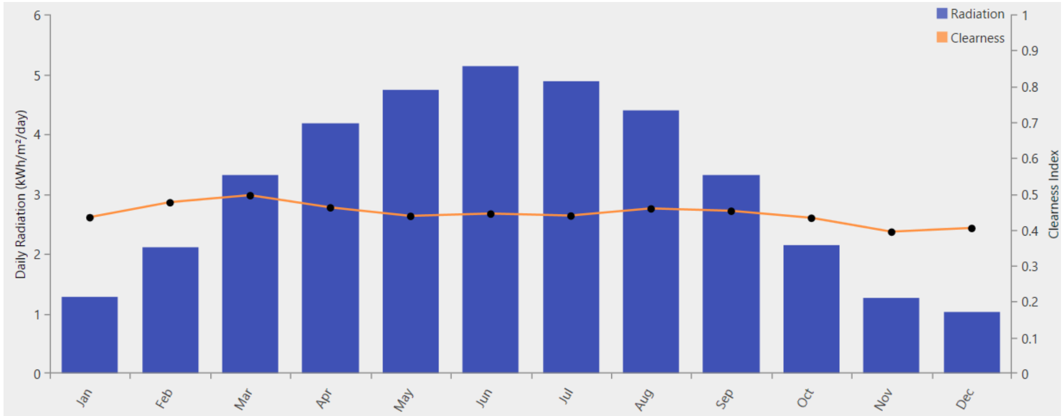

Figure 4.1 – Solar insolation and clearness index of the selected site.

4.2.3 Site's power requirement from BEopt

The annual power requirement for the selected site was estimated using BE opt software. Figure 2.2 illustrates the power requirement of the house. It comes to around 21111 kWh/year. This includes all the loads in the house and considering the type of insulation, heaters, boiler, lights, ventilation, and other factors like plugin loads, etc.

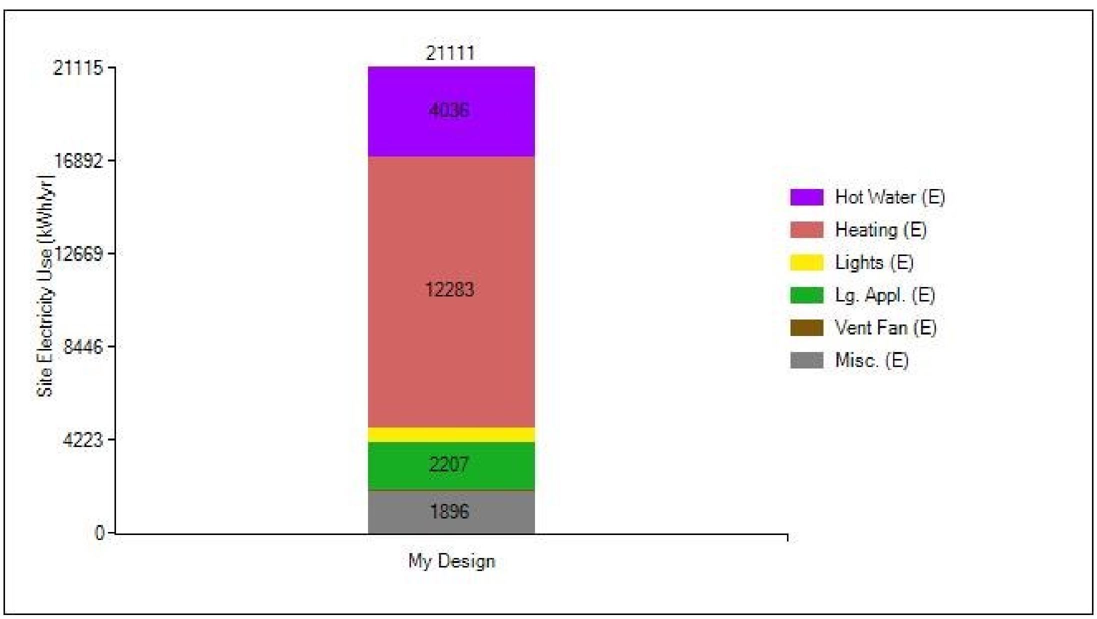

Figure 4.2 – Annual power requirement of the selected site from BEopt.

4.2.4 Site's Photovoltaic panel area calculation

Average daily sunlight in St. John's = 1633 h for 272 days, where h is hours.

Output from BE opt = 21111 kWh/ Year

$$Per\ month = \frac{21111}{12}$$

$$= 1759.25\,\frac{kWh}{month}$$

$$Per\ day = 58.641\ kWh/day$$

$$Power\ output\ = \frac{energy\ usage\ per\ day}{number\ of\ full\ sun\ hours\ per\ day}$$

$$= \frac{58.641\,\frac{kWh}{day}}{4.47}$$

$$= 13.118\ kW$$

For PV sizing considering derating factor as 0.8

$$= 13.118/0.8 = 16.3984\ kW$$

$$PV\ size\ array\ = \frac{Total\ calculated\ capacity\ of\ PV}{Wattage\ of\ one\ panel}$$

For calc power output

$$= \frac{13118\ W}{340\ W}$$

$$= 38.582 \sim 39 \sim 40\ Modules$$

For derating factor

$$= \frac{16398.4\ W}{340\ W}$$

$$= \ 48.230 \sim 48\ Modules$$

Area Calculation

For desired power output

$$40\ x\ 1.88\ =\ 75.2m^2$$

Including the derating factor

$$48\ x\ 1.88\ =\ 90.24m^2$$

Available area = 185.89 m^2

Bus voltage = 48 V

For desired power output, number of strings = 20 Strings

Number of panels in each string = 2

Voltage output = 48 V per string

Including derating factor the number of strings = 24 Strings

Number of panels in each string = 2

Voltage output = 48 V per string.

Figure 4.3 represents the schematic of the proposed system in homer software. Canadian solar CS6U – 340M is used as the PV panel, SmatLi-672V-100AH-F/S is considered as the battery, 12.5kW inverter and the home load profile comes to 58.641 kWh/d with 12.07 kW as the peak. With the help of Homer, the system size for the selected site is calculated which includes PV area calculation, battery calculation.

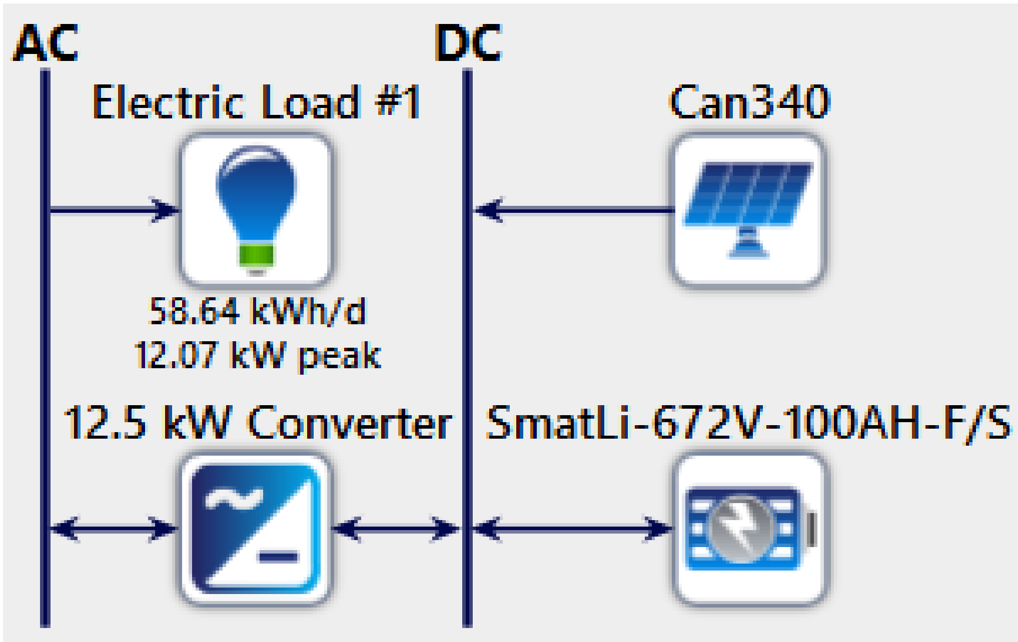

Figure 4.3 -Homer schematic of the proposed system.

4.3 Methodology

The system incorporates a PV system which acts as power generation point [3], a converter to help charge battery and inverter used to convert power stored in the battery to power the home loads. When the system lacks the power to meet the power demand of the house, electric vehicle – Nissan Leaf would reel power from the car's battery to the house. In this case, the energy stored (DC power) is converted to AC power with the help of a bidirectional converter [4], that comes along with the vehicle. This, in turn, is plugged onto the mains of the house to meet the energy demand or in case of emergency [5].

Figure 4.4 illustrates the overall block diagram of the proposed system. It can be seen from the block diagram that the power generated by the photovoltaic panels are passed on to a battery charger or converter which helps in charging the battery. In this case, the in-house battery also acts as a source to the inverter and for charging the EV during its charging cycle. Since the home loads are AC loads, an inverter is used to convert DC to AC. Smart sensors are implemented to ease up the work (figure 4.6) and to constantly monitor the load's power requirement versus power produced, versus power available as stored energy in the battery. Figure 4.6 illustrates the implementation of the smart sensor.

In this case, the data generated by the sensor is fed to an algorithm in the cloud with the help of IoT, which acts a medium of communication between the field level devices and the algorithm in the cloud. When one of the parameters starts failing, when PV generation is low and is not able to meet the power requirement of the load, in house battery is used for powering the home loads till it reaches 30% of its %SOC [6] [7]. In this case, the algorithm uses the power stored in EV by implementing V2H concept. In the designed system, Nissan Leaf is used for powering home loads until the demand is met. Once the load drops and PV production can meet the load's power requirement Nissan Leaf is disengaged from acting as the point of power. [8] When the load's power requirements are met, the excess power is used for charging the inhouse battery [9] and EV. Figure 4.5 is a circuit illustration of the proposed system.

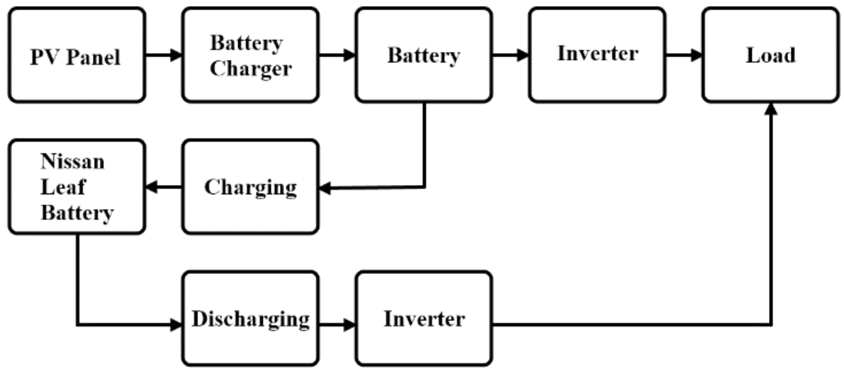

Figure 4.4 – Overall block diagram of the proposed design.

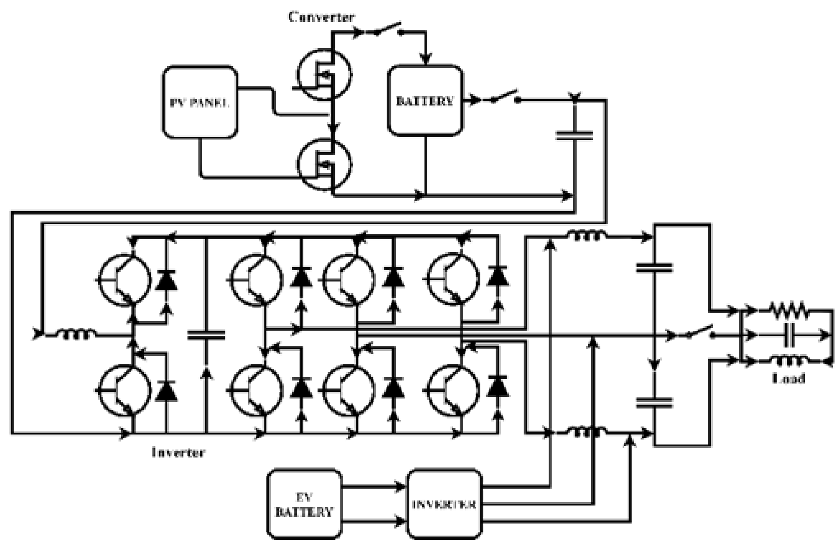

Figure 4.5 – Circuit diagram of proposed system design.

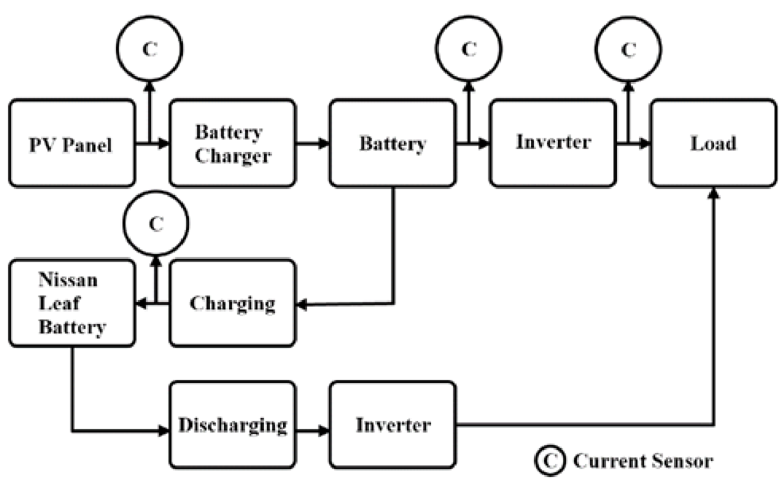

Figure 4.6 – Smart sensor implementation in the proposed system.

4.3.1 PV Arrays

The panel considered for this design in Canadian Solar CS6U 340M which outputs 340W and is of 1.8m^2 in area.

4.3.2 Battery

SmartLi-672V-100AH-F/S was selected as a battery for the application. The calculation for the battery is as follows with three days backup. Therefore, from calculations, 92 batteries are required.

Wh/day	$= 58641\ Wh/day$
3 days	$= 58641\ x\ 3\ =\ 175925\ Wh$
40% DOD	$= 175925\ /\ 0.4\ =\ 439812.5\ Wh$
Temp Cons (>80F)	$= 439812.5\ x\ 1\ =\ 439812.5\ Wh$
Ah cap of Bt bank	$= 439812.5\ /\ 48\ =\ 9162.760\ Ah$
Number of Batteries	$= 9162.760\ /\ 100\ =\ 91.6 \sim 92\ Nos.$

4.3.3 Inverter

An inverter is considered for the design with 12.5 kW output capacity as the peak load value comes to around 12.3 kW. The inverter, in this case, is a single-phase to three-phase inverters. Figure 5 illustrates the invert circuit diagram.

4.3.4 Nissan Leaf S plus – Electric Vehicle

S plus variant of Nissan Leaf with 62 kW lithium-ion battery pack and 6.6kW onboard charger is considered in this design. The other reason for choosing Nissan Leaf is that it has an inbuild Bidirectional converter that is used for charging and discharging (reeling power to home).

There can be two cases discussed in the case of the Nissan Leaf.

Case 1: where Nissan Leaf is reeling out power or in the discharge cycle. This cycle is called upon as an emergency response as the PV panels fail to meet the home load demand. Figure 4.7 illustrates the discharge mode of the Nissan Leaf.

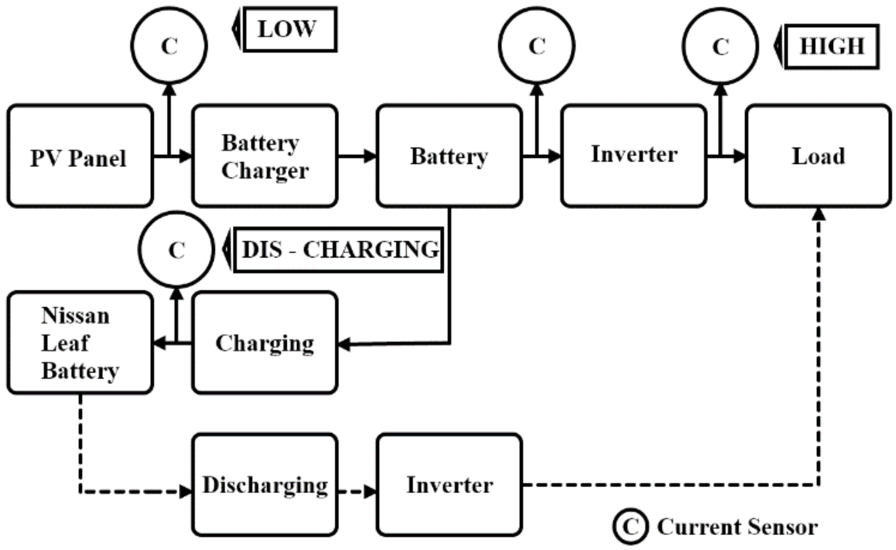

Figure 4.7 – Discharging mode of Nissan Leaf.

Case 2: Where Nissan Leaf is in charging mode, figure 4.8 illustrates charging mode of Nissan Leaf, here in this case the following are assumed. The home loads are met, and the excess energy produced is used for charging the EV. [10] [11]

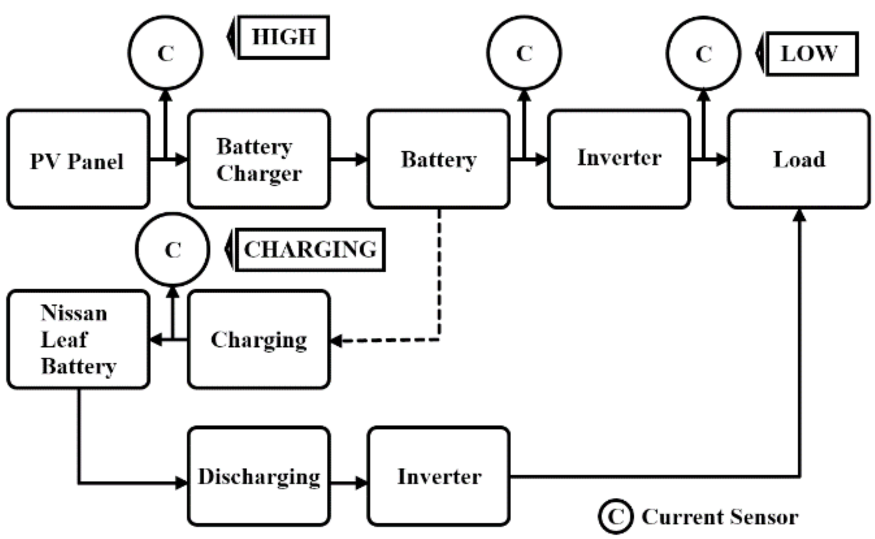

Figure 4.8 – Charging mode of Nissan Leaf.

4.4 Algorithm

The developed algorithm runs in the cloud and with the help of IoT that helps in transferring data generated by smart sensors in real-time to the cloud. Figure 4.9 illustrates the flow chart of the proposed algorithm. The algorithm measures the inhouse batteries SOC, voltage and current, loads energy demand, produces PV power, SOC, voltage and current of Nissan Leaf. The algorithm works as follows as the load energy demand rises and falls the change in load values by a difference of 2 values triggers a post-call to the smart sensor that in turn pushes the data to the server. The server on receiving the push request checks the power production data from the PV panel, SOC of the in-house unit and SOC of Nissan Leaf. Furthermore, on change in SOC of an inhouse battery or Nissan Leaf by two value, it triggers the post call to the smart sensor that in turn pushes the data to the server. The server on receiving the push request checks the power production data from the PV panel, loads power demand and SOC of Nissan Leaf and vice versa. The algorithm on getting a response that is triggered when the SOC of inhouse battery or SOC of Nissan Leaf falls below a set SOC threshold, that part of the system breaks from circuit till the SOC raises more than the set threshold.

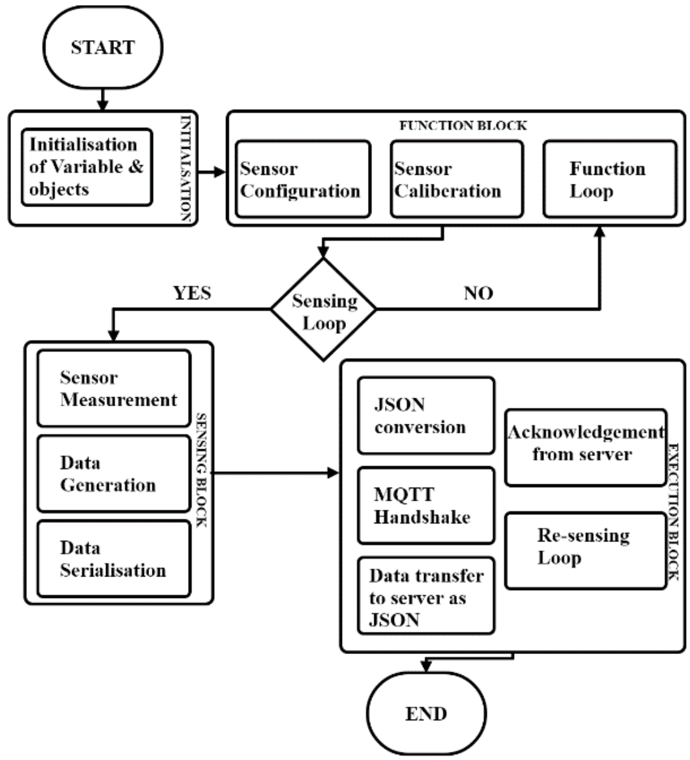

Figure 4.9 – Flowchart of the implemented algorithm.

4.5 Conclusion

The solar energy system to meet the energy demand of a house for Newfoundland condition with V2H was successfully designed. It can be seen from figure 2.1 that the solar irradiation index is 3.15 kWh/m^2/day, the number of PV panels used were 48 numbers producing 16.398 kW which are placed in 20 strings with two panels in each string. A commercially available inverter of 12.5 kW capacity was incorporated with 92 batteries each of 48 V and 100 Ah. However, the smart sensors played a major role in generating and transferring data to the cloud with the help of IoT. The system was successfully designed, and the developed algorithm is the main driving factor, as the algorithm ruins in the cloud and uses the data generated by the sensors in the home, the data transfer is handled with the help of IoT. The benefit of this algorithm is its scalability; it can be scaled to a locality or to a city. This algorithm also gives us the individual load consumption at any point of time in the day. This algorithm is deployed in the cloud with an idea emphasizing an initiative towards a smart grid. This algorithm will act as an application that gives insights on load utilization of a house, of locality or of a city. The main reason for implementing V2H is to support the energy demand of loads during peak time and to act as backup power when the photovoltaic system is not able to meet the load's energy demand. Further research would be directed towards scheduling of loads and scheduling charging and discharging routines for the EV and smart home. Furthermore, the research extends towards forecasting the load's energy requirements and EV usage patterns [12] [13] [14].

Acknowledgments

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Chapter 5

Hardware Implementation of a Solar Energy System with Vehicle to Home and Vehicle to Grid option for Newfoundland Conditions using Mozilla IoT*

Preface

A version of this manuscript has been submitted with the ***Jordan Journal of Electrical Engineer (JJEE)****. I am the lead author, and I did most of the research, conducted the literature reviews, and designed the system. I also wrote the first draft of the manuscript and then amended it after receiving comments from the co-author and going through the peer review process. Dr. M. Tariq Iqbal, as a co-author, oversaw the study, provided research components, evaluated, and revised the paper, and offered research ideas in the actualization of the manuscript.*

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*This chapter is a version of "Hardware Implementation of a Solar Energy System with Vehicle to Grid Option for Newfoundland Conditions using Mozilla IoT", R. Sundararajan and M. T. Iqbal, *JJEE, 2021.*

Abstract

The hardware implementation of a solar energy system with vehicle to home (V2H) and vehicle to grid (V2G) options for Newfoundland conditions through Mozilla IoT is discussed in this chapter. To illustrate IoT, remote monitoring, and control concepts, a prototype was created in the lab that was entirely a 12Vsystem. To operate in multiple modes, the system checks the current and voltage parameters. The data is transmitted to the gateway using an ESP 32 microcontroller and the IoT (Internet of Things). Mozilla IoT is the platform that hosts the Raspberry Pi Things Gateway and serves as a dashboard to remotely control and monitor the system. The data that is transmitted is logged, and the logged data is shown as a graph. This chapter presents the system design, details of demo experimental setup and some test results.

Index Terms: PV, V2H, V2G, Renewable energy, IoT (Internet of Things), solar energy.

5.1 Introduction

Electric vehicles (EVs) are the next major advancement in the transportation industry. EVs offer several benefits, including being more powerful than vehicles with internal combustion engines and functioning as mobile power reservoirs. Electric vehicles (EVs) must be charged, and renewable energy sources like solar energy systems can help satisfy this need while also reducing carbon emissions. A backup battery is required since renewable energy is naturally variable. Because Evs can also function as reservoirs, vehicle to home (V2H) and vehicle to grid (V2G) concepts can be implemented. We have already published system design in [1] [2], a 12 V lead acid battery is being considered for the inhouse battery in order to provide continuous power to the system. Another lead acid battery is used in place of the Nissan Leaf's battery to accomplish the V2H concept. When the load's energy demand exceeds the PV's generated power, the lead acid battery in place of the Nissan Leaf begins to power the load until the PV's produced power meets the load's energy demand; otherwise, PV is the primary source of power. If the PV power generated is inadequate to satisfy the energy requirement of the loads, the in-house battery is used to power them. When the system reaches 30% SOC, it enters V2H mode [3], which means the Nissan Leaf's battery is discharging in order to satisfy the load's energy demand. In V2G mode, the car disconnects from the house and supplies electricity to the grid [4] [5].

In general, the Internet of Things (IoT) refers to a collection of physical objects (or things) embedded in electronics, sensors, actuators, and connected devices that are linked together in a network to allow data exchange with other interconnected devices in order to provide users with more benefits and services. In other words, it turns non-smart objects into smart ones [6]. In the realm of modern information and communication technology, the phrase "Internet of Things" (IoT) is now widely used. This topic has sparked several arguments since its implementation in industry and services results in more effective action, but it also presents a number of concerns, such as privacy, interoperability. Mozilla IoT was considered because of its privacy and interoperability features in its Web of Things gateway.

In this research, we propose a method that tackles this challenge by integrating Mozilla IoT with the Vehicle to Home (V2H) and Vehicle to Grid (V2G) concepts.

5.2 Components Used

Table 1 lists the components that were used in the implemented system.

Table 5.1: Components Used.

Serial Number	Component Name
1	Raspberry Pi Model B
2	ESP 32
3	PV Panel
4	Current Sensor (ACS 712)
5	Voltage divider
6	Inverter
7	Battery
8	Bulbs
9	Relays
10	Connecting wires

5.2.1 Raspberry Pi – Things Gateway

The Raspberry Pi 4 Model B is one the latest single board computer with 4 GB RAM, ARM Cortex CUP running at 1.5 GHz with Bluetooth and Wi-Fi capabilities. It is used to setup Mozilla Things Gateway.

5.2.2 ESP 32

The ESP 32 is a microcontroller which has Bluetooth and Wi-Fi capabilities and has dual core. It can be clocked up to 240 MHz, it also has an ultra-low power processor. It comes with 512 KB SRAM and 8 MB external memory. This is a best suited for the considered - streaming data to the gateway. In this case, ESP 32 collects the data from sensors and sends that to IoT server.

5.2.3 Photovoltaic Panel

The Sun force 260 W solar kit (130 W + 130 W), 12 V is considered for the proposed test setup.

5.2.4 Current Sensor (ACS 712)

ACS 712 – 20 A current sensor module is considered for current measurement in the implemented system. The sensor is used to measure PV current, Battery current and the load current. The generated data is sent to the ESP 32 microcontroller and then sent to the gateway with the help of IoT.

5.2.5 Voltage Divider

It is a common circuit that takes higher voltage and converts it into a lower one by using a pair of resistors. This was used in the implemented system to measure the voltage across various measure points (12 V to 3.3 V, since ESP 32 needs less than 3.3V as analog input).

5.2.6 Inverter

The Sun force 200 watts 12 V modified sinewave inverter is considered for the implemented system. The Output capacity of 120V, 200 W is implemented.

5.2.7 Battery

For this application, the Panasonic LC-R 127R2P 12 V, 7.2 Ah battery was selected. This battery is used in place of Inhouse battery and Nissan Leaf's battery.

5.2.8 Bulbs

Blubs are used as loads in the implemented test system. In this case, the house loads, Nissan Leaf as load, grid as load.

5.2.9 Relay

Relays are implemented to execute the switching operation between different system modes based on the control scheme.

5.3 Methodology

PV panel, in-house battery, battery charger, inverter, Nissan Leaf battery, and loads are all part of the system. Figure 5.1 depicts the proposed system's overall block diagram as published in our previous paper [1]. PV power is utilized to charge the in-house battery through a charger, and then an inverter converts the battery's stored power to AC to power the house load. In V2H mode, a Nissan Leaf's battery is also utilized to charge the in-house battery while also powering the house loads. Figure 5.2 depicts an overview of the implemented system's switching control logic. Charging and discharging the in-house battery, powering loads with the in-house battery, a 120V inverter, V2H, overnight charging, and V2G mode are all simulated in this system [7]. Note that for the test setup we are using only 12V batteries to check IoT and control logic.

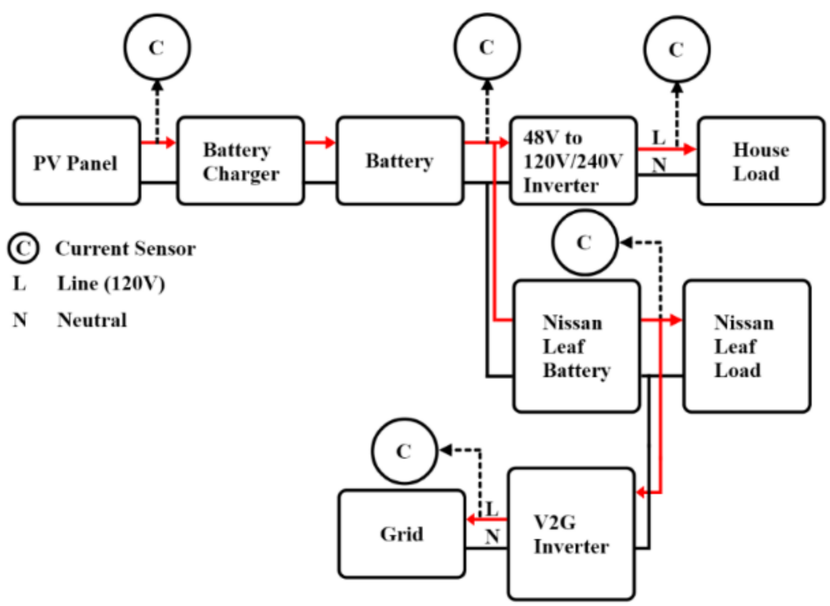


Figure 5.1 - Overall block diagram.

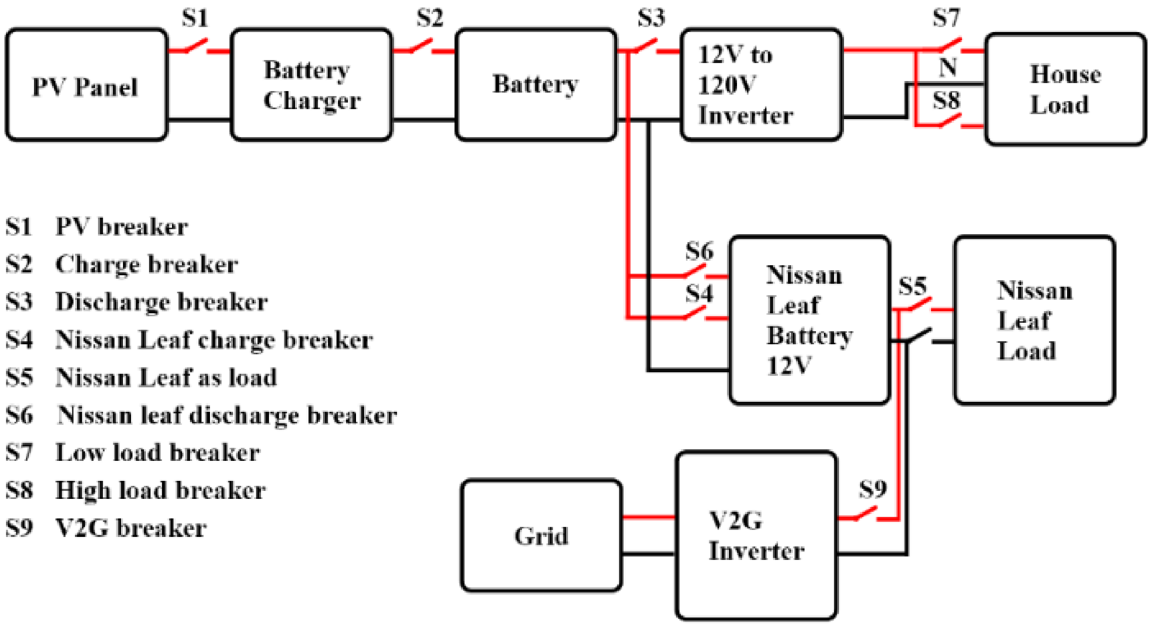


Figure 5.2 - Switching control logic of the implemented system.

Furthermore, the hardware implementation was carried out incorporating eight modes representing different modes [10] of operation.

Table 5.2: Switch control logic for the implemented system.

MODES	S1	S2	S3	S4	S5	S6	S7	S8	S9
Mode 1	HIGH	HIGH	HIGH	LOW	LOW	LOW	HIGH	LOW	LOW
Mode 2	LOW	LOW	HIGH	LOW	LOW	LOW	LOW	HIGH	LOW
Mode 3	HIGH	HIGH	HIGH	HIGH	LOW	LOW	HIGH	LOW	LOW
Mode 4	-	-	-	-	HIGH	-	-	-	-
Mode 5	LOW	LOW	HIGH	LOW	LOW	HIGH	HIGH	LOW	LOW
Mode 6	-	HIGH	HIGH	-	-	-	-	-	LOW
Mode 7	LOW	LOW	HIGH	HIGH	LOW	LOW	HIGH	LOW	LOW
Mode 8	-	-	-	-	-	-	-	-	HIGH

5.3.1 Mode 1 - Inhouse battery charging mode

In this mode, the PV output is used to charge the in-house battery and power the loads. In this condition, the loads consume very little energy. By charging the battery, the excess energy is put to good use. Figure 5.3 shows the control logic for charging the in-house battery. Mode 1 is implemented by setting switches S1, S2, S3, and S7 to HIGH, as shown in figure 5.3 and Table 5.2 (HIGH means break is ON).

Switches	S1	S2	S3	S7
Mode 1	HIGH	HIGH	HIGH	HIGH

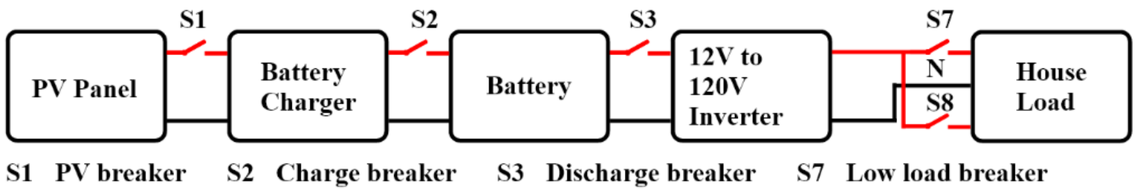


Figure 5.3 – Control logic for inhouse battery charging.

5.3.2 Mode 2 – Inhouse battery discharge mode

In this mode, PV production is low in comparison to the load's energy demand. In this case, the load is powered by the in-house battery. Fig. 4 shows the control logic for the in-house battery in discharge mode. An inverter with output voltages of 120V is also utilized. Mode 2 is implemented by setting switches S3, S8 to HIGH, as shown in figure 5.4 and Table 5.2.

Switches	S3	S8
Mode 2	HIGH	HIGH

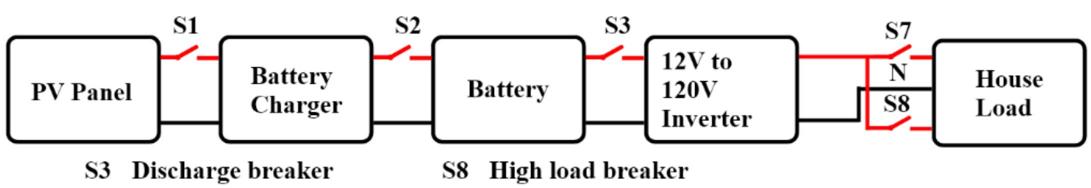


Figure 5.4 – Control logic for inhouse battery discharging.

5.3.3 Mode 3 – Nissan Leaf charge mode

The device will charge the Nissan Leaf battery when the PV output exceeds the load's energy requirement and the in-house batteries SOC surpasses 60% [8] [9] Figure 6 shows the control logic for Nissan Leaf charging. Mode 3 is implemented by setting switches S1, S2, S3, S4, S7 to HIGH, as shown in figure 5.5 and Table 5.2.

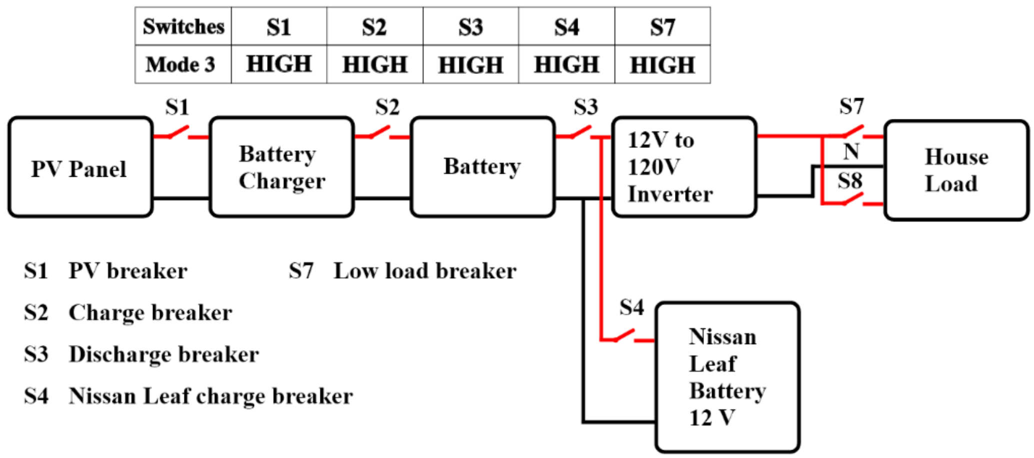


Figure 5.5 – Control logic for Nissan Leaf charging.

5.3.4 Mode 4 – Nissan Leaf as load

The Nissan Leaf is considered as a load in this mode. Travel-related energy is estimated to account for 25% of the Nissan Leaf's battery depletion. The control logic for the Nissan Leaf as a load is shown in Figure 5.6. As shown in figure 5.6 and Table 5.2, only switch S5 is set to HIGH to implement mode 4.

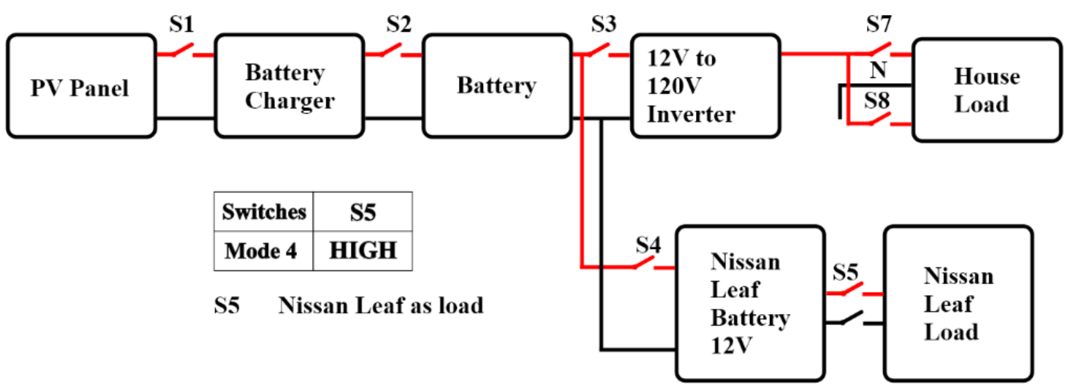


Figure 5.6 – Control logic for Nissan Leaf as load.

5.3.5 Mode 5 – Nissan Leaf discharge mode

Nissan Leaf reels out stored energy to the home to fulfil the load energy demand when the PV output is less than the load energy demand and the inhouse batterie SOC is less than 30% [10] [11]. Figure 5.7 shows the control logic for the Nissan Leaf in discharge mode. Mode 5 is implemented by setting switches S3, S6, S7 to HIGH, as shown in figure 5.7 and Table 5.2.

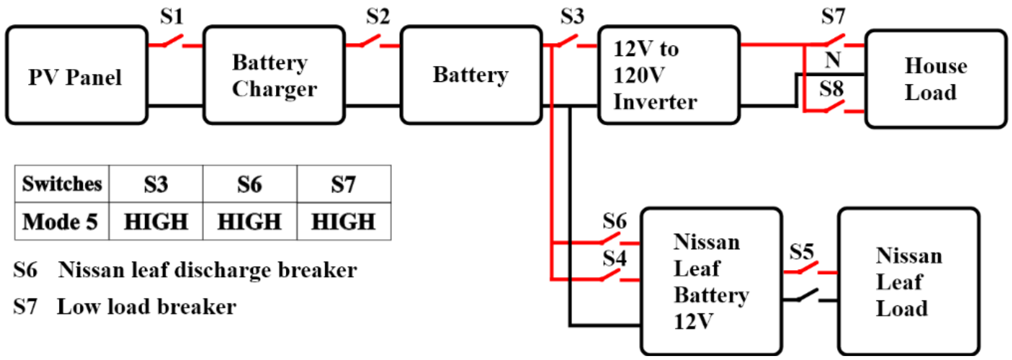


Figure 5.7- Control logic for Nissan Leaf discharge mode.

5.3.6 Mode 6 – Inhouse battery protection mode

This option is added to help save the in-house battery by tracking its state of charge (SOC). The discharge breaker and the charge breaker will both go HIGH to charge the battery when the SOC of in-house batteries falls below 30%. Mode 6 is implemented by setting switches S2, S3 to HIGH, as shown in Table 5.2.

5.3.7 Mode 7 – Nighttime charging mode

The energy stored in the inhouse battery is utilized to charge the Nissan Leaf's battery at night, when the loads energy demand is lower and the inhouse battery's SOC is more than 60% [12] Figure 5.8 shows the control logic for the evening charging mode. Mode 7 is implemented by setting switches S3, S4, and S7 to HIGH, as shown in figure 5.8 and Table 5.2.

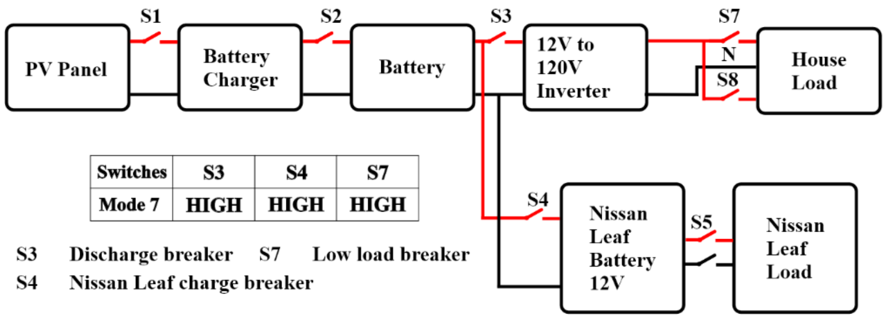


Figure 5.8 – Control logic for nighttime charging mode.

5.3.8 Mode 8 – V2G mode

In this mode, the car disconnects from the house and connects to the grid [13]. The control logic for the vehicle to grid (V2G) mode is shown in figure 5.9. As seen in figure 5.9 and Table 5.2, switch S9 is HIGH to implement mode 9.

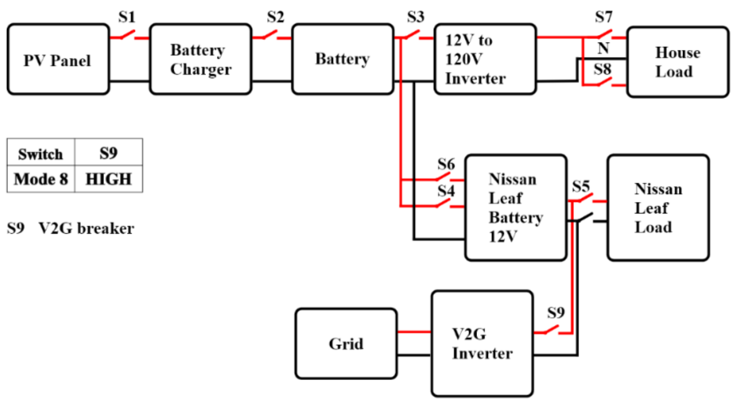


Figure 5.9 – Control logic for Vehicle to Grid (V2G) mode.

5.4 Implemented System

The implemented system comprises of ESP 32 microcontroller boards, Raspberry Pi, Current sensor, voltage dividers, relays, PV panels, inverters and loads. The experimental setup is a 12V based system. It was executed to demonstrate IoT and control concept. The actual system has different voltage levels and involves multiple DC-DC converters. Figure 5.10 illustrates the block diagram of the implemented system. The IoT part is handled by Mozilla IoT and ESP 32 microcontroller is used for handling updating the data to the gateway and also to control and monitor remotely using the dashboard.

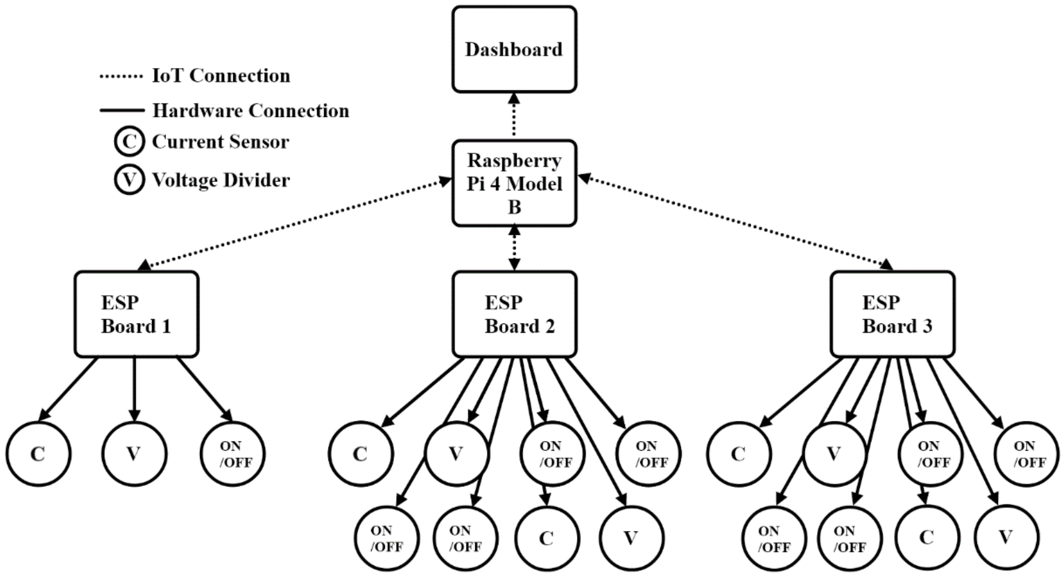


Figure 5.10 – Block diagram of the implemented system.

5.4.1 Mozilla IoT

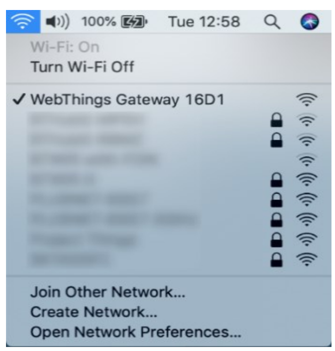
Because of its security, privacy, interoperability, and overall value, Mozilla IoT was chosen for this study. In most IoT applications, the device sends data to the cloud, which is then monitored and controlled by a dashboard or a mobile app. However, in this scenario, the full web of things interoperability is carried out locally, with data shared with the cloud through a JWT or oAuth framework. The web of things aims to create a decentralized internet of things by assigning URLs to objects on the internet, allowing them to be linked, discovered, and interoperable [14].

5.4.1.1 Getting started with Mozilla IoT – Webthings Gateway on Raspberry Pi

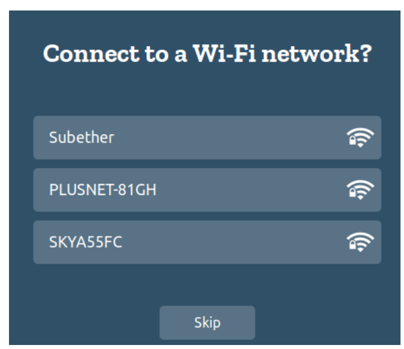
Webthings gateway is a smart home gateway software distribution that allows users to manage and monitor their devices directly over the internet, without the middleman. The gateway image is obtained from the Mozilla IoT website and flashed onto a microSD card with the downloaded image file. The microSD card is put into the microSD slot after successful flashing, and the Raspberry Pi is booted.

5.4.1.2 Connecting WebThings gateway to Wi-Fi

After successfully booting, the Raspberry Pi will function as a gateway, connecting to the internet and communicating with all devices through Wi-Fi. As illustrated in figure 11 a), the gateway generates a hotspot called "WebThings Gateway XXXX," with the XXXX being the four numbers from the Raspberry Pi's MAC address. Scanning and connecting to the network can be done with a computer or a mobile phone. As illustrated in figure 5.11 b), when you join, it creates a captive gateway page that displays neighboring Wi-Fi networks. When asked, select the preferred network and input the password. This takes you to the “Connecting to Wi-Fi...” page.



(a)



(b)

Figure 5.11 (a) Gateway hotspot on network and internet setting, (b) Gateway’s connect to a Wi-Fi network page.

5.4.1.3 WebThings gateway – Choosing Subdomain

After connecting the Raspberry Pi to Wi-Fi, make sure your computer or phone is connected to the same network and go to http://gateway.local in your browser. It takes you to a welcome screen, as shown in figure 5.12, where you may register a free domain to safely access the gateway via the internet using Mozilla's https tunneling, fill in the data, and click Create. This generates your subdomain, which you can load into https://SUBDOMAIN.mozilla-iot.org using a computer or a mobile phone.

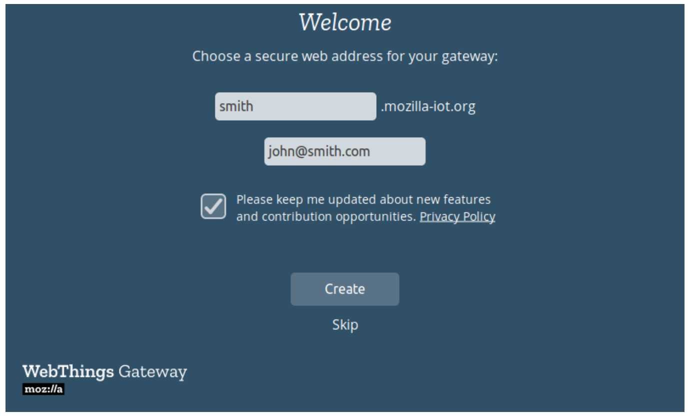
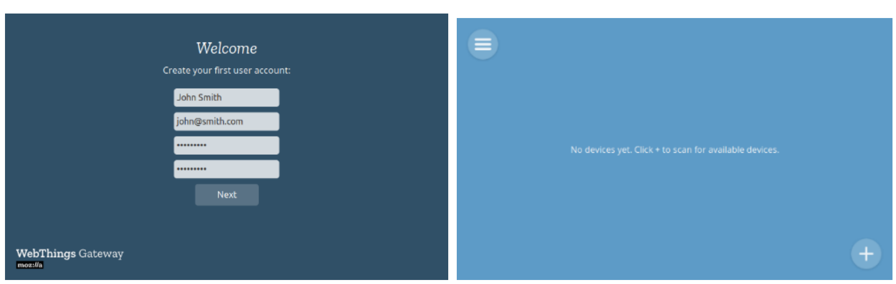


Figure 5.12 – Domain registration page.

5.4.1.4 WebThings gateway – Creating user account.

After completing the subdomain registration procedure, the user is redirected to the next stage of the setup process, which requires the user to provide their name, email address, and password (see figure 5.13 a). This action establishes a user account in the gateway, which may be used to find, add, monitor, and manage all connected devices. After successfully creating an account, the gateway sends users to an empty Things screen where you may begin adding devices, as seen in figure 5.13 b).



(a) (b)

Figure 5.13 (a) Account creation process, (b) Landing page – Things screen of the gateway.

5.4.1.5 WebThings gateway – Programming things.

The microcontroller is an ESP 32 board, and programming is done using the Arduino programming language. The Webthings and Arduino JSON libraries are installed, and the code for the chosen use case is executed. The implemented system was executed using three ESP 32 microcontroller boards for PV measurement, Battery measurement, and V2G, V2H measurement, as shown in figure 5.14. Figure 5.14 depicts the implemented system lab setup, and figure 5.15 depicts the overall GUI for the WebThing dashboard. Six set of PV panels are installed on the roof and connections are available in the lab for experiments.

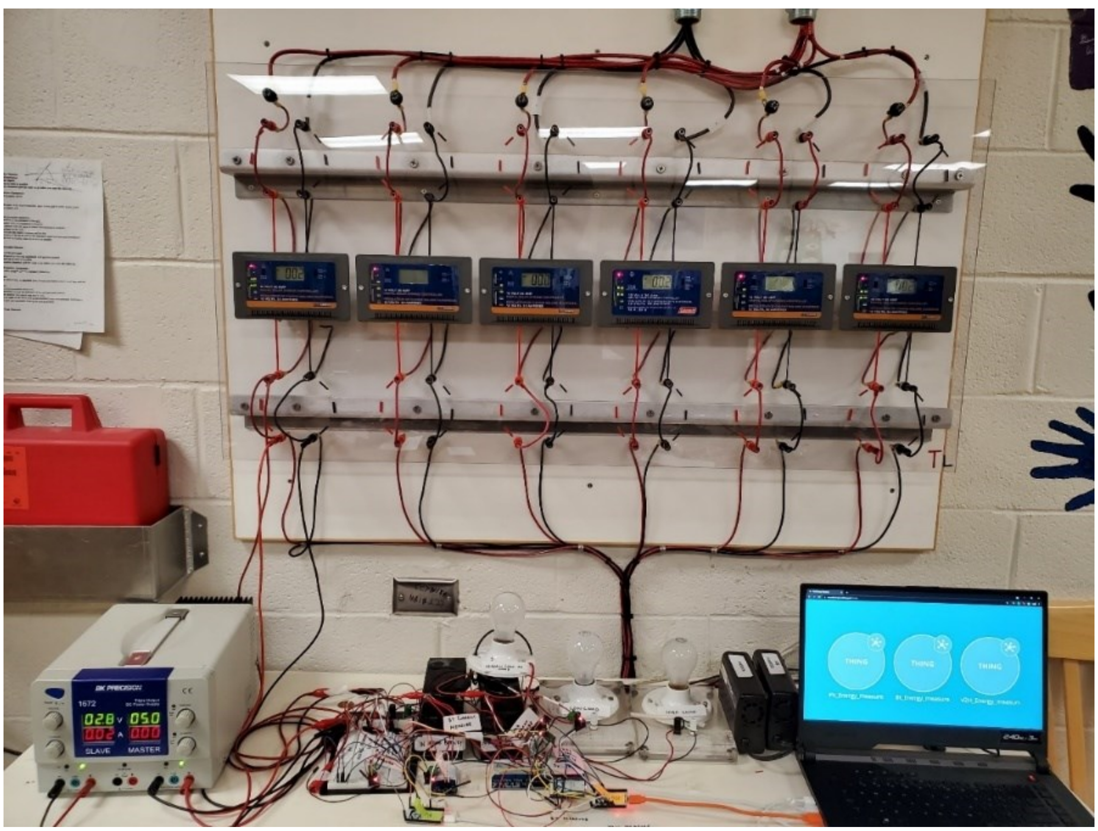


Figure 5.14 – Lab setup of the implemented system.

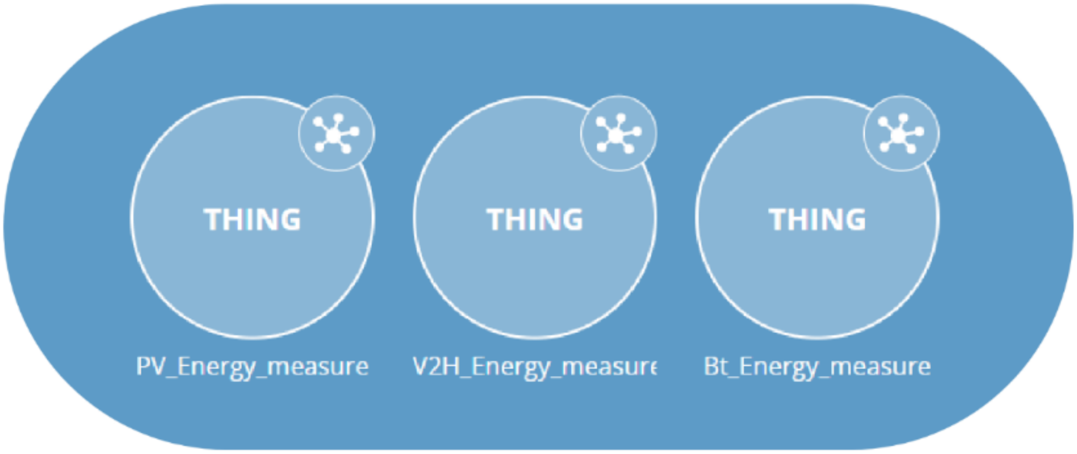


Figure 5.15 – GUI for Web Things gateway.

5.4.2 Implemented system.

As seen in fig. 14, the entire system is powered by 12 V. The experimental system is being used to illustrate the concept of IoT, monitoring, and control. The following modes were simulated, and the results are displayed as graphs [15] [16].

5.4.2.1 Inhouse battery charge mode.

PV serves as the primary source of energy in this mode [17] [18 [19], powering the load and charging the battery. The PV's overall GUI is seen in Figure 5.16. Switch S1 is HIGH, as can be seen in figure 5.16, and 13 V is generated. The in-house battery is charged with one amp of electricity. The recorded data of PV voltage and current is shown as graph in figure 5.17. The PV panel produced 13 V and the battery was charged with 1A amp of current. The voltage and current graph for in-house batteries is shown in Figure 5.18. The battery was being charged at 13 volts and 1 amp.

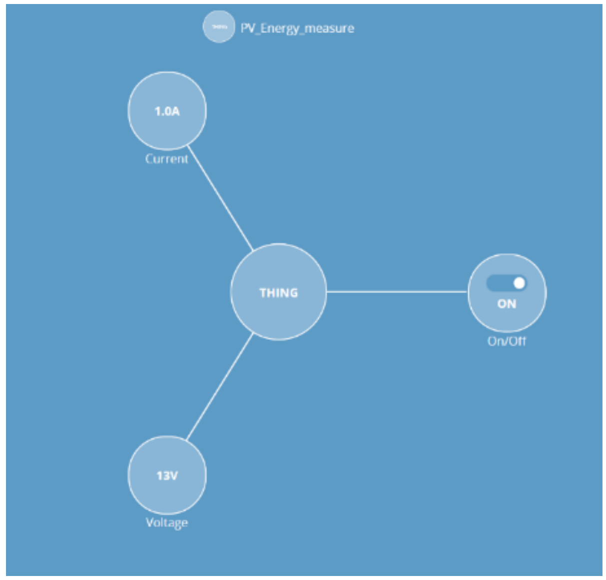


Figure 5.16 Overall GUI for PV Energy Measure.

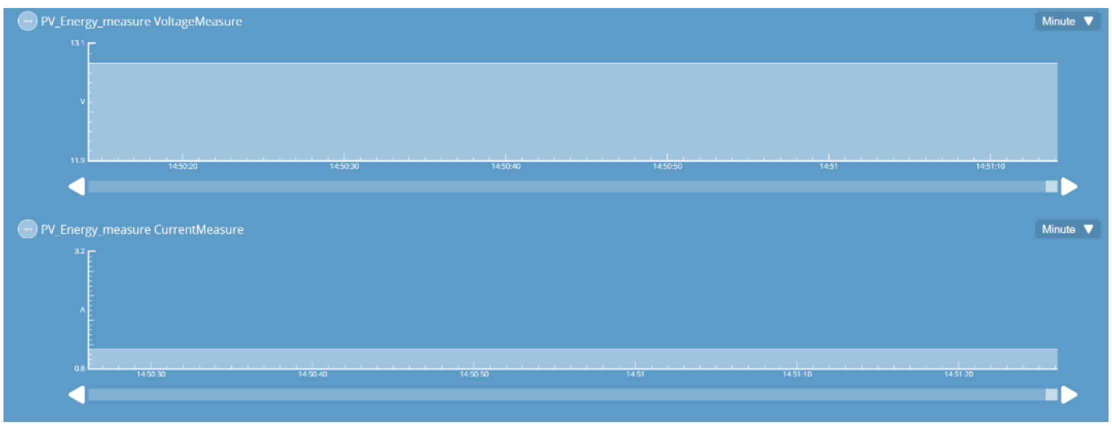


Figure 5.17 - Voltage and current measurement graph for PV.

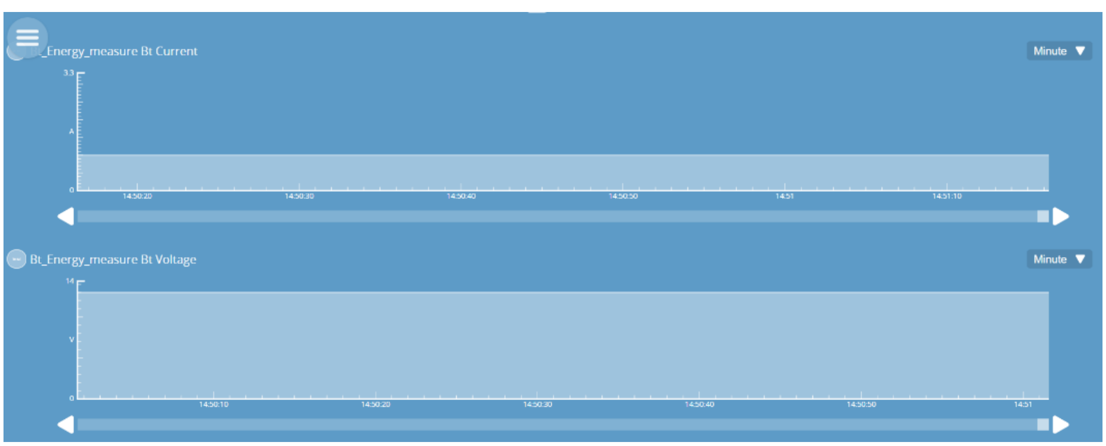


Figure 5.18 - Voltage and current measurement graph for in-house battery.

5.4.2.2 Inhouse battery discharge mode.

In this mode, the battery acts as the source of power, powering the load. Fig. 19 depicts the overall user interface for Inhouse batteries. As shown in figure 5.19, switches S3, S8 are HIGH and the battery is at a voltage of 13V and discharging at 3 amps to satisfy the energy requirement of the house load with the help of the inverter. The load is 120 V and draws 1.3 A; in this situation, the load is a lightbulb. The inhouse battery is draining at 13 V, 3 A, as shown in figure 5.20, while the load is running at 120 V, 1.3 A, as shown in figure 5.21. The experimental setup for an in-house battery in discharge mode is shown in figure 5.22.

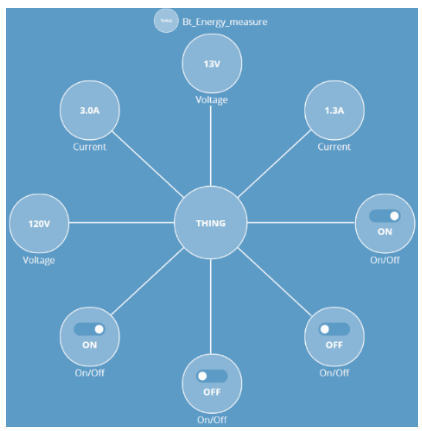


Figure 5.19 - Control logic for inhouse battery charging.

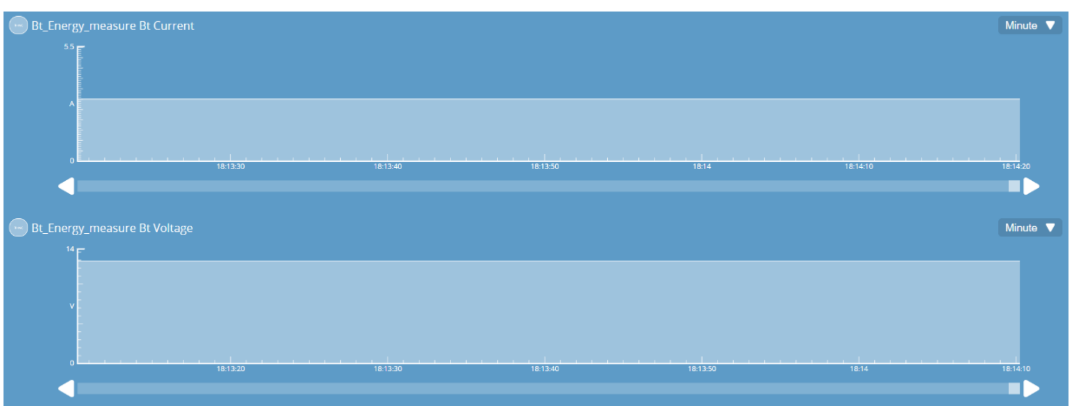


Figure 5.20 - Voltage and current measurement graph for inhouse battery.

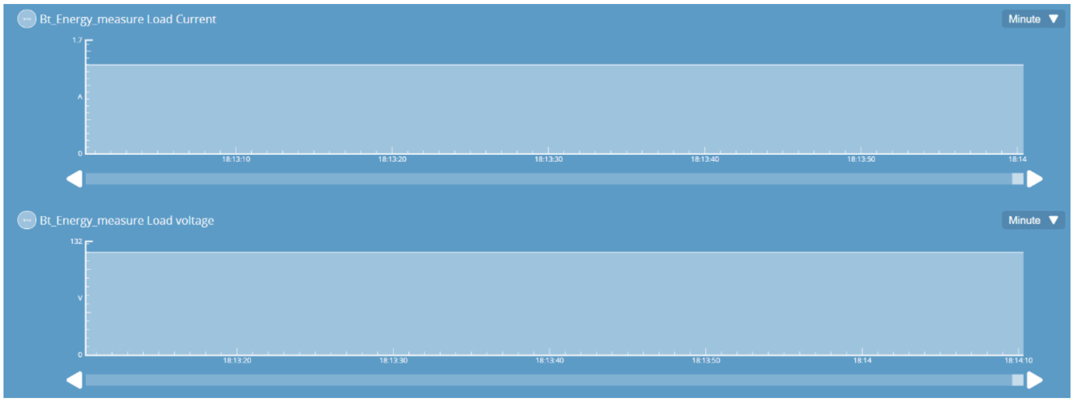


Figure 5.21 - Voltage and current measurement graph for load.

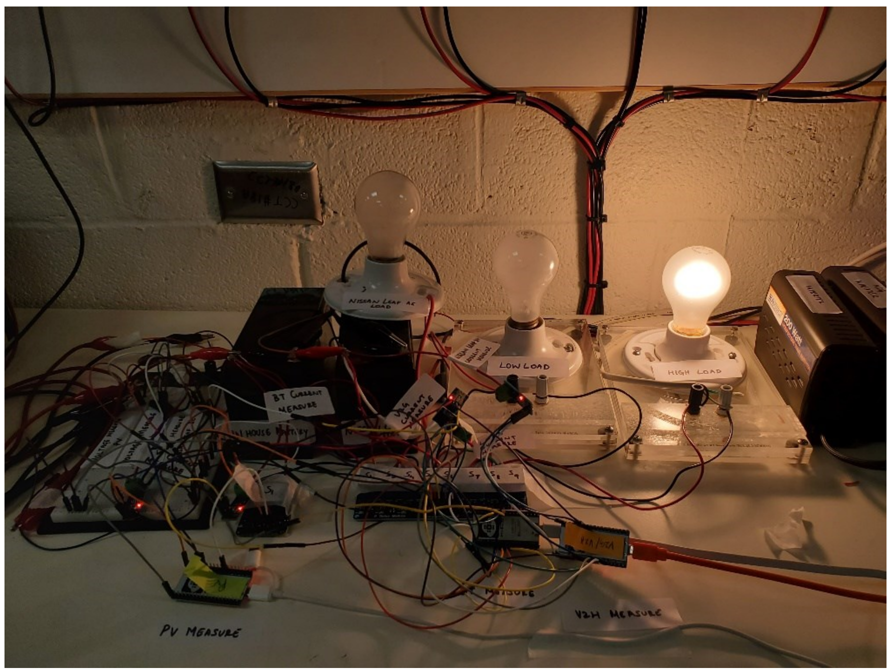
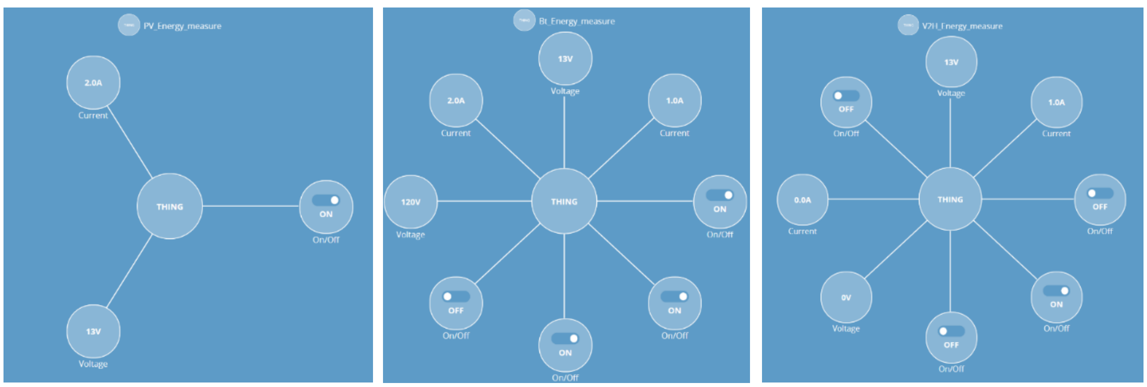


Figure 5.22 – Experimental setup for inhouse battery in discharge mode.

5.4.2.3 Nissan Leaf in charging mode.

In this mode, the remaining energy after satisfying the load's energy demand is utilized to charge the Nissan Leaf's battery [20], which is a 12 V lead acid battery in this case. PV is providing 13 V and simultaneously charging the battery and powering the load at 2 A, thus switches S1, S2, S3, S4, S7 are HIGH. In this example, the load consumes 120V at 1 amp. The Nissan Leaf battery is also charged at 1 A and 13 V. Figure 5.23, The overall PV GUI is shown in (a), the overall inhouse battery GUI is shown in (b), and the overall V2H/V2G GUI is shown in (c). From figure 5.24. it can be observed that the PV produces 13V, and that 2 amp of electricity is used to power the load and charge the in-house battery. From figure 5.25. the inhouse battery is shown to be at 13V, with 2 amps of current going to the load and charging the inhouse battery. The voltage and current measurement graph for the load is shown Figure 5.26. From figure 5.27, the Nissan Leaf battery is charging at 13 volts and 1 amp, as can be observed.

Nissan Leaf battery is charging at 13 volts and 1 amp, as can be observed.



(a) (b) (c)

Figure 5.23 (a) Overall PV GUI, (b) Overall Battery GUI (c) Overall V2H/V2G GUI.

Figure 5. 24 - Voltage and current measurement graph for PV.

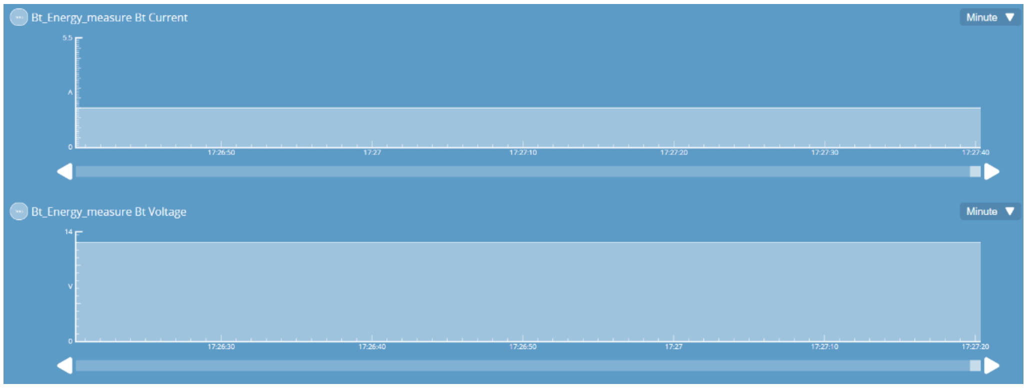


Figure 5.25 - Voltage and current measurement graph for inhouse battery.

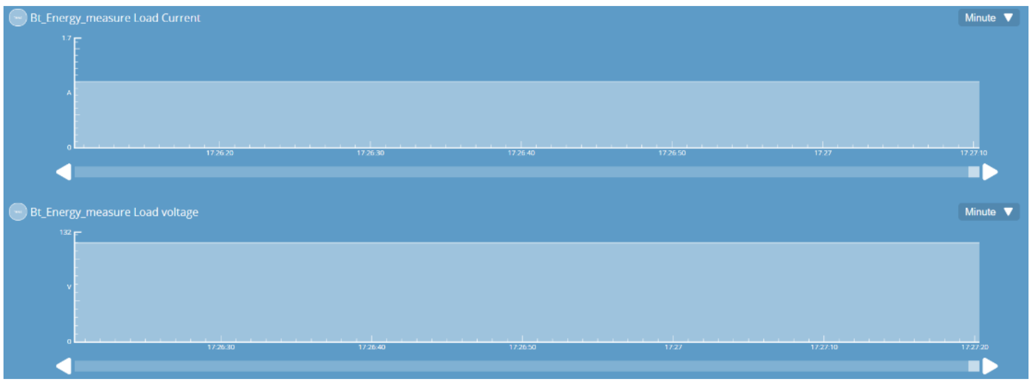


Figure 5.26 - Voltage and current measurement graph for load

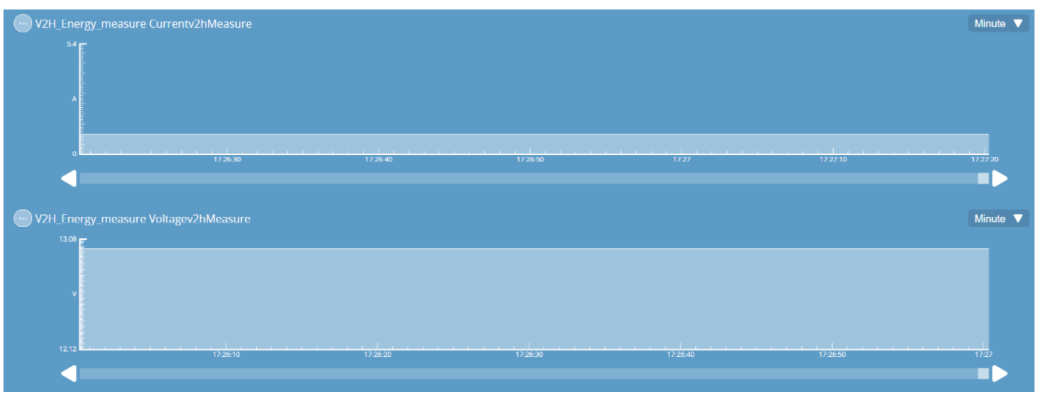


Figure 5.27 - Voltage and current measurement graph for Nissan Leaf.

5.4.2.4 Nissan Leaf as load.

In this mode, the Nissan Leaf serves as a load, and a DC light bulb is used to imitate the Nissan Leaf as a load. Switch S5 is HIGH in this mode, as seen in figure 5.28. The entire V2H/V2G GUI is seen in figure 5.28. The Nissan Leaf battery is draining at a rate of 13V and 5 amps, as seen in figure 5.29. The voltage and current measurement graph of a Nissan Leaf battery is shown in figure 5.29. Figure 5.30 depicts the experimental setup for demonstrating the working on a Nissan Leaf as a load.

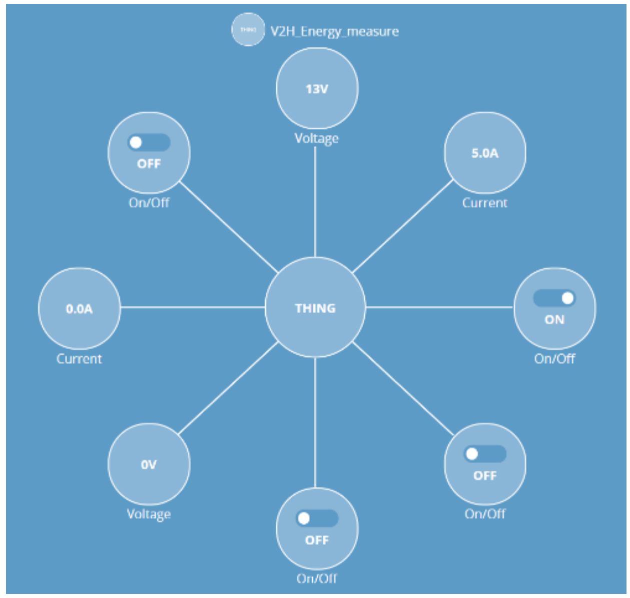


Figure 5.28 Overall V2H/V2G GUI.

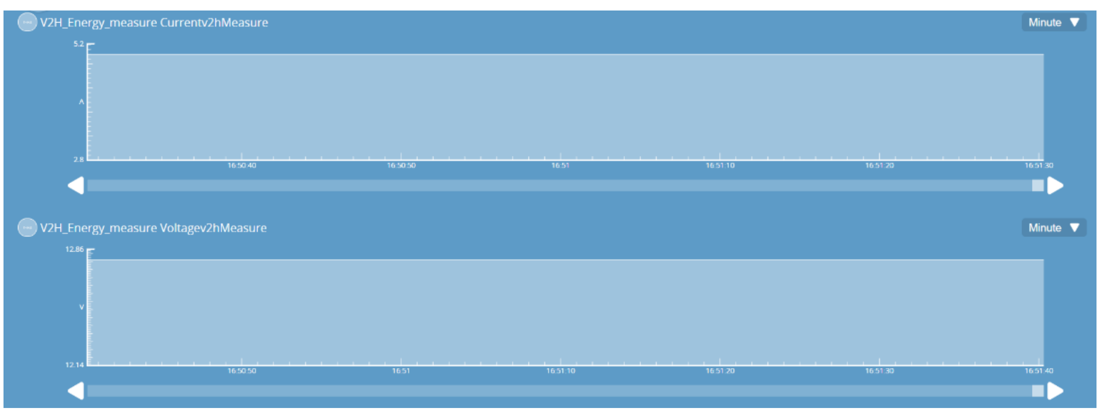


Figure 5.29 - Voltage and current measurement for Nissan Leaf battery.

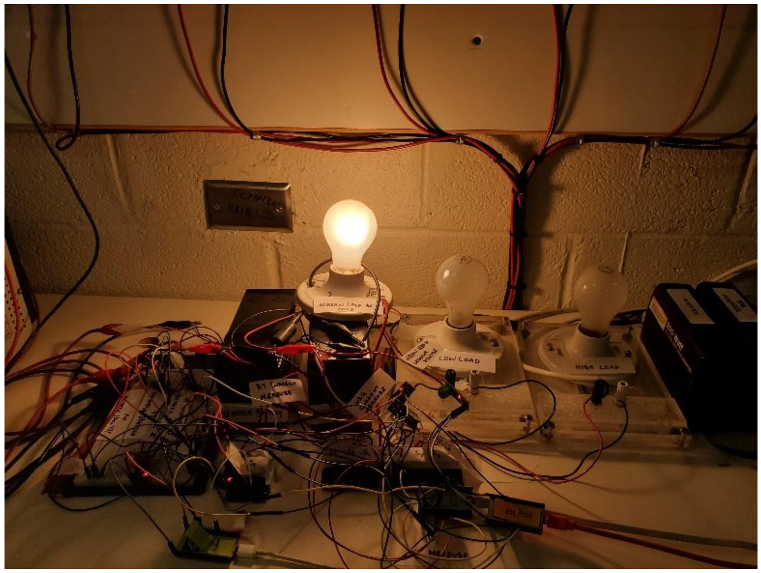


Fig. 5.30 - Experimental setup for Nissan Leaf as load.

5.4.2.5 Nissan Leaf in discharge – Vehicle to Home (V2H) mode

When the power of the in-house batteries is low and the energy demand of the loads is high, this mode is used. Nissan Leaf reels the stored power to fulfil the load's energy requirement while also charging the in-house battery. Figure 5.31. (a) overall V2H/V2G GUI and (b) overall Inhouse battery GUI, shows that switches S6, S3, and S7 are HIGH. The Nissan Leaf battery is also discharged at 12V and 1.5 amps to power the load and charge the inhouse battery, as shown in figure 5.31. (a). The voltage and current measurement graph for the in-house battery is shown in figure 5.32. The load is operating at 120V and 1 amp, as shown in figure 5.33. The voltage and current measurement graph for Nissan Leaf is shown in fig. 34. Fig. 35, depicts the V2H mode experimental setup.

(a) (b)

Figure 5.31 (a) Overall V2H/V2G GUI, (b) Overall inhouse battery GUI

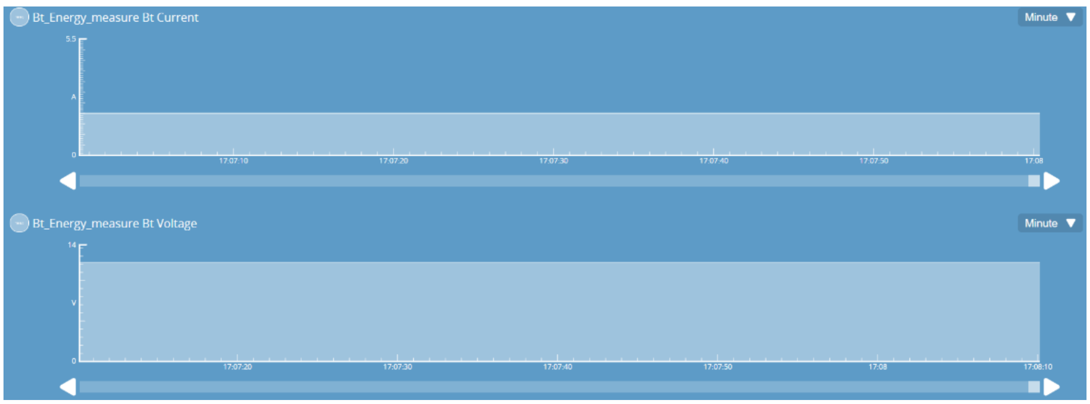


Figure 5.32 - Voltage and current measurement graph for inhouse battery.

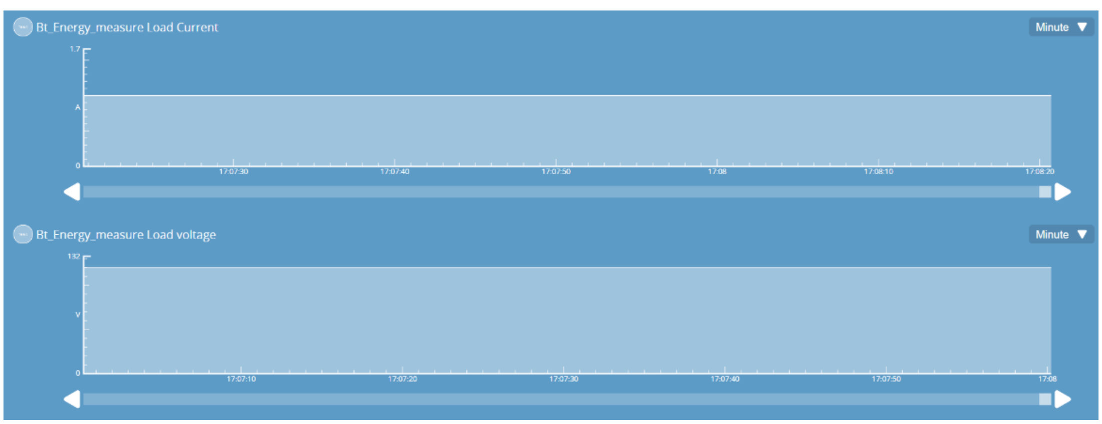


Figure 5.33 - Voltage and current measurement graph for load.

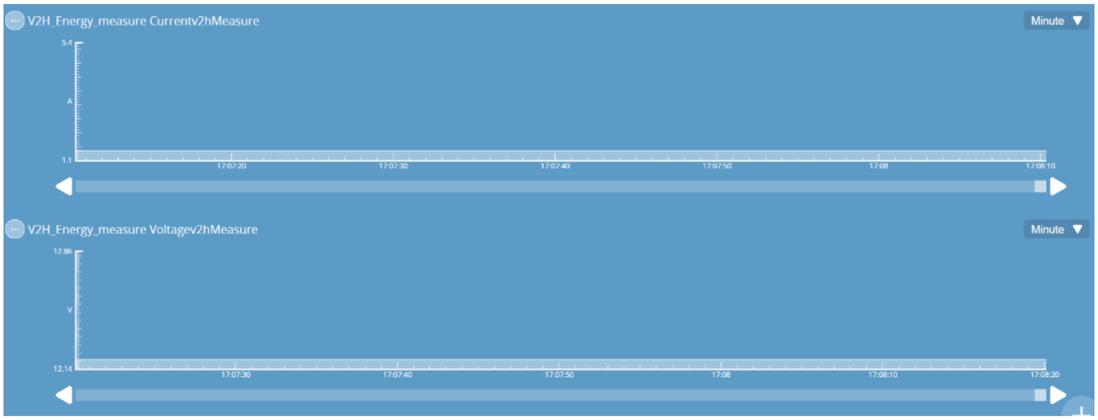


Figure 5.34 - Voltage and current measurement graph for Nissan Leaf battery.

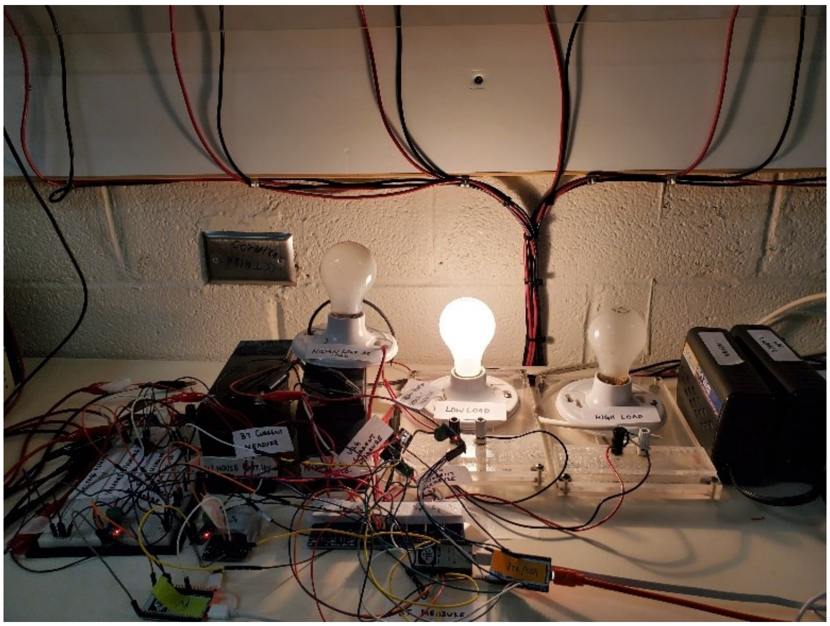
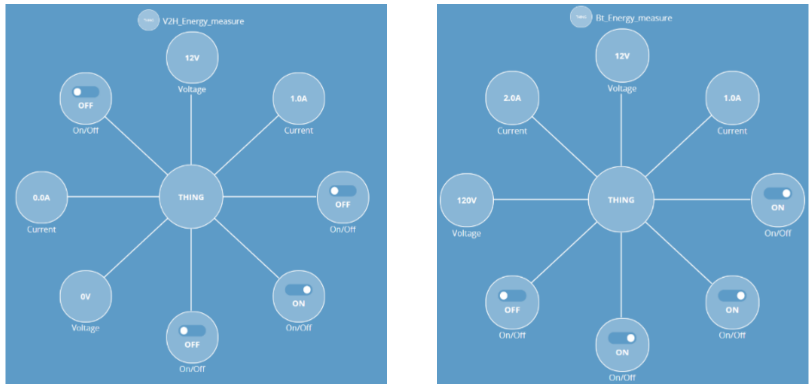


Figure 5.35 - Experimental setup for V2H mode.

5.4.2.6 Nighttime charging mode.

When the load energy demand is minimal, the in-house battery is utilized to charge the Nissan Leaf battery [21]. As shown in figure 5.36 (a) overall V2H/V2G GUI, (b) overall inhouse battery GUI), switches S3, S4, and S7 are HIGH in this mode. The voltage and current measurement graph for the in-house battery is shown in figure 5.37. The load is working at 120V and 1 amp, as shown in figure 38, while the Nissan Leaf battery is charging at 12 V and 1 A, as shown in figure 5.39.



(a) (b)

Figure 36 (a) Overall V2H/V2G GUI, (b) Overall Inhouse battery GUI.

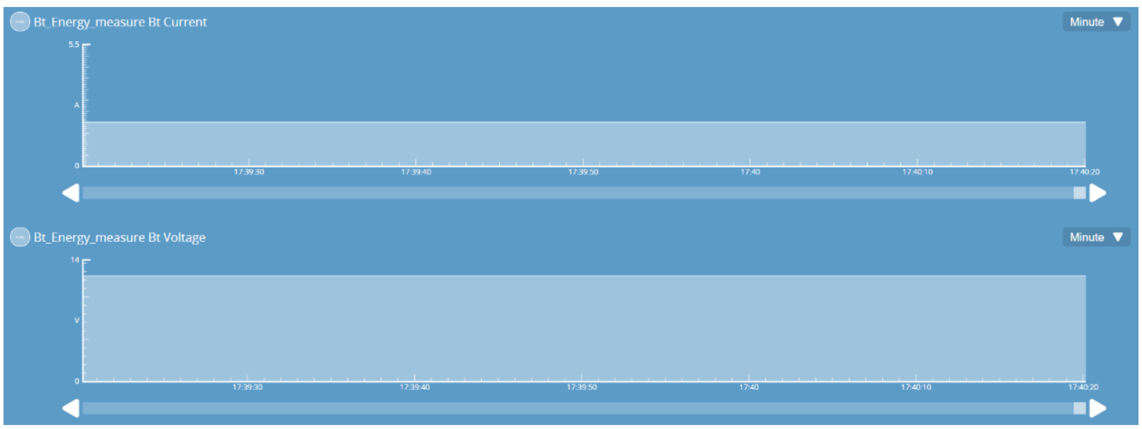


Figure 5.37 - Voltage and current measurement graph for inhouse battery.

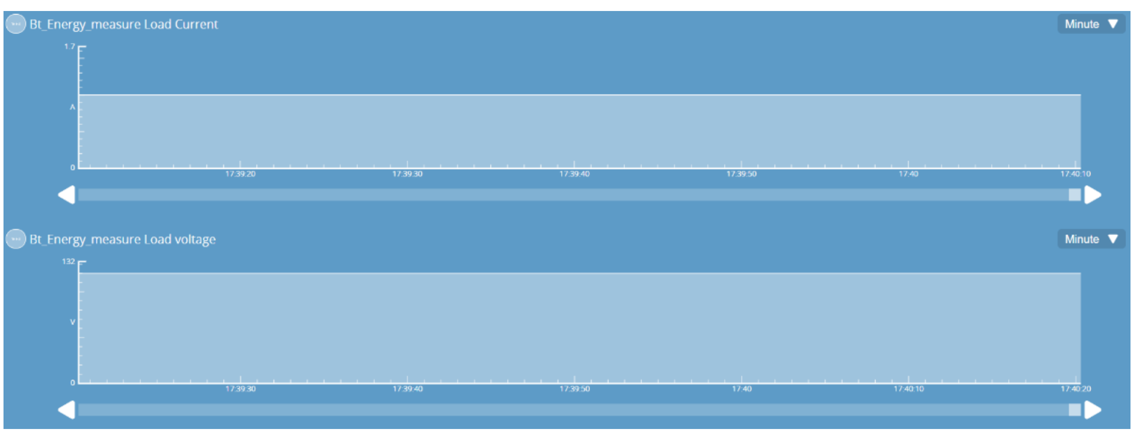


Figure 5.38 - Voltage and current measurement graph for load.

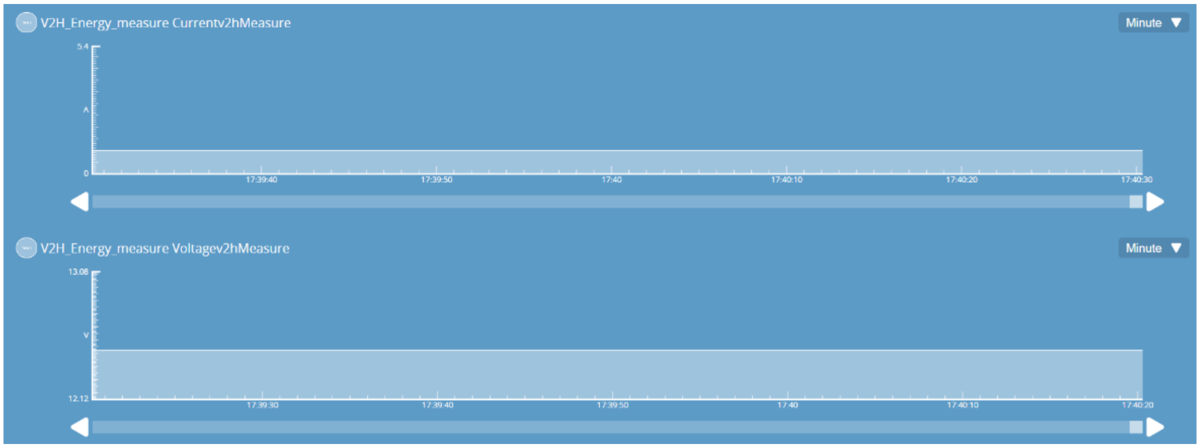


Figure 5.39 - Voltage and current measurement graph for Nissan Leaf battery.

5.4.2.7 Vehicle to Grid (V2G) mode.

The car disconnects from the home in this mode, and the stored energy is redirected to the grid. A light bulb is used as a load in this example, and the load is powered by an inverter. Figure 5.40 depicts the entire V2H/V2G GUI with switch S9 in the HIGH position. The Nissan Leaf battery is discharging at 3 A and 12 V, as shown in figure 5.41, while the load is consuming 1 A and functioning at 120 V, as shown in figure 5.42. The experimental setup for the V2G mode is shown in figure 5.43.

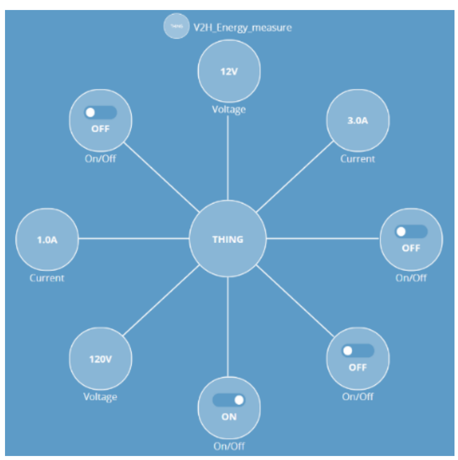


Figure 5.40 - Overall V2H/V2G GUI.

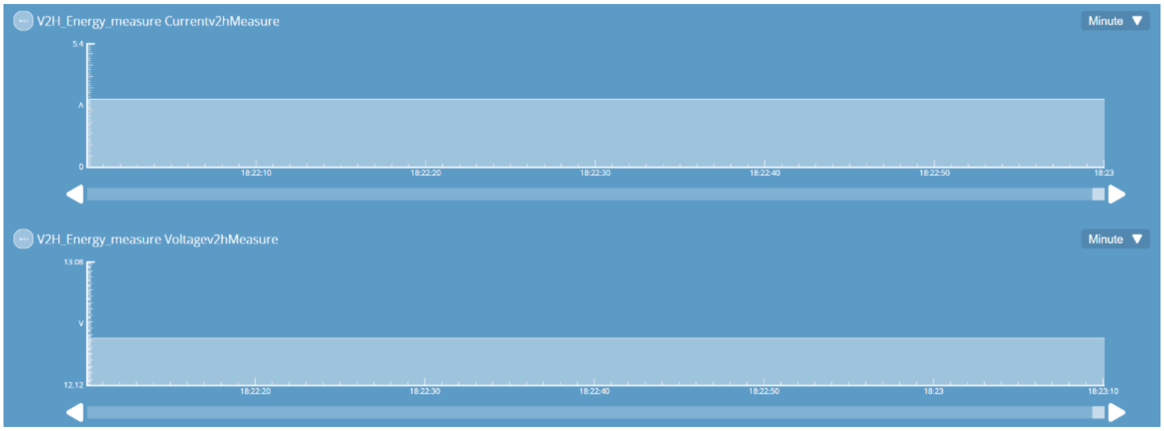


Figure 5.41 - Voltage and current measurement graph for Nissan Leaf battery.

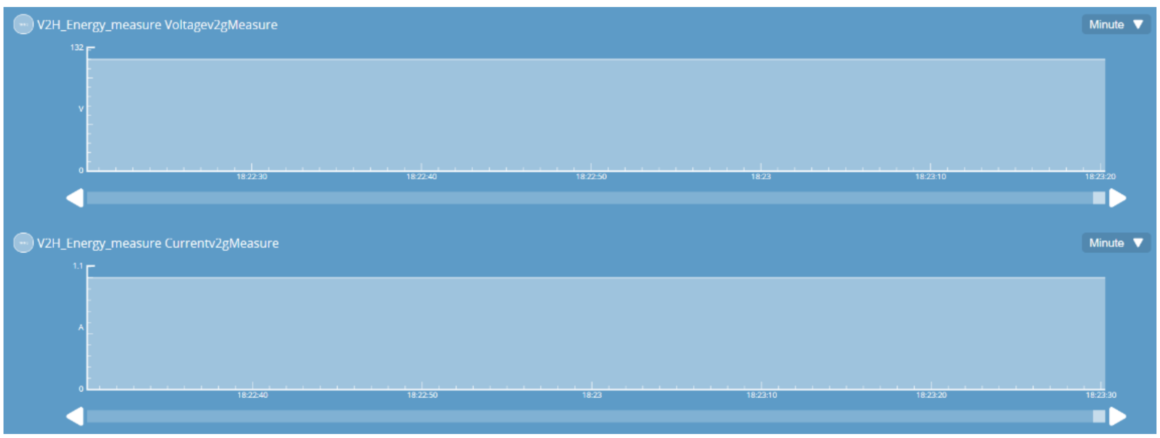


Figure 5.42 - Voltage and current measurement graph for grid as load.

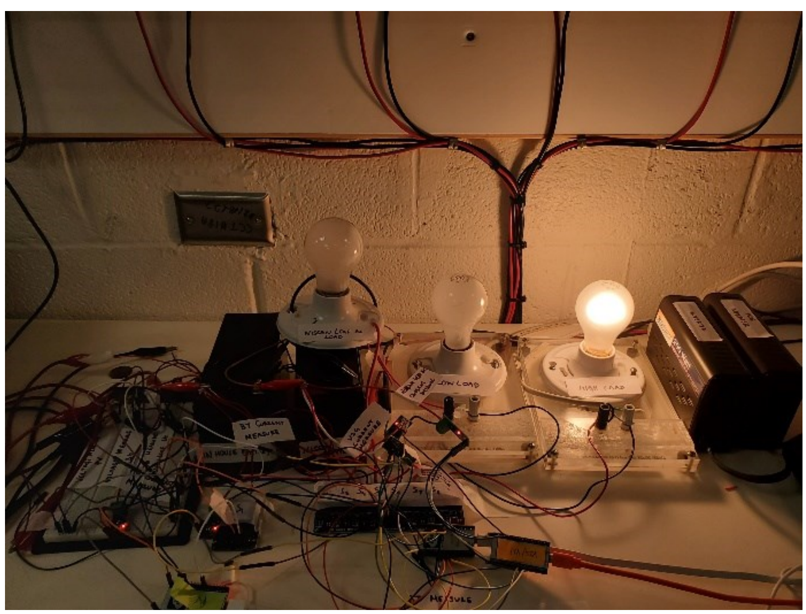


Figure 5.43 - Experimental setup for V2G mode.

5.5 Conclusions

Through Mozilla IoT, a solar energy system supervisory control was successfully implemented with vehicle to home (V2H) and vehicle to grid (V2G) options for Newfoundland conditions. The entire experimental system was powered by 12V, and it was used to demonstrate the concept of IoT, as well as remote control and monitoring. The actual system, on the other hand, contains several DC-DC converters and a variety of voltage levels. The current and voltage sensors generate data, which the ESP 32 microcontroller collects and sends to the WebThings gateway hosted on the Raspberry Pi. Using Mozilla's https tunnelling, the data transferred would be seen on the web. Because of its interoperability and privacy, Mozilla IoT was considered. The data is sent to the gateway through IoT, but it is not saved in the cloud; instead, it is kept locally. Three ESP 32 were used to run the experiment in eight different modes, with various parameters such as PV current and voltage, Inhouse batteries current and voltage, load current, and Nissan Leaf batteries current and voltage being monitored and logged. These parameters were transmitted in real time to the gateway. Because of WebThings, this system is scalable, open source, and interoperable, and it can also be implemented in production. Furthermore, because this research is scalable, it can be used to implement in EV parking lots, connect several residences to form a microgrid, implement a V2X model, where cars are used to schedule loads [22] [23], power microgrids or enterprises, or implement V2V charging [24] [25].

Acknowledgments

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Chapter 6

Conclusions and Future Works

6.1 Conclusions

With the increased interest towards greener environment, people have become more conscious of the impact that fossil fuels and rising Co2 output have on out environment, in turn paving the way for EVs and renewable energy development. Small renewable energy systems with V2H and V2G options are becoming increasingly popular among residential installations. Although hydro and wind energy account for a significant portion of the current renewable energy industry, solar photovoltaic systems are the most often employed for residential applications. Electric vehicles (EVs) feature large batteries, making them mobile power banks. EVs may also be utilized to provide V2H and V2G support, which would be achieved through their batteries, rather than merely reducing greenhouse gas emissions. When connected to the home for V2H operation, it will use the stored energy to power the house until the need is met by another source of power. When connected to the grid, the energy stored in batteries may also be used to deliver power to the grid, therefore balancing the demand. This indicates that electric vehicles might help with the energy balance (frequency stabilization) of the electric power grid.

Furthermore, to ensure smooth execution and transition between various modes, such as charging the inhouse battery, charging EV batteries, discharging the inhouse battery to meet the home's load demand or charging the electric vehicle, or implementing V2H or V2G concepts, an efficient system design is required. Extensive research was conducted in order to design and construct a solar energy system for a home with Vehicle to Home and Vehicle to Grid options in this thesis. BEopt software was used to design a standalone hybrid PV system based on annual load data from the selected site's thermal modelling.

Furthermore, HOMER software was used to size the system, providing information on the size of the PV array and strings, the number of batteries, the inverter, and the energy requirements of the loads throughout the year. The dynamic modelling of PV based system for a home with V2H option was simulated using MATLAB/Simulink. PV panels considered are 340 W modules producing 16.3984 kW implemented in 24 strings with 2 panels in each string along with MPPT algorithm to maximize the power output. A commercially available inverter of 20 kW capacity was incorporated with 80 Trojan SAGM 12 105 batteries each of 12 V and 100 Ah along with a 10 kW backup genset, Nissan Leaf is implemented as deferrable load with 9.90 kWh/d with 6.60 kW peak. The implemented simulation consists of eight main operating modes i) Inhouse battery charging mode- power produced by PV is used for charging the inhouse battery and for powering the loads simultaneously, ii) inhouse battery discharge mode – The stored power in the inhouse house battery is used to meet the loads energy demand, iii) Nissan Leaf charging mode – The loads energy demand is met and the inhouse battery is charged, the excess power is used for charging Nissan Leaf, iv) Nissan Leaf discharge mode- the loads energy demand is high and the output form PV and inhouse batteries SOC is low Nissan Leaf reels out the stored energy to meet the loads energy demand, v) inhouse battery protection mode – prevents the inhouse battery from going into degenerative discharge condition, vi) system isolation mode – to prevent the system from failing, vii) excess power handing mode – to handle the excess power produced, viii) nighttime charging mode – To charge Nissan Leaf to get it ready for next day's use.

In addition, for the dynamic modelling of V2G systems, a new control mode, V2G mode – Power is reeled to the grid, was introduced. MPPT controller, Current controller (PI), PLL, buck converter, boost converter, center tap transformer, and charge controllers are all part of the proposed control system. The results show that the designed system performed flawlessly in all modes.

As a result, the Internet of Things (IoT) could be used as a platform for remotely controlling and monitoring system execution in real time. Because IoT is such a powerful platform, software vulnerabilities, complexity, interoperability, privacy, and scalability are just a few of the major issues. Software attacks, poor cryptography, authentication problems, and the complexity of deploying software make devices vulnerable. Furthermore, flaws in IoT devices lead to attack points that expose the networks on which they reside in the event of software vulnerabilities. This applies to both homes and businesses, because an IoT device that fails to secure the wireless network's security credentials exposes the whole network. With so many individuals working remotely these days, a single IoT failure might result in an attack that impacts both residential and corporate networks.

In terms of complexity, the main issue is that the Internet of Things has proven to be far more complex than originally anticipated. To begin with, there are various IoT connectivity choices, but this diversity is more confusing than being helpful. Aside from that, most connected devices have limited computational power and are designed incompatible with robust protection mechanisms. IoT adopters must equip their networks with multi-layered security controls to minimize this serious vulnerability and protect them from hackers and malware. One of the most essential features is interoperability. Businesses want to reduce risk, and one way to do so is to avoid relying on a single provider. Multi-vendor systems can also be more robust. The IT systems that connect to the operational systems are also crucial. However, without proper data sharing and security standards, the IoT concept would fall short of its full potential. IoT devices unquestionably provide customers with a wonderful experience, but security concerns have long accompanied the Internet of Things.

To prevent data leaking, IoT devices must communicate information using advanced encryption. This would take a very long time to happen. Another factor that raises questions about the system's dependability is its increased complexity. Because the Internet of Things is such a large and varied network, it's likely that apps may fail or the IoT infrastructure will go down. IoT systems are changing the way we connect with the world in terms of scalability. The infrastructure paradigm lends itself to global size, and global scale leads to the development of global public clouds. Large-scale public cloud projects began with software porting to the cloud. This lift-and-shift strategy, in which on-premises applications are moved to the cloud without being rebuilt, works, but it doesn't utilize native cloud features, resulting in waste, expensive AWS/Azure costs, and inefficiency.

As a result, many businesses are updating their IoT strategies by deploying updated Kubernetes-based public cloud installations, which will require significant extra expenditure before IoT can be implemented globally. In this thesis, Mozilla IoT is used as a platform for providing real-time remote control and monitoring of the proposed system. Because of its security, privacy, interoperability, and overall value, Mozilla IoT was chosen for this study. In the proposed system, key parameters including current and voltage are monitored, analyzed, and sent in real time to Mozilla IoT's WebThings gateway. Depending on the parameters, the system can operate in a number of modes.

The designed system was implementation as a all 12 V system to demonstrate the IoT, remote control and monitoring concept. While the actual system has different voltage levels and involves multiple DC-DC converters. The presented IoT system consist of current and voltage sensors, ESP 32, Mozilla IoT, Raspberry Pi, batteries, inverters and WebThings gateway. The IoT aspect is handled by Mozilla IoT, and the ESP 32 microcontroller is utilized to transmit data to the gateway as well as control and monitor remotely through the dashboard. The Mozilla IoT WebThings gateway is installed locally on the Raspberry Pi to assure data integrity, security, and interoperability by only allowing access through Mozilla's http tunneling. The implemented system was thoroughly tested, and the results show that it performed accurately in all modes.

6.2 Future Works

The work presented in this thesis points to new directions in the development of a reliable, secure, IoT-based solar energy system for a house with V2H and V2G options. However, the system was intended and developed to be scalable, the following are some ideas for further work:

- Implementing the designed system in EV parking lots
- Connecting number of parking lots together to power several houses or a microgrid or businesses or a city.
- Implement V2X concept, where EVs can be used to schedule loads.

- Providing this system as an application in the Smart Grid.

6.3 List of Publications Refereed Journal Articles

1. R. Sundararajan, M. T. Iqbal, "Dynamic Modelling of Solar Energy System with Vehicle to Home option for Newfoundland Conditions" EJERS 2021, Volume 6, Issue 5, doi:10.24018/ejers.2021.6.5.2497.
2. R. Sundararajan, M. T. Iqbal, "Dynamic Modelling of Solar Energy System with Vehicle to Home and Vehicle to Grid option for Newfoundland Conditions" EJECE 2021, Vol 5, Issue 3, doi: 10.24018/ejece.2021.5. 3. 329.
3. R. Sundararajan, M. T. Iqbal, "Hardware implementation of Solar Energy System with Vehicle to Home option for Newfoundland Conditions through Mozilla IoT" JJEE 2021 (submitted).

Refereed Conference Publication

4. R. S. Sundararajan and M. T. Iqbal, "Design of an IoT interface for a solar energy system with vehicle to home option for Newfoundland conditions," 2020 11th IEEE Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), 2020, pp. 0597-0601, doi: 10.1109 /IEMCON51383.2020.9284859.

Regional Conference Publications

5. R. S. Sundararajan and M. T. Iqbal, "Design of Solar Parking lot for 20 electric vehicles in St.John’s, NL," 29th Annual Newfoundland Electrical and Computer Engineering Conference (IEEE NECEC 2020), St.John’s, NL, Canada, November 19, 2020.

6. R. S. Sundararajan and M. T. Iqbal, "Dynamic Simulation of an isolated Solar powered charging facility for 20 Electric Vehicles in St.John’s, Newfoundland," 29th Annual Newfoundland Electrical and Computer Engineering Conference (IEEE NECEC 2020), St.John’s, NL, Canada, November 19, 2020.