SOLAR ENERGY MANAGEMENT SYSTEM WITH SUPERCAPACITORS FOR RURAL APPLICATION

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ABSTRACT

Growing energy demands are expected to exceed the supply from current energy resources. Therefore, renewable energy and energy management systems will become more crucial for increasing supply and efficiency of energy usage. The novelty of this research is an energy management system (EMS) based on fuzzy logic for a solar house to ensure the maximum utilisation of renewable sources, protect components from being damaged due to overloading, and manage energy storage devices to increase stability in the power system. There is no published analysis of hybrid energy storage between battery and supercapacitor using fuzzy logic as EMS. The energy management system is implemented in a solar cabin system developed by IBC Solar to mimic a typical rural house. The solar cabin is equipped with solar photovoltaic panels, solar charger, battery and inverter. Supercapacitors and a custom made DC to DC converter were added to the system to support the batteries during high current load demand and manage energy flow. Three sets of experiments were conducted in the solar cabin system with the new energy management system. Power consumption usage of a typical rural household was studied to create two load profiles that were used as load for the experiments. The results show an efficiency of 95.9% by using the new energy management system and supercapacitors to the solar cabin, which is higher than recent research (95.2% and 84.4%). The result is on par with the Malaysian and International Standard in energy efficiency of around 95%. The energy management system controlled the charging and discharging of the battery and supercapacitor using fuzzy logic. The novelty of this thesis is use of supercapacitors to reduce stress on the battery and an energy management system to control and manage the system for efficient energy usage.

LIST OF PUBLICATIONS

1. M. I. Fahmi, M Shahrukh, Aravind, D Isa, “Design of a Half-Bridge DC/DC Converter for Supercapacitor based Hybrid PV Storage System”, 6th International Grand Challenges Engineering Research Conference (6th eureca) 2016. Pages 1017-1022.

2. M. I. Fahmi, Rajkumar, R.K, Wan WY, Lee Wai C, Arelhi R, Isa D. “The Effectiveness of New Solar Photovoltaic System with Supercapacitor for Rural Areas”. International Journal of Renewable Energy Development 2016; 5:249. doi:10.14710/ijred.5.3.249-257.

3. M. I. Fahmi; Rajkumar, R.K.; Arelhi, R.; Isa, D. "Study on the effect of supercapacitors in solar PV system for rural application in Malaysia", Power Engineering Conference (UPEC), 2015 50th International Universities, UK. Page: 1 – 5. doi:10.1109/UPEC.2015.7339921.

4. M. I. Fahmi, Rajkumar, R., Arelhi, R., Rajkumar, R., & Isa, D. The performance of a solar PV system using supercapacitor and varying loads. 2014 IEEE Student Conference on Research and Development (pp. 1–5). doi:10.1109/SCORED.2014.7072984

5. M. I. Fahmi, Rajkumar, R., R. Arelhi and D. Isa,. "Solar PV system for off-grid electrification in rural area," Clean Energy and Technology (CEAT) 2014, 3rd IET International Conference on, Kuching, 2014, pp. 1-6. doi: 10.1049/cp.2014.1496

6. M. I. Fahmi, Rajkumar, R., Arelhi, R., Rajkumar, R., & Isa, D. Solar Hybrid PV System for Off-Grid Electrification in Semenyih, Malaysia. 2014 Applied Mechanics and Materials, 704, 195–198. doi:10.4028/www.scientific.net/AMM.704.195

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LIST OF ABBREVIATIONS

Abbreviations	Meanings
ADC	Analog-to-digital converter
BJT	bipolar junction transistor
DAQ	data acquisition system
DC	direct current
ECMS	equivalent consumption minimization strategy
EDLC	electrochemical double layer capacitor
EMS	energy management system
ESR	equivalent series resistance
EV	electric vehicle
FiT	Feed in Tariff
GA	genetic algorithm
GUI	graphical user interface
IGBT	insulated-gate bipolar transistor
LPSP	Loss of Power Supply Probability
MBIPV	Malaysian Building Integrated Photovoltaic
MIAD	multiplicative-in-crease-additive-decrease
MOSFET	metal–oxide–semiconductor field-effect transistor
MPPT	maximum power point trackers
MWh	Megawatt-hours

NRSE	Non-referenced single ended
PV	Photovoltaic
RSE	Referenced single-ended
RTDS	Real Time Digital Simulator
SC	Supercapacitor
SEDA	Sustainable Energy Development Authority of Malaysia
SEPIC	single-ended primary inductance converter
SOC	state-of-charge
SVM	support vector machine
tcf	trillion cubic feet
UNMC	University of Nottingham Malaysia Campus
UPS	Uninterruptible Power Supplies
VRLA	valve regulated lead acid
WG	Wind Generator

CHAPTER I: INTRODUCTION

1.0 Background

Presently, the world faces the problem of reducing reliance on fossil sources to generate energy. Fossil sources such as coal, natural gas, etc. are non-renewable, and reserves are increasingly becoming depleted [1]. Due to this concern, the need to develop alternative energy sources becomes very critical especially to stem the increase of the world ambient temperature from the effects of the usage of fossil fuels [2]. Long-term new and renewable energy sources are needed to replace dependence on fossil fuels and coal. Electrical power usage and demands now show a rapid growth especially in industrial and residential sectors [3].

In recent times, there is an increased awareness and attention on various issues relating to human technology advancements and increased energy utilisation. Keywords like greenhouse gases, global warming, pollution and reduction in world reserve of fossil fuels are extremely eye-catching and controversial nowadays. As shown in data provided by BP (international oil and gas company), global primary energy consumption has increased by 2.3% in the year 2013, compared to 2012 which was only 1.8%. Fossil fuel dependence is estimated to be 82% globally on energy consumption and production in the year 2013 [4].

In order to control this high reliance on fossil fuels to generate energy, the world has slowly turned to the utilisation of renewables. In 2013 the renewable energies contributed to more than 5% of global power output and almost 3% of primary energy consumption, with an increase of their consumption in the world by about 6% since 2012 [4].

According to Denholm[5], the worldwide solar PV average annual growth rate is estimated to be 37%. Hence, it is evident that utilisation of renewable energy sources has been given more focus in industry.

Solar energy is one of the renewable energy sources with the most potential [6]–[8]. This source of energy is ultimate and infinite. If used in the right way, the production from this power source can fulfil energy needs around the world. The emission power from the sun is approximately 1.8 x 10^{11} MW [9]. These large figures of emission power show that the energy is ready to use and can meet the energy demands of the future, so more research is needed to maximise energy available from the sun. According to Renewables 2014 Global Status Report, the total world energy consumption is 1,560 GW in 2013[10], and by 2050, it is projected to be about 30 TW [10].

These significant figures on the world energy consumption, show the need for extensive research to find innovative technologies to maximise usable energy available from the sun to fulfil future demands [9]. The total renewable energy power capacity in 2013 shown in Figure 1 is approximately 139 GW which is a growth of 55% from 2007 [10].

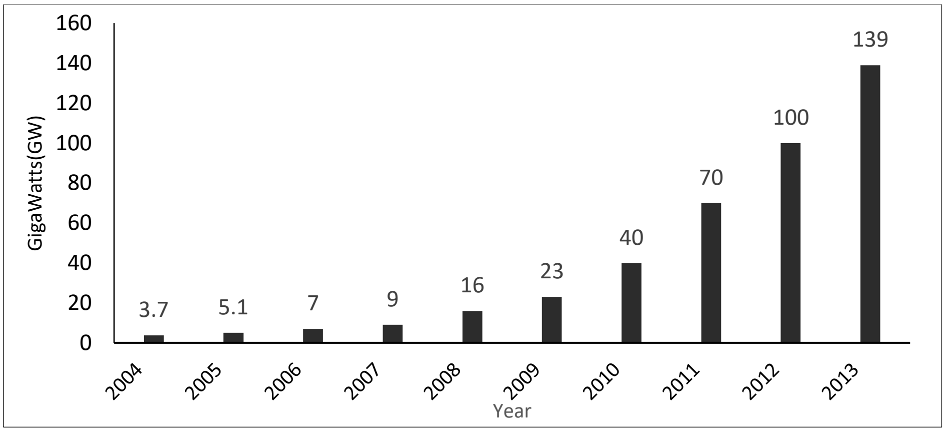


Figure 1. Solar PV Total Global Capacity 2004-2013 [9]

Meanwhile, to reduce the dependence on fossil fuels and higher demands in the future, the solar cabin system developed in UNMC consists of 20 interconnected modules of PV panels as a research platform to investigate energy generation for rural homes.

The PV modules are connected to the solar charger which in turn will charge the batteries and supercapacitors as well as directly supplying the DC load. An inverter is located between the output of the battery and supercapacitors to convert the energy from 48VDC to 230VAC. A programmable AC load is used to act like loads in a typical rural household. The whole system has a total capacity of 2kW and a full power of 7.2kWh from the batteries.

The non-grid connected solar cabin was developed in UNMC with the intention to prove that the proposed system can meet the energy demand of a typical rural household with solar power alone. The solar cabin was developed to study the feasibility of such a system to replace current diesel generators and to generate sufficient power to rural households.

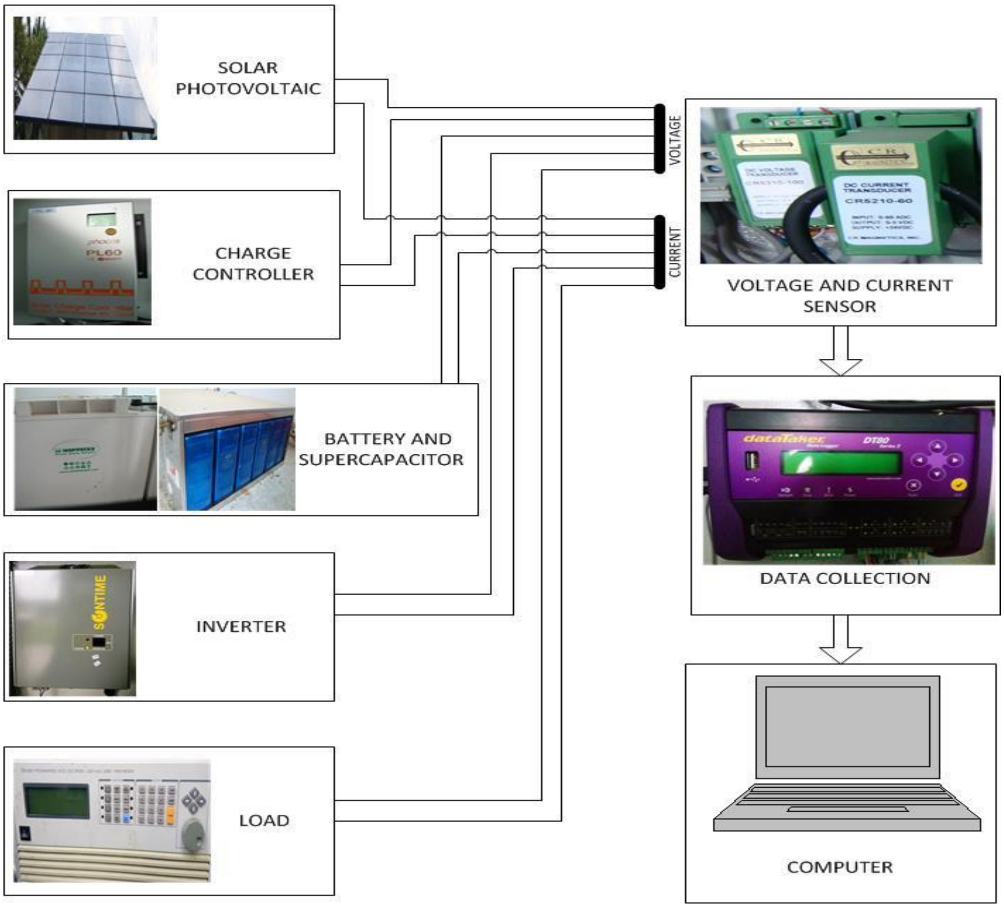


Figure 2. Solar Cabin Block Diagram

Figure 3. Solar Cabin at UNMC

Figure 2 shows the block diagram of the solar cabin system. Each of the solar PV panels are connected attached to a solar charger which will charge batteries with a total capacity of 300Ah to directly supply the DC load. The solar cabin is shown in Figure 3 and developed by IBC Solar and the University of Nottingham.

Growing consumption demands will eventually exceed the supply of critical resources, and the need for an energy management system becomes more important [11]. There are multiple roles of an energy management system in standalone solar systems. Namely, to protect the stability of a load supply in all situations, to ensure the maximum utilisation of renewable sources, protect components from being damaged due to overloading, and increase the stability of the power system [12].

In this thesis, the primary objective is to develop a monitoring and controlling system for the solar cabin using LabVIEW software and Fuzzy Logic using hybrid energy storage between supercapacitor and battery. A GUI is designed containing the live monitoring of relevant parameters in the solar cabin such as solar irradiation, load profile, solar power, etc. This is essential as it serves as the platform for the ease of further research and improvement in solar energy in which data parameters are continually utilised. For example, voltage and current data obtained from the sensor displayed in the GUI can be used to control charging of the battery and supercapacitor. This control enables longer life for the batteries and as a result can improve the efficiency of the solar cabin.

Furthermore, by developing a GUI which is user-friendly, the system can be implemented in numerous other applications and industries, without the users having to know the entire system in detail. Hence the main benefit from the installation of this application is in rural and remote areas where knowledge of such energy systems is significantly less. This system is known as the Energy Management System and is developed using LabVIEW. By using LabVIEW, this allows the use of Fuzzy Logic as the control mechanism in the Energy Management System. Fuzzy logic is easy to use compared with complex logic and rule-based controls which are also discussed in this thesis.

Despite the high photovoltaic (PV) fabrication cost and low conversion efficiency, the solar energy source is still reliable over a long term when compared with the skyrocketing fuel price in the future [13]. A stand-alone PV system needs a power buffer when there is a mismatch between available and required energy [14]. Solar PV systems use batteries as the primary energy storage. Lead-acid battery is the most popular energy storage device as it is low cost and widely available [15]. The output from a solar PV panel is unreliable due to its dependence on weather conditions thus making the charging of a battery not ideal. The battery will also frequently incur deep discharge, and this will damage and reduce the lifetime of the batteries. The biggest problem with batteries is the charge and discharge efficiency, relatively short lifetime and lower energy density [16]–[22].

A supercapacitor works like a larger version of the conventional electrical capacitor and it is an electrochemical storage device. The energy is stored in an electrostatic field instead of the chemical form used in batteries [23], [24]. Supercapacitors are also recognised as ultracapacitor or electrochemical double layer capacitor (EDLC).

With coupling batteries and supercapacitors together, it reduces the current stress on the batteries to decrease its size, improve its lifetime, minimise the depth of discharge of the battery and ultimately reducing the operating and maintenance cost of the system [25]. Integration of supercapacitors to battery systems as a single hybrid storage system has also been reported to be beneficial in terms of power quality [26]. Supercapacitors store energy by physically separating positive and negative charges, instead of chemically storing charge like batteries [27].

A novel and efficient method proposed in this thesis is to control the charging current and power flow within the storage system for optimisation. The present photovoltaic system in the cabin runs in a regular operating system without any effective control system. In addition, the solar cabin does not have a monitoring system which can display relevant parameters in real-time. The solar cabin is tested with the latest load profile showing the energy usage of a typical rural house.

1.1 Problem Statement

Due to the intermittent nature of solar energy, the power obtained from PV panels is unpredictable and unstable. This condition is highly unfavourable for power systems with storage consisting of only batteries. The battery charging cannot be done consistently as the state of charge of battery is likely to go very low during insufficient solar PV power output, or high charging current may be suddenly introduced to the battery during high solar output. In some cases, the load demand may surge very high for a very short duration. If the battery is used to supply this large surge current, it will be very harmful to the lifetime of the battery that has a high-energy density but not power density. An alternative storage technology that can supply large instantaneous current needs to be implemented in parallel with batteries to reduce these negative impacts. There are also no automatic/intelligent monitoring and control of the system to control charge and discharging between battery and supercapacitor to improve system efficiency. The charging and discharging between battery and supercapacitor needs to be performed with control and protection and the entire system of the solar cabin system needs to be integrated and controlled centrally.

1.2 Aim and Objectives

The aim of this thesis is to design and implement an energy management system in a solar cabin and a hybrid renewable energy storage system with supercapacitors.

The aim will be achieved upon completion of the following objectives:

i. To collect all solar PV system, battery from system data and configurations able to implement in a rural area using latest load profile.
ii. To implement and investigate supercapacitor as a hybrid energy storage with battery to improve system performance in the hybrid system.
iii. To design and implement an energy management system to optimise the efficiency of the system by using LabVIEW.
iv. To implement DC to DC Converter into the solar system to control charge and discharge in the hybrid storage system.

1.3 Project Scope

The scope of the project involves many areas and each has its importance towards completing this thesis. Firstly, research and experiments were performed using the load profile of a typical rural area house to collect data consisting of with and without supercapacitor in the solar cabin. The energy management system uses LabVIEW software and DAQ from National Instruments to improve the efficiency of the hybrid battery-supercapacitor energy storage system and allows management and control of the energy flow. A DC to DC converter was implemented between the battery and supercapacitor to give supply to the inverter and protect the storage devices.

1.4 Deliverables

In this thesis, the expected result is the implementation of the hybrid system in the solar cabin to show improvement of the system with supercapacitors and a new energy management control software using LabVIEW.

i. All the data and experiments performed using a real load profile of a typical rural home so the system can eventually be implemented in rural areas.
ii. The supercapacitors in the system supports batteries during peak current and improves battery efficiency.
iii. The new Energy Management System (EMS) implementation to control the charging and discharging of battery and supercapacitor and the whole system automatically. The EMS will also provide real-time monitoring for data collection.
iv. DC to DC Converter is implemented to control the charging and discharging of the supercapacitor to the system.

1.5 Organization of Thesis

Chapter 2: Literature Review - consists of literature review which discusses related projects in optimising energy systems for solar PV and hybrid systems. Discussions are also performed on the background research of the project, including the solar PV system, hybrid energy storage systems and control systems on Energy Management Systems. Besides that, this chapter also reviews the load profiles used in other applications and also the types of houses in rural areas.

Chapter 3: Solar Cabin – This section will discuss all components in the solar cabin such as supercapacitors, solar panel, charged controller and programmable load. This chapter also reviews DC to DC converter specifications, operation and applications including energy management systems. Explanations are also given on the energy management system which includes the hardware, software, monitoring, control and all the sensors involved in the solar cabin. The implementation of fuzzy logic for control is also presented in this chapter.

Chapter 4: Results and Discussion – This chapter explains the functions of the whole system including the system tests performed in the solar cabin. The solar cabin test results are discussed and evaluated for both hardware (solar cabin) and software (EMS) design as well as integrated system testing. Detailed discussions on each set of results are also presented.

Chapter 5: Conclusion and future work - This section summarises the major accomplishments and reviews the objectives achieved especially regarding successfully detecting and classifying the defects. It also discusses the limitations and possibilities for improvements and future works for this project. Finally the conclusions of the project are given including proposals on future development to enhance the quality and performance of the system.

CHAPTER II: LITERATURE REVIEW

2.0 Introduction

This chapter reviews some of the most important literature that has been done on particular areas. The emphasis is placed on reviewing literature in renewable energy in Malaysia, hybrid energy storage (battery and supercapacitor), energy management system and load profile for rural area. Figure 4 shows the flow chart for this chapter's organization.

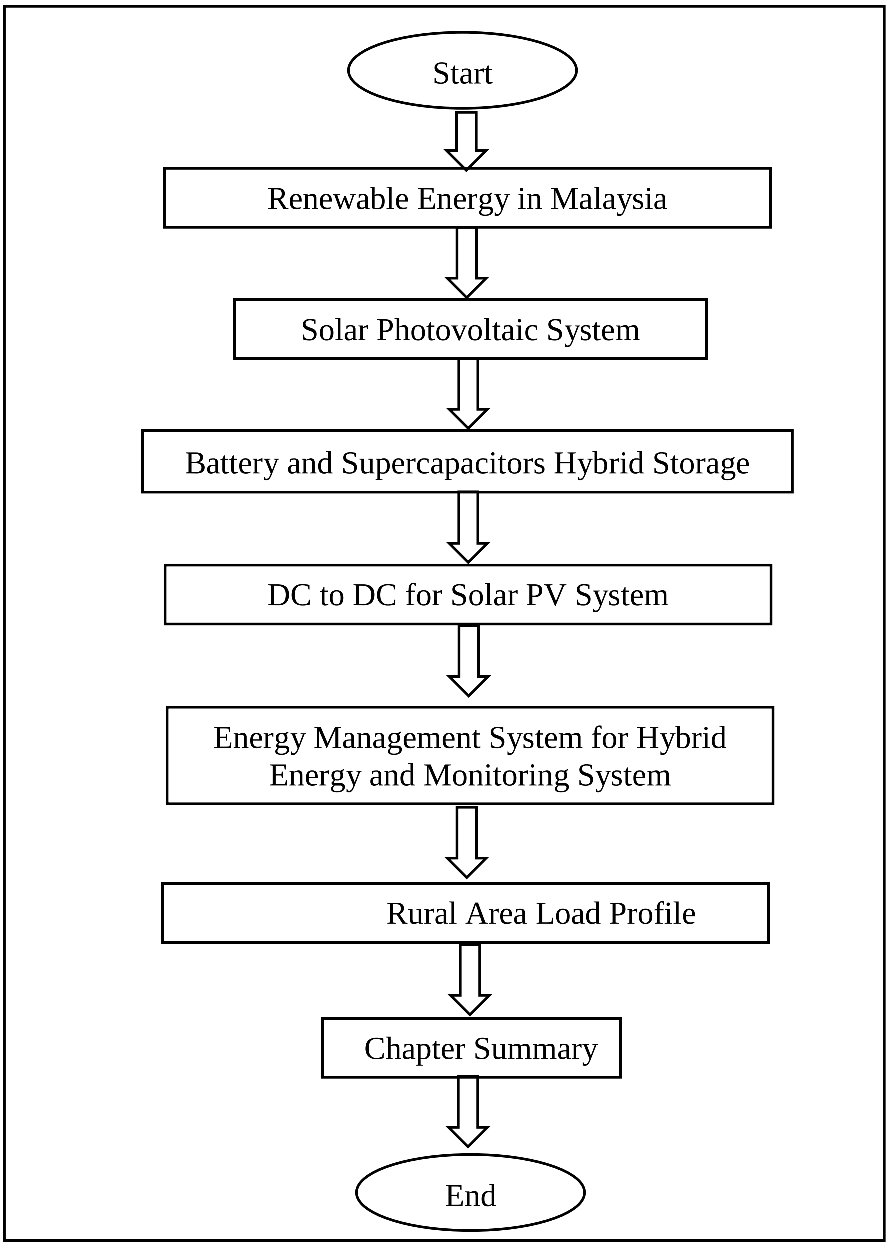


Figure 4. Flow Chart for Chapter 2

2.1 Renewable Energy in Malaysia

Malaysia relies heavily on fossil sources for energy generation such as natural gas, coal and crude oil. In 2009, the energy generated from fossil sources contributed to 94.5% of the total electricity in the country [28]. Malaysia's geological gas reserves stood at about 82 trillion cubic feet (tcf) in 2011, and natural gas production stood at 2.0 tcf. In 2011, Malaysia delivered about 2% of global natural gas production. Based on these statistics, Malaysia's production life cycle is theoretically 34 years [29]. At the current production rate, Malaysia has a life of about 38 to 58 years for oil reserves [30] with total reserves in oil equivalent barrels in Malaysia at 19,547 Million Barrels [31].

Renewable energy is becoming a more attractive choice in Malaysia due to the richness of sources such as hydro power, solar energy, biomass and biogas [32], [33]. Policies on renewable energy have been developed to lay out the strategy to manage and protect the resources in Malaysia. In 1981, the Four-Fuel Diversification Strategy was introduced to diversify the fuel mix used in generating electricity. The main focus of this policy was to reduce the over-dependence on oil as the primary energy source and target for an option to mix the oil, gas, hydro and coal to generate the electrical energy [34].

Sustainable Energy Development Authority of Malaysia (SEDA) was set-up to administer and manage Renewable Energy (RE) in Malaysia. The total number of houses installed with renewable energy systems is 3099 in Malaysia from 2004 until 2010 with a total capacity of 5460 kW. The types of installation are mainly solar hybrid system and wind turbine [35]. The data given in Table 1 shows the amount of RE generated under the Feed-in Tariff (FiT) system, in Megawatt-hours (MWh). These readings represent RE made on an annual basis for the respective year. Table 2 shows the total RE capacities in megawatt (MW) granted with Feed-in Approvals under the FiT mechanism since the FiT commencement date [36].

Table 1. Annual Power Generation (MWh) of Commissioned RE Installations

Year	Solar PV
2012	4714.01
2013	48415.83
2014	148799.38
2015	249515.19

Table 2. Feed-in Approvals (MW) and Already Achieved under the FiT Mechanism

Year	Solar PV	Total
2012	31.53	94.19
2013	106.90	113.48
2014	64.87	78.47
2015	56.80	89.80

Being at the equator, Malaysia has a strategic geographical location with sustained massive solar irradiation from 1400 to1900kWh/m^2 [37], averaging about 1643 kWh/m^2 per year [38] with more than ten sun hours per day [39]. It is calculated that a 1kW power of solar panels installed in an area of 431km^2 in Malaysia could generate enough electricity to satisfy the electricity requirement of the country in 2005[38], and the potential for solar power generation in Malaysia is estimated at four times the world fossil fuel resources [40]. It is thus important to tap into this potential for Malaysia's benefit. From Table 3, the maximum solar radiation in Sabah is about 6.027 kWh/m^2 per day while in Sarawak is 5.303 kWh/m^2 per day. Other places like Kedah, Perlis and Peninsular Malaysia also have a very high potential for applying solar energy for electrification [41].

The implementation of the policy resulted in a steady decrease in the use of fuel sources which is replaced by coal and gas to generate electricity. In 2002, the Five-Fuel Diversification Strategy was introduced to integrate with new renewable energy sources, bringing together oil, gas, coal and hydro [42].

Table 3. Solar Radiation, Peak Solar Hours, Daily Energy Output and Annual Energy Output in Malaysia [41]

Provinces	Solar radiation (kWh/m^2/d)	Peak solar hours	Daily energy output (Wh)	Annual energy output (kWh/kW_p)
Sabah	5.35	5.353	535.3	1465.475
Sarawak	5.04	5.041	504.1	1380.161
Kedah	5.51	5.512	551.2	1509.064
Perlis	5.26	5.265	526.5	1441.394
Peninsular Malaysia	5.16	5.166	516.6	1414.27

The government's tool for development of solar energy is the Malaysian Building Integrated Photovoltaic (MBIPV) Project and the introduction of the SURIA1000 programme. The SURIA1000 programme is a financial incentive programme for the market which is based on Japan's Sunshine Project also known as the Solar Photovoltaic Programme [35]. The biggest drive for this programme is the feed-in tariffs (FiTs). It is primarily providing a premium price for grid-connected PV electricity paid to system owners by the utility or regulator body, and the price is typically guaranteed for over 20 years. FiTs is the best tool to generate the fastest and low-cost deployment of renewable energy [43]. Tax incentives were also introduced in the purchase of PV panels and systems to promote more companies to join this programme [44].

A grid extension to rural areas through difficult terrains and thick jungles is not feasible and economically viable [35]. More than 800 schools currently in Malaysia are not supplied with 24-hour electricity as these schools are mostly located in the rural areas of Sabah and Sarawak [44]–[46]. The off-grid electricity which can be generated in these areas is solar, wind and hydro due to the low maintenance cost, reliability and environmental friendliness. The current system of producing energy is mainly by using solar photovoltaic (PV) with a diesel generator as the backup power supply. There are many problems for a rural area to maintain electricity supply by depending on diesel generator, including having travel long distances from the petrol station to buy diesel, higher maintenance costs and environmental pollution [47]–[49].

2.2 Solar Photovoltaic System

A standard grid-connected photovoltaic (PV) power system consists mainly of a PV panel connected to a utility grid. Other subsystems are solar charge controller, grid charger, power condition units, batteries, inverters and grid connection equipment as shown in the general architecture in Figure 5. The solar cabin units will monitor the charging/discharging of the battery voltage, solar power output and the loads [40].

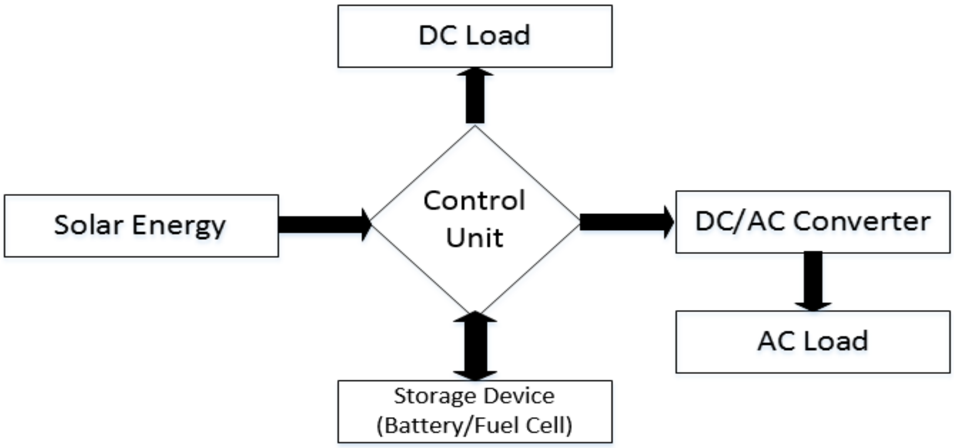


Figure 5. General Architecture of Solar Energy Systems [40]

Stand-alone PV systems, most commonly found in remote areas where grid penetration is impossible or costly, is the best solution for most rural countries like Malaysia. Most of these systems integrate valve regulated lead-acid (VRLA) batteries as their energy storage, primarily due to cost and market abundance to decouple demand from supply and to stabilise output power [18].

2.3 Battery and Supercapacitor Hybrid Storage

2.3.1 Battery

Batteries have already been widely used and are still a favourite energy storage device up until today. There are many variants of batteries existing nowadays, either non-rechargeable or rechargeable, with different types such as lithium-ion, lead-acid, nickel-metal-hydride and plenty more.

Overall, batteries have high power densities, low self-discharge rate and cost much less when compared to supercapacitors. Though extensively used, there are nevertheless many inferior elements affecting the batteries. These are temperature, slow charging time, high energy density and short life cycle [50].

A battery contains chemicals which can convert chemical energy to electrical energy and vice-versa. Batteries are typically rated in terms of energy and power capacities. There are some essential elements that need to be taken into account when purchasing batteries [51]:

- Battery efficiency
- Lifespan
- Operating temperature
- Depth of discharge
- Self-discharge rate
- Energy density

When the high load demands cause high surge current, in a short duration, it will be very disadvantageous to the lifetime of the battery because the battery is high in energy density but not suitable for high power density [52]. The stress factor on the battery such as variable discharging rate and extensive time at the low state-of-charge (SOC) could increase the rate of damage to the battery.

In certain applications of batteries such as motor starting, portable power systems, electric vehicles and digital communication systems, the batteries were sized to meet the requirements of peak currents spanning a short duration, causing unnecessary expenses which are hardly justified [26]. An oversized battery system is suggested to provide the peak power and also to extend the battery lifespan. Lead acid batteries, which offer deep cycles, large capacity and wide availability, are typically the choice for these applications. It has a relatively high energy density, but it does not have the capability of instantaneous charging and discharging [53].

2.3.2 Supercapacitor

General Electronics developed the first supercapacitor in 1957. This supercapacitor was based on a double layer mechanism in the clear using a porous carbon electrode [54]. These devices can charge and discharge extremely fast compared to batteries, while having much higher load capacity compared to conventional capacitors. Supercapacitors can be recharged hundred thousand times compared with only a few thousand recharge cycles for conventional batteries [55].

The rate of self-discharge is higher compared with batteries, but the power generated by a supercapacitor is for a short duration only. There are no chemical reactions when supercapacitors charged, while batteries undergo an internal chemical reaction while charged. This chemical reaction will be reversed during discharge to deliver the absorbed energy. Examples of applications that use supercapacitors are uninterruptible power supplies and hybrid electric vehicles [56].

The Ragone plot in Figure 6 shows the power density (W/kg) versus energy density (Wh/kg) comparison for various energy storage technologies. The plot shows the lead-acid batteries have a high energy density in the range of 10–30Wh/kg but the power density is lower than 100 W/kg. These results show that batteries take a long time to fully charge in solar PV systems. In contrast, supercapacitors retain high power densities in the range of 1000– 5000 W/kg and also charge and discharge at a fast rate typically in the range of 0.3–30s [57].

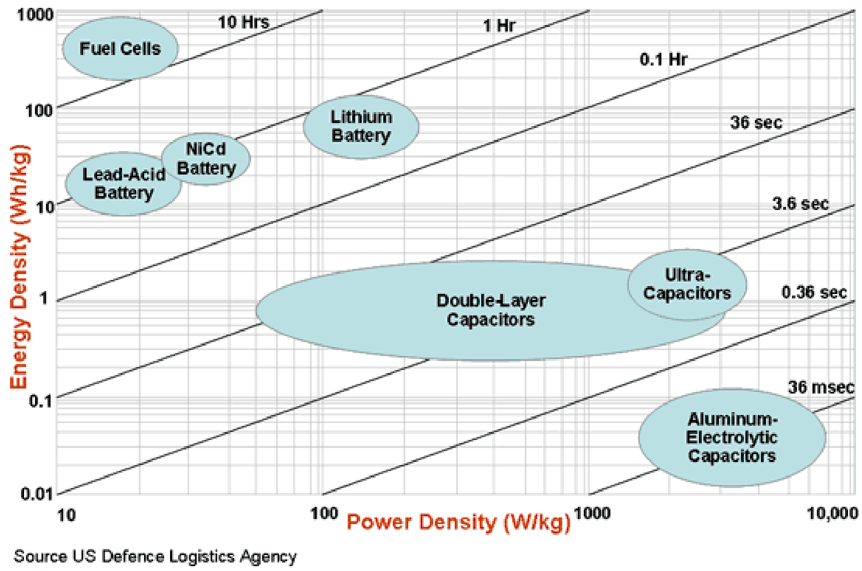


Figure 6. Ragone Plot [57]

The comparison of the advantages and disadvantages of a supercapacitor with batteries are [58]:

The advantages of supercapacitors compared with batteries:

• Very high rates of charge and discharge.

• Lightweight.

• More than hundred thousand cycles.

• Contain less toxicity.

• High cycle efficiency (>95%).

The disadvantages of supercapacitors compared with batteries:

• The energy stored per unit weight amount is considerably lower than the electrochemical battery (3-5 Wh/kg for a supercapacitor compared to 30-40 Wh/kg for a battery).

• The energy stored in a supercapacitor is variable voltage based. Sophisticated electronic control and switching equipment are required to recover and store energy efficiently.

2.3.3 Hybrid Energy Storage System

The battery and supercapacitor need to combine together due to the advantage and disadvantage of both storage devices. Once batteries are paired with supercapacitors, the supercapacitors can act as a buffer, relieving the battery of pulsed or high power drain, as well as reducing the depth of charge-discharge cycles using buffering. The supercapacitors can charge and discharge at a higher, faster rate compared to batteries and have significantly larger load capacity compared to conventional capacitors [59]. The advantages such as fast charging time, endless life cycle, low equivalent series resistance (ESR), robust and high power density make it attractive and have been used to replace batteries in some applications [60].

The combination of the high energy density of the battery with the high power density of the supercapacitors makes this a perfect hybrid system. The greater power of supercapacitors allows it to provide sufficient energy for peak power requirements in a short period, and the battery with higher energy density allows the battery to store more energy and supply to the continuous load power at a nominal rate over a longer period of time [52]. To achieve higher impact on the lifetime of the battery, the size of supercapacitor that needs to be applied to the system must be sufficiently large [61].

Integration of supercapacitors to the battery systems as hybrid storages has been reported to be beneficial in regards to power quality [24]. Implementation of hybrid energy storage with the use of supercapacitors can reduce battery size, decrease depth of discharge of the battery, increase the lifetime of batteries, ultimately reducing operating and maintenance cost of the system [25], [62].

2.4 DC to DC Converter

DC to DC Converter is required to properly interface the combination of energy storage between battery and supercapacitor. DC to DC converter functions by shifting the voltage levels without adding or taking power [63]. In terms of its basic functions, it is similar to a transformer, except that there is no necessary isolation between input and output and no need for AC waveforms. Various topologies exist within the DC to DC Converter family, which is subdivided into isolated and non-isolated ones. Isolated converters which include flyback converter and forward converter have magnetically coupled coils which act like inductors and transformers at the same time, providing galvanic isolation between stages. Non-isolated converters are namely buck converter, boost converter, buck-boost converter, Cuk converter and single-ended primary inductance converter (SEPIC).

2.4.1 Bi-Directional DC to DC converter

A bi-directional DC to DC converter allows transfer of power in both directions between two DC sources. For example, the usage in applications like battery charging circuit and uninterruptable power supplies for these converters is the result of the reverse direction of power flow, and also maintained the voltage polarity [64]. All these topologies will make the circuit more complex, and result in conduction losses and component ratings. The effect of topologies also happened in a resonant mode, the higher ripple of output current and soft switching losses [64], [65].

A bi-directional DC to DC converter is used for power conversion applications. Two full bridge converters (inverter and rectifier) are used in this power of converter which is best for electrical applications [66]. Figure 8 is an example of a bi-directional application in fuel cell application in a vehicle using power electronics modules. At the start, the battery pack (low voltage) will supply power to the fuel stack (high voltage) and to the main motor. This condition is called the LV to HV mode. After the fuel cell stack is ready, it supplies the voltage to the motor and recharges the battery pack (low voltage) and this condition is known as HV to LV mode. This system can deliver power from both directions of voltage, depending on the state of the battery voltage of the fuel cell [67]. The comparison table for existing project with battery, supercapacitor and bi-directional DC to DC converter is shown in Table 4.

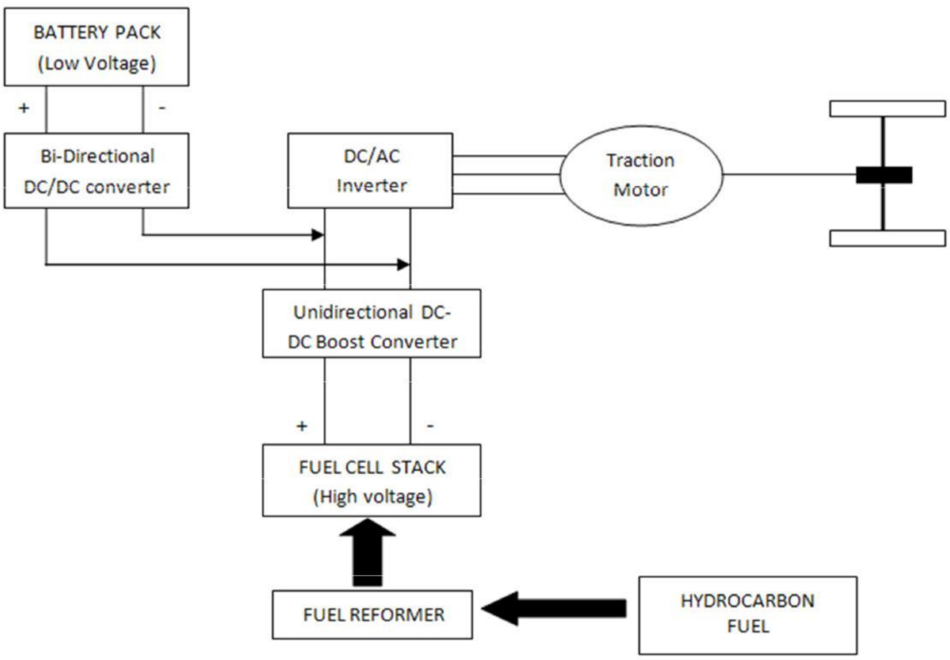


Figure 7. Block Diagram of Bi-Directional Application use in Vehicle-Based on Fuel Cell using Power Electronics Modules [67]

Table 4: Comparison Table for Existing Projects with Battery, Supercapacitor and Bi-Directional DC to DC Converter

Ref	Type	Power Source	Function	Advantages	Remarks
[68]	step up and step down	Solar PV, Battery	For battery charging in the solar system to achieve optimising component.	High gain, high-efficiency bi-directional converter	The efficiency of the converter is as high as 98%. Simulation of the converter has performed for a 40V/400V, 200W system
[69]	buck boost	Solar PV, Battery	Using FPGA for controlling high gain in both buck and boost modes.	Control charging and discharging the battery storage system to increase it is efficient.	Using FPGA to control converter. Regulated output DC voltage under the input voltage conditions and load changing conditions.
[70]	buck and boost	Fuel Cells, ultracapacitor, batteries	applied to the interface circuit between ultracapacitors and batteries or fuel cells	the energy conversion through the converter using soft-switching is highly efficient	The converter efficiency up to 96%. Tested in laboratory prototype.

[20]	(boost) – full bridge	Wind turbine, Battery, Supercapacitor	Draw power from two different dc sources individually and simultaneously. Obtain the desired level during charging and discharging times.	Limit the current ripple and increase the lifetime of batteries	Done by using Matlab. Battery stress reduce by SC overcome the power surges and reduce high-power demands
[71]	isolated symmetry half-bridge	Supercapacitor	Solved the decrease of terminal voltage will lead to high leakage inductance current and failure to meet the problem in Zero Voltage Switching conditions	Phase-shifted plus feed-forward control stabilize the primary voltage of the transformer and reduce the leakage inductance current.	The control converter targets: 1) Stabilize the output voltage, 2) Maintain the relationship of capacitor voltage to keep the efficiency, current stress and reactive power in reasonable ranges.

[72]	Buck/boost	batteries, supercapacitor	Balance the fluctuate power from RE sources and extend batteries lifetime by optimizing its operating process.	Reduce the depth of discharge and the cycle times	A 5kW laboratory system. The Control the operation mode, energy flow, and energy consumption.
[73]	Buck and boost	Fuel Cell, Supercapacitor	SC interfacing in high-power applications, as a voltage source during the SC charging mode and as a quasi-Z-source inverter based step-up DC to DC converter during the energy recovery mode.	The higher voltage boost of the SC voltage during the discharge, the qZSI with a two-stage quasi-Z-source (qZS) network.	Simulation PSIM. Flexibility of energy transfer control between the SC and the supported energy system.

2.5 Energy Management System for Hybrid Energy and Monitoring System

Energy management systems (EMS) and power converters (DC to DC Converters) need to be implemented together to control any system. Energy storage system requires management to decide which storage should be used in hybrid energy storage system and for selection of the wide range of charge-discharge cycles from preferred storage [74] to prevent the varied range of discharge voltage of energy storage devices [75]. EMS ensures the system operates with high efficiency and with dynamic performance [76].

The difficulties in any hybrid energy storage system are how to manage the current flow to obtain two main objectives, namely, to minimise the magnitude/fluctuation of the current flowing in and out of the battery and the energy loss by the supercapacitors. This kind of problem has not been recently analytically investigated to obtain an optimal solution for these two goals [77]. Mathematical models usually require a long time to develop, sometimes producing alternatives that are not used to far below expected conditions [78]. Recently, many studies have been conducted on energy management of hybrid systems using intelligent techniques, such as genetic algorithm (GA), differential evolution, neural network, fuzzy logic, and neuro-fuzzy and more [12].

2.5.1 Fuzzy Logic in EMS

Fuzzy logic controllers have been extensively studied by researchers to perform energy management in stand-alone or grid-connected hybrid renewable energy systems. Fuzzy logic can effectively manage hybrid energy systems, especially for battery and supercapacitors [79]. The simple adaptability of complicated systems, the provision of computational efficiency and effectiveness in modelling uncertainties are additional features of fuzzy logic controllers [12]. The processing of fuzzy logic rules generates a result for every input, and then combines the results of the rules. Finally, the output converts the results back to the output value [80].

The energy management system tends to have the following characteristics. First, the energy management system needs to be generic and be efficient in response, independent of the continuance or shortage of complete particular energy source or user. For instance, it can be a plug-and-use system which satisfies a set number of ports, with no restrictions when connected to port. A rule-based system is where the system can regulate to an arbitrary collection of sources/users by seldom updating the dynamic rule library.

Second, the rules themselves are subjected to improvement or change with time to serve the different requirements of a human user. A rule-based system provides flexibility and upgrading ability. It is consistently easier to achieve and simulate. Ideally, a rule-based expert system which dynamically adapts to new rules in the library is a valuable design for such generic energy management systems. In this function, we have explored an easily done rule-based allocation algorithm based on the supply-demand optimal from economics to assist the characteristic roles of an energy management system in a theoretical multi-source multi-sink framework [81], [82]. The classical logic requires a deep understanding of a system, exact equations, and precise numerical value, while the fuzzy logic controller incorporates an alternative way of thinking that enables the easy modelling of complex systems [82].

2.5.2 Existing Project EMS with Battery and Supercapacitor

Table 4 shows the existing EMS with battery and supercapacitor systems including research, software or methods and the advantages of the research. The comparison between main source of the system and backup power source are also shown in the table.

Table 5. Comparison Table for Existing Project EMS with Battery and Supercapacitor

Ref	Main source.	Backup source	Energy management proposed	Software/ method	Advantages	Applications	Remarks
[83]	hybrid wind = 50Kw photovoltaic (PV) = 33kW	fuel cell (FC) = 20Kw electrolyser =50Kw battery=10kWh	To manage power flows among the different energy sources and the storage unit in the system.	MATLAB/Simulink. Test performance under different scenarios using practical load profile and real weather data.	Simulation studies have been carried out to verify the system performance under different scenarios using practical load profile and real weather data	Stand-Alone Wind / Photovoltaic / Fuel Cell Energy System	Only in simulation. No specific control strategy

[84]	fuel cell =35V	Supercapacitors (291 F, 30 V, and 400 A) Battery (24 V)	in an electrical hybrid power source (EHPS) for electric vehicular applications	based on the flatness control technique (FCT) and fuzzy logic control (FLC) using dSPACE	A single general control algorithm in different operating modes, consequently avoiding any algorithm commutation.	Electric Vehicular Applications	For hybrid car. 24V
[77]	fuel cell	battery, supercapacitor = 2.7V	Minimise the magnitude/fluctuation of current flow input and output of the battery and minimise the energy lost using a mathematical formula.	mathematically formula based on multiplicative-increase-additive-decrease (MIAD) principle	Solve the original nonconvex problem by converting it to a convex optimization problem.	Hybrid Energy Storage System	Only simulation using MATLAB

[85]	solar photovoltaic (PV) = 240W	Battery = 12V 14Ah, supercapacitor= 16.2 V, 58F	Battery SOC estimation, battery reference current generation, and generation of the manipulate variable.	Rule based - Filter	Reduce stress on battery pack, effective on dc link capability	plug-in hybrid electric bus	12V, when average load using only battery.
[86]	batteries (BT) (528V 2.3Ah in series) and supercapacitors (480.6 3000F (SC)		power losses and lengthen the battery lifetime by minimalizing the battery current magnitude and differences	fuzzy logic and the optimal sizing using genetic algorithms (GA) – Matlab Simulink	estimate the forward energy consumption and adapt the instantaneous power target	tramway	Reduce operation cost efficiency around 84.4%

[87]	Solar PV (240W)	Supercapacitor (16.5V, 58F), Battery (48V, 14Ah)	For battery: SOC estimation, battery reference current generation, and generation of control variable. For SC: the generation of SC reference current and fast acting current control loop.	Filtration based control	quick fluctuations of load are supplied by the supercapacitors and the average load demand is controlled by the batteries	hybrid energy storage system with high-gain PV converter	Less computationally intensive, stress on battery is reduced
[88]	Solar PV (1480.6W), Fuel Cell (1.26kW)	Battery (24V 100Ah), Supercapacitor (300F)	Share load from all energy sources, limit battery discharging and charged by FC, SC as fast response source.	classical PI controller based control strategy	Reduce usage of FC. Only used to charge battery when SOC it's lower than limit.	standalone DC load	Only in simulation Matlab. Main objective to reduce cost of FC

[89]	Solar PV, Wind turbine	Battery	determining on the switching of five relays inside an off-grid renewable power system in a rural location located in Northern Tunisia	Fuzzy Logic, Genetic Algorithm	Maximise the use of the RE, minimise the installation's operation cost, ensuring a safe operation of the battery bank.	stand-alone photovoltaic-wind system	For rural area. Simulation only. No SC. Energy sources and rating based on other's work
[90]	PV (1.5 kW), Wind Generator (WG) (1kW)	Battery (120 Ah), diesel engine (DE)	Manage the power flow between the components and consumed powers from energy sources to satisfy the load demand.	Power prediction using algorithm neuro-fuzzy logic interference system network (ANFIS) ;	Predict the weather, generate power reference to satisfy load, controller to track the power references.	Weather Prediction for Hybrid Stand-alone System	One family house. Satisfy load demand. Simulation only USING MatLAB.

[91]	Solar PV (72.5W)	Supercapacitor (22.7F)	Incremental Conductance to control the duty of the buck converter and the MPPT. P-Q control for the VSI to transfer the DC link power to the grid.	Rule base control;	Minimise the short-term fluctuation and during fault at grid side, SC will be charged by the PV array.	Grid-Connected PV Array with Supercapacitor	Three phases. No battery
[19]	PV Panel – 5W	Battery – 4.2V, 680mAh; Supercapacitor – 1050F	To increase the lifetime of the storages, especially the lifetime of the Li-ion battery by control charge voltage and current strategy.	Rule based control; MATLAB Simulink	Simulation in 238 days. Reduces the number of charge/discharge cycle of the Li-ion battery, improving the battery lifetime	Hybrid renewable energy systems for power generation	Only run in simulation. Low power experiment.

[92]	Solar PV – 80W	Supercapacitor – 8.3F	Control for the PV system, and the state of charge control for the supercapacitor. coordinating the power flows among the two energy sources	Rule based Control; MATLAB/Simulink	EMS strategy efficient and the power flows among the different energy sources and the load demand is balanced successfully.	Stand-Alone Photovoltaic Energy	Small/short scale experiment, proof concept.

2.6 Rural Area Load Profile

The current load profile is important towards finishing the thesis titled “Solar energy management system with supercapacitors” to run the experiments based on usage per day. By using the load profile and testing with and without supercapacitor in the solar cabin, we can observe the effect of the supercapacitors taking over the sudden high current load demand in the system. The testing of the new energy management system (EMS) will use the same load profile, and the results of the experiment will be compared with the improvements from the supercapacitors and EMS.

Authorities like Jabatan Kerja Raya (JKR), Tenaga Nasional Berhad (TNB), Sustainable Energy Development Authority of Malaysia (SEDA) and Suruhanjaya Tenaga (ST) do not have the exact information for appliance usage in a house and energy consumption, and only provide a guidelines on the installation and wiring standard and maximum power demand. In TNB’s electrical supply application handbook [93], TNB provides an estimated maximum demand usage depending on the type of premises as shown in Table 6.

Table 6. Range of Maximum Demand (M.D) for Domestic Consumer Sub-Classes or Premises [93]

No.	Type of Premises	Rural (kW)	Suburban (kW)	Urban (kW)
1	Low cost flats, single storey terrace, studio apartment (<600 sqft)	1.5	2.0	3.0
2	Double storey terrace or apartment	3.0	4.0	5.0
3	Single storey, semi-detached	3.0	5.0	7.0
4	Double storey, semi-detached	5.0	7.0	10
5	Single storey bungalow & three-room condominium	5.0	7.0	10
6	Double storey bungalow & luxury condominium	8.0	12	15

A few researchers have done studies on rural areas and came up with a table for appliance used and operating hours. Fadaeenejad M *et al.* [94] from UPM proposed electrical applications for Kampung Opar village located 34 km from Kuching in Sarawak.

The power consumption for a rural house in Malaysia, especially in Sarawak and Sabah based on simple electric appliances like lighting lamp, refrigerator, TV, fan, etc. for their houses is shown in Table 7.

Table 7. Proposed Appliances and Energy Consumptions For Rural House by Fadaeenejad M *et al.* [94]

Electric Appliances	Power (Watts) per hour	Operating hour per day	Average usage (hour/day)	Usage for 1 unit per day (Wh)	Number of units	Total usage for 1 house per day (kW/h)
Fluorescent light bulb	33	18 to 23	5	110	2	0.22
Refrigerator	120	0 to 24	8	960	1	0.96
TV	70	18 to 23	5	350	1	0.35
Fan	50	18 to 23 13 to 14 (for lunch)	6	300	1	0.30
Water pump	150	12 to 14	2	300	1	0.30
Total						2.13

Wong Sy *et al.* [95] from Swinburne University Sarawak configured the solar system for a rural village in the state of Sarawak, based on a community-based project. The project implemented the installation of a photovoltaic system to supply electricity to the rural community. The Public Works Department of Sarawak, under the stimulus of rural electrification project in 2009/2010 implemented the installation of a 54kWp photovoltaic system to supply electricity to the 54 households in Long Beruang. The appliances used and analysis of daily energy consumption are shown in Table 8.

Table 8. Proposed Appliances and Energy Consumptions for Rural House by Wong Sy *et al.* [95]

		Power (W)	**No. per unit**	**Unit**	**Daily Hours (h/day)**	**Daily Energy (Wh/day)**
PWD Centre	Lighting Point	8	5	1	0.1	4
	Power Point	150	5	1	0.1	75
Church	Lighting Point	8	5	1	2	80
	Power Point	150	5	1	2	1500
House	Lighting Point	8	3	54	3	3888
	Icebox	80	1	30	24	57600
	Washing Machine	500	1	30	1	15000
	Rice cooker	300	1	30	1	9000
	TV	150	1	30	2	9000
	Radio	5	1	54	5	1350
	Table fan	25	1	54	5	6750
Total						104247

N. A Ahmad *et al.* [96] from UiTM Perak, studied a rural house in Malaysia with a 16m x 15m floor plan, built on stilts (for the living room and two bedrooms), and an attached building for kitchen and bathroom. The household's occupation was considered over a duration of 24 hours and divided into three types of occupants, i.e. those who stay at home, few person stay at home and those working outside the home. The length of occupancy can vary, depending on the lifestyles of the households, and type of occupations of the home owners. The consumption of electricity for these different types of households is shown in Table 9.

Table 9. Proposed Appliances and Energy Consumptions for Rural House by N. A Ahmad *et al.* [96]

TYPES OF OCCUPANTS			**STAY-AT-HOME**			**FEWER OCCUPANTS AT HOME**			**WORKING OUTSIDE OCCUPANTS**		
Appliance	**Standard Load (W)**	**Quantity**	**Daily avg usage (h)**	**Total Wh/ day**	**Kwh/ daily**	**Daily avg usage (h)**	**Total Wh/ day**	**Kwh/ daily**	**Daily avg usage (h)**	**Total Wh/ day**	**Kwh/ daily**
Fridge/ Freezer	300	1	24	2400	2400	24	2400	2400	24	2400	2400
Rice Cooker	905	1	1	905	0.905	1	905	0.905	0.4	362	0.362
Television	100	1	10	1000	1000	12	1200	1.200	5	500	0.500
Table/ Stand Fan	60	2	16	1920	1.920	16	1920	1.920	7	840	0.840
Ceiling Fan	120	1	11	1320	1.320	11	1320	1.320	5	600	0.600
Washing machine	1080	1	0.15	162	0.162	0.3	324	0.324	0.3	324	0.324
Fluorescent Lights	30	5	6	900	0.900	6	900	0.900	5	750	0.750
Bulb Light	70	2	6	840	0.840	6	840	0.840	5	700	0.700
Electric Kettle	1400	1	0.2	280	0.280	0.2	280	0.28	0.2	280	0.280
Iron	1000	1	0.45	450	0.450	0.15	150	0.150	0.150	150	0.150
TOTAL LOAD FOR ELECTRICAL APPLIANCE					10.177	-	-	10.239	-	-	6.906
Others:											
Cell phone chargers	35	2	8	560	0.560	9	630	0.630	9	630	0.630
Blender	300	1	0.3	90	0.090	0.3	90	0.090	0.15	45	0.045
Microwave/ Oven	1100	1	0.1	110	0.110	0.05	55	0.055	0.05	55	0.055
Radio	20	1	7	140	0.140	5	100	0.100	0	0	0.00
Satellite TV	200	1	10	2000	2.00	12	2400	2.400	5	1000	1.000
Computer	200	1	8	1600	1.600	4	800	0.800	3	600	0.600
Night Lamp	70	1	9	630	0.630	9	630	0.630	9	630	0.630
TOTAL LOAD (kWh) FOR OPTIONAL APPLIANCES:					5.130	-	-	4.705	-	-	2.960
OVERALL TOTAL (kWh/daily)					**15.307**	**-**	**-**	**14.944**	**-**	**-**	**9.866**

IBC Solar made a study on the information of usage capacity as shown in Table 10 before developing the solar cabin in UNMC, Semenyih. The data is based on the estimated usage in rural areas where only important items are used, such as television, freezer, ceiling fan, light and socket outlet. The total energy usage is 3760W and is expected that this energy demand will grow by 20% in 5 years. The load profile (Load Profile 1.0) is generated from the information given by IBC Solar to run an experiment to test the solar cabin system as shown in Figure 8. For example, the item expected to use at 9am is TV, fan and exhaust fan.

Table 10. Solar Cabin Information of Usage Capacity [97]

NO	ITEM	POWER (W)	QTY	TOTAL POWER (W)	USE (H)	ENERGY (WH)	NIGHT/ DAY (%)	ENERGY NIGHT (WH)	ENERGY DAY (WH)
1	TV	130	1	130	4	520	50	260	260
2	Freezer	440	1	440	4	1760	50	880	880
3	Fan	25	2	50	4	200	50	100	100
4	Light	16	6	96	4	384	50	192	192
5	Washing Machine	500	1	500	2	500	50	250	250
6	Switch Socket Outlet	80	4	320	4	1280	50	640	640
7	Exhaust Fan	17	2	34	8	272	0	0	272
TOTAL ENERGY USAGE (WH)				1570		4916		2322	2594
20% GROWTH				314		983.2		464.4	518.8
TOTAL ENERGY USAGE + 20% GROWTH (WH)				1884		5899.2		2786.4	3112.8

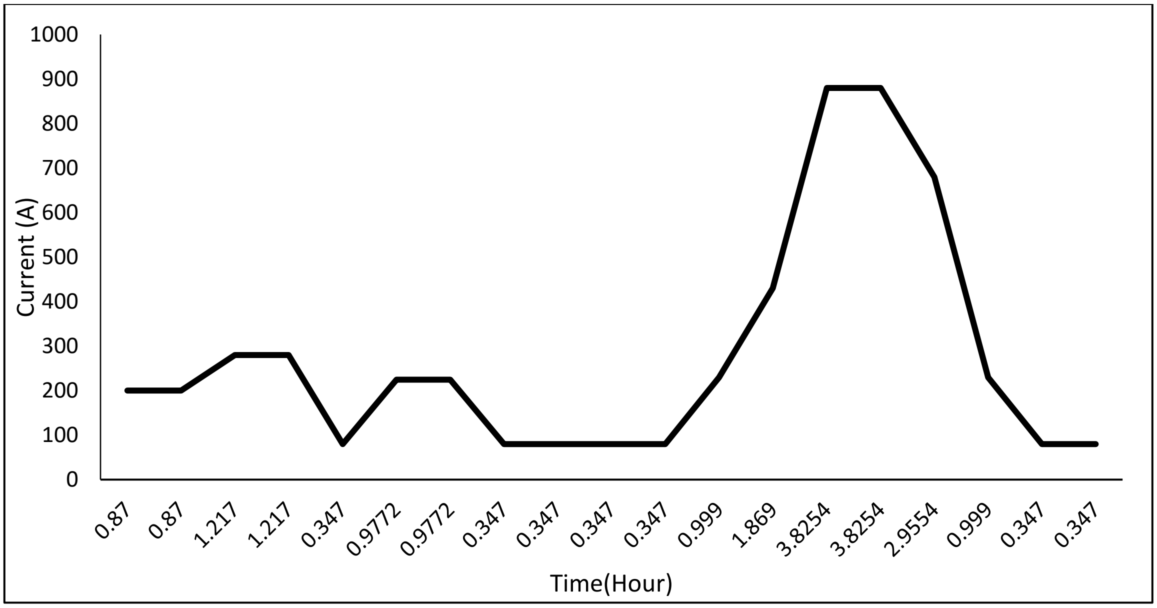


Figure 8. Current Load Profile Generate from Information of Usage Capacity (Load Profile 1.0) [97]

2.6.1 House in Rural Area

The target house for this research is a standard low-cost house which was developed by the Jabatan Kerja Raya (JKR) with Government Malaysia funds for a low-income family in the rural area. When installing this solar system, people can save their money on electrical bills.

The number of houses connected to the system will increase when the capacity of the system is increased. The house developed in Jeli, Kelantan was involved in a great flood in 2015 [98]. The house specification designed by JKR consists of 3 bedrooms, one bathroom, one toilet, one kitchen, one living hall and one dining hall with the total area of 660 square feet (sqft). The layout of the house is shown in Figure 9 and appendix.

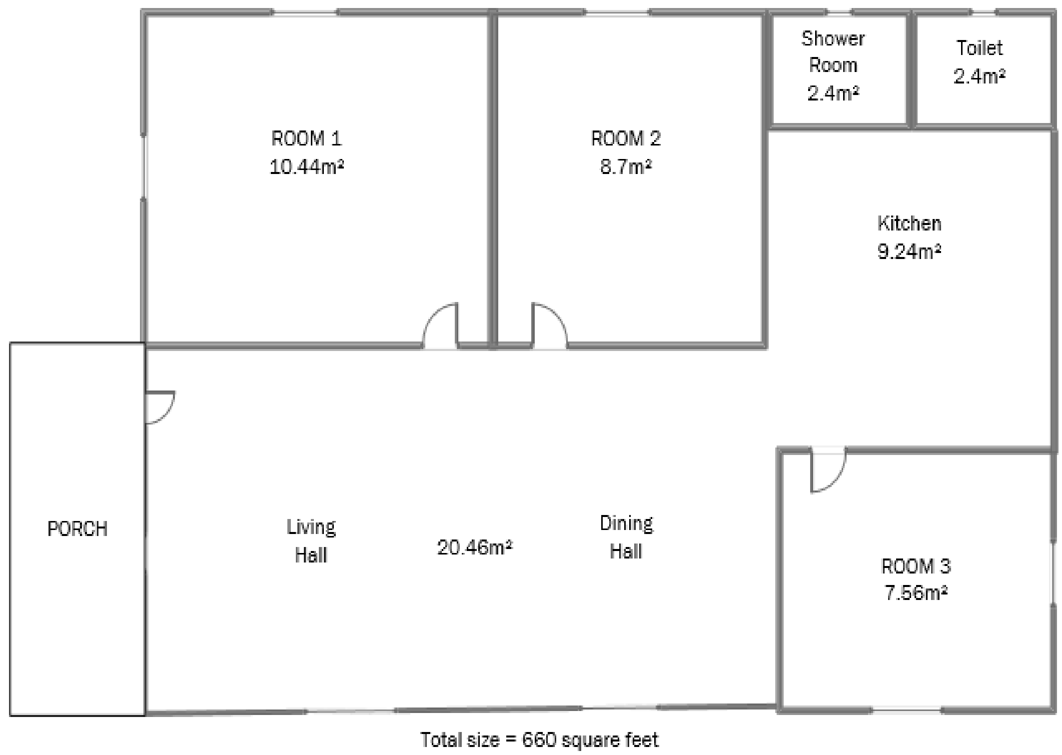


Figure 9. Rural House Plan Layout [98]

2.7 Standards

The standard usually used for battery in hybrid power system is IEEE 1561-2007. This standard set the efficiency of battery in hybrid solar system at 95% [99]. Energy management system based on ISO 50001 is identify and analysing opportunity for improving energy performance, and effectively implement into the system [100]. In Malaysia, Ministry of Energy, Green Technologies and Water (KeTTHA) setup the National Energy Efficiency Action Plan. KeTTHA targets that Malaysia can increase the efficiency in energy system to 94% in ten years, from the current performance 91% [101]. The National Electrical Manufacturer Association target to increase the efficiency in power grid from 80% in 2010 to 90% in 2026 [102].

2.8 Chapter Summary

Based on the review done in this chapter, Malaysia is ideal for implementing solar energy systems as a power source due to the rich resources of energy from the sun. The government also gives an initiative like Four-Fuel Diversification Strategy and Feed-in Tariff (FiT) to gain the interest of the public and private companies to install the solar systems. When installing a solar system, energy storage devices are needed as an energy backup for the off-grid solar system. The energy storage usually used as energy backup is the battery. However, there is a disadvantage when the battery acts as energy storage by itself. The battery has a high energy density but low power density. The combination of battery and supercapacitor is perfect because the supercapacitor has low energy density but high power density.

DC to DC converters are usually used in conjunction with the energy storage to smooth the charging and discharging process and also as a protective device. The bidirectional DC to DC converter is able to transfer power in both directions in the solar system. The EMS was used to control and manage the energy storage and all the solar system components. The EMS will decide which energy storage will be utilised at any one time or both will be used. Fuzzy Logic was used in EMS as a controller because it is straightforward and easy to implement and also efficient in the control system. The existing research is tabled in Table 5. Most of the existing EMS with hybrid energy storage focus on hybrid car and simulation. For load profile, previous research has already been done for the rural area but the load profile is taken from the research done in Malaysia only.

CHAPTER III: METHODOLOGY

3.0 Introduction

This chapter consists of two parts. The first part details the solar cabin system developed in UNMC and adding the supercapacitors as a hybrid energy storage. The second part of the chapter presents the new energy management system implemented in solar cabin. The EMS monitors and controls the solar cabin system. The schematic of the solar cabin system developed by IBC Solar is presented in Figure 10. The solar cabin consists of 20 solar panel, charge controller, battery and inverter.

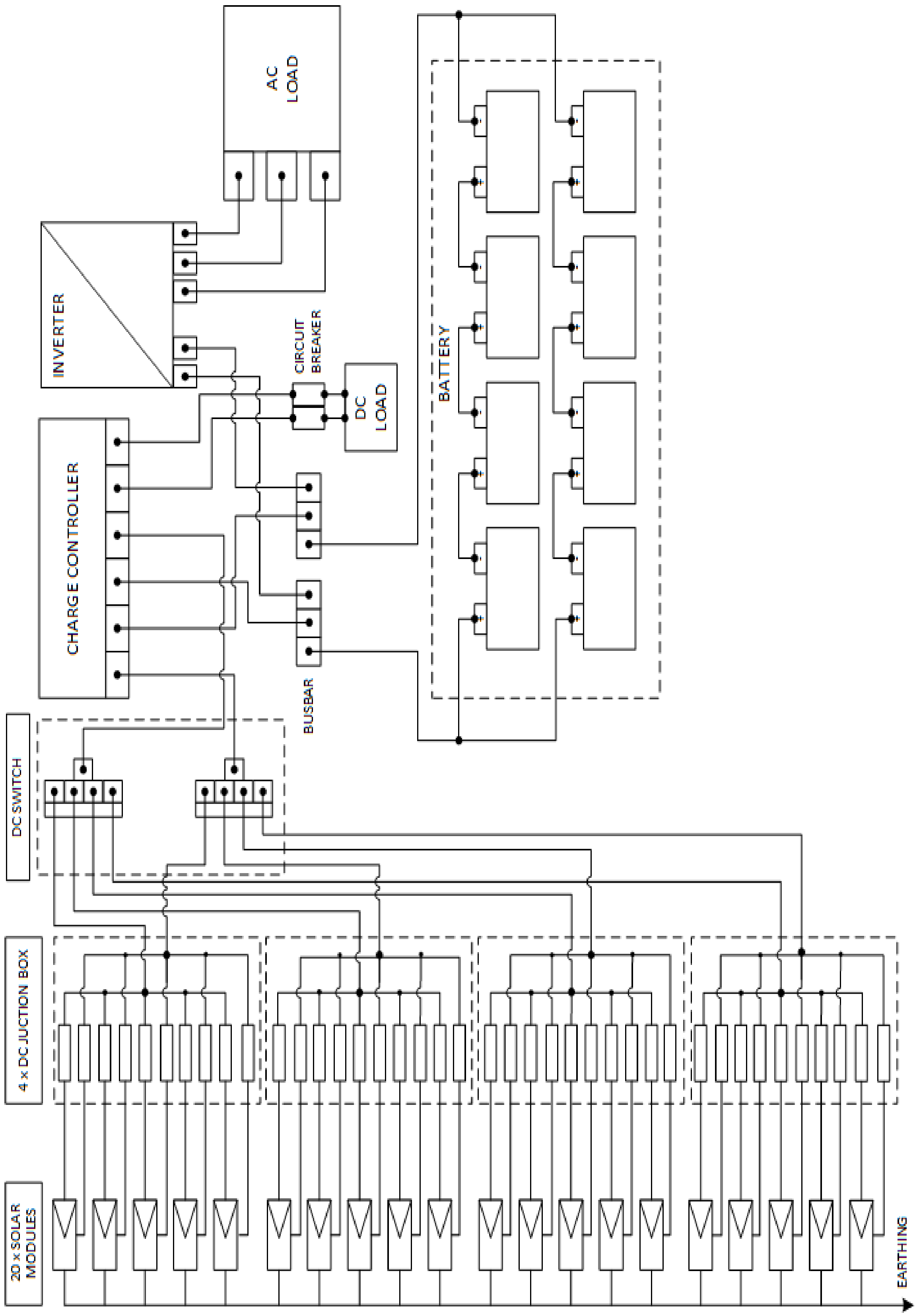


Figure 10. Solar PV System Schematic

3.1 Solar Panel [Kaneka U-EA100]

A Kaneka's hybrid solar panels was used in the solar cabin system. The solar panel used is the latest hybrid innovation that can generate more power and is environmentally friendly [103]. It's made from a dual-layer structure of microcrystalline and amorphous silicon. The specification is shown in Table 11.

Table 11. Information Specification of Solar Panel from Kaneka

SPECIFICATION	VALUE
Cell Type	Thin film (amorphous Si/thin film microcrystalline Si)
No of cells	106 (53 in series/ 2 in parallel)
Dimension [mm]	W1,210 x L1,008 x T40
Weight [kg]	18.3
Model no	U-EA100
Maximum voltage [V]	600
Limiting reverse current [A]	3.5
Maximum Load [Pa]	2,400
Maximum Power (Pmax) [W]	100
Tolerance	-5%/+10%
Minimum value of Pmax [W]	95
Open circuit voltage (Voc) [V]	71
Short Circuit Current (Isc) [A]	2.25
Voltage at Pmax (Vmpp) [V]	53.5
Current at Pmax (Impp) [A]	1.87
Module Efficiency (n) [%]	8.2
Efficiency reduction at 200W/m^2	<5%

3.2 Battery

The model of the battery, as shown in Figure 11, is Hoppecke 12 V 3 OPzV 150. It was selected due to the following specifications [104]:

- High expectancy on service life
- Excellent cycle stability – tubular plate design (OPzV cell)
- Maximum capability
- Easy assembly and installation
- Higher short-circuit safety even during installation
- Maintenance free
- Battery life up to 18 years

Figure 11. Battery used in Solar Cabin System

The operating system voltage is 48V. From the data sheet [104], the operating battery voltage is 12V. So,

$$Minimum\ number\ of\ battery\ required = \frac{\text{Operating system voltage}}{\text{Operating battery voltage}} \ \ldots\ldots\ldots (3)$$

By using Equation 3, the minimum number of batteries required in this system is four units. However, in this system, eight batteries are used to supply more current.

3.3 Charged Controller

The charger used is Phocos PL60 (Figure 12) which is capable of complete control over the charge cycle. Its nominal voltage can set to 12V, 24V, 32V, 36V and 48V.

Table 12 presents the specification of the charger.

Figure 12. Solar Chargers PL60

Table 12. Specification of Solar Charger PL60 [105]

TYPE	PL60
Nominal Voltage	12, 24, 32, 36, 48V
Solar Charge Current Max.	60A
Load Current max.	30A
Max. Voltage Drop	0.42V
Supply Current	20mA
Temperature Sensor Range	-15 to + 50 ^{0}C
Regulation Set Point	4 present programs, one user adjust
Ambient Temperature	-20 to +50 ^{0}C
Dimensions	225 x 175 x 62mm
Weight	110gram

3.4 Programmable Load

Chroma's 63800 Series AC & DC Electronic Loads as shown in Figure 13 were designed for testing Uninterruptible Power Supplies (UPS), Off-Grid Inverters, AC sources and other power devices such as switches, circuit breakers, fuses and connectors. This programmable load was used as a dummy load for real load in rural experiment [106]. Its specification is shown in Table 13.

Figure 13. Chroma's 63800 Series AC&DC Electronic Loads

Table 13. Information Specification of Chroma's 63800 Series AC&DC Electronic Loads [106]

MODEL 63800 SERIES
■ Power Rating: 1800w, 3600w, 4500w
■ Voltage Range: 50v ~ 350vrms
■ Current Range: Up to 18arms, 36arms, 45arms
■ Peak Current: Up to 54a, 108a, 135a
■ Frequency Range: 45 ~ 440hz, Dc
■ Cc, Cr, Cv, Cp for DC Loading
■ Constant & Rectified Load Modes for AC Loading
■ Analogue Voltage & Current Monitor
■ Short Circuit Simulation
■ Gpib & Rs-232 Interfaces

3.5 Inverter

The inverter used in solar cabin system is Sontime 4830N as shown in Figure 14. The inverter will invert the solar cabin system rating from 48V to 230V. The maximum power rating for this inverter is 3kiloWatt as shown in Table 14.

Figure 14. Inverter Sontime 4830N

Table 14. Specification of Sontime 4830N [107]

Characteristics	48 VDC/230 VAC/3000VA
Dimensions (W *x* T *x* H)	270 x 150 x 435
Weight	11,00 kg
Batteries Rated voltage DC	12 V / 24 V / 48 V / 60 V / 120 V
Output Voltage AC	230 V ± 5 % / 115 V ± 5 %
Output Frequency	50 Hz ± 0,5% / 60 Hz ± 0,5 % / 400 Hz ± 0,5 %
Rated Power	600 ... 5000 VA
Connection Threshold	2 W / 6 W adjustable
Consumption (Standby)	< 1 W
Efficiency	> 91 %
Overload Capacity	300 % short-term
Working Temperature Range	-10° C ... + 45° C

3.6 Transducer

The transducer is the main component in the system to measure current and voltage before sending to the computer as data through DataTaker. Figure 15 shows the entire connection from the transducer to the DataTaker in the solar cabin. The type of sensor used in the system is:

- DC Voltage Transducer CR6310-100
- DC Current Transducer CR5210-60
- True RMS AC Voltage Transducer CR4510-250
- Loop Powered AC Current Transducer CR4220-15

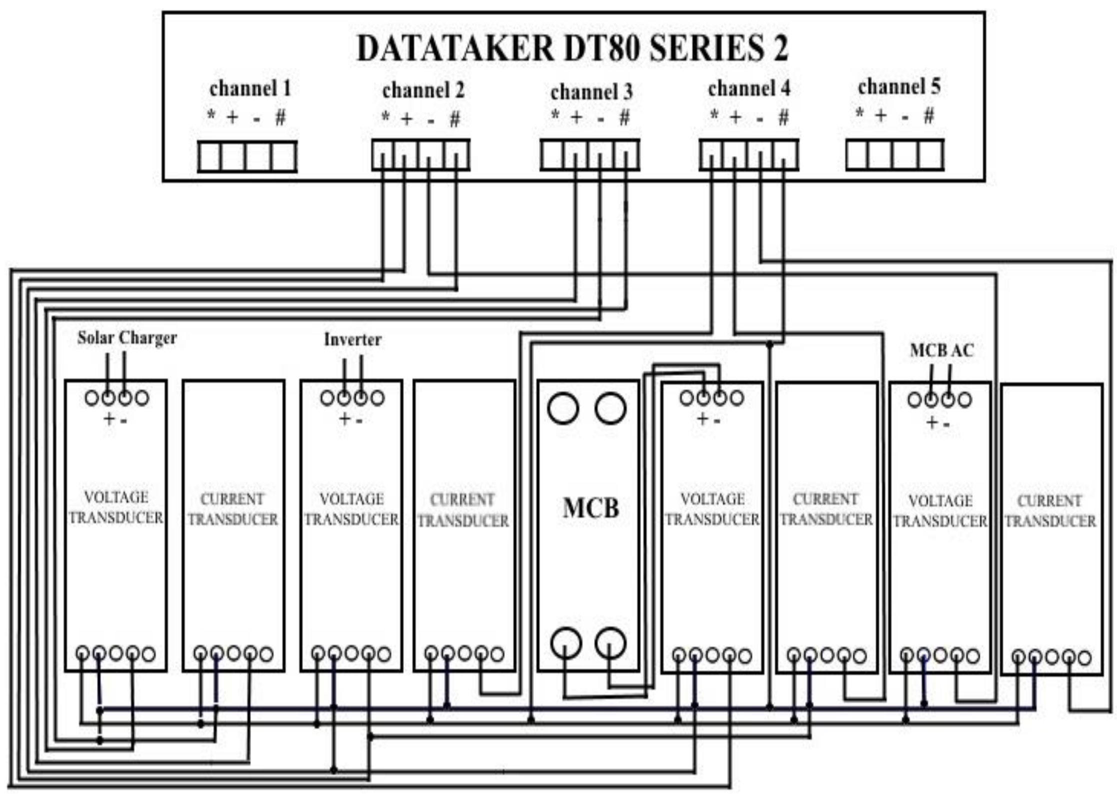


Figure 15. Transducer Connection to DataTaker

DC Voltage sensor and DC Current Transducer were used to capture voltage and current from solar, load, and battery. True RMS AC Voltage Transducer is to take AC Voltage and Loop powered AC Current Transducer to get a data AC Current for AC Load. All transducers are connected to the system as shown in Figure 16 and Figure 17. The voltage and current sensors will send the readings to a data logger which is attached to a PC for storage as shown in Figure 18.

Figure 16. Transducer Connection at Solar Cabin

Figure 17. Transducer Connection at Solar Cabin

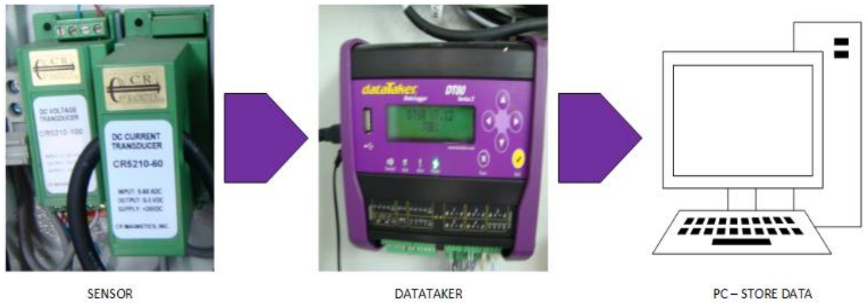


Figure 18. Data Flow for Sensor Signals

3.7 Supercapacitor for Solar PV System

Figure 19 shows the supercapacitor bank combined with the solar PV system developed in UNMC. The supercapacitor is added as an extra feature to this system to support the battery and make the system more efficient.

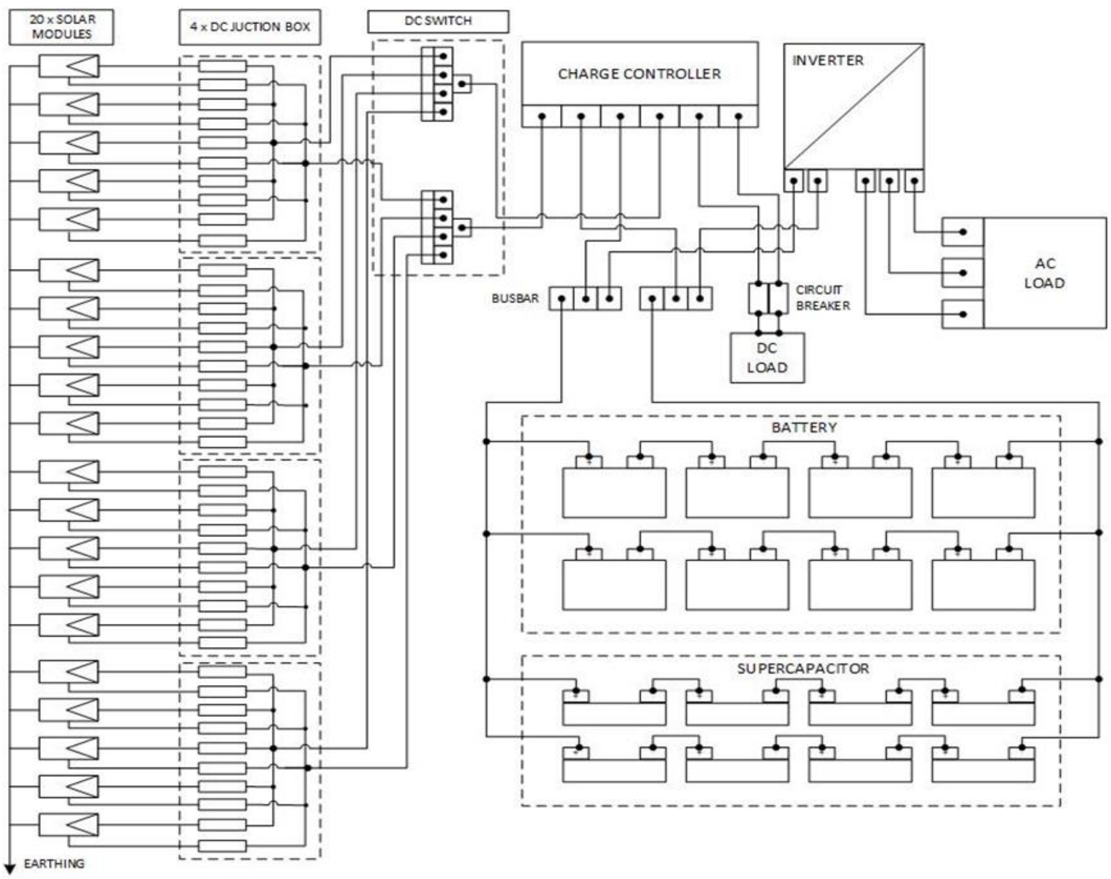


Figure 19. Solar Cabin System with Supercapacitor

3.7.1 Supercapacitor

A supercapacitor bank was integrated into the solar cabin by combining four smaller supercapacitor bank modules in series and in parallel with the other series connection as shown in Figure 20. The actual supercapacitor bank used is shown in Figure 21. The ratings of the supercapacitor bank module used are listed in Table 15.

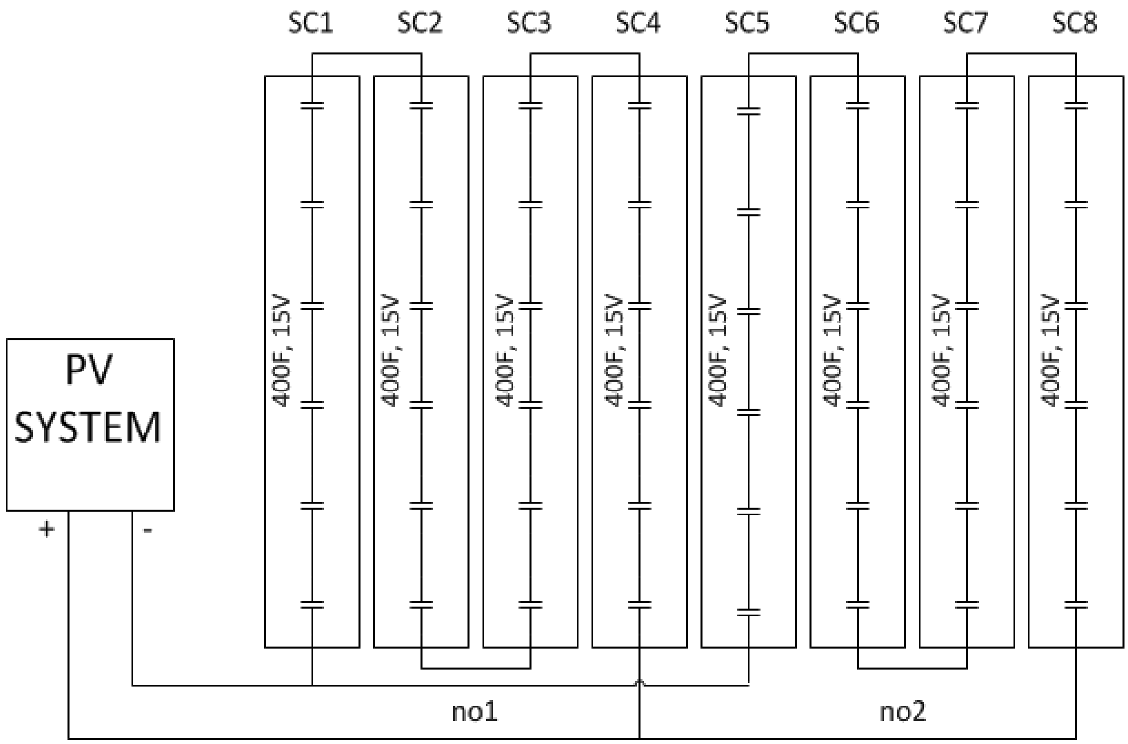


Figure 20. Supercapacitor Connection to System

Figure 21. Supercapacitor in Solar Cabin

Table 15. Standard Ratings for Supercapacitor [108]

RATED VOLTAGE [V]	15
CAPACITANCE [F]	400
INTERNAL RESISTANCE [MΩ]	5.4
INSULATION WITHSTAND VOLTAGE [KV]	1.0

Using this system configuration, it assists in charging and discharging in higher voltage with the larger capacitance. It is also used to provide [108]:

- Energy saving
    - Peak power assistance
    - Efficient use of regenerated energy
- New energy
    - High efficient charge of solar energy
    - Stabilisation of wind energy (will be added in the future)
    - Electricity assists for fuel cell
- Voltage balance circuit installed

3.8 New Rural Area Load Profile (Load Profile 2.0)

The new load profile is developed based on reviews from Chapter 2 in Table 7, Table 8 and Table 9. All the appliances used in a rural area have already been identified. From the house layout plan in Figure 9, the appliances have been located based on the area in the house as shown in Table 5. The estimated number of people living in this house is 4 to 6, and during the day, only the housewife remains in the house. The power consumption of each appliance is taken from the respective official brand's website as shown in Table 16.

Table 16. Appliance Divide based on Area in the House

Appliances	Area						
	Porch	Room 1	Room 2	Roo m3	Living /Dining	Kitchen	Bathroom /Toilet
Ceiling fan (Hall)	0	0	0	0	1	0	0
Ceiling fan (Room1)	0	1	0	0	0	0	0
Light Fluorescent 18w	0	1	1	1	0	0	1
Light Fluorescent 36w	0	0	0	0	1	1	0
Light Fluorescent (Porch)	1	0	0	0	0	0	0
TV 32 Inch (Sony)	0	0	0	0	1	0	0
Table Fan 12'	0	0	1	1	0	0	0
Washing Machine (automatic) 7kg	0	0	0	0	0	1	0
Exhaust Fan 200mm 8inch	0	0	0	0	0	1	0
Water Pump	0	0	0	0	0	0	1
Refrigerator (1door)	0	0	0	0	0	1	0
Iron	0	1	0	0	0	0	0

Table 17. Appliance Power Consumption

Appliance	Reference	Brands	Power Consumption (W)
Ceiling fan (Hall)	CF1	KDK	82.5
Ceiling fan (Room1)	CF2	KDK	82.5
Light Fluorescent 18w	LF1	Philips	18
Light Fluorescent 36w	LF2	Philips	36
Light Fluorescent (Porch)	LFP	Philips	36
TV 32 Inch (Sony)	TV	SONY	39
Table Fan 12'	TF	KDK	42.5
Washing Machine (automatic) 7kg	WM	Toshiba	423
Exhaust Fan 200mm 8inch	EF	KDK	18.3
Water Pump	WP	Hitachi	100
Refrigerator (1door)	RF	Panasonic	93.3
Iron	IR	Philips	1000

From Table 17, the table shows the estimation of appliance usage based on time (hour). For ceiling fan at the main hall (living hall + dining hall) (CF1), the fan is ON from 7 am until 12 am because of the housewife's presence in the main hall and outside room. The ceiling fan (CF2) at room1 only operates at night from 7 pm until 7 am. The fluorescent light 18watt (LF1) is stored in a small place like the room, bathroom and toilet, and fluorescent light 36watt in large areas like the main hall, kitchen, and porch. LF1 and LF2 are ON at night from 7 pm until 12 am and morning from 6 am until 7 am. The light at the porch (LFP) is ON only for three hours from 8 pm until 11 pm. Since the housewife stays at home, the television (TV) is ON during the day from 8 am until 12 am at night. Table fan (TF) is placed in room2 and room3 and operates from 6 pm until 7 am. Washing machine (WM) is used for half an hour during morning to wash the clothes. An exhaust fan (EF) is placed in the kitchen.

The exhaust fan is ON when cooking during breakfast (7 am), lunch (12 pm) and dinner (7 pm until 8 pm). Water pump (WP) is used during a peak hour because the water pressure is low. The pump is operated in the morning (6 am to 8 am), afternoon (1 pm) and during the night (7 pm until 8 pm). The refrigerator (RF) is on 24 hours. The iron is used during morning for around 30 minutes.

Table 18. Estimation of Appliance Usage based on Time

Time (Hour)	Appliance (Reference)											
	CF1	CF2	LF1	LF2	LFP	TV	TF	WM	EF	WP	RF	IR
0:00	0	1	0	0	0	0	1	0	0	0	1	0
1:00	0	1	0	0	0	0	1	0	0	0	1	0
2:00	0	1	0	0	0	0	1	0	0	0	1	0
3:00	0	1	0	0	0	0	1	0	0	0	1	0
4:00	0	1	0	0	0	0	1	0	0	0	1	0
5:00	0	1	0	0	0	0	1	0	0	0	1	0
6:00	0	0	1	1	0	0	1	0	0	1	1	0
7:00	1	0	1	1	0	0	1	0	0	1	1	0.5
8:00	1	0	0	0	0	1	0	0.5	0	0	1	0
9:00	1	0	0	0	0	1	0	0	0	0	1	0
10:00	1	0	0	0	0	1	0	0	0	0	1	0
11:00	1	0	0	0	0	1	0	0	0	0	1	0
12:00	1	0	0	0	0	1	0	0	1	0	1	0
13:00	1	0	0	0	0	1	0	0	0	1	1	0
14:00	1	0	0	0	0	1	0	0	0	0	1	0
15:00	1	0	0	0	0	1	0	0	0	0	1	0
16:00	1	0	0	0	0	1	0	0	0	0	1	0
17:00	1	0	0	0	0	1	0	0	0	0	1	0
18:00	1	0	0	0	0	1	1	0	0	0	1	0
19:00	1	1	1	1	0	1	1	0	1	1	1	0
20:00	1	1	1	1	1	1	1	0	1	0	1	0
21:00	1	1	1	1	1	1	1	0	0	0	1	0
22:00	1	1	1	1	1	1	1	0	0	0	1	0
23:00	1	1	1	1	0	1	1	0	0	0	1	0

From Table 17, the total usage time in an hour and power used per day is shown in Table 18 for each appliance. The total energy used per day is 9528.1W while the total capacity of the system is 14400W. The total power used per day for each appliance is calculated by:

Total power of each appliance = Power each appliance *x* quantity *x* total hour used.(9)

Table 19. Total Usage Time in Hour and Power Used Per Day

Appliance	Power (Watt)	Quantity	Total Hour used	Power/day (Watt)
Ceiling Fan (Hall)	82.5	1	17	1402.5
Ceiling Fan (Room1)	82.5	1	12	990
Light Fluorescent	18	4	7	504
Light Fluorescent	36	2	7	504
Light Fluorescent (Porch)	36	1	3	108
TV 32 Inch (Sony)	39	1	16	624
Table Fan 12'	42.5	2	14	1190
Washing Machine (Automatic)	423	1	0.5	211.5
Exhaust Fan 200mm 8inch	18.3	1	3	54.9
Water Pump	100	1	4	400
Refrigerator (1Door)	93.3	1	24	2239.2
Iron	1000	1	0.5	500
			Total Power Used/ day	8728.1

Table 20 and Figure 22 show the total watt-hour and the current based on usage by time from Table 19. The maximum total power is 8728.1 W which is lower than at power peak demand for the rural house by TNB in Table 6. For example, the total power used per hour and current at 12 am is calculated. Thus:-

Total power used per hour (at 12 am)

= sum of (power for each appliance *x* quantity)………. (10)

$$\text{The current (Ah) (at 12 am)} = \frac{\text{Total power at 12 am}}{\text{230V (Standard Malaysia Rating)}} \ldots\ldots\ldots (11)$$

Table 20. Total Watthour and Current based on Usage Time (Hour)

Time (Hour)	Total (Wh)	Current (Ah)
0:00	260.8	1.13
1:00	260.8	1.13
2:00	260.8	1.13
3:00	260.8	1.13
4:00	260.8	1.13
5:00	260.8	1.13
6:00	504.8	2.19
7:00	1004.8	4.37
8:00	426.3	1.85
9:00	214.8	0.93
10:00	214.8	0.93
11:00	214.8	0.93
12:00	233.1	1.01
13:00	314.8	1.37
14:00	214.8	0.93
15:00	214.8	0.93
16:00	214.8	0.93
17:00	214.8	0.93
18:00	299.8	1.30
19:00	644.6	2.80
20:00	580.6	2.52
21:00	562.3	2.44
22:00	562.3	2.44
23:00	526.3	2.29

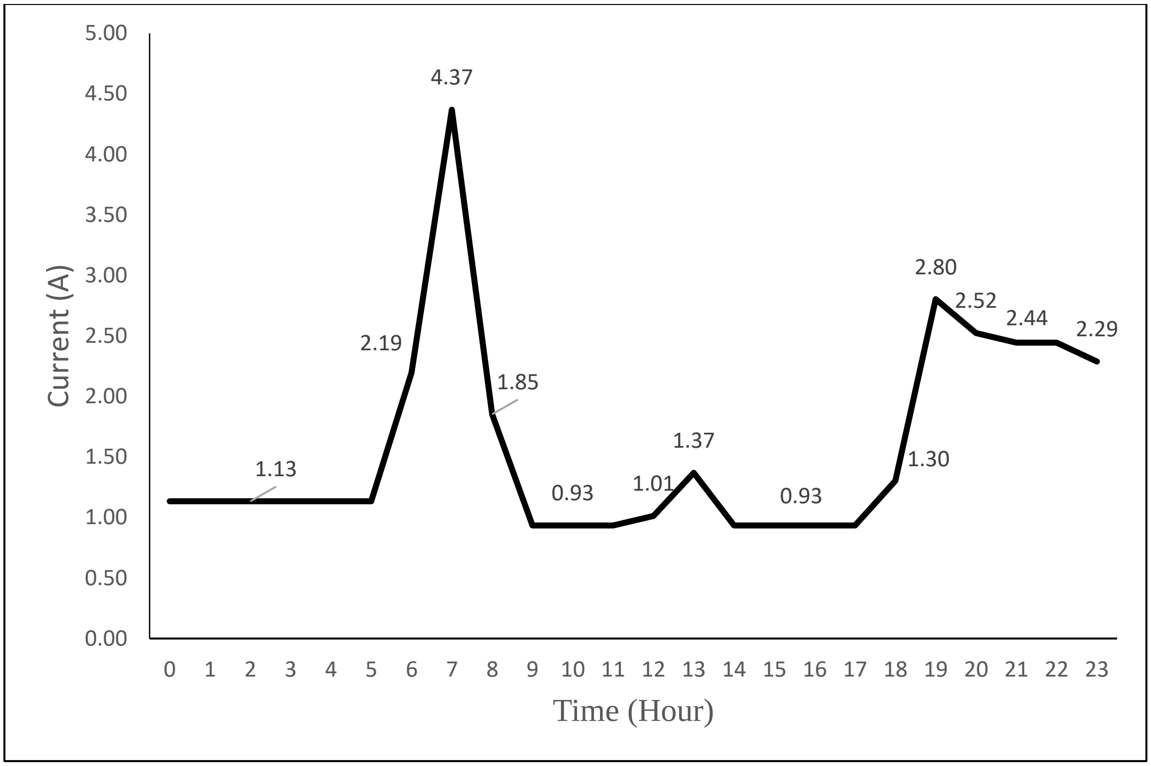


Figure 22. New Current Load Profile Based on Real-Time Usage

3.9 Solar PV System Modelling

As can be seen in Table 19, the system can be expected to supply sufficient power to a non-grid connected area up to 8.7kWh per day. The current demand per day is calculated based on the expected energy used per item in one day.

The amount of current needed in this system is:

$$Current = \frac{Power}{Voltage} = 181.69Ah \ldots\ldots\ldots\ldots\ldots \text{(12)}$$

$$System\ Capacity = Battery\ Current\ x\ Battery\ Voltage \ldots\ldots\ldots\ldots \text{(13)}$$

$$Estimated\ Day = \frac{Capacity}{Demand\ per\ day} = 1.65\ Days \ldots\ldots\ldots\ldots\ldots\ldots \text{(14)}$$

From Equation 5, the system capacity of 150Ah can meet the supply demand which is 181.69Ah. The energy demand is expected to grow by 20% in 5 years; the system will still be able to meet the energy demand (190Ah). The solar cabin has a capacity of 7.2kWh from Equation 5. Hence, the cabin is able to supply power without being charged for 1.65 days without charging from Equation 6.

The capacity of the supercapacitor applied to the system is 200F at 48V. The calculation for this supercapacitor is shown below.

$$no1 = \left(\frac{1}{SC1} + \frac{1}{SC2} + \frac{1}{SC3} + \frac{1}{SC4}\right)^{-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$= \left(\frac{1}{400} + \frac{1}{400} + \frac{1}{400} + \frac{1}{400}\right)^{-1} = 100\text{F}$$

$$no2 = \left(\frac{1}{SC5} + \frac{1}{SC6} + \frac{1}{SC7} + \frac{1}{SC8}\right)^{-1} \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$$= \left(\frac{1}{400} + \frac{1}{400} + \frac{1}{400} + \frac{1}{400}\right)^{-1} \qquad = 100\text{F}$$

Total capacitance = 100F + 100F = 200F.

3.10 Solar PV and Supercapacitor Experiments

Four sets of experiments were conducted in the solar cabin system for data collection and supercapacitor influence into the system. All the results were collected by using DataTaker as a data logger and using the Delogger Software to acquire data. Firstly, the battery performance in the solar cabin was investigated. Analysis was done to test the effect of the system power during the day and night using two fluorescent lights and two exhaust fans.

The second set of the experiment is to analyse the performance of the system in a rural area day by day for one month (December 2013). All results shown in this experiment are taken from 12 am on 1st December until 11:59 pm on 31 December 2013. The data collected in these experiments are solar irradiation, solar power, battery power and solar PV efficiency. This experiment conducted in three (3) days without supercapacitor and the best solar irradiation per day was choose.

The third set of experiments is to test whether the solar cabin system is the same with real time usage, based on the load current profile that has been set up and tabled in Table 20. The experiment was carried out to provide the average hourly usage of power in a rural area for analysis. From the result of this experiment, it is possible to prove that the system is capable of working properly and is able to supply sufficient power for the typical rural house.

3.10.1 Charging Supercapacitor Process.

Before starting the experiment using a supercapacitor, the supercapacitor must in fully charged condition. This is to avoid the supercapacitor being charged directly from the battery in high current (>60A) which will reduce the battery performance and damage the circuit breaker. The charging process was done using DC power supply. If supply current 2 Amps is continuous, the supercapacitor is fully charged (15V) in 2 hours for one set each. The whole set of supercapacitor used in this solar cabin is 8.

After finish charging the supercapacitor, all supercapacitors connected are in parallel with the battery. The next experiments were conducted in the solar cabin based on a real living situation to compare the effect of the supercapacitor and without supercapacitor in a solar system already done in the third set of an experiment using same load profile in Table 20. Various voltages and current transducers were placed to obtain the readings of the battery voltage, battery current and supercapacitor current.

Figure 23. Manual Charging Supercapacitor

Figure 24. Supercapacitor after Charging

3.11 Bi-Directional DC to DC converter

The main objective of this part is to attach the bi-directional DC to DC converter to the solar cabin system to control the charging and discharging of the supercapacitor and battery (busbar) in EMS. Bi-directional DC to DC converter is becoming more common in recent technology such as hybrid vehicles, due to high voltage bus needed to be supplied to the motor and also in renewable energy for energy distribution. The existing energy storage like supercapacitor needs to be interlinked with the bi-directional DC to DC converter to reduce the unbalanced output current produced by the supercapacitor.

Initially, before implementing the converter, an appropriate data measurement and ratings and the requirements of the system need to be collected and analysed. The ratings and requirements of the system are observed through specification of the system primarily based on the accumulated facts on requirements.

The converter needed for operation in the solar cabin was chosen according to the following parameters:

- Minimum supercapacitor voltage : 30V
- Minimum battery DC bus voltage : 48V
- Maximum battery DC bus voltage : 58V
- Battery DC bus voltage setpoint : 56V (only when supercapacitors connected)
- Minimum supercapacitor voltage : 30V (assuming SOC should not go below 50%)
- Maximum supercapacitor voltage : 60V
- Input power : 2000W

From the solar cabin specification above, the type of converter used in this project is multifunctional bi-directional DC to DC converter USCDCDCca-6-80-24-IP20 (Figure 25). This converter has low ripple current, very low noise emission, bidirectional fully controlled H-Bridge and CAN bus interface. The charging and discharging of energy storage systems can configure the operation make this converter suitable for this project and solar cabin system. The technical specification of this converter is shown in Table 21.

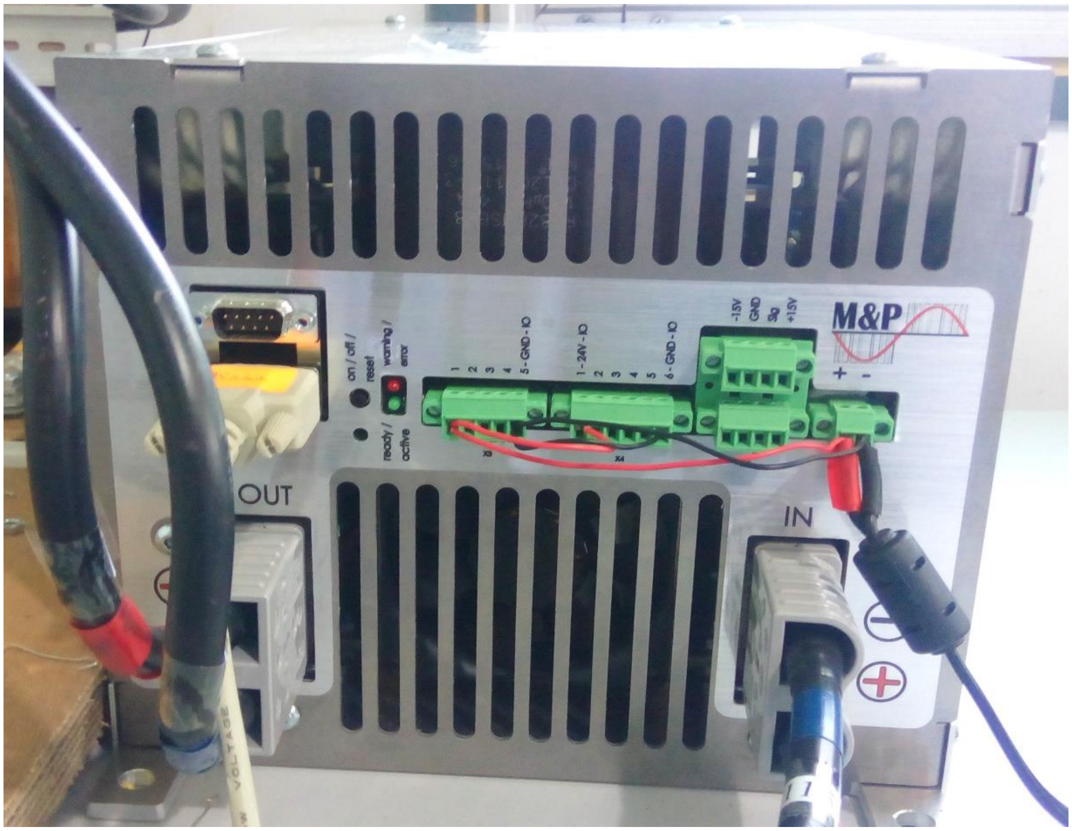


Figure 25. Multifunctional Bi-Directional DC to DC Converter

Table 21. Technical Specifications of Multifunctional Bi-Directional DC-DC Converter [109]

General		
P_r	Rated Power	48V 6 kW
f_r	Switching frequency	24 kHz
η_r	Efficiency	>95 %
Primary Side / Secondary Side		
U_{pr}	Voltage Range	0 - 80 V DC
U_p,max	Max. operating voltage	80 V DC
I_p,max	Maximum current	150 A

3.12 Energy Management System

The main aim of this part is to build and design a new intelligent energy management system (EMS) which consists of monitoring and controlling the system in the solar cabin to create a data storage system in the solar cabin using LabVIEW software. The following objectives must be met to archive the purpose:

• Build and design a Graphical User Interface (GUI) to monitor and control the energy system in solar cabin using LabVIEW.

• Interface all sensors and useful solar parameters into the designed GUI using data acquisition software (DAQ) hardware.

• Incorporate optimisation/control into the designed GUI for efficient energy management system.

• Build an efficient data storage system using LabVIEW to replace the built in current DataTaker.

3.13 Data Acquisition

Data acquisition or DAQ is the measurement of electrical data and storing them in some coherent mode [110][111]. This part reviews the basic components in data acquisition, a process for the project using the DAQ Assistant from LabVIEW. Also, signal conditioning for each raw signal acquired from the solar cabin is discussed.

3.13.1 Components of DAQ System

The DAQ hardware acts as the interface between the sensors or transducers with the computer. Its main function is to digitise incoming analogue signals for analysis in the computer. Signal conditioning, Analog-to-digital converter (ADC) and computer bus are the three main components in DAQ hardware as shown in Figure 26. The computer is used for visualising, analysing and storing measurement data.

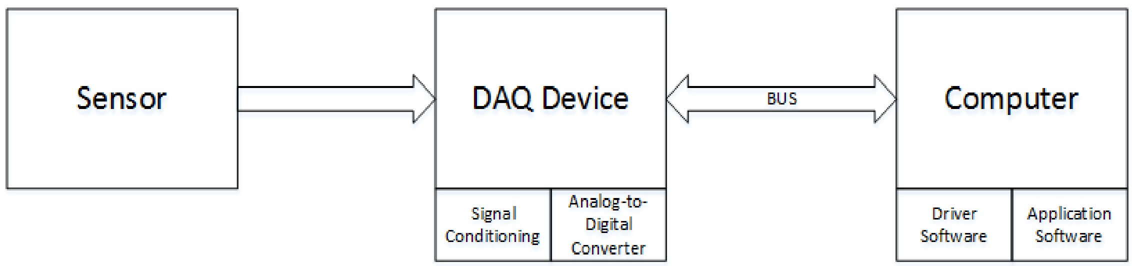


Figure 26. Process of Data Acquisition

3.13.2 Signal Conditioning

In this project, all the output transducers from the solar cabin are analogue DC signals and consequently only the signal type is used in DAQ. Nonetheless, the implementation of the Rule-based Fuzzy Logic algorithm in the system require the conversion of the analogue DC signals to digital (ON-OFF) signals for control of the relays. Since the output of transducers is normally low, some types of signal conditioning such as linearization and scaling can be done in the LabVIEW software itself. In this project, amplification is used to maximise the use of the available range for higher accuracy of signal and also to increase the signal-to-noise ratio. Since the amplification is only applied at DAQ device, it has an approximate signal to noise ratio of 10dB. Table 22 below displays the amplification made to each sensor signal based on their specifications.

Table 22. Types of Sensor in Solar Cabin

No.	Types of Sensor	Models	Scaling Factor
1	DC Current Transducer	CR5210-60	12
2	DC Voltage Transducer	CR5310-100	30
3	AC Voltage Transducer	CR4510-250	50
4	AC Current Transducer	CR4220-15	200
5	Pyranometer (Solar Irradiation Sensor)	SP Lite2	20000

3.13.3 DAQ Hardware

This project involves the use of the NI DAQ 6353 DAQ as a hardware device. DAQ is used for the complete testing of the system. Moreover, all sensors are wired to the analogue input pin. Each sensor will be wired to one channel of the DAQ hardware. Figure 27 illustrates the connection between the sensors to the DAQ device and from the DAQ device to the computer. By connecting the DAQ hardware to the computer through USB cable, the DAQ Assistant Express VI provided in LabVIEW can be configured.

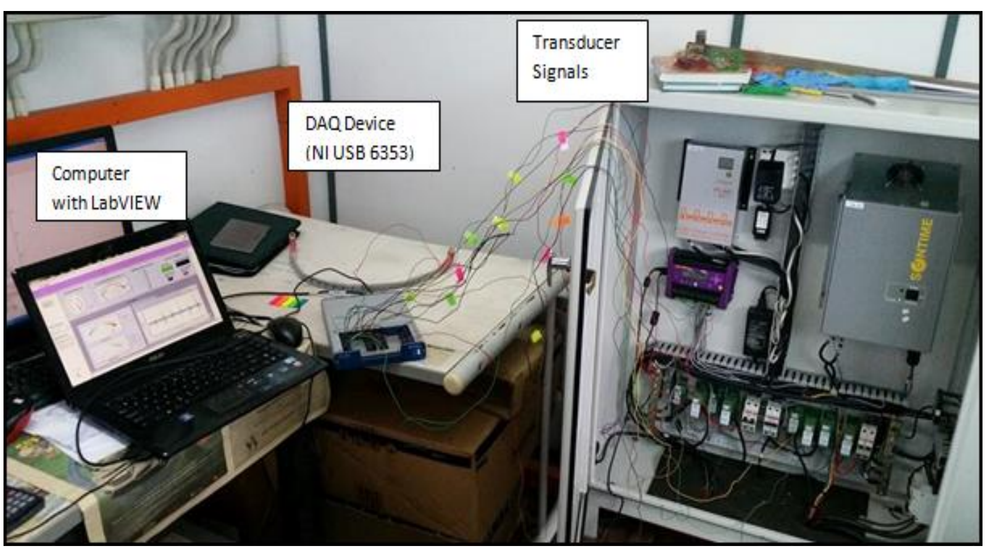


Figure 27. Connections between Computer, DAQ Device and Sensor Signals

3.14 Graphical User Interface

In this section, the GUI was developed using LabVIEW for implementation in the solar cabin system. The first step in designing the functional GUI is to gather and obtain parameters that are necessary to be displayed. Table 23 shows the basic parameters that are required in the GUI system and the indicators used for each parameter. The different indicators were used for illustrating the parameters in the cabin system.

Table 23. Parameters in Solar Cabin with Indicators

No.	Parameter	Indicator(s)
1	Solar Irradiance (W/m^2) Solar: Voltage (V), Current (A), Power (P) Battery: Voltage (V), Current (A), Power (P) Supercapacitor: Voltage (V), Current (A), Power (P) AC Load: Voltage (V), Current (A), Power (P)	Meter & Numeric Indicator
2	SOC Battery SOC Supercapacitor	Graduated Bar & Numeric Indicator
3	Battery Voltage (V) vs Supercapacitor Voltage (V) Battery Current (A) vs Supercapacitor Current (A)	Waveform Graph
4	ON/OFF Relays	LED's

A toggle switch button is included in the GUI for each relay which enables the termination of execution when the button is pressed by users. Indicator value range is determined by data that is previously logged by the DataTaker in the solar cabin. The EMS Profile 2.0 is shown in Figure 28. The indicators in the designed GUI display output are in accordance with all the sensor signals in the solar cabin. To allow the signals to be fed and wired to the indicators in LabVIEW, data acquisition needs to be done to all the connections.

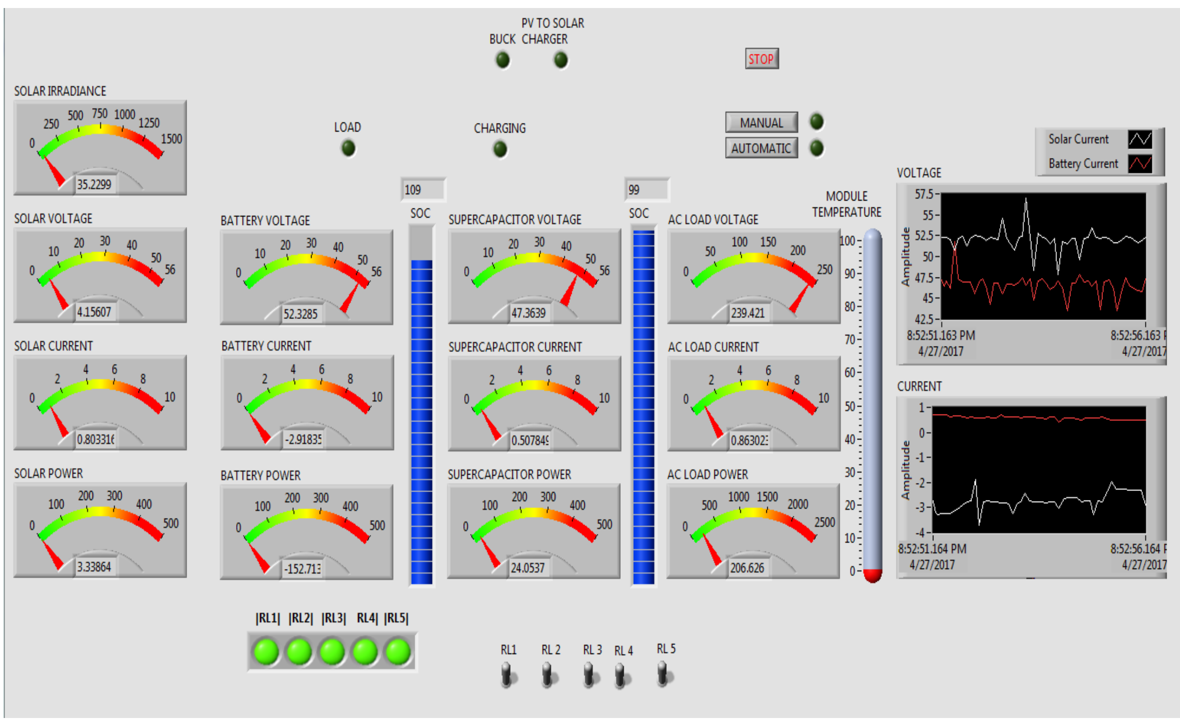


Figure 28. GUI Energy Management System Profile 2.0

3.14.1 Live Monitoring Using LabVIEW

By using LabVIEW and DAQ in this project, the monitoring system is replaced by DataTaker thus providing an easy way to store data automatically to the computer. The item monitored by this system is:

- Solar irradiation
- Solar panel Voltage, current and Power
- AC Voltage, current and Power AC
- Low battery condition – alarm triggered
- Battery and Supercapacitor Percentage and status (Full, Charging and Discharging)
- Status connection in solar cabin
- History data
- Energy source to Load (Supercapacitor or Battery)

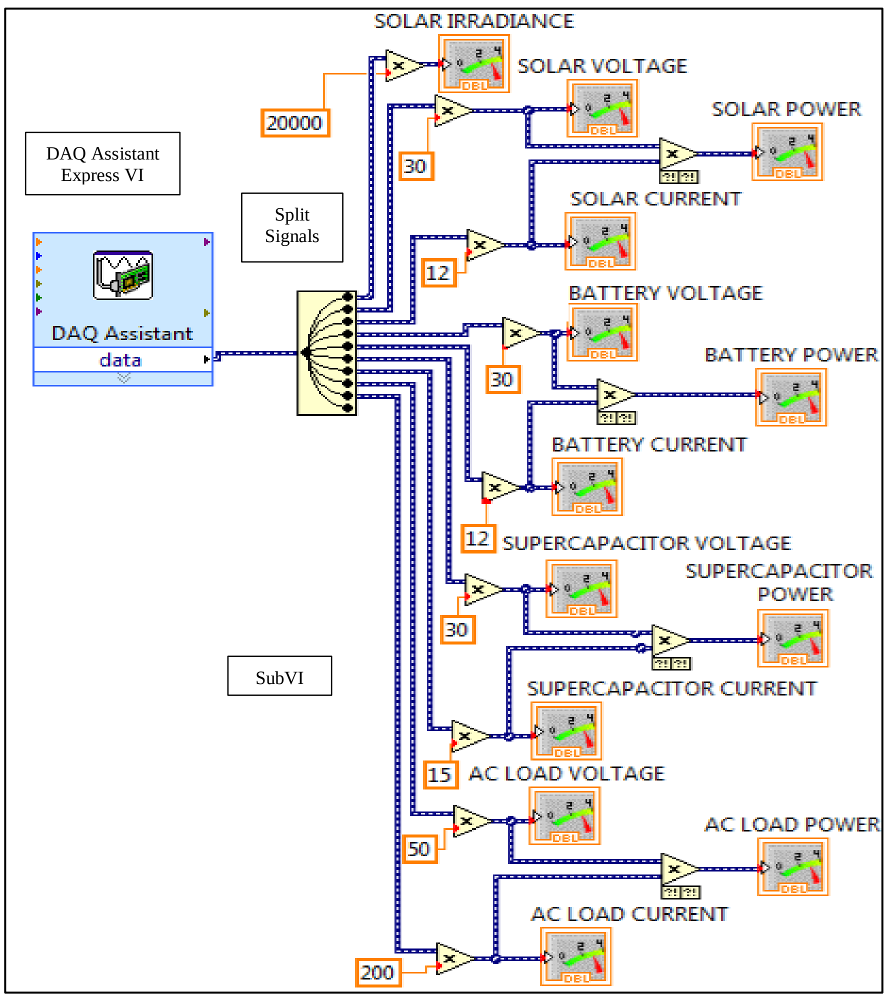


Figure 29. Block Diagram Energy Management System using LabVIEW

Figure 29. Block Diagram Energy Management System using LabVIEW shows a part of the block diagram of the designed GUI in LabVIEW for the data acquisition process. As seen from the figure, the DAQ Assistant Express VI is used to acquire data from the sensors, with each sensor occupying one channel from the DAQ device. All the sensors are analogue input and RSE terminal configuration. At this point, it measures the difference between the positive inputs with respect to ground. Since the GUI are designed for continuous monitoring, the acquisition mode is set to continuous samples with a default rate of 1 KHz with a 1K number of samples. The signals are split from the DAQ output for individual display and analysis of the signals. Also, the scale factor of each sensor as mentioned in Table 22 is built as SubVIs. The scaled values are then connected to indicators for display from the front panel of LabVIEW.

3.14.2 LabVIEW Data Collection

The data collection is of main importance in this project. The data is collected using LabVIEW and it will be compared with previous device (DataTaker). The data will write to measurement file as shown in Figure 30. The configuration to write the data from signal to file is shown in Figure 31, and Figure 32 is a configuration to make sure that data is written continuously.

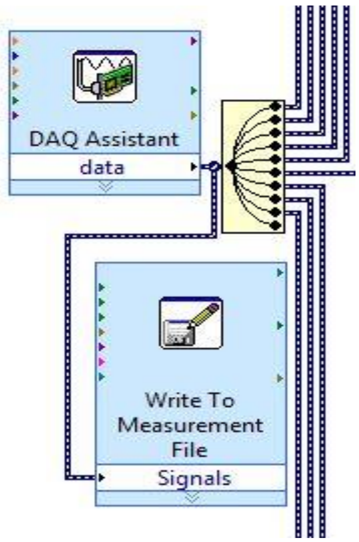


Figure 30. Write to Measurement File

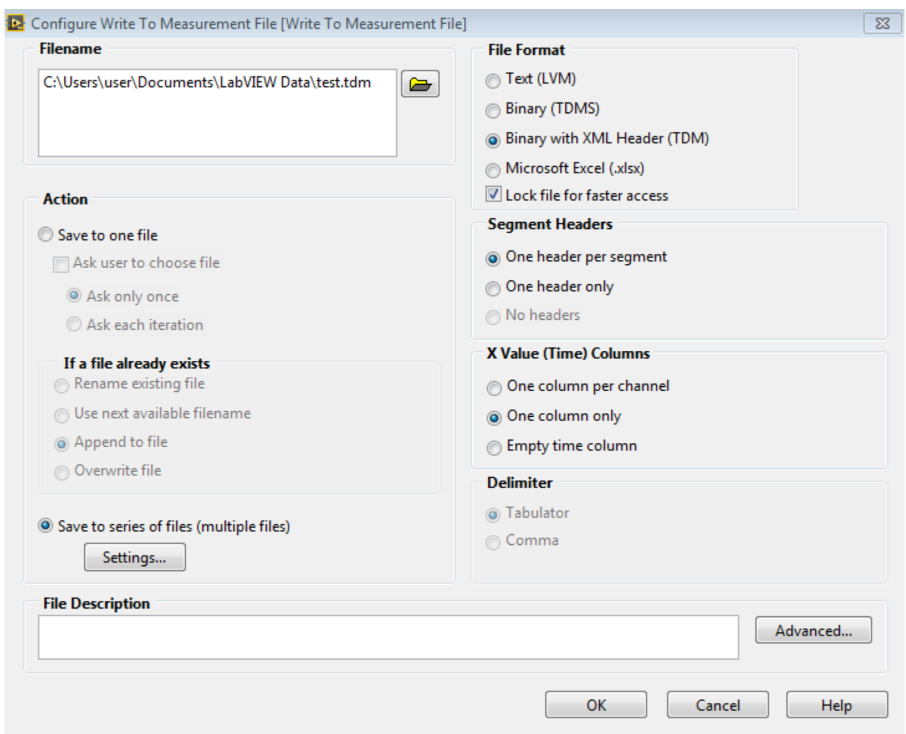


Figure 31. Configuration Write to Measurement File

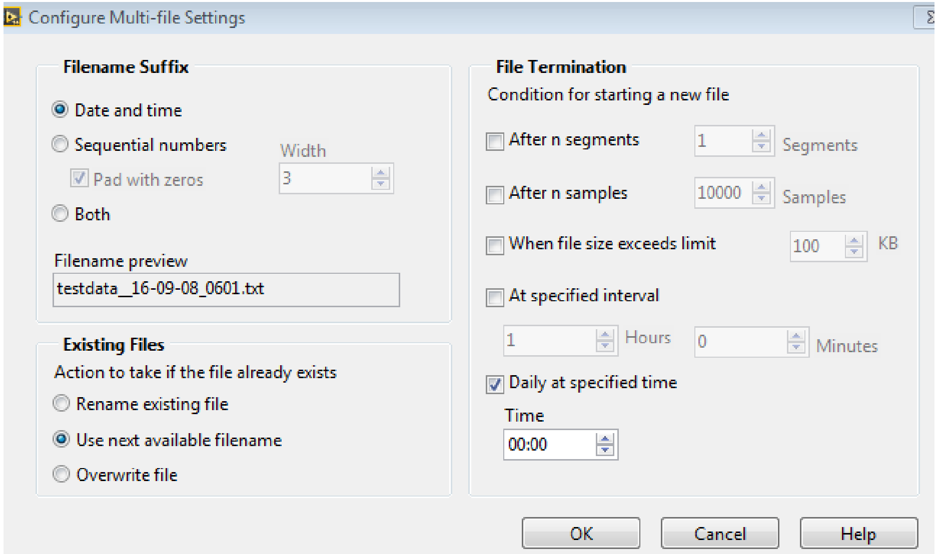


Figure 32. Configuration Multi-File Settings

3.15 New Energy Management System Load Profile 2.0

Figure 33 show a diagram of the new energy management system proposed in the solar cabin for Load Profile 2.0. This new EMS diagram also includes the relay attached to the system. The total number of relays used in this system is five (5). The function of the relay in the new EMS system is to ON or OFF the connection on the system based on a condition in Table 24. All conditions are created based on analysis of data from the experiments that have been performed in solar cabin. The details of the conditions are:

1. Relay1- when solar PV current is 0A or less than 0A, Relay1 is OFF. When solar PV current more than 0A, Relay1 is ON. The function of Relay1 is to easily control the output from solar PV and to protect from unwanted current to the system.
2. Relay2 – when solar charger current output is 0A or less than 0A, Relay2 is OFF. When solar charger current more than 0A, Relay2 is ON. The function of Relay2 is to easily control the output from the solar charger to busbar and battery.

3. Relay3 – when the load current is 0A or less than 0A, Relay3 is OFF. When load current is more than 0A, Relay3 is ON. The function of Relay3 is to easily control the current flow to the load and protect from unwanted current to the load.
4. Relay4 – when load current more than 15A, Relay4 is OFF. When load current is lower than 15A, Relay4 is ON. The function of Relay4 is to protect the battery from discharging current to depth.
5. Relay5- when load current is higher than 15A, Relay5 is ON to cover battery from supply sudden high current to the load. While solar PV current is more than four Amps and load current is lower than 15A, Relay5 is ON to cover battery from overcharging during a day. Meanwhile when load current is lower than 15A, the Relay5 is OFF.

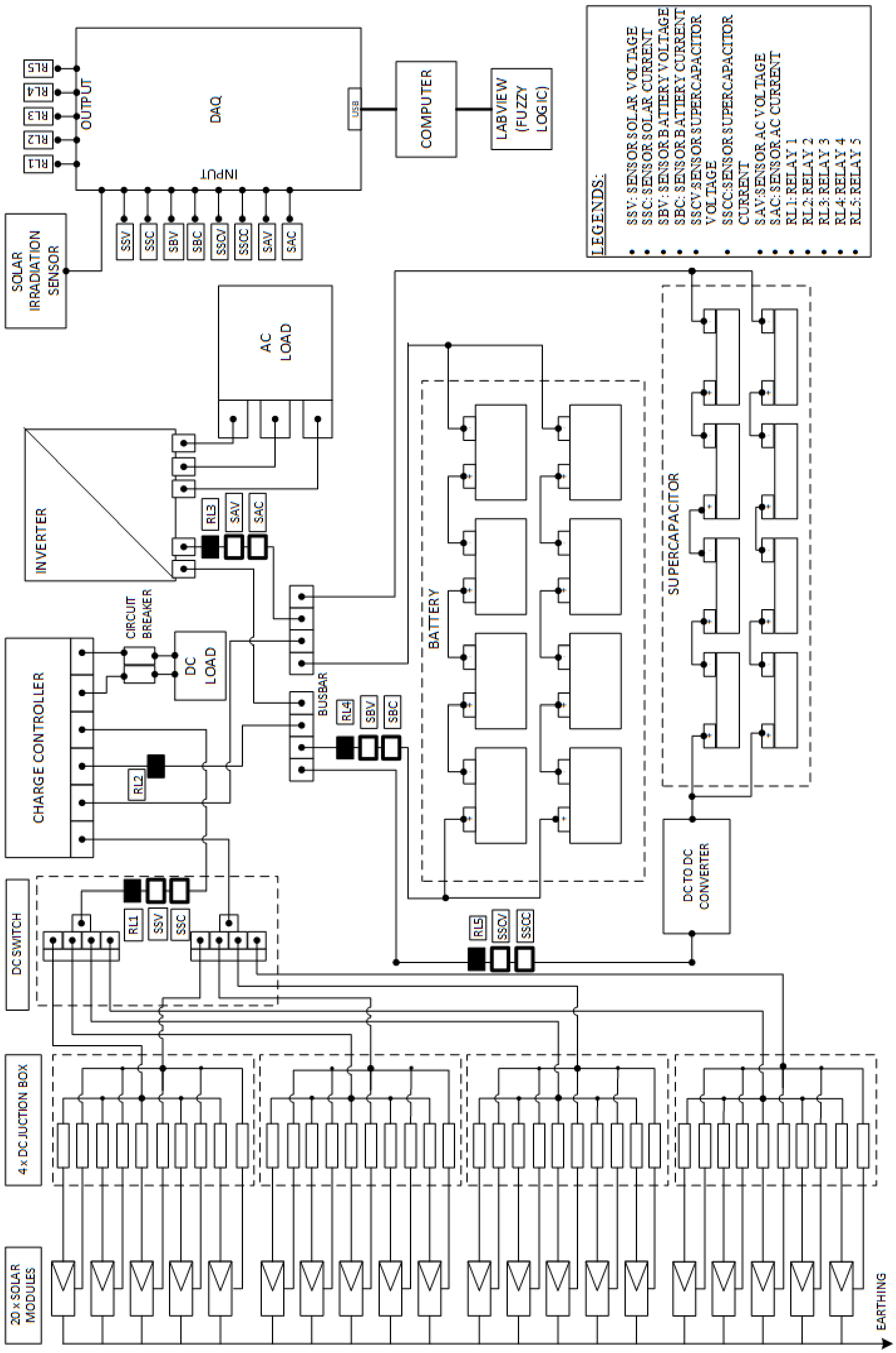


Figure 33. Solar PV System Schematic with Energy Management System

Table 24. Solar Cabin Status Rules for Energy Management System

RELAY	SOLAR CABIN STATUS	RELAY ON/OFF
1	Solar PV <= 0A Solar PV > 0A	OFF ON
2	Solar Charger <= 0A Solar Charger > 0A	OFF ON
3	Load Current <= 0A Load Current > 0A	OFF ON
4	Load Current >15A Load Current <15A	OFF ON
5	Load Current => 15A Solar PV>4A & Load Current <15A Load Current <15A	ON ON OFF

The solar cabin status based on relay and number of rules the system is defined in detail in Table 25. For example, when the status of the solar cabin system is ISolarPV<0A, the Relay1 (R1) and Relay2 (RL2) are OFF or 0. Relay3 (R3), Relay (R4) and Relay (R5) are either ON or OFF depending on other status and rules. IB-pv is solar PV current minus load current and extra current will charge the battery.

Table 25. Solar Cabin Status Based on Relay and Number of Rules

Solar Cabin Status\Relay		R1	R2	R3	R4	R5
ISolarPV<0		0	0	0/1	0/1	0/1
ISolarPV>0		1	1	0/1	0/1	0/1
ISolarCharger<0		0	0	0/1	0/1	0/1
ISolarCharger>0		1	1	0/1	0/1	0/1
Iload<0		0	0/1	0/1	0/1	0/1
Iload>0		1	0/1	0/1	0/1	0/1
IBattery	IB-pv					
<-2	<-2	0/1	0/1	1	1	1
<4	<-2	0/1	0/1	1	1	0
<15	<-2	0/1	0/1	1	1	1
<30	<-2	0/1	0/1	1	1	1
<-2	<4	0/1	0/1	1	1	1
<4	<4	0/1	0/1	1	1	0
<15	<4	0/1	0/1	1	1	0
<30	<4	0/1	0/1	1	1	1
<-2	<15	0/1	0/1	1	1	1
<4	<15	0/1	0/1	1	1	0
<15	<15	0/1	0/1	1	1	1
<30	<15	0/1	0/1	1	1	1
<-2	<30	0/1	0/1	1	1	1
<4	<30	0/1	0/1	1	1	1
<15	<30	0/1	0/1	1	1	1
<30	<30	0/1	0/1	1	0	1

3.15.1 Fuzzy Logic Rule Base Control

A Fuzzy Logic Rule Base Control is designed to replace the Classic Logic Rule Base control. Classic rule base needs to be replaced to simplify the complex logic gate in Classic Logic Rule Base Control. Figure 34. Fuzzy Logic Rule Base Control for EMS Design in LabVIEW. Battery and Supercapacitor current range is between -30A to 30A while solar PV and solar charger current range is between -10A to 30A.

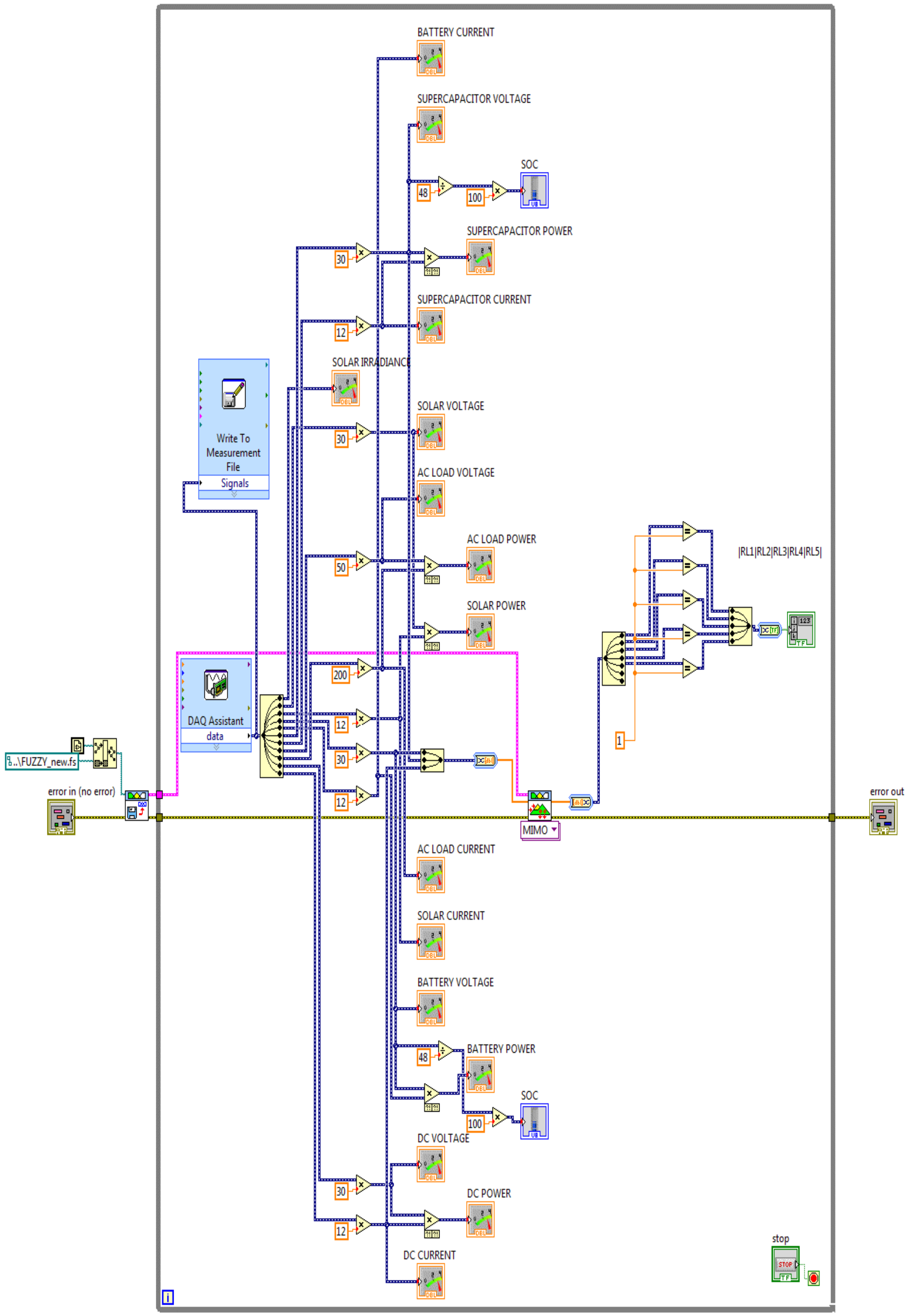


Figure 34. Fuzzy Logic Rule Base Control for EMS Design in LabVIEW

3.15.1 Defuzzification Method: Centre of Area

3.15.1.1 Input membership functions

3.15.1.1.1 IBattery

Table 26 shows the battery input membership function in EMS Fuzzy Logic rule base control. Membership function for the battery is IBattery <-2 for battery current lower than -2A, IBattery >4 for the battery current more than 4A, IBattery >15 for the battery more than 15A and IBattery >-2 for battery current more than -2A. Figure 35 shows the graph of the battery current membership function by using Trapezoid and Gaussian shape. The point use for IBattery <-2 is between -30 and -1. For IBattery >4, the point is between 3 and 16 because of ±1 based on status and condition rules. The point used for IBattery >-2 is between -3 and 5. The point used for IBattery >15 is between 14 and 30 while the maximum point in solar cabin is 30A for maximum reading in the solar cabin.

Table 26. IBattery Input Membership Function in EMS Fuzzy Logic Rule Base Control

Membership function	Shape	Points
IBattery <-2	Trapezoid	-30; -29; -2 ; -1
IBattery >4	Trapezoid	3; 4; 15; 16
IBattery >15	Gaussian	14; 15; 29; 30
IBattery >-2	Gaussian	-3; -2; 4; 5

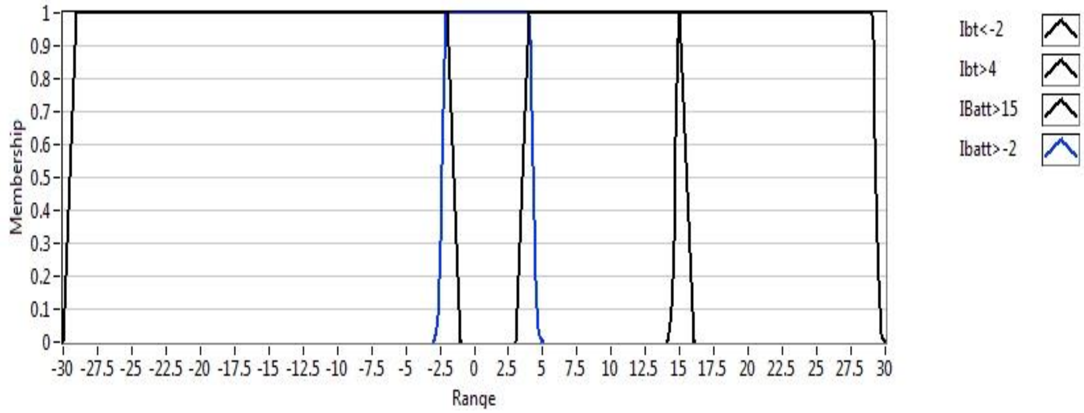


Figure 35. IBattery Input Membership Function in EMS Fuzzy Logic Rule Base Control

3.15.1.1.2 ISolarPV

Table 27 show the ISolarPV input membership function in ems fuzzy logic rule base control. Membership function for the solar PV is PV<0 for solar PV current lower than 0A and PV>0 for solar PV more than 0A. Figure 36 shows the graph of the solar PV current membership function by using Gaussian shape. The point use for PV<0 is between -10 and 0. For PV>0, the point is between 0 and 30. The point of solar PV current membership function is determined by result analysis from solar cabin.

Table 27. ISolarPV Input Membership Function in EMS Fuzzy Logic Rule Base Control

Membership function	Shape	Points
PV<0	Gaussian	-10 ; -9 ; -1 ; 0
PV>0	Gaussian	0 ; 1 ; 29 ; 30

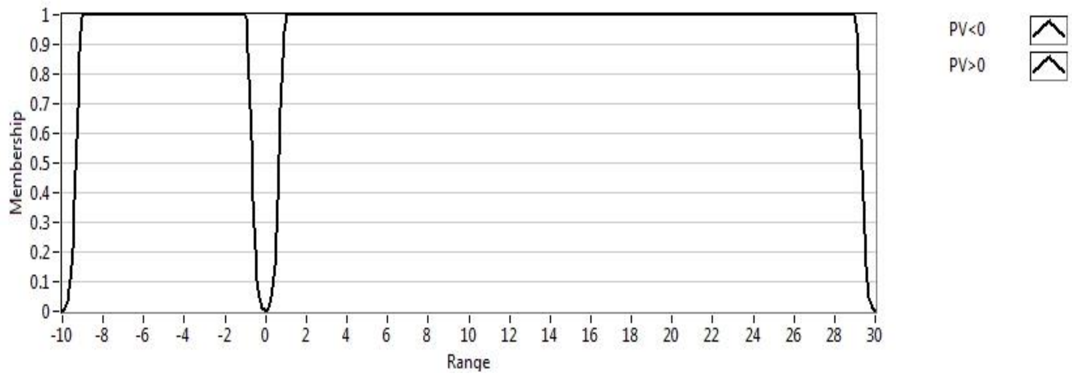


Figure 36. ISolarPV Input Membership Function in EMS Fuzzy Logic Rule Base Control

3.15.1.1.3 IB-pv

Table 28 shows the IB-pv input membership function in ems fuzzy logic rule base control. Figure 37 shows the graph of the IB-pv membership function by using Gaussian shape. Membership functions for both table and figure when:

- IB-pv>15, points is from 14 until 30.
- IB-pv<15, points is from 3 until 16.
- IB-pv<4, points is from -3 until 5.
- IB-pv<-2, points is from -30 until -1.

Table 28. IB-pv Input Membership Function in EMS Fuzzy Logic Rule Base Control

Membership function	Shape	Points
IB-pv>15	Gaussian	14 ; 15 ; 29 ; 30
IB-pv<15	Gaussian	3 ; 4 ; 15 ; 16
IB-pv<4	Gaussian	-3 ; -2 ; 4 ; 5
IB-pv<-2	Gaussian	-30 ; -29 ; -2 ; -1

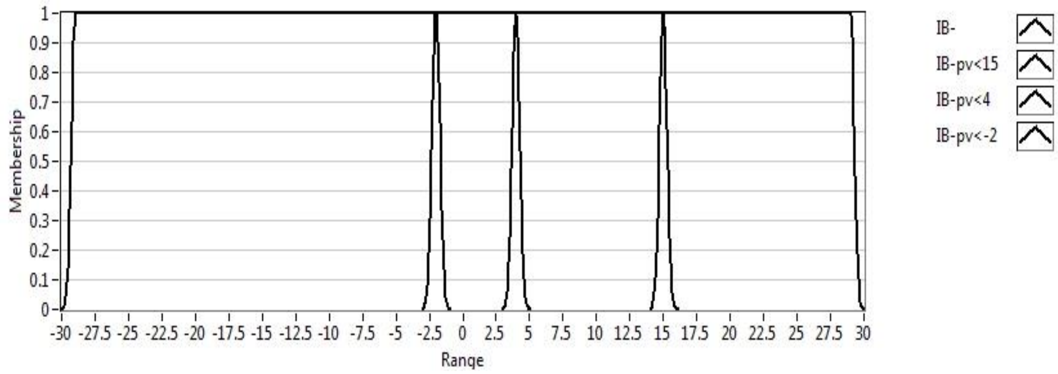


Figure 37. IB-pv Input Membership Function in EMS Fuzzy Logic Rule Base Control

3.15.1.1.4 ISolarCharger

Table 29 shows the ISolarCharger input membership function in ems fuzzy logic rule base control. Membership function for the solar charger is sch<0 for solar charger current lower than 0A and sch>0 for solar charger current more than 0A. Figure 38 shows the graph of the solar charger current membership function by using Gaussian shape. The point of use for sch<0 is between -10 and 0. For sch>0, the point is between 0 and 30. The point of solar charger current membership function is determined by result analysis from solar cabin.

Table 29. ISolarCharger Input Membership Function in EMS Fuzzy Logic Rule Base Control

Membership function	Shape	Points
sch<0	Gaussian	-10 ; -9 ; -1 ; 0
sch>0	Gaussian	0 ; 1 ; 29 ; 30

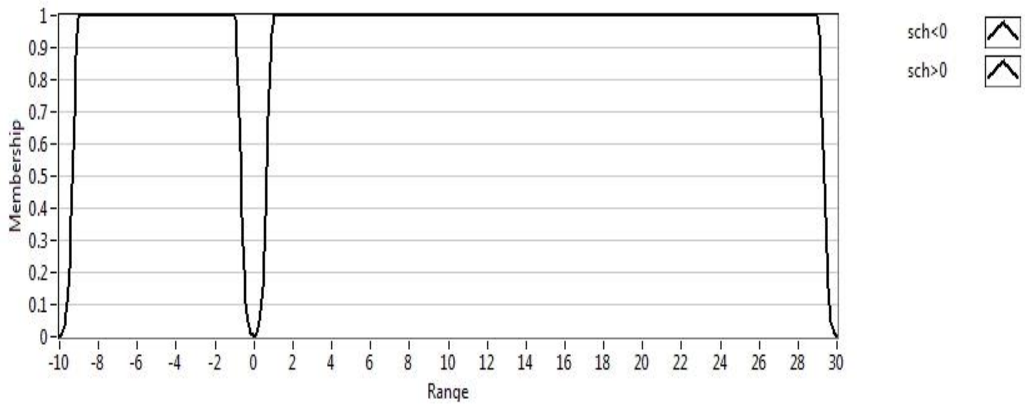


Figure 38. ISolarCharger Input Membership Function in EMS Fuzzy Logic Rule Base Control

3.15.1.1.5 Iload

Table 30 shows the Iload input membership function in ems fuzzy logic rule base control. Membership function for the load is IL<0 for load current lower than 0A and IL<0 for load current more than 0A. Figure 39 shows the graph of the load current membership function by using Gaussian shape. The point of use for IL<0 is between -10 and 0. For IL<0, the point is between 0 and 30. The point of load current membership function determined by result analysis from solar cabin.

Table 30. Iload Input Membership Function in EMS Fuzzy Logic Rule Base Control

Membership function	Shape	Points
IL<0	Gaussian	-10 ; -10 ; 0 ; 0
IL>0	Gaussian	0 ; 0.5 ; 29.5 ; 30

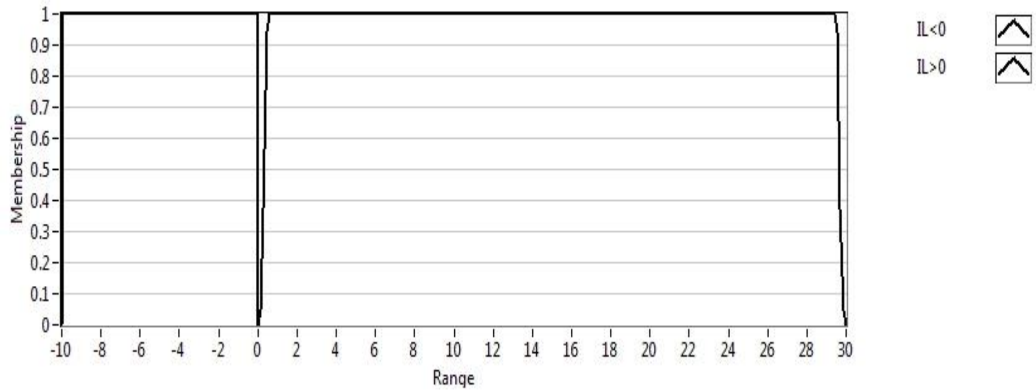


Figure 39. Iload Input Membership Function in EMS Fuzzy Logic Rule Base Control

3.15.1.2 Output membership functions

Table 31. Example of the Output Relay Membership Function in EMS Fuzzy Logic Rule Base Control shows the output relay membership function in ems fuzzy logic rule base control. Membership function for the relay OFF (RLoff) is 0 while relay ON (RLon) is 1. Figure 40 show the graph of the output relay membership function by using Singleton shape. The point use for RLoff is 0. For RLon, the point is 1. The point of output relay membership function is equivalent for all relays.

Table 31. Example of the Output Relay Membership Function in EMS Fuzzy Logic Rule Base Control

Membership function	Shape	Points
RLoff	Singleton	0
RLon	Singleton	1

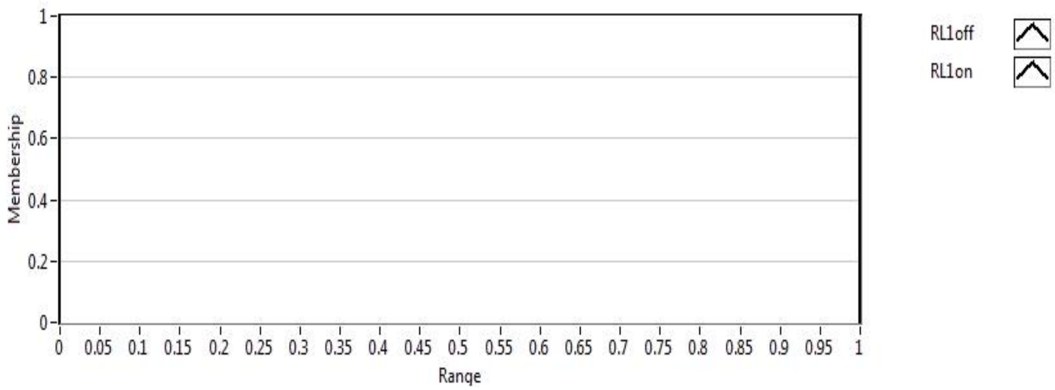


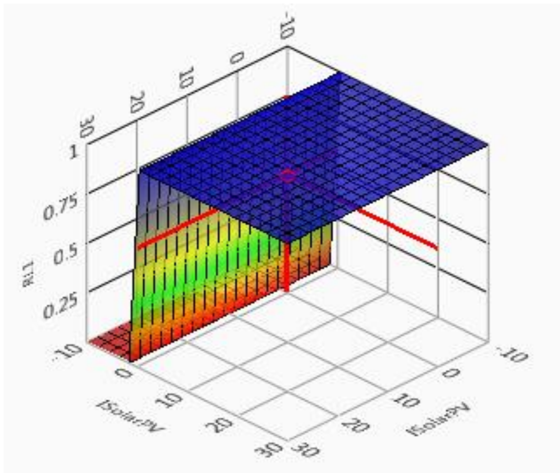
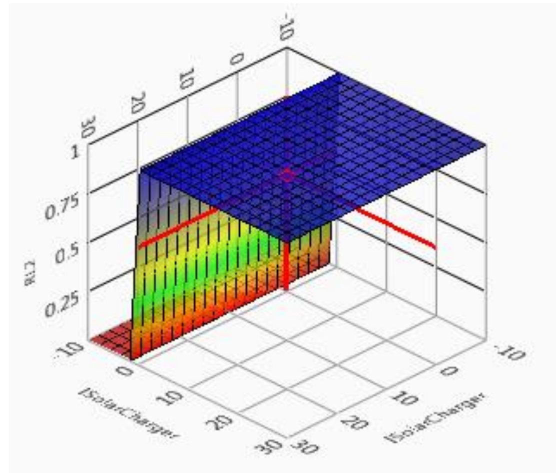
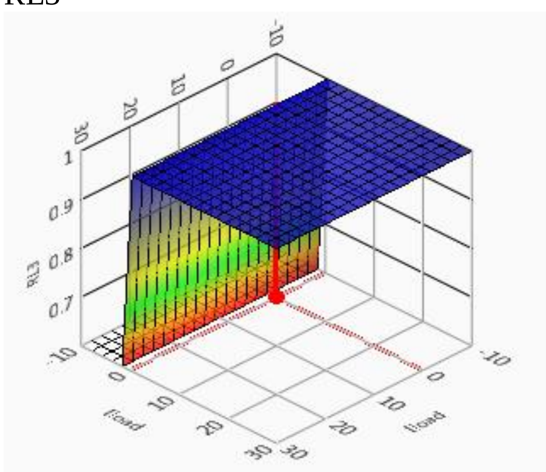
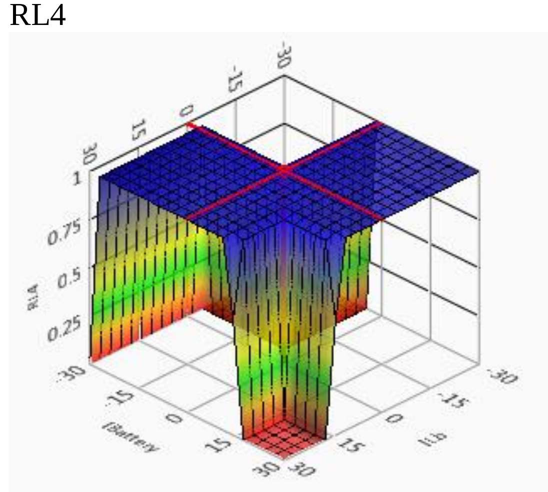
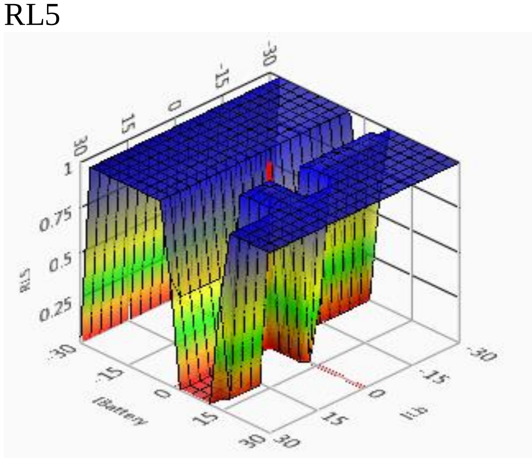
Figure 40. Output Relay Membership Function in EMS Fuzzy Logic Rule Base Control

3.15.1.3 Input/output Membership Function

Table 32 shows the input/output membership function of the RL1 until RL5 versus ISolarPV, ISolarCharger, Iload and IBattery based on input and output membership discussed in Table 25.

- RL1, the ISolarPV less than 0, RL1 is 0 and ISolarPV more than 0, RL1 is 1.
- RL2, the ISolarCharger less than 0, RL2 is 0 and ISolarCharger more than 0, RL2 is 1.
- RL3, the ILoad less than 0, RL3 is 0 and ILoad more than 0, RL3 is 1.
- RL4, the IBattery and Iload less than 0, RL4 is 0. When the IBattery and Iload more than 0, RL4 is 1. While the IBattery and Iload more than 15, RL4 is 1.
- RL5:
    - IBattery from -30 to 0 and Iload from -30 until 30, RL5 is 1.
    - IBattery from 1 to 30 and Iload from -30 until 30, RL5 is 1.
    - IBattery from 15 to 30 and Iload from 0 to 4, RL5 is 1.
    - IBattery from 0 until 15 and Iload from 0 to 4, RL5 is 0.
    - IBattery from 15 until 30 and Iload from 15 to 30, RL5 is 0.

Table 32. Input/Output Membership Function

RL1 	RL2 
RL3 	RL4 
RL5 	

3.15.2 Fuzzy Logic RULES

The Fuzzy Logic diagram to generate rules is shown in Figure 41 from Profile 2.0. This diagram is created in LabVIEW with fuzzy logic control. The slider uses as a dummy ready data from the sensor. The Fuzzy Logic has been tested using Fuzzy Logic Test System in LabVIEW. The rules and simulation results have been a tabled in Table 33 for testing the system before generating other results.

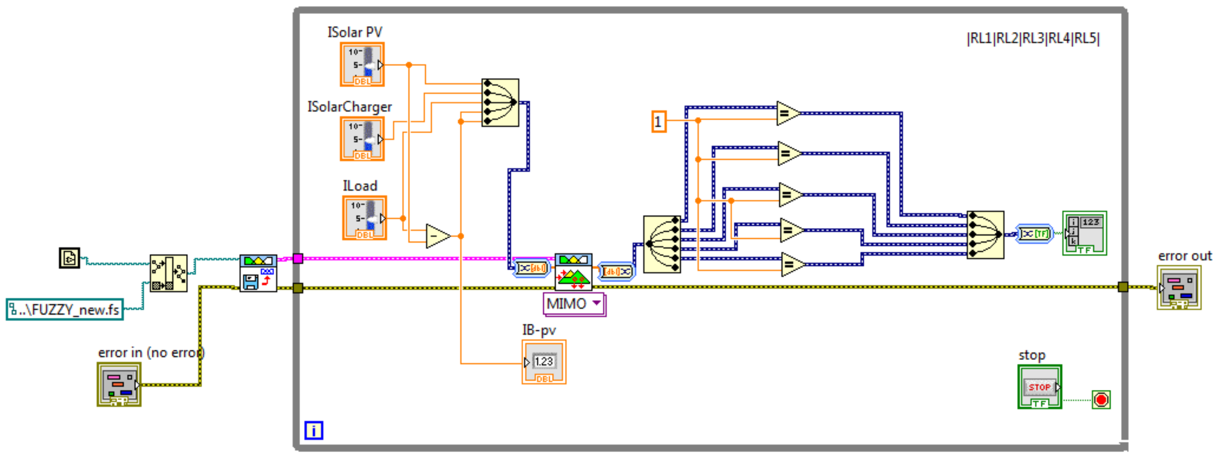
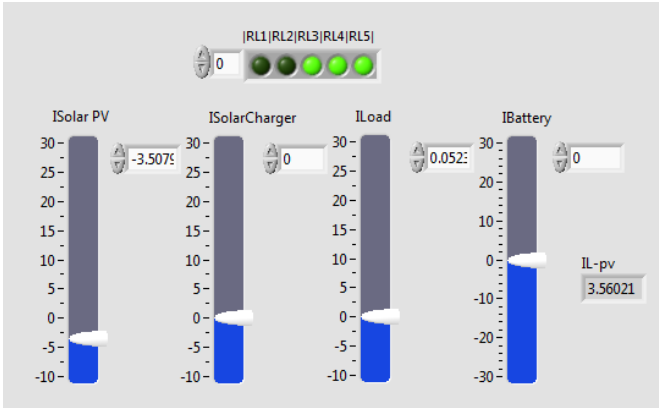
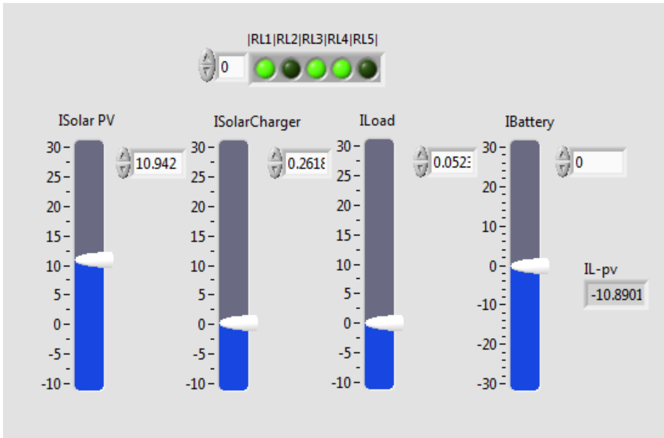
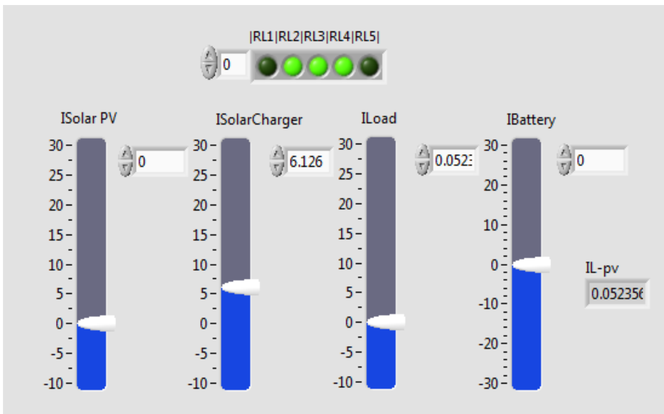
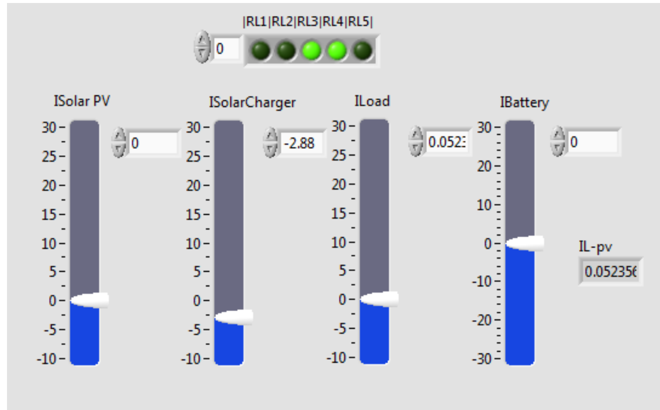
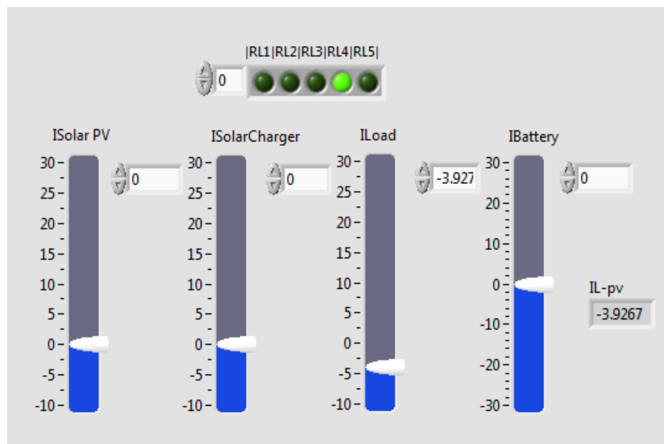
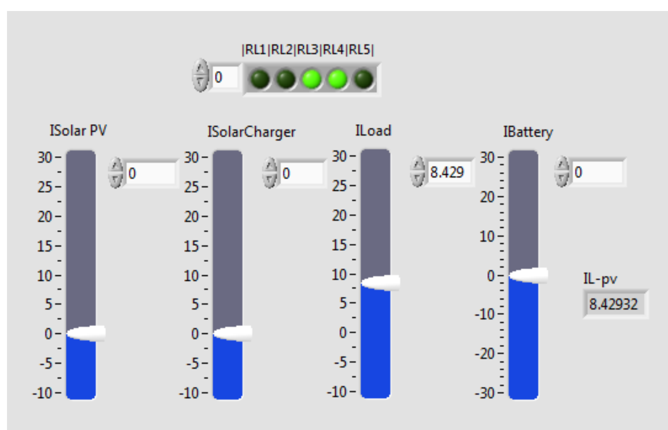
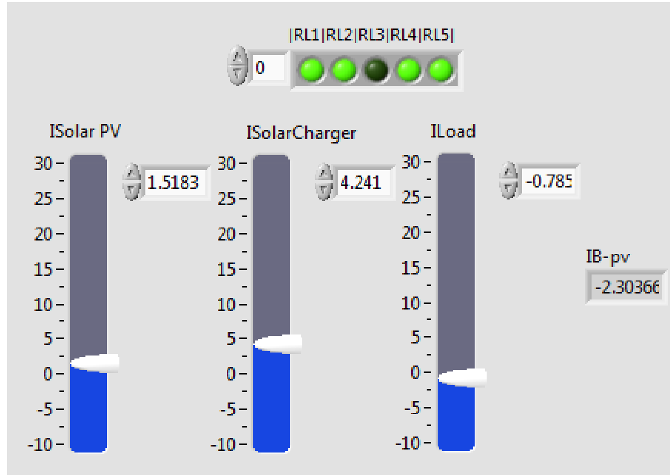
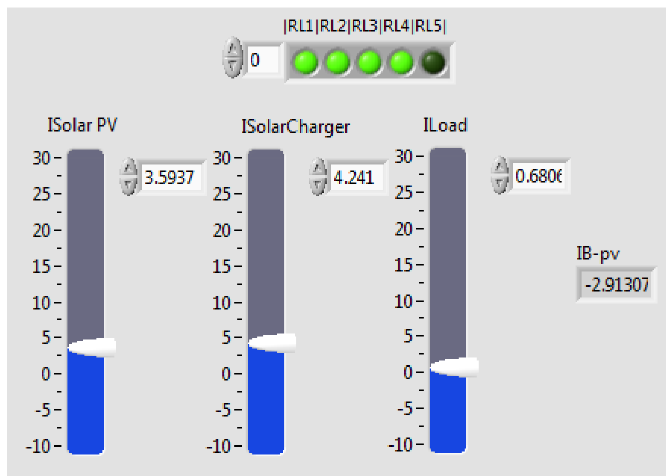
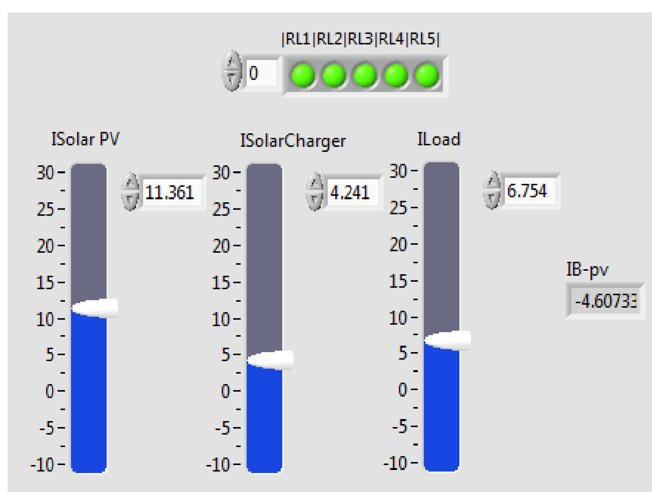


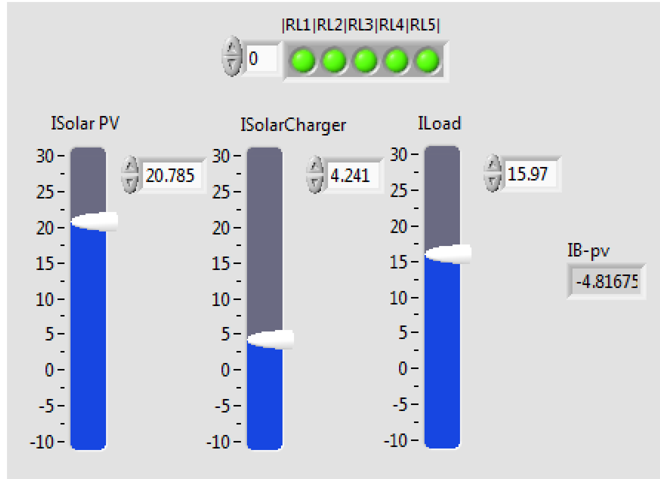
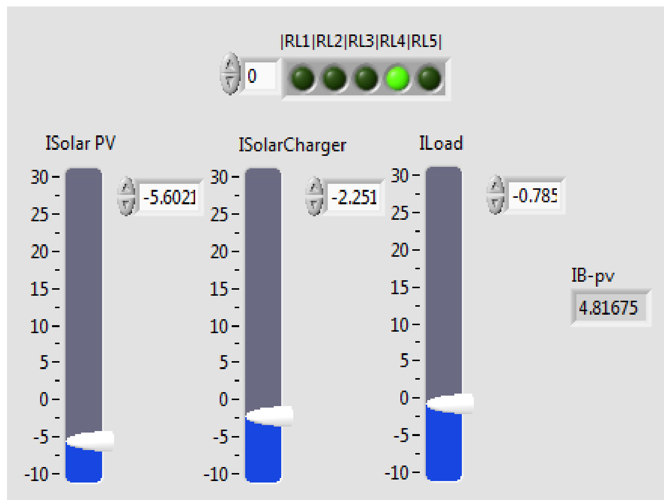
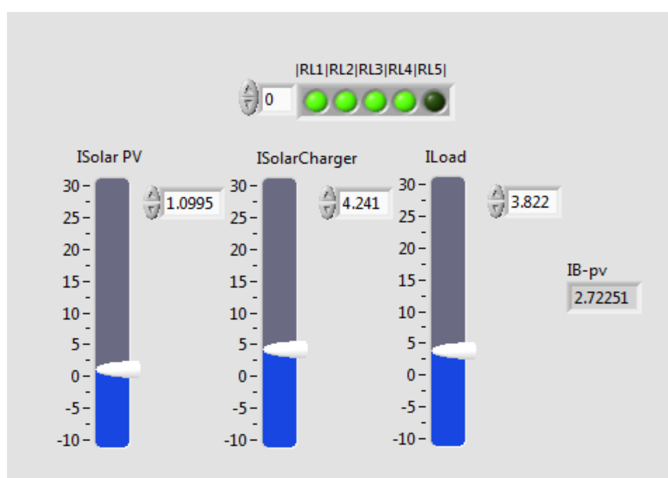
Figure 41. Diagram of EMS with Fuzzy Logic in LabVIEW

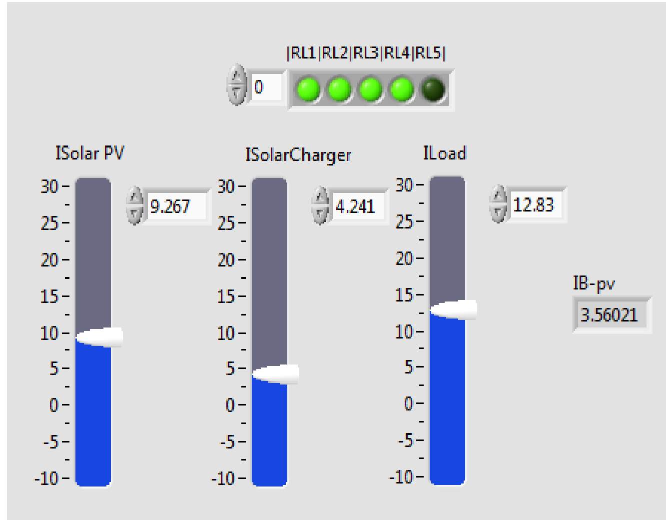
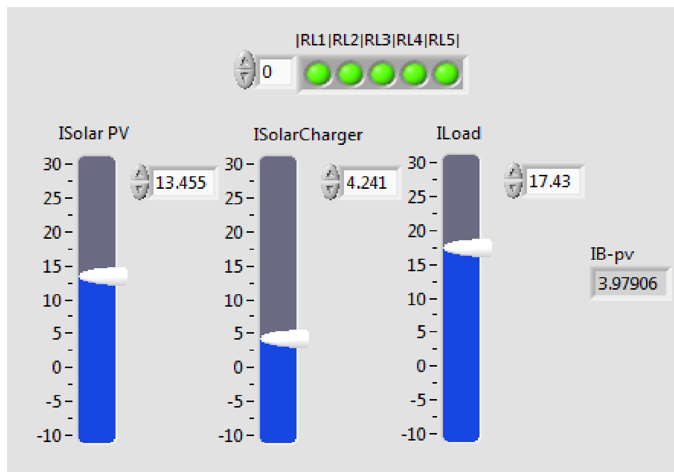
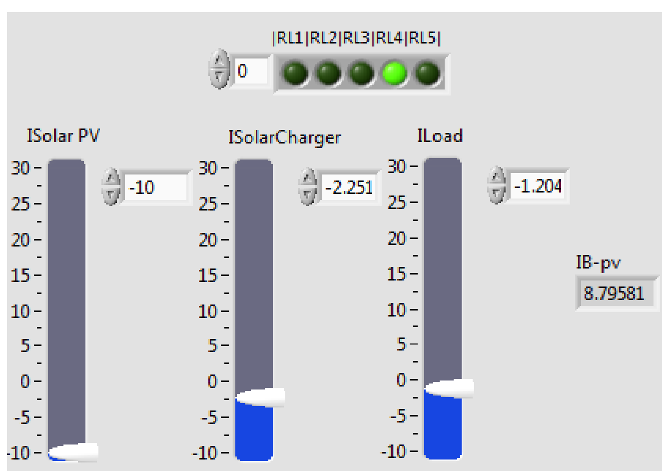
Table 33. Rule Base Fuzzy Logic Rules with LabVIEW Output

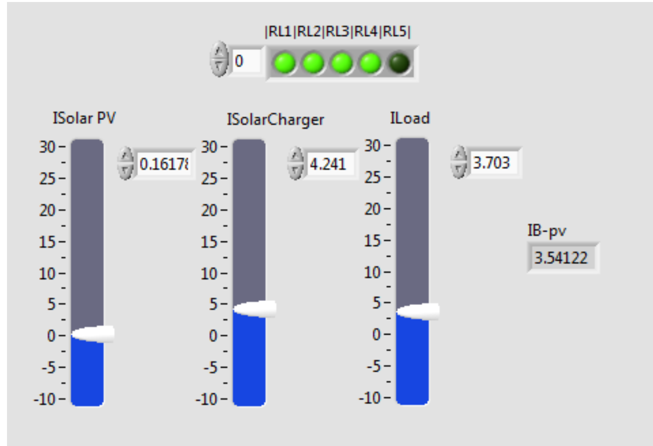
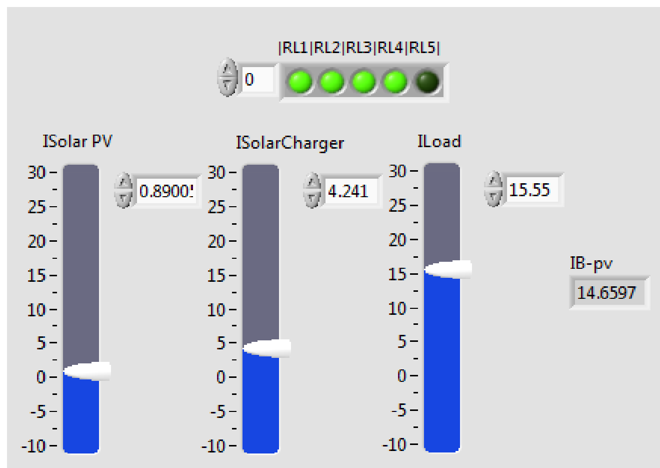
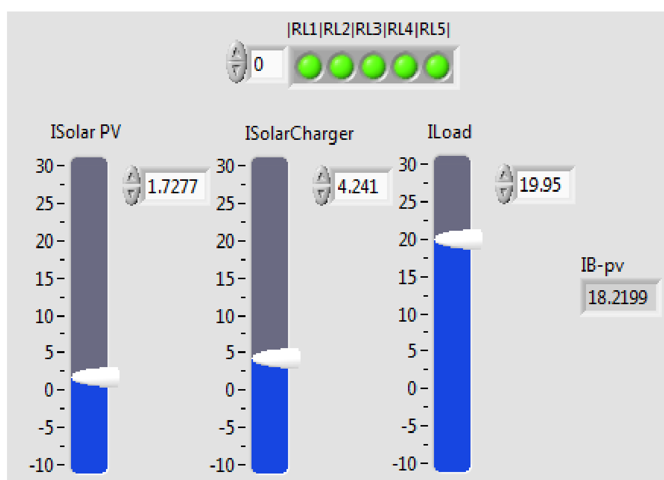
No	Rules	LabVIEW Output
1	IF 'ISolarPV' IS 'PV<0' THEN 'RL1' IS 'RL1off'	
2	IF 'ISolarPV' IS 'PV>0' THEN 'RL1' IS 'RL1on'	
3	IF 'ISolarCharger' IS 'sch<0' THEN 'RL2' IS 'RL2off'	

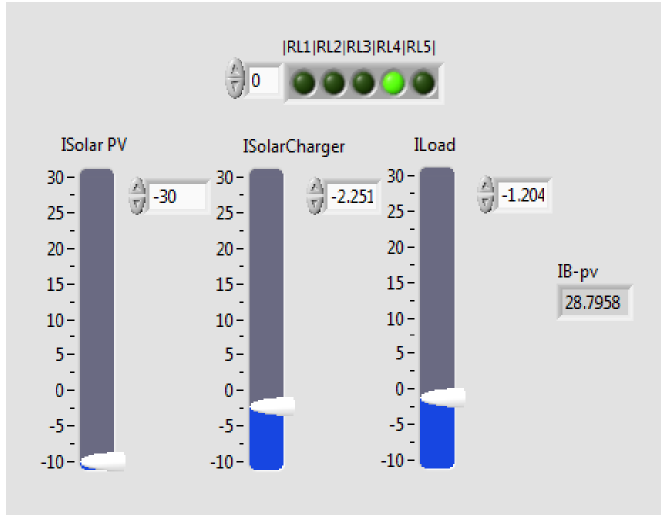
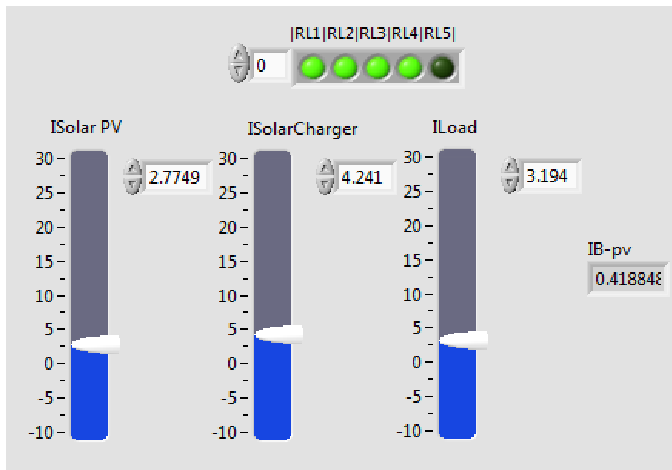
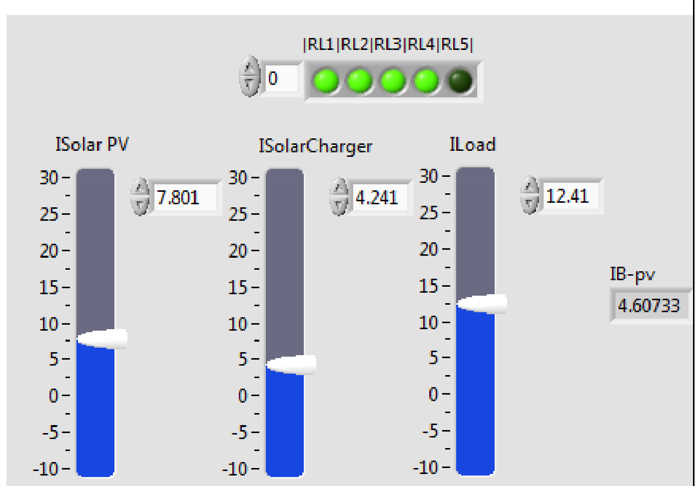
4	IF 'ISolarCharger' IS 'sch>0' THEN 'RL2' IS 'RL2on'	
5	IF 'Iload' IS 'IL<0' THEN 'RL3' IS 'RL3off'	
6	IF 'Iload' IS 'IL>0' THEN 'RL3' IS 'RL3on'	

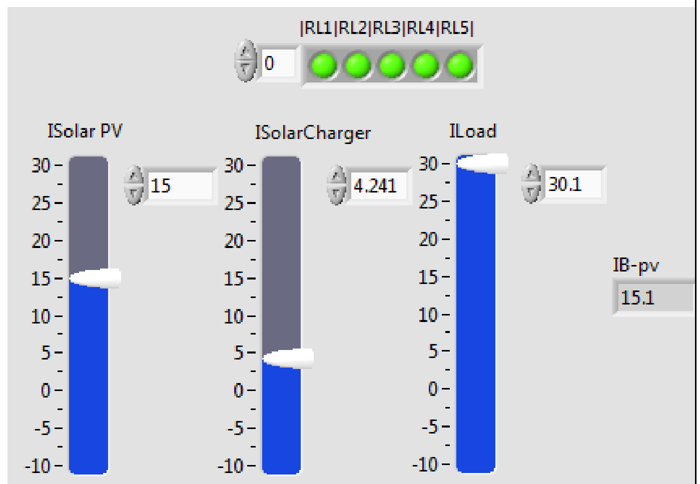
7	IF 'IB-pv' IS 'IB-pv<-2' AND 'IBattery' IS 'Ibt<-2' THEN 'RL3' IS 'RL3on' ALSO 'RL2' IS 'RL2on' ALSO 'RL5' IS 'RL5on'	
8	. IF 'IB-pv' IS 'IB-pv<-2' AND 'IBattery' IS 'Ibatt>-2' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5off'	
9	IF 'IB-pv' IS 'IB-pv<-2' AND 'IBattery' IS 'Ibt>4' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5on'	

<table>
<tr><td>10</td><td>IF 'IB-pv' IS 'IB-pv<-2' AND 'IBattery' IS 'IBatt>15' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5on'</td><td>
</td></tr>
<tr><td>11</td><td>IF 'IB-pv' IS 'IB-pv<4' AND 'IBattery' IS 'Ibt<-2' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5on'</td><td>
</td></tr>
<tr><td>12</td><td>IF 'IB-pv' IS 'IB-pv<4' AND 'IBattery' IS 'Ibatt>-2' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5off'</td><td>
</td></tr>
</table>

13	IF 'IB-pv' IS 'IB-pv<4' AND 'IBattery' IS 'Ibt>4' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5off'	
14	IF 'IB-pv' IS 'IB-pv<4' AND 'IBattery' IS 'IBatt>15' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5on'	
15	IF 'IB-pv' IS 'IB-pv<15' AND 'IBattery' IS 'Ibt<-2' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5on'	

16	IF 'IB-pv' IS 'IB-pv<15' AND 'IBattery' IS 'Ibatt>-2' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5off'	
17	IF 'IB-pv' IS 'IB-pv<15' AND 'IBattery' IS 'Ibt>4' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5on'	
18	IF 'IB-pv' IS 'IB-pv<15' AND 'IBattery' IS 'IBatt>15' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5on'	

19	IF 'IB-pv' IS 'IB-pv>15A' AND 'IBattery' IS 'Ibt<-2' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5on'	
20	IF 'IB-pv' IS 'IB-pv>15A' AND 'IBattery' IS 'Ibatt>-2' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5on'	
21	IF 'IB-pv' IS 'IB-pv>15A' AND 'IBattery' IS 'Ibt>4' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5on'	

<table>
<tr><td>22</td><td>IF 'IB-pv' IS 'IB-pv>15A' AND 'IBattery' IS 'IBatt>15' THEN 'RL3' IS 'RL3on' ALSO 'RL4' IS 'RL4on' ALSO 'RL5' IS 'RL5on'</td><td>
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3.15.3 Hardware Setup

3.15.3.1 5v 30A Relay

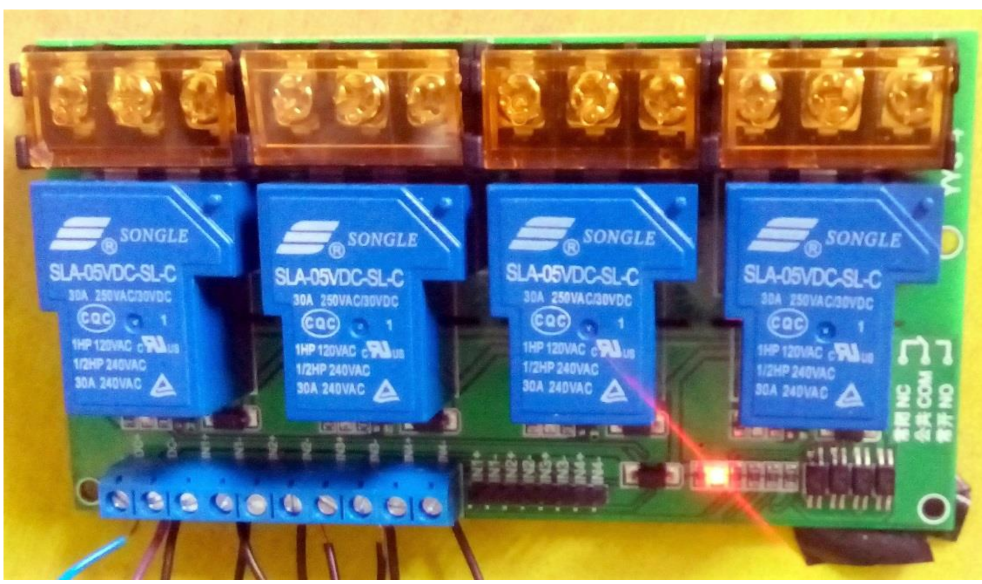

Figure 42. 5v 30A Relay Breakout Board

This energy management system uses the 5V relay breakout board from Songle as shown in Figure 42. The breakout board is a convenient board to be used with 5V microcontroller and 4 relay attached in one board. The goal of the common relay is to control high power devices using low power signals.

The relay can be easily controlled using the 5V output pin. The on-board relay is rated at 30A. The status of the relay is indicated by a LED. The board consists of 3 control pins which are used to interface it to the microcontroller:

i. "- "pin (GND)
ii. "+" pin (VCC)
iii. "S" pin (Signal)

The relay breakout board acts like a switch to control the signal from DAQ. The fuzzy logic will be used to control all the relays depending on the condition of the system. The output of fuzzy logic will be fed into the DAQ which in turn will trigger the relay to ON or OFF.

3.15.4 Testing

The testing of this energy management system is divided into a few tests that are integrated with the solar cabin. First, the test on of energy management system by using variable resistor as a dummy for input reading to make sure no defect on the LabVIEW as in Figure 43. The variable resistor is connected to the input of the DAQ NI USB-6353. Second, Figure 44 shows the connection of EMS thru DAQ to the Solar Cabin System. The input of the DAQ is from the sensor attached in solar system and the output from the DAQ connected to the relay. All wire connections in solar cabin system have been modified for EMS purpose. DC to DC converter and programmable load is connected to solar cabin system as shown in Figure 45. A DC to DC converter is connected to the supercapacitors and the programmable load connected to the battery and supercapacitor as a dummy load.

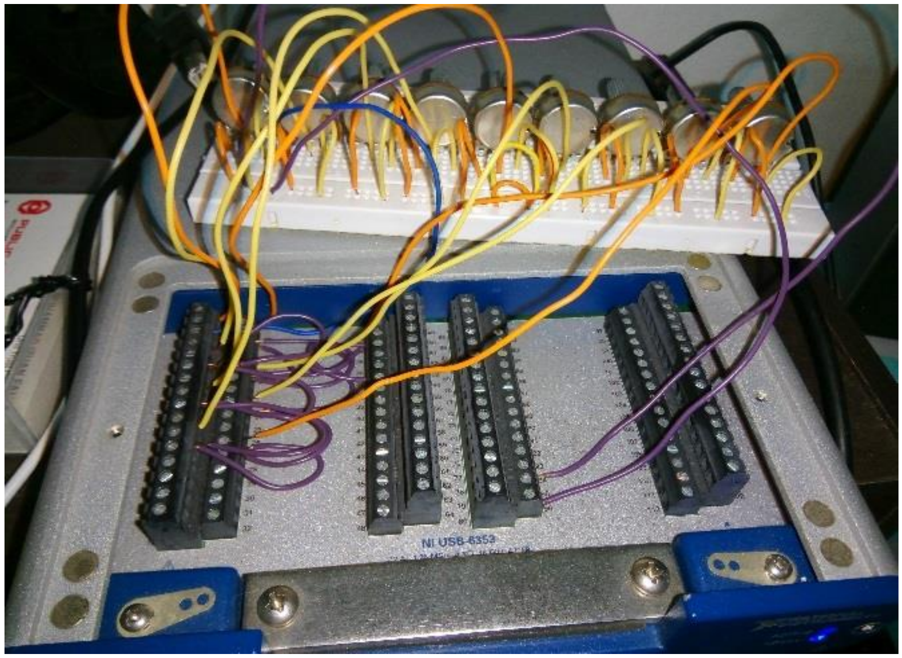

Figure 43 Manual Test of EMS

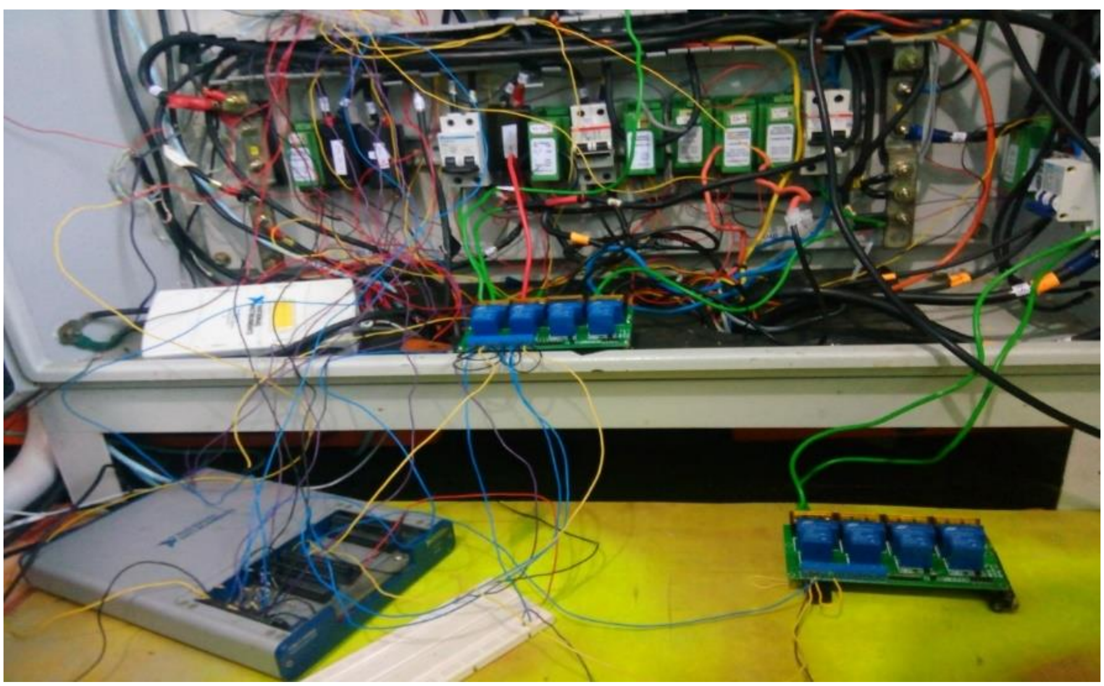

Figure 44. Connection of the EMS to the Solar Cabin System

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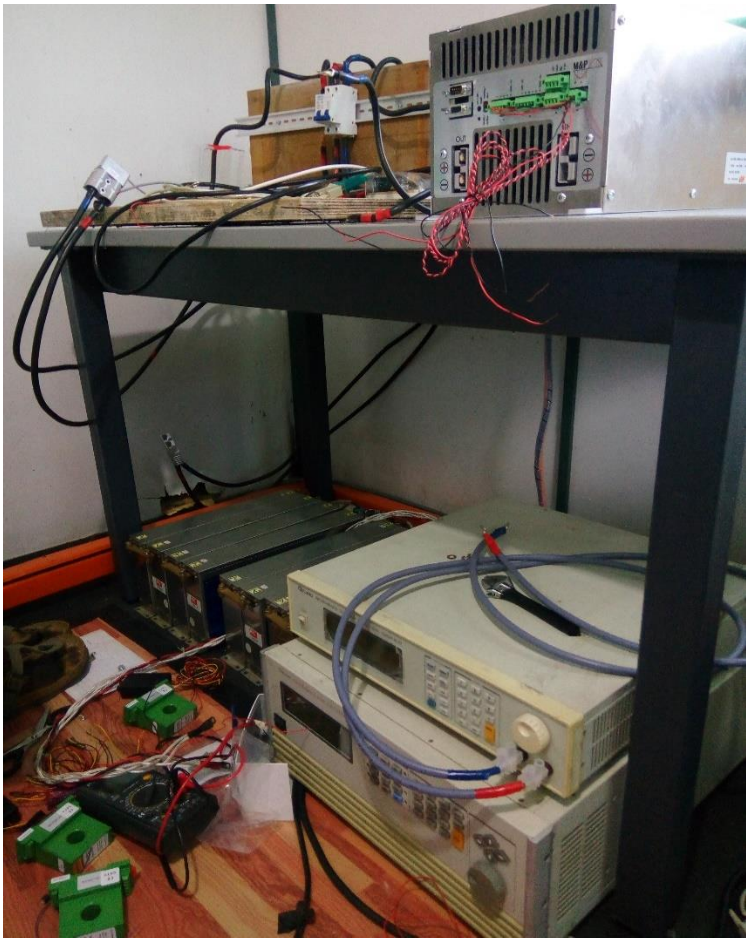

Figure 45. Connection of EMS with DC to DC Converter

3.16 Chapter Summary

The methodology was developed based on the research objectives. The first part introduces all the equipment in the solar cabin system. The equipment used in the solar cabin system are solar PV, charged controller, battery, programmable load, inverter, transducer and the supercapacitor. Table 34 shows the overview of the equipment implemented in the solar cabin. From this table, all equipment rating in the solar cabin were discussed.

Table 34. Summary of Equipment in Solar Cabin

Equipment	**Value**
Solar PV Power	2000W
Battery Power	48V 150Ah
Charge Controller	48V
Inverter	48VDC to 230AC (3000W)
Transducer	DC Voltage = 100V DC Current = 60A AC Voltage = 250V AC Current = 15A
Supercapacitor	48V 200F

A DC to DC converter was added to the solar cabin system to control the charging and discharging of the supercapacitor. The EMS manages the control system of the solar cabin, stores the data in the computer and monitors all the information display in GUI. The latest Load Profile 2.0 is used to show the real usage in the rural area with real current demand. The appliance is used in a house and also usage per hour is shown in Table 16, Table 17 and Table 18.

CHAPTER IV: RESULTS AND DISCUSSION

4.0 Introduction

The solar cabin system experiments are performed with real time usage from the rural area. Based on "Information of Usage Capacity" for a house in a rural area, the load current (Load Profile 1.0 and Load Profile 2.0) has been set up. The experiment was conducted to see the improvement in efficiency of power usage in a rural area for analysis. These results will prove if the system is able to work properly and supply sufficient power for a typical rural house. Figure 46 shows the flow chart for the solar cabin and the associated systems necessary for implementation.

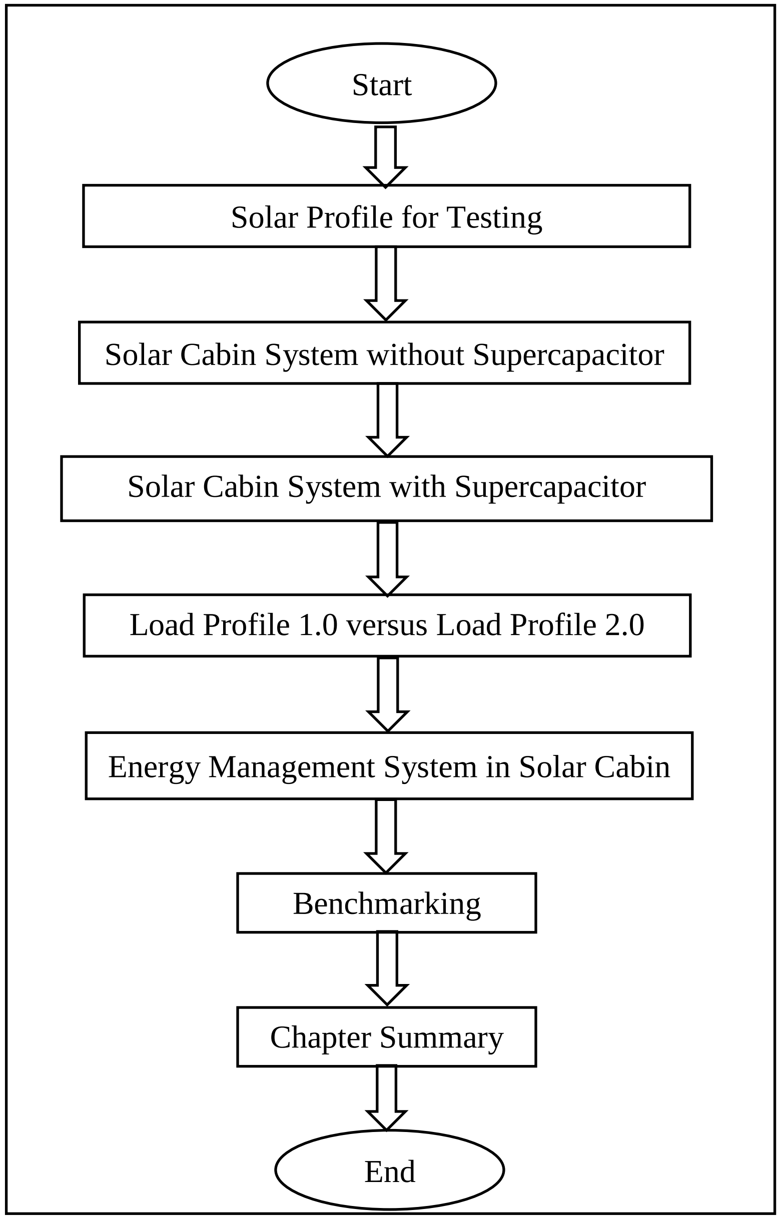

Figure 46. Flow Chart for Results and Discussion

4.1 Solar Profile for Testing

Before running the experiments, the solar irradiance profile is taken from the solar cabin on the same day as the experiments. This profile is based on a one-day data collection from the solar cabin with several experiments. The irradiation profile is different for each experiment because the results are fully dependant on weather conditions and it is not possible to use the same solar profile every day to run the experiment. Table 35 shows the summary from the Figure 47 until Figure 51 for solar load profile. There are two different load profiles to be tested using the solar profiles which is Load Profile 1.0 and Load Profile 2.0. Figure 47 and Figure 49 show the solar profile for testing without supercapacitor. Figure 48 and Figure 50 show the testing of the solar cabin system with supercapacitor while Figure 51 is the solar profile for testing the solar cabin system with supercapacitor and EMS. The average irradiation for Figure 47 and Figure 48 is higher than other solar profiles because it recorded data only for 16 hours while other solar profile recorded for 24hours. But, the average in a day between all the solar profiles is almost the same. The average irradiation per day recorded is between 201.47 W/m^2 and 282.16 W/m^2. The average irradiation per day indicates all experiments received almost the same power from solar irradiation to the solar cabin system. The highest peak irradiation recorded is 964 W/m^2 and lowest is 587.99 W/m^2. All peak currents were recorded between 12pm and 2.15pm.

Table 35. Summary of Solar Irradiation Profile

	Load Profile	Supercapacitor	Average (W/m^2)	avg day (7am-7pm) (W/m^2)	Peak (W/m^2)	Peak Time
Figure 47	1.0	No	288.87	253.70	885.51	12:35
Figure 48	1.0	Yes	305.72	282.16	964.60	13:05
Figure 49	2.0	No	95.21	201.47	689.31	14.13
Figure 50	2.0	Yes	102.67	230.85	587.99	14:04
Figure 51	2.0	Yes + EMS	117.88	234.73	734.56	13:59

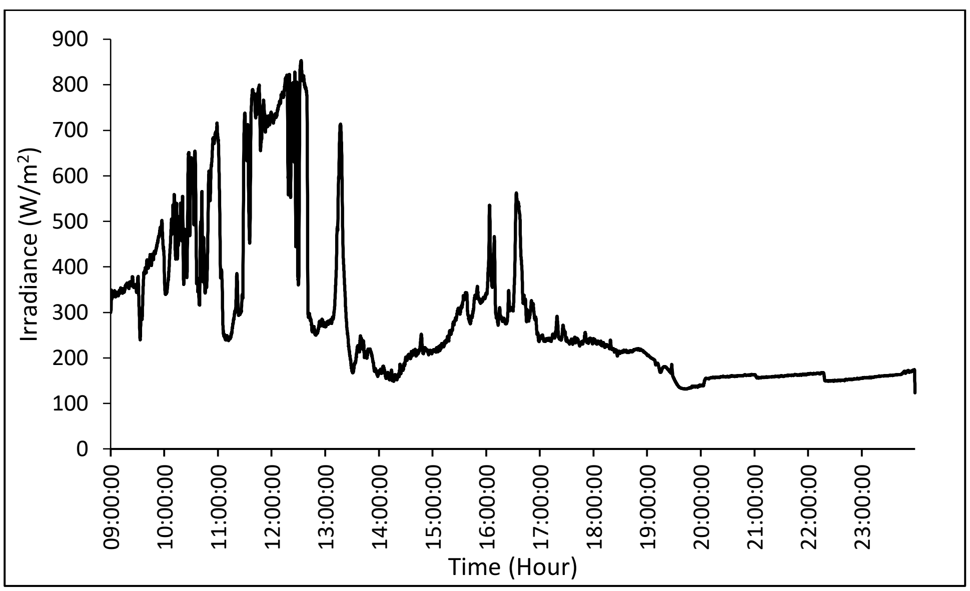

Figure 47. Solar Profile Real Usage for Rural Area without Supercapacitor and Load Profile 1.0

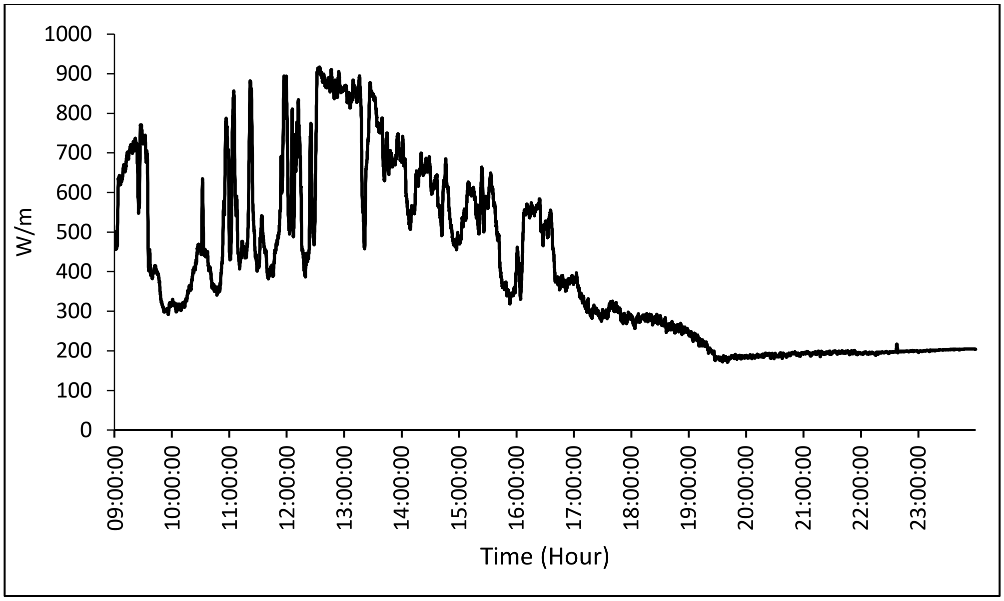

Figure 48. Solar Profile Real Usage for Rural Area with Supercapacitor and Load Profile 1.0

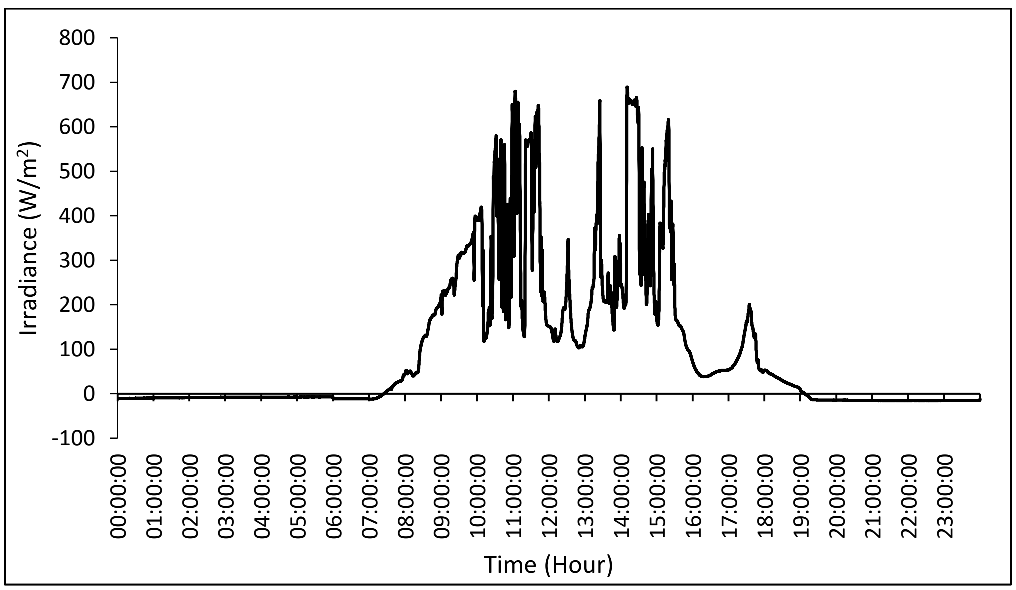

Figure 49. Solar Profile Real Usage for Rural Area without Supercapacitor Load Profile 2.0

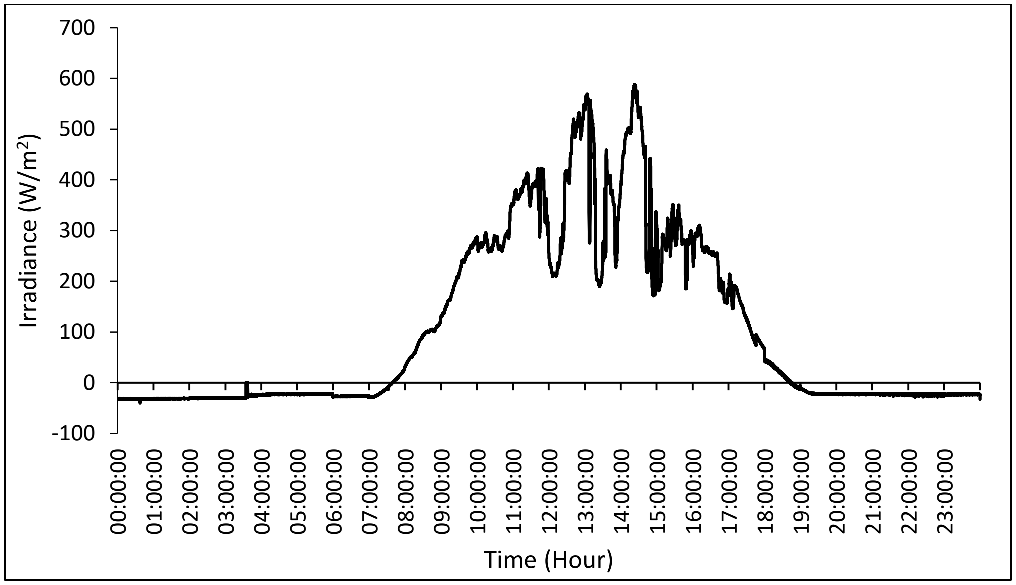

Figure 50. Solar Profile Real Usage for Rural Area with Supercapacitor and Load Profile 2.0

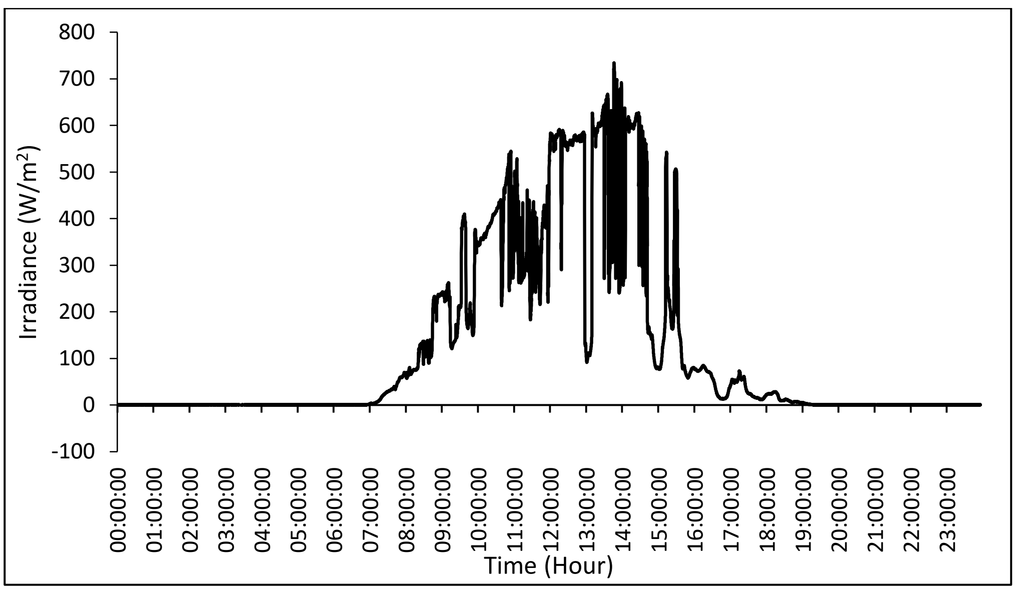

Figure 51. Solar Profile Real Usage for Rural Area with Energy Management System and Load Profile 2.0

4.2 Solar Cabin System without Supercapacitor

4.2.1 Load Profile 1.0 Solar Cabin System without Supercapacitor

The graph in Figure 52 shows the battery voltage results and Figure 53 shows the battery current results with real load current Profile 1.0. The battery voltage goes higher during a day because solar power charges the battery. The battery voltage drops from 13:30:00 to 16:00:00 when the solar power dropped, as seen on the irradiation profile in Figure 47. At night, there is no power from solar and the battery voltage decreased. The load current also takes part in the battery voltage drop during the high load power demand. The voltage is reduced to 50.18V at night from the highest voltage recorded during a day 55.6V.

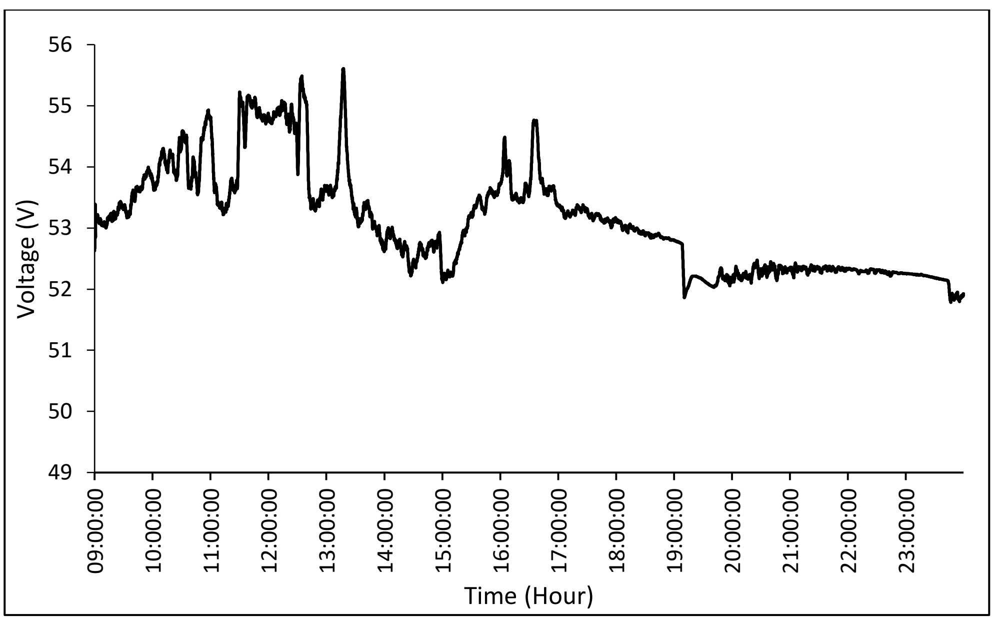

Figure 52. Battery Voltage for Experiment without Supercapacitor

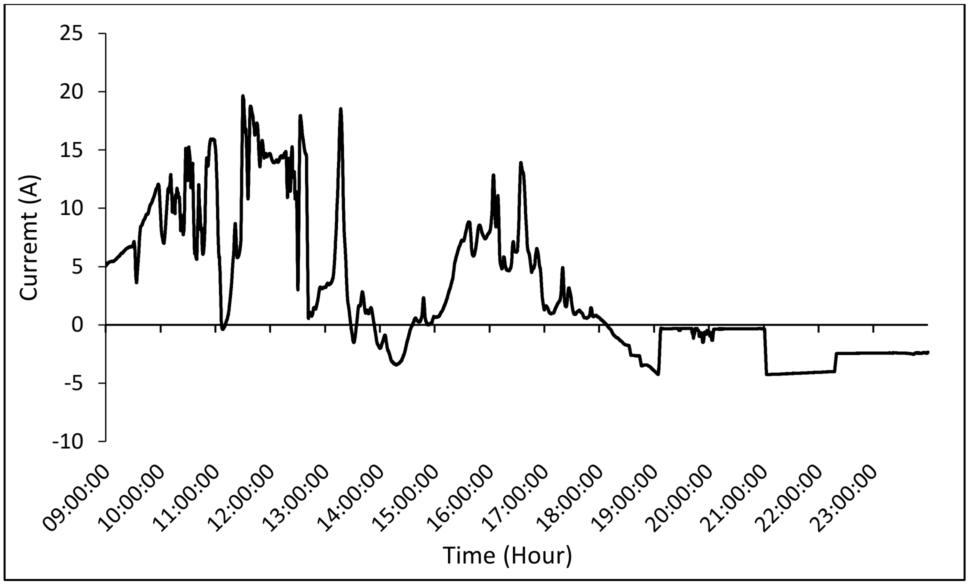

Figure 53. Battery Current for Experiment without Supercapacitor

The data obtained from Figure 53 shows the battery current discharged during the night because of high load demand during that time, and there was no supply from solar power. The highest current discharged from the battery is -4.16A when the load current is at its maximum demand at 20:00:00. During the day, the solar power charges the battery and at same time supplies power to the load. The highest current charging the battery is at 19.56A. The charging graph is unstable which is not good for the battery health. The battery current discharged is directly proportional to the load current demand.

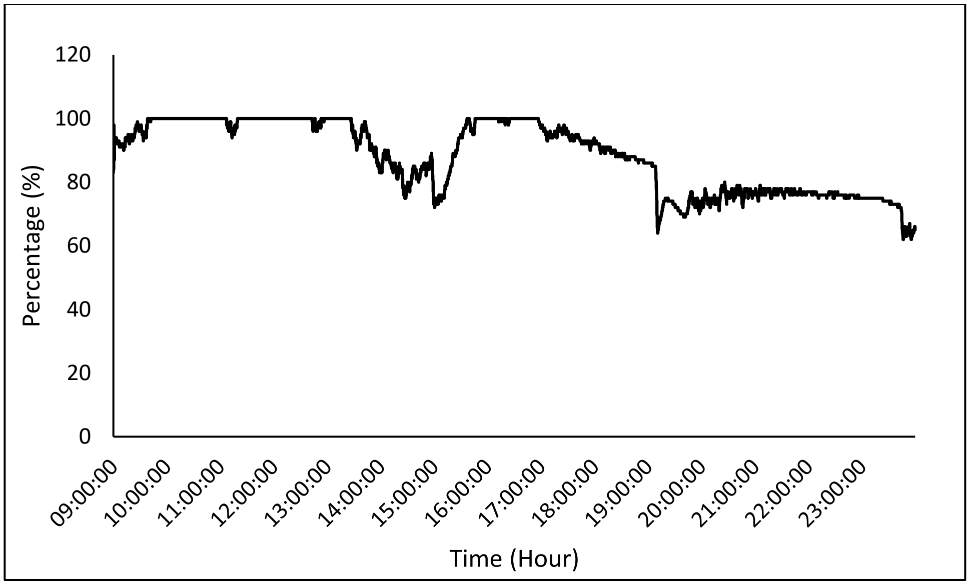

Figure 54. SOC of Battery without Supercapacitor

Figure 54 shows the State of Charge (SOC) of the battery. As can be seen, the lowest capacity of the battery is still above 50% when the system supplies a rural house for one day, using Load Profile 1.0. The highest SOC is 88.14%, and the lowest SOC is 62%. Based on datasheet of the battery [104], when fully discharged (0%) is 47.9V and while fully charged is 50.8V (100%) as shown in Figure 55.

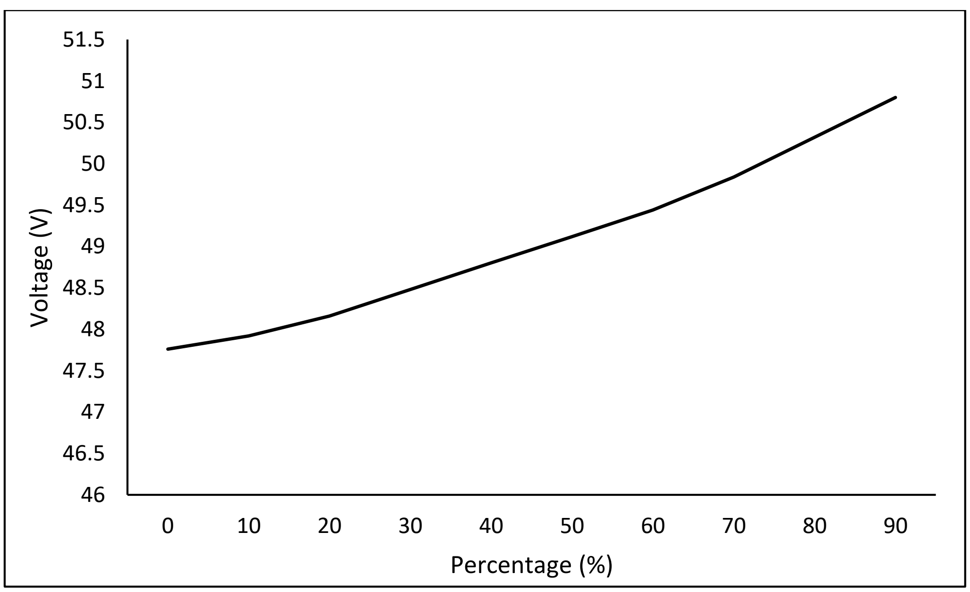

Figure 55. SOC Battery from Datasheet [104]

4.2.2 Load Profile 2.0 Solar Cabin System without Supercapacitor

A graph in Figure 56 shows the battery voltage results and Figure 57 shows battery current results with real load current Profile 2.0. When the load current increases, the battery voltage is decreased. Furthermore, the battery can support high user demand, especially during night time. The voltage was reduced to 50.18V at night from the highest voltage recorded during the day at 61.32V. There was no effect on the battery voltage during the day as the solar power constantly charged the battery.

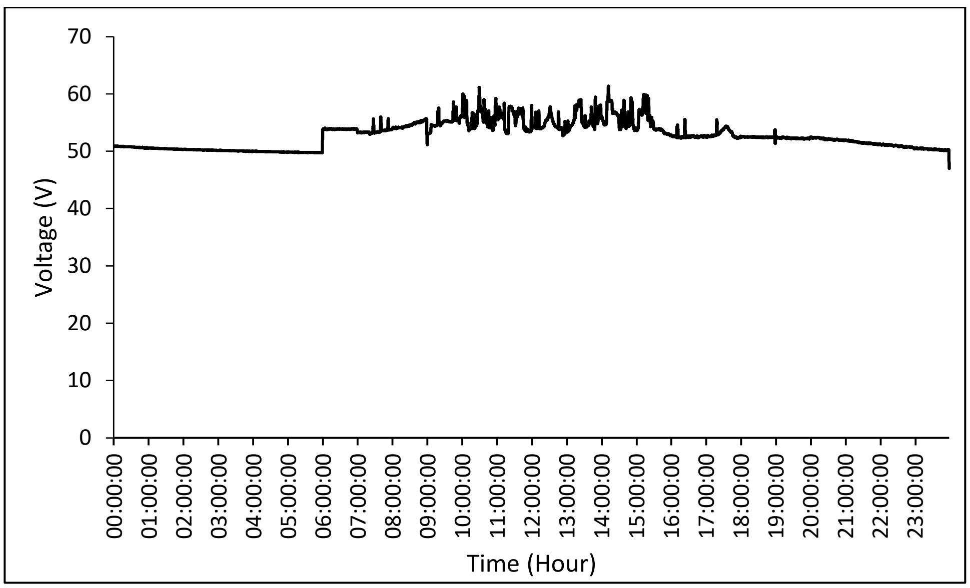

Figure 56. Battery Voltage for Experiment without Supercapacitor

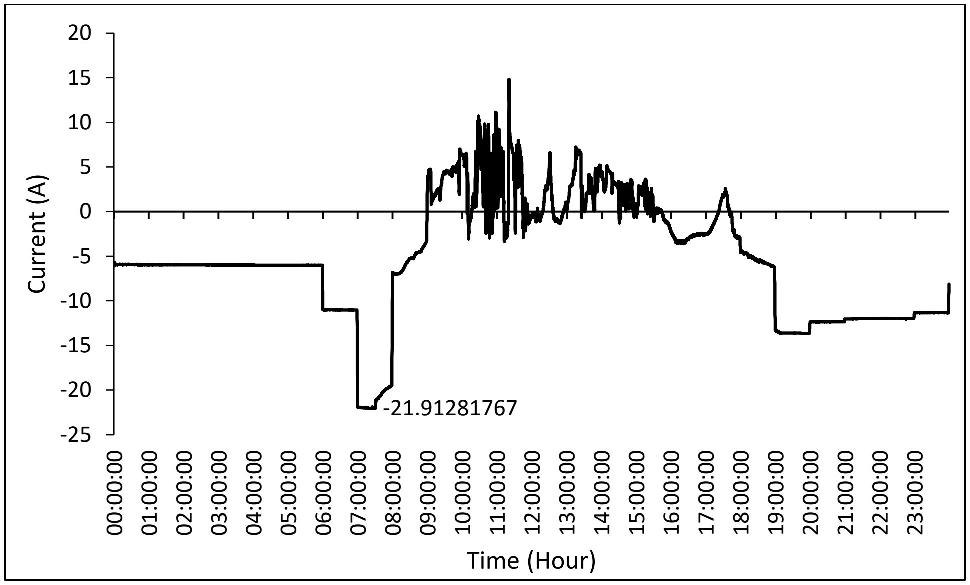

Figure 57. Battery Current for Experiment without Supercapacitor

The data obtained from Figure 57 shows the battery current discharged in the morning and night because of high load demand during that time, and there was no supply from solar power illustrated in Figure 49. The highest current discharged from the battery is -21.9A when the load current is at the maximum demand of 07:00:00. During the day, the solar power charges the battery and at same time supplies power to the load. The battery current discharged is directly proportional to the load current demand during no current supply from solar.

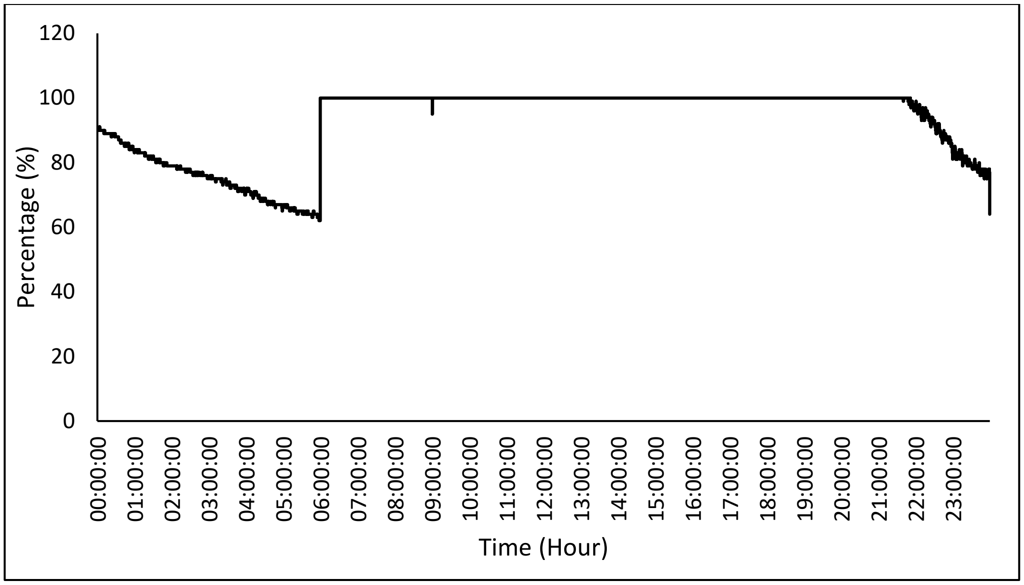

Figure 58. SOC of Battery for Experiment without Supercapacitor

Figure 58 shows the SOC of the battery. As can be seen, the lowest SOC of the battery is 62% and average SOC is 92.65%. With the current load demand high at 7 am, solar cabin system is able to supply power to the rural house before it starts charging with solar power. This experiment only runs one day because the system capacity is small compared to the Load Profile 2.0 demand which had increased more than two times from Load Profile 1.0.

4.3 Solar Cabin System with Supercapacitor

The supercapacitor has been set-up to the system for next experiment. An experiment by combining hybrid energy storage battery with supercapacitor used Load Profile 1.0 and Load Profile 2.0 to analyse the effect of the supercapacitor in solar cabin system.

Before starting the experiment, the supercapacitor needs to charge until the voltage is more than 50V, to avoid the system from charging the supercapacitor at high speed and also to protect the battery. The supercapacitor is supplied with 2A direct current until the supercapacitor reaches more than 13V. The charging process takes maximum time of around 2 hours, depending on the supercapacitor condition and supply current to the load for charging. After the supercapacitor finishes the charging process, it than connects to the system and the experiment is ready to run.

4.3.1 Load Profile 1.0 Solar Cabin System with Supercapacitor

Figure 59 shows the battery voltages with supercapacitor experiment using Load Profile 1.0. This result indicates that the battery voltage maximum is 57.19V, and the lowest is 49.03V. The battery voltage drops at night because the battery has charged the supercapacitor, and this causes the battery voltage to reduce. The result of battery voltage is more volatile because of the resistance in the system and other factors when the charging and discharging processes not controlled.

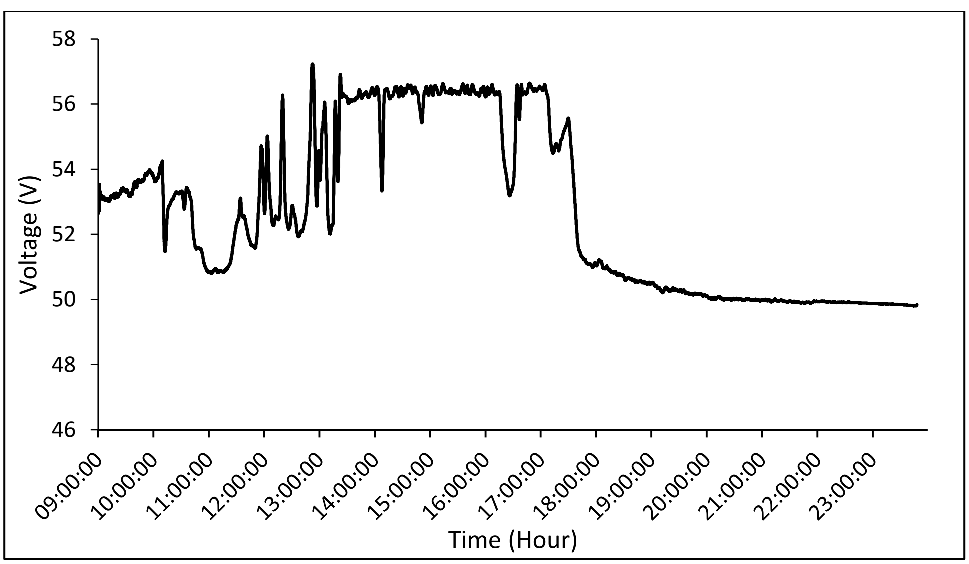

Figure 59. Battery Voltage for Experiment with Supercapacitor

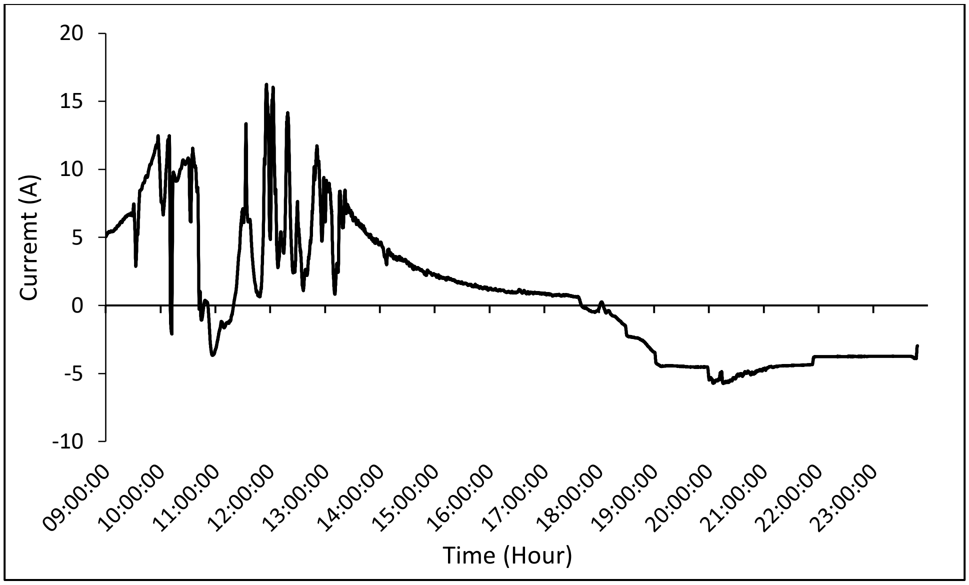

Figure 60. Battery Current for Experiment with Supercapacitor

For battery current shown in Figure 60, the peak battery current discharged is reduced during the experiment with the supercapacitor. The peak current of the battery for charging is 16.2A while during discharging is -5.07A. The battery current graph is more stable because the peak current for discharging is covered by a supercapacitor. The current at night was negative because there was no supply from solar power and battery discharge current. The supercapacitor voltage in Figure 61 is the same as the battery voltage when connected as both components share the same DC Busbar in the system.

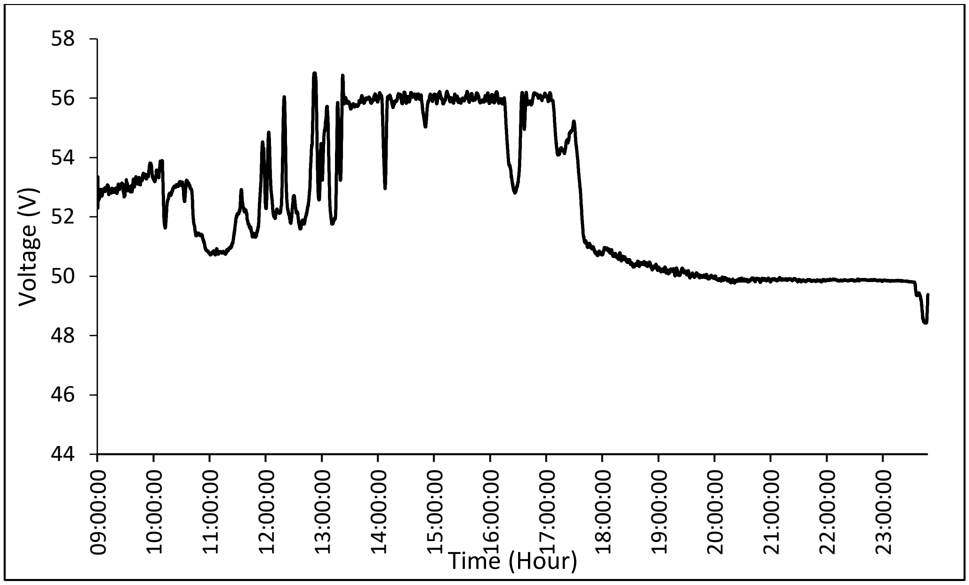

Figure 61. Supercapacitor Voltage for Experiment with Supercapacitor

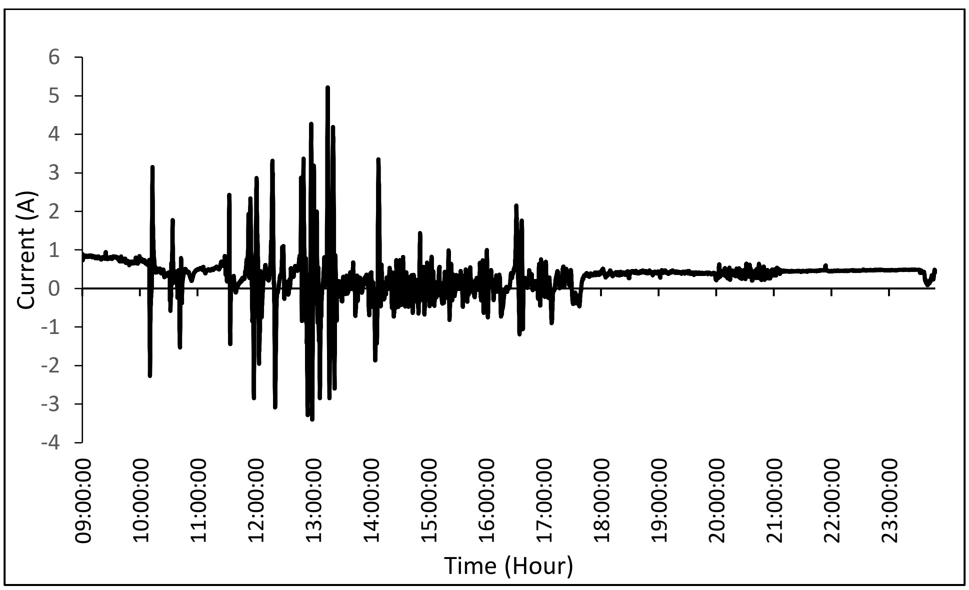

Figure 62. Supercapacitor Current for Experiment with Supercapacitor

Figure 62 shows the supercapacitor current. As can be seen, the supercapacitor supplies the peak current load demands with a maximum peak current recorded at 5.21A. The graph fluctuated up and down because of its simultaneous charge and discharge action. The supercapacitor discharged large current to support battery from peak current. The solar power charged back the supercapacitor after discharging current.

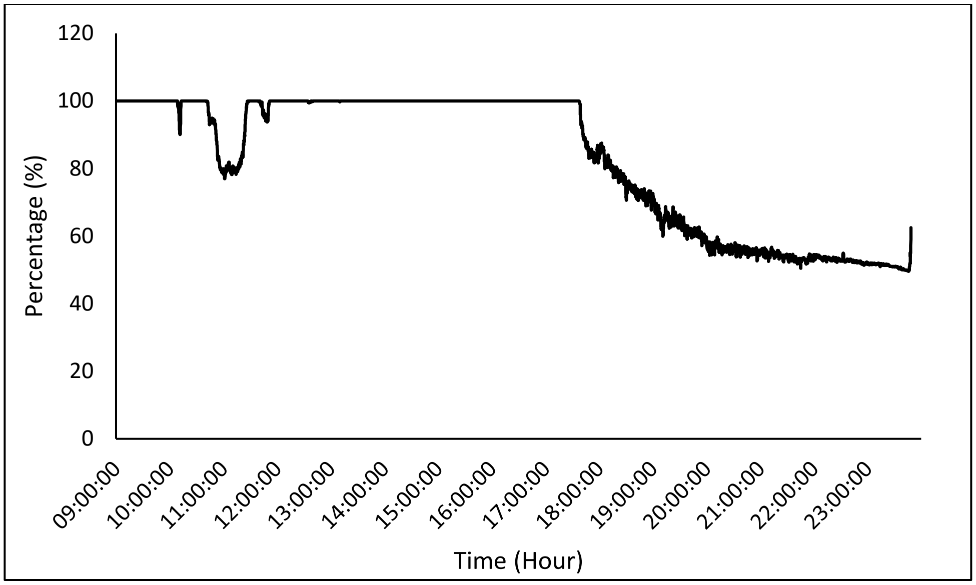

Figure 63. SOC of Battery with Supercapacitor

Figure 63 shows the state of charge (SOC) of the battery with a supercapacitor. The SOC at night drops by around 40% for battery with a supercapacitor. The lowest SOC at night is 50% at night, and the average SOC for battery with supercapacitor is 82.89%.

4.3.2 Load Profile 2.0 Solar Cabin System with Supercapacitor

Figure 64 shows the battery voltage during a normal day cycle. This result indicates that the battery voltage is maintained at a higher level when supercapacitor is attached to the system. At night, the battery charges the supercapacitor, and this causes the battery voltage to reduce. At 3 AM, the battery voltage dropped from 57.89V to 49.3V because of high demand from the load.

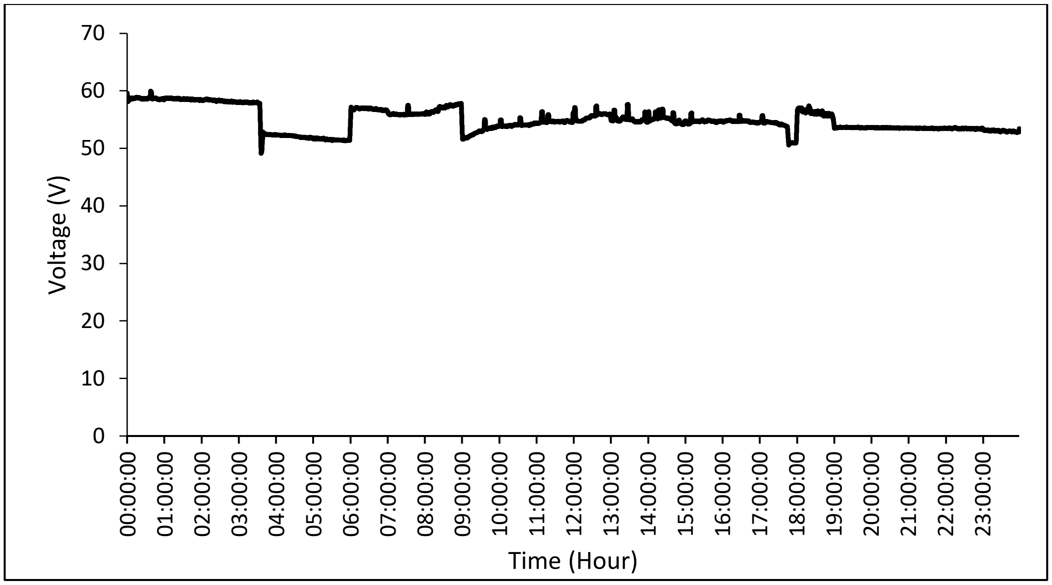

Figure 64. Battery Voltage for Experiment with Supercapacitor

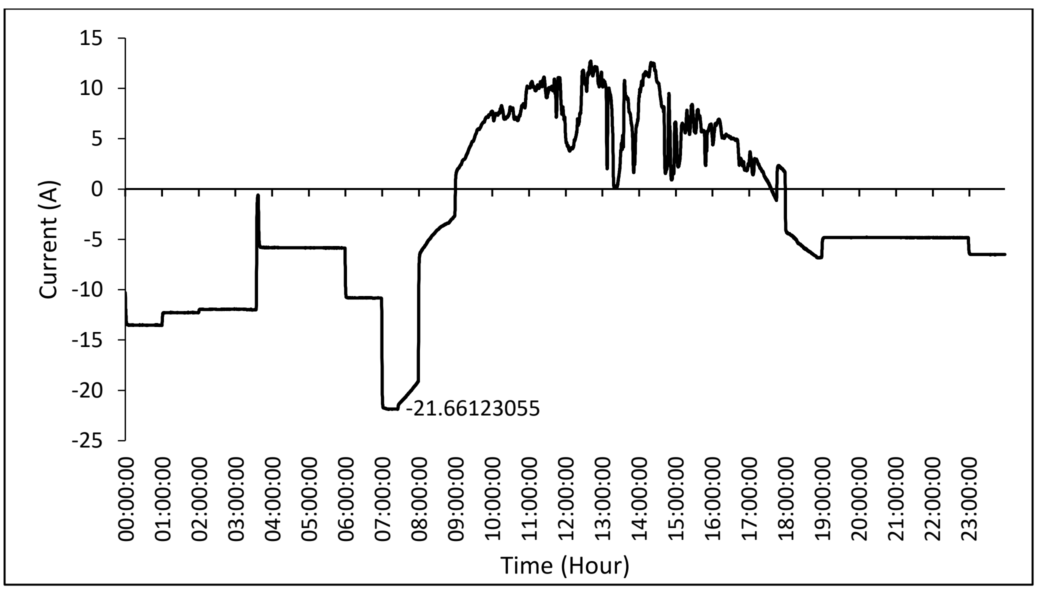

Figure 65. Battery Current for Experiment with Supercapacitor

For battery current results shown in Figure 65, the battery current with supercapacitor is more stable than without supercapacitor, and there is no significant difference between battery current with supercapacitor and battery current without the supercapacitor. The battery current without supercapacitor fluctuates seriously and is not good for battery health. The peak current of the battery without supercapacitor shows higher results than a battery with a supercapacitor. The battery current with supercapacitor is low fluctuated because the supercapacitor covers the immediate peak current load demand and protects the battery from sudden peak current. The supercapacitor voltage shown in Figure 64 and Figure 66 is the same because both components share the same DC Busbar in the solar cabin system. The fluctuation in voltage and current reading is because of the noise and distortion from the reading sensor and there being no filter from the reading solar power output.

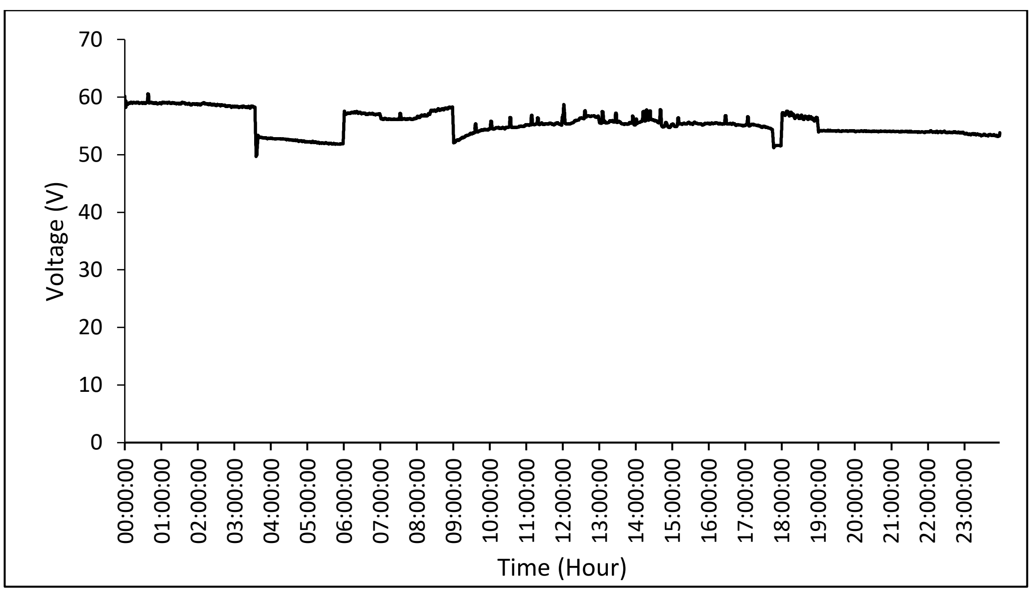

Figure 66. Supercapacitor Voltage for Experiment with Supercapacitor

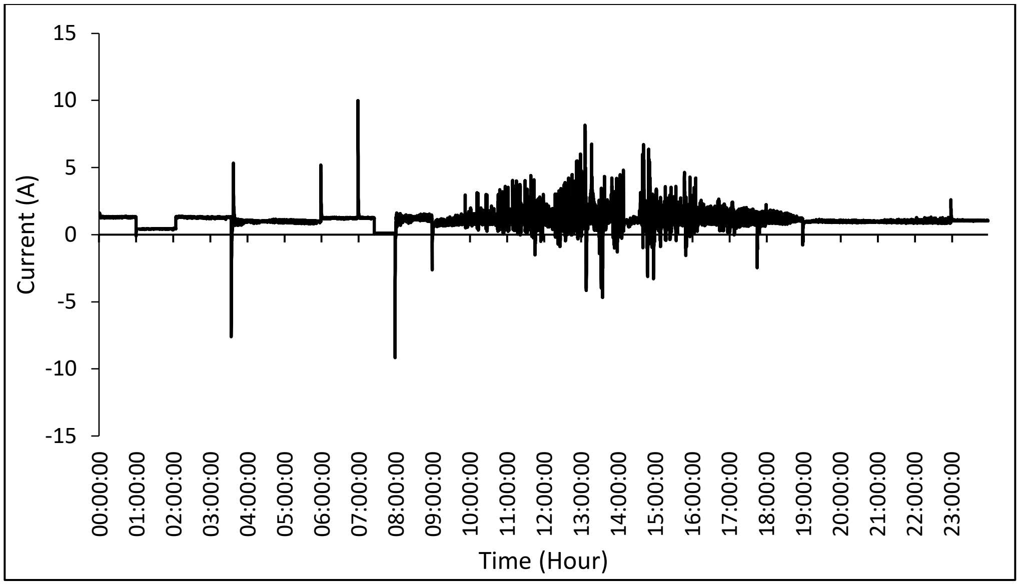

Figure 67. Supercapacitor Current for Experiment with Supercapacitor

Figure 67 shows the supercapacitor current with Load Profile 2.0. Moreover, the supercapacitor delivers the peak current load demands during morning and at night with a maximum peak charging current recorded at 9.97A at 7 am, and get power from solar and the highest current discharged from supercapacitor is -9.15A at 8 am because of low power from solar during that time.

The graph fluctuated up and down because of its charging and discharging at the same time. The supercapacitor discharged large current to support battery from peak current. The solar power charged back the supercapacitor after discharging current. At night, the supercapacitor current is more stable because of the battery's ability to handle load current demand.

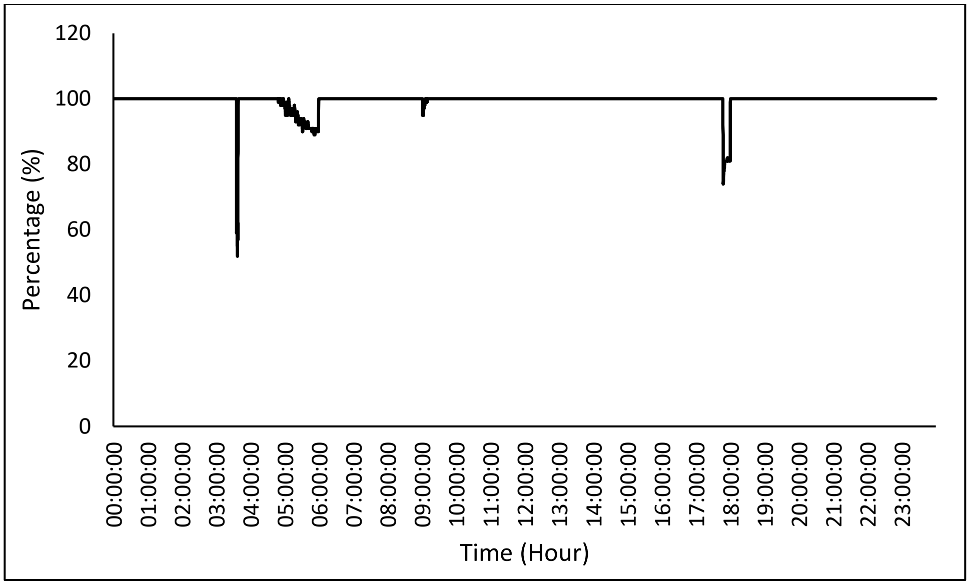

Figure 68. SOC of Battery for Experiment with Supercapacitor

Figure 68 shows the SOC of the battery with a supercapacitor. The battery drops to 52% from 100% because only battery current was supplied to the load at a night time. The battery also charged directly to the supercapacitor as it was not possible to avoid battery charging the supercapacitor directly. The average battery SOC is 98.46% which is good for battery health. Because battery and supercapacitor voltage cannot be controlled from charging each other, the SOC reached almost 100% all the time.

4.3.3 Battery versus Supercapacitor

In this part is shown the effect of a supercapacitor in the system by comparing the performance with and without supercapacitor current in 1 hour using Load Profile 1.0. The comparison between battery and supercapacitor current in 1 hour is necessary to show the effectiveness of the supercapacitor in the system during a short time period. Figure 69 shows the difference between current profiles for battery with a supercapacitor, for battery without supercapacitor and for supercapacitor current at 10 AM. From the graph, battery current without supercapacitor fluctuates quickly compared with battery current with a supercapacitor. The graph of battery current with supercapacitor is much more stable. In the circle indicated on the graph, the supercapacitor supported the battery when the current was changing fast, while battery without supercapacitor has much larger fluctuations.

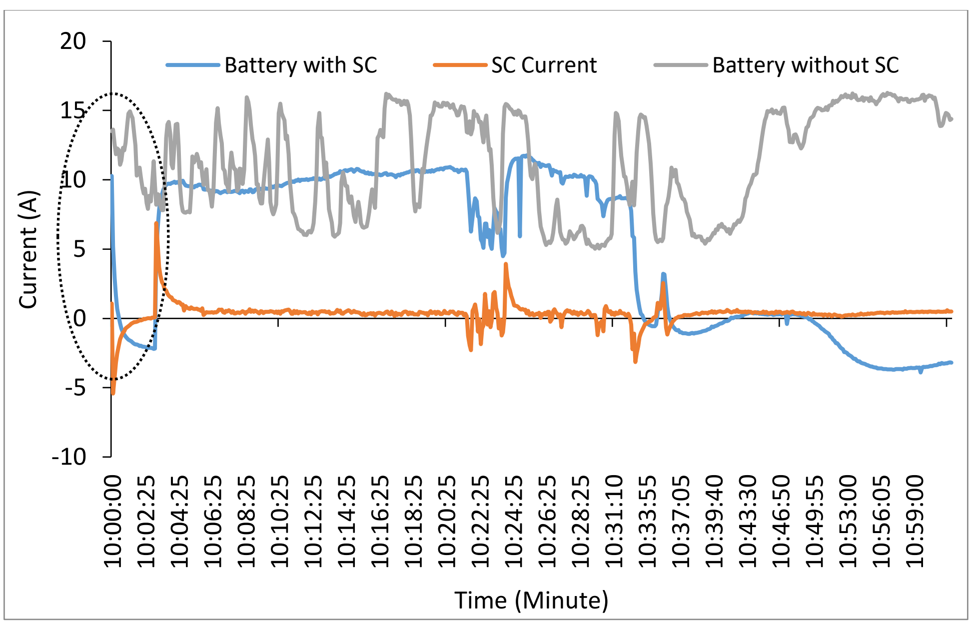

Figure 69. Comparison between Battery without Supercapacitor, Battery with Supercapacitor and Supercapacitor Current at 10 AM

Next analysis in Figure 70 is at 12 PM because this time the solar power output is at its highest and is actively charging the battery and supercapacitor. The current fluctuations are huge without supercapacitor while battery current with supercapacitor is more stable and has no sudden drops and rises. The peak current for the battery without supercapacitor is 19A which is the highest in the graph. The supercapacitor current graph shows that it does support the battery in instances of the rapid current surge.

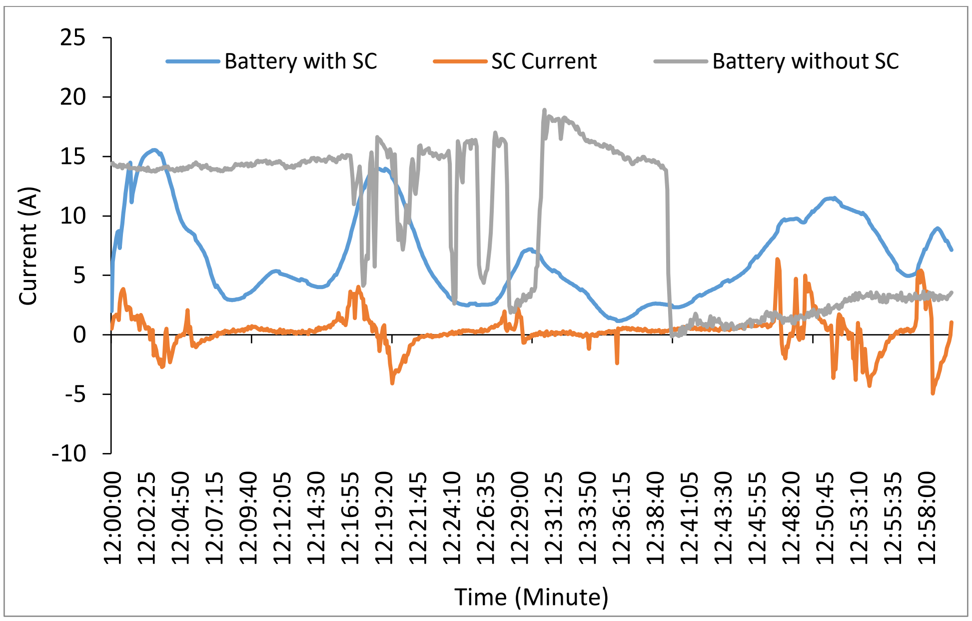

Figure 70. Comparison between Battery without Supercapacitor, Battery with Supercapacitor and Supercapacitor Current at 12 PM

4.4 Load Profile 1.0 versus Load Profile 2.0

In this part, the Load Profile 1.0 result will compare with the Load Profile 2.0 result. The result analyses in this section are to observe the difference between battery voltage and current.

Figure 71 and Figure 72 show the results for battery voltage comparison for Load Profile 1.0 and Load Profile 2.0. The differences between these two results are during the day, the battery was charged from solar power and during morning and night, and the battery was discharge to the load. The solar profile influences the output during the day by charging and supplying power to the load. In the morning, night or with no solar power, the battery voltage was reduced depending on the load profile. The difference is with the solar power and load power. The average battery voltage without supercapacitor Load Profile 1.0 is 53.11V and Load Profile 2.0 is 52.78V.

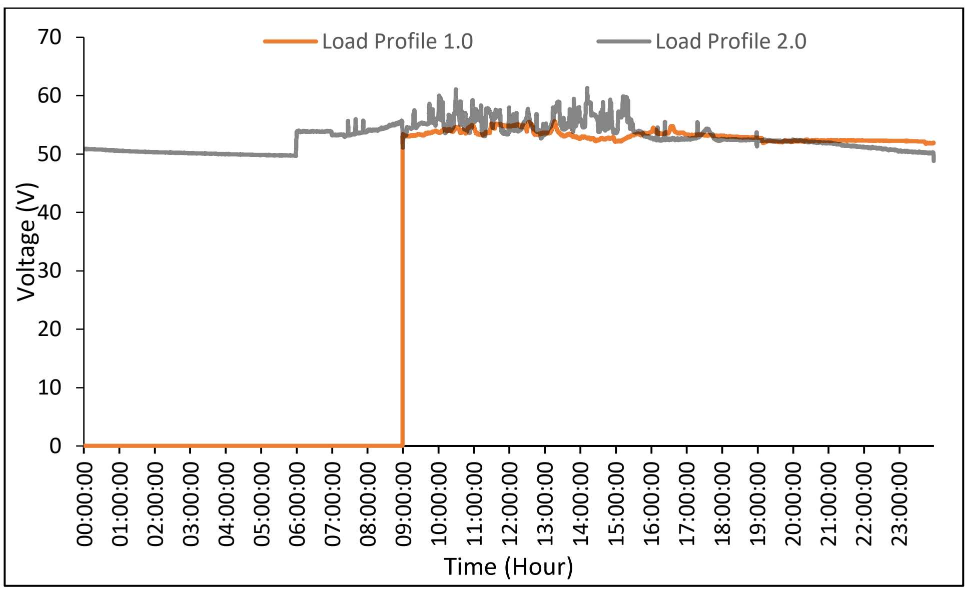

Figure 71. Load Profile 1.0 versus Load Profile 2.0 for Battery Voltage without Supercapacitor.

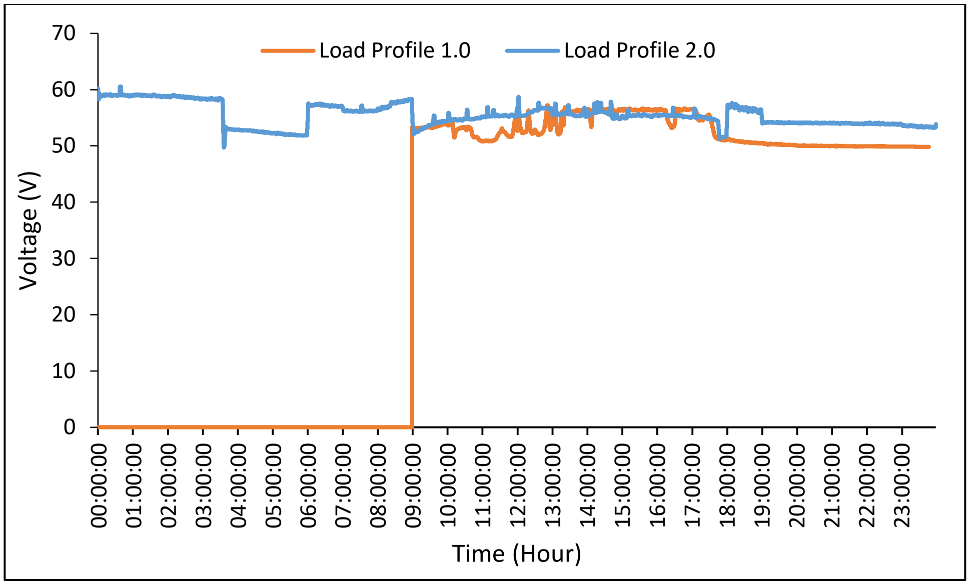

Figure 72. Load Profile 1.0 versus Load Profile 2.0 for Battery Voltage with Supercapacitor.

Similarly, the comparison of battery current shows the same results. The battery current results in Figure 73 and Figure 74 illustrate the difference between the load current and solar profile. The average battery current from Table 36 without supercapacitor with Load Profile 1.0 is 2.84A and with Load Profile 2.0 is -5.28A. Load Profile 2.0 shows a large discharged current because of high load demand compared with Load Profile 1.0. The full comparison for battery and current for Load Profile 1.0 and Load Profile 2.0 is tabled in Table 36. In short, there is no significant difference between Load Profile 1.0 and Load Profile 2.0 for battery voltage. The difference between Load Profile 1.0 and Load Profile 2.0, based on the value of the load current and the effect of the supercapacitor in the system, is not changed.

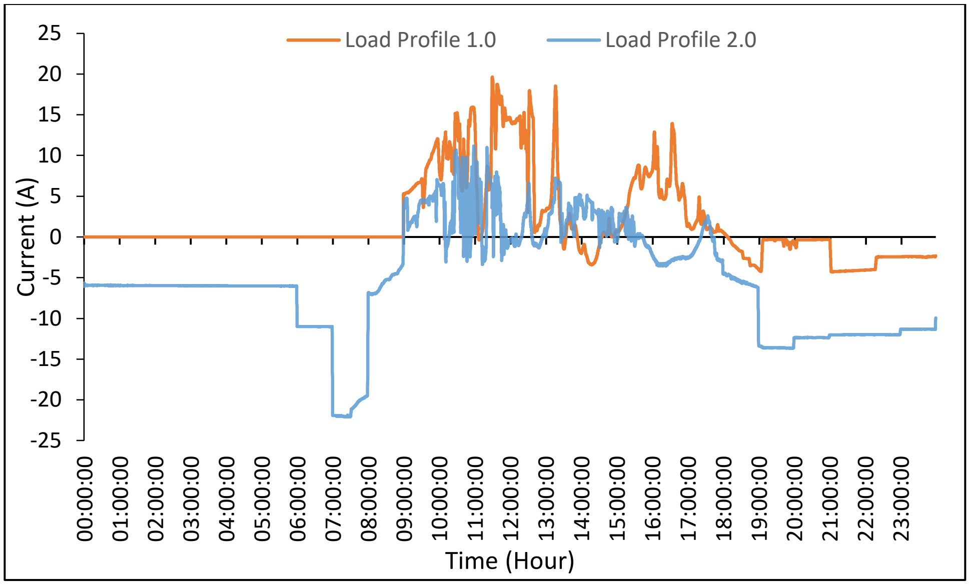

Figure 73. Load Profile 1.0 versus Load Profile 2.0 for Battery Current without Supercapacitor.

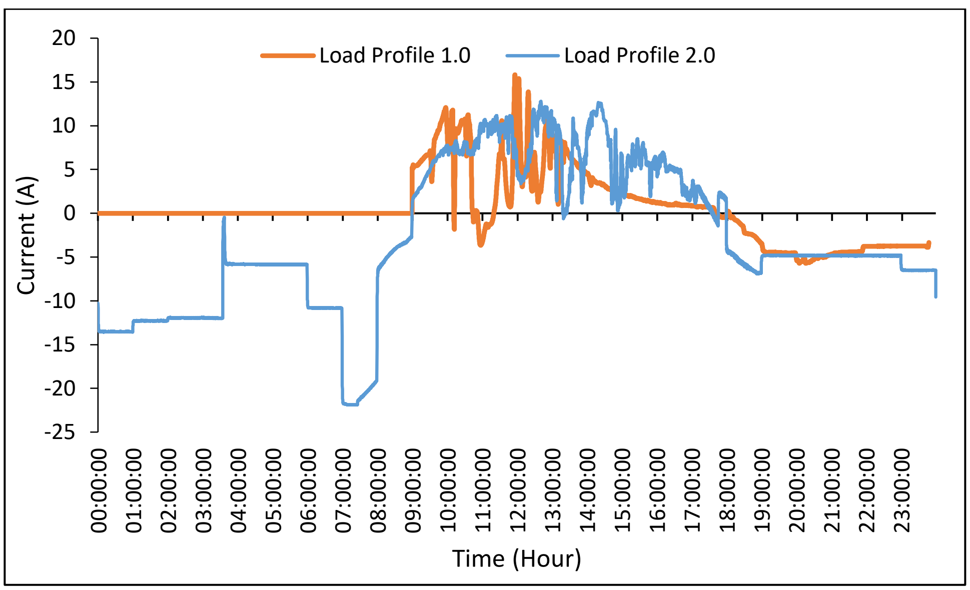

Figure 74. Load Profile 1.0 versus Load Profile 2.0 for Battery Current with Supercapacitor.

Table 36. Full Comparison between Load Profile 1.0 and Load Profile 2.0 for Battery Voltage and Current

	Load Profile 1.0				**Load Profile 2.0**			
	Without Supercapacitor		With Supercapacitor		Without Supercapacitor		With Supercapacitor	
	Battery Voltage (V)	Battery Current (A)	Battery Voltage (V)	Battery Current (A)	Battery Voltage (V)	Battery Current (A)	Battery Voltage (V)	Battery Current (A)
Average	53.11	2.84	52.66	0.84	52.78	-5.28	55.45	-2.86
Max	55.61	19.63	57.23	15.83	61.33	11.15	60.54	12.82
Min	51.79	-4.27	49.80	-5.72	48.80	-22.07	49.71	-21.89

4.5 Energy Management System in Solar Cabin

As highlighted in Chapter 3, this new energy management system is designed to increase the effectiveness of the system control. The expected result from this new EMS is to protect the battery from overcharging, to control too-fast charge and discharge currents and to manage the storage system and supply the load. The connections in the solar cabin are newly set-up to implement this new system. The results shown in this part are from this new set up and implemented with the EMS. All the results are compared with those taken from the previous experiments. These results were taken with Load Profile 2.0 because the EMS will be applied to the latest load profile since there is not much difference between the two load profiles as discussed before.

4.5.1 Energy Management System using Load Profile 2.0

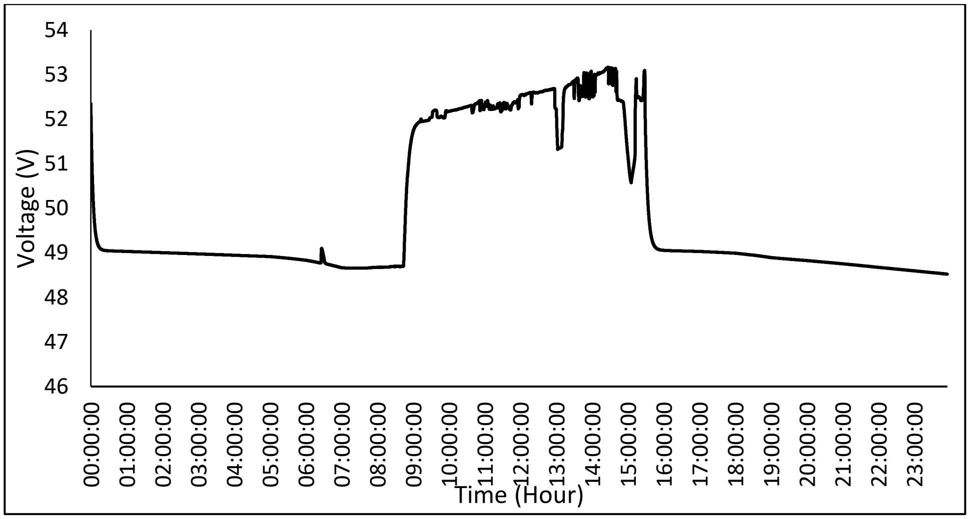

Figure 75. Battery Voltage for Experiment with Energy Management Systems

Figure 75 shows the battery voltage result for EMS with Load Profile 2.0. The battery voltage is much more stable compared to the system without the EMS. The battery voltage drop at 15:00:00 is due to drop in solar power. The solar power drop is due to cloudy conditions. The lowest battery voltage recorded is 48.6V at 23:00:00 and highest battery voltage recorded is 53.09V at 15:30:00.

The battery current results with EMS are shown in Figure 76. The EMS reduced the discharge time from the battery to load and prevented a deep battery discharge. At 06:30:00, the battery stopped discharging to the load because the supercapacitor fully supplied the current when load demand was more than 15A. After the supercapacitor SOC reached 20% as shown in Figure 76, the supercapacitor stopped discharging, and the battery took over the current supply to the load and took over again after 15 minutes. The supercapacitors stopped discharging after 15 minutes as the supercapacitors have low energy density. The maximum discharging current reduced to 20.3A from 21.3A which is less than 4.7%.

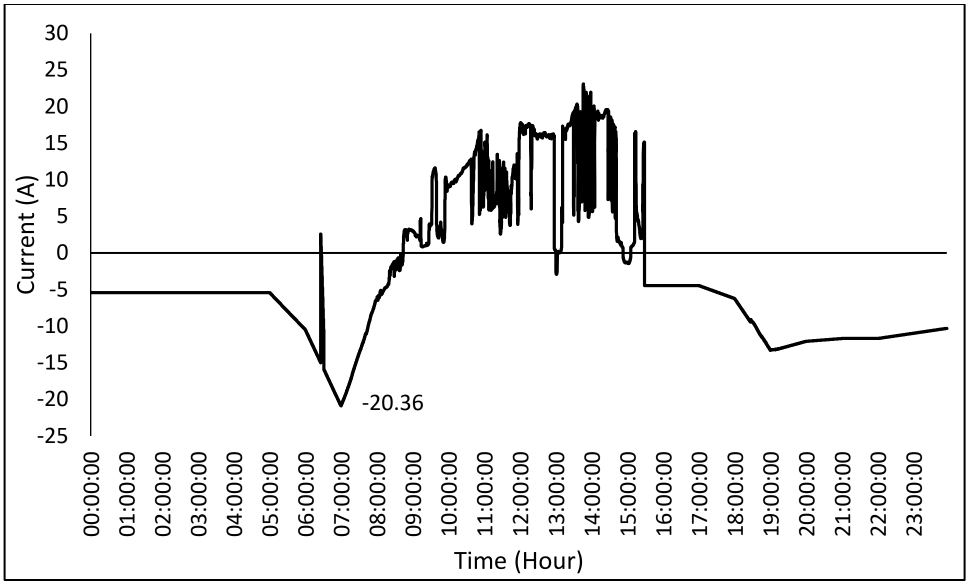

Figure 76. Battery Current for Experiment with Energy Management Systems

From Figure 77, the supercapacitor voltage result shows the supercapacitor working, depending on the conditions set in the EMS. Supercapacitors start to discharge at 06:00:00 based on the setting by the EMS. The supercapacitors start working when the load current is more than 18A to prevent the load discharging at high current and deep discharging from the battery. The minimum value of the supercapacitor reaches 14.18% or 15% from supercapacitor voltage rating in the solar cabin for safety purpose. At 13:00:00, the supercapacitor supports the battery to avoid battery from overcharging.

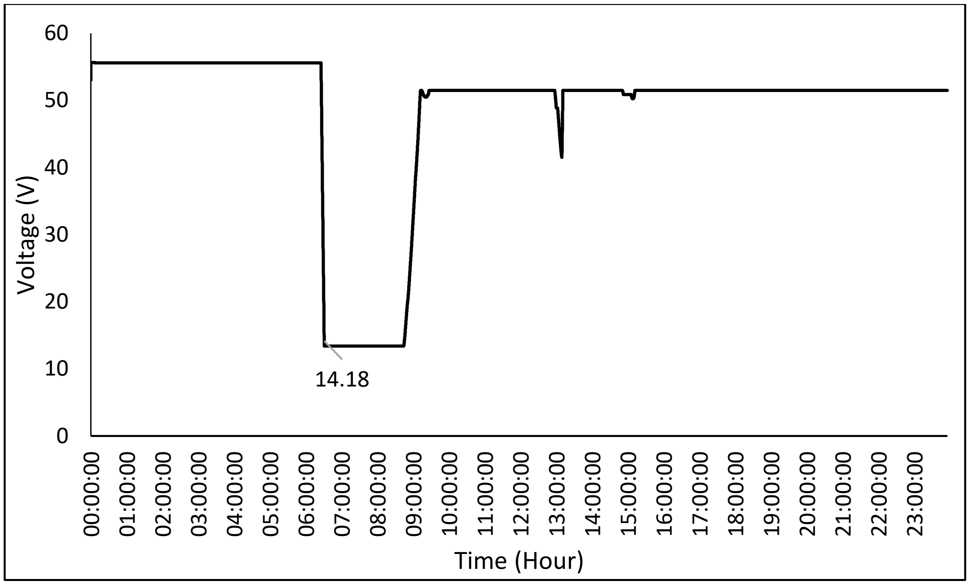

Figure 77. Supercapacitor Voltage for Experiment with Energy Management Systems

In addition, the supercapacitor current result shows the same working pattern with the supercapacitor voltage graph for charge and discharge time. The supercapacitor starts charging by solar power at 08:30:00 as shown in Figure 78. After the charging process is finished, the supercapacitor voltage and current went into standby mode based on setting in EMS. At 13:00:00 and 15:00:00, the current from supercapacitor was discharging to the load and charging directly from solar power because the solar irradiation was low at the time and stopped using the battery for a while. The maximum discharging current is 20.21A and charging current is 17.71A.

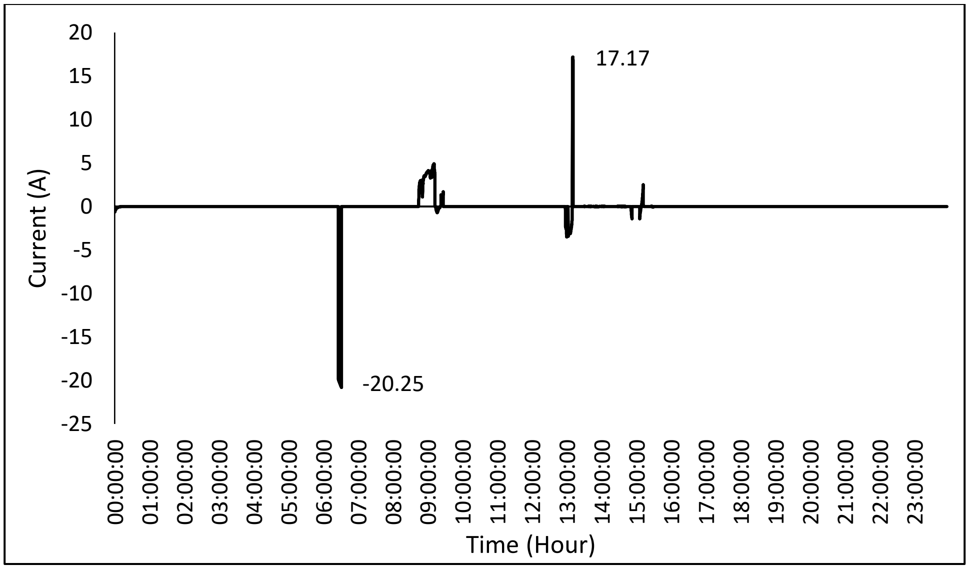

Figure 78. Supercapacitor Current for Experiment with Energy Management Systems

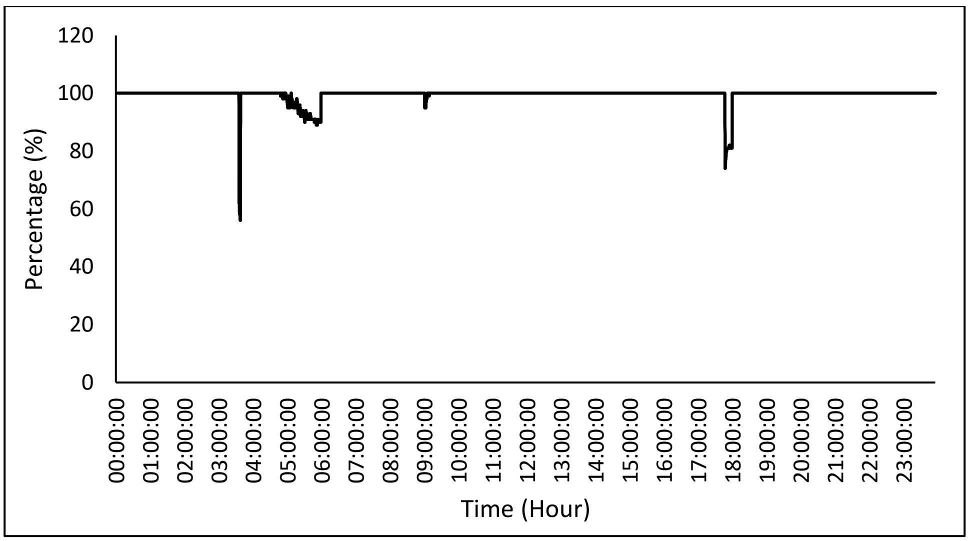

Figure 79. SOC of Battery for Experiment with Energy Management Systems

Figure 79 shows the state of charge (SOC) of the battery with Energy Management Systems. The SOC of the battery drops until 80% and then increases while starting to charge. The average SOC is 98.54%. The battery is fully utilised and supports the supercapacitor. By this time, the battery is not able to charge the supercapacitor and just supplies power to the load. During high current demand from the load, the battery stopped supplying current to the load.

4.6 Benchmarking

Based on Table 5, there is no previous research done on the combination of battery, supercapacitor and energy management system control by fuzzy logic.

- Latest real load profile for one house at rural area compared with load profile in Chapter 2 Table 7, Table 8 and Table 9.
- Scale – this project is in real scale. Usually other research is done to prove the theory only from simulation and lab scale.
- Hybrid car - most of the research with similar project specifications are in hybrid cars. The energy storage uses batteries combined with supercapacitors and fuel cells as the main power source. The supercapacitors will cover the battery during high current demand i.e. when the car starts to move.

The target for this research is to minimize the fluctuation of the battery current and cut down stress of battery by reducing the direct supply from battery to the load. Based on

- Table 37, No. 1 is developed by IBC Solar (Industry Standard), No. 2 is the improvement from No. 1 using Supercapacitor and No. 3 is with an EMS. Total Power Supply to Load per Day (W) is total power from solar, battery and supercapacitor supplied to the load.

- Total power supply from energy storage to load (W) is the total battery power and supercapacitor power supplied to the load. Losses in energy (in percent) are the total power supply to load minus the total load power usage per day. Total load power per day is 8728.1W. The loss happens because of less efficient control, charging and discharging of energy storage.

- The efficiency of the system is 95.9% with EMS in comparison with no-control and solar PV single results. The result of the efficiency shows the improvement on EMS comparable to the research in Table 4 and Table 5, but the control method implemented to the system is effortless and straightforward compared to others with supercapacitor as the hybrid energy storage. By comparing the efficiency from other research, Peng, *et al.* [85] is 95.2% and Herrera *et al.* [86] is 84.4%.

Table 37. Efficiency of Solar Cabin Based on Standard, System with Supercapacitor and Energy Management System

No.	Total Power Supply to Load per Day (W)	Total Power Supply from Energy Storage to Load (W)	Loss (%)	Efficiency (%)	
1	10641.35	1913.24	17.978	82.02	Alone
2	12505.08	3776.98	30.20	69.79	Need control
3	9100.87	372.77	4.096	95.90	Efficient

4.7 Chapter Summary

The solar profile used is different because the experiments were performed on different days. The experiments for the cabin system without supercapacitor and with supercapacitor were performed using Load Profile 1.0 and Load Profile 2.0. The results showed the only difference between this two load profiles running in the solar cabin is a solar profile and load current demand. The EMS can manage and control the solar cabin system and also increase the efficiency to utilise the power source and energy storage in the system.

Table 38. Summary Results for Experiment using Load Profile 2.0

Load Profile 2.0	AVG	PEAK	MIN
Solar Cabin System without Supercapacitor			
Solar Irradiance (W/m^2)	95.18	689.31	-15.56
Battery Voltage (V)	52.77	61.32	48.80
Battery Current (A)	-5.27	11.14	-22.07
Solar Cabin System with Supercapacitor			
Solar Irradiance (W/m^2)	102.67	587.99	-40.32
Battery Voltage (V)	55.45	60.53	49.70
Battery Current (A)	-2.86	12.82	-21.88
Supercapacitor Voltage (V)	55.45	60.53	49.70
Supercapacitor Current (A)	-0.97	9.15	-9.97
Solar Cabin System with Energy Management System			
Solar Irradiance (W/m^2)	117.88	734.56	-0.31
Battery Voltage (V)	49.84	53.16	48.52
Battery Current (A)	-3.31	23.07	-20.89
Supercapacitor Voltage (V)	48.53	55.63	14.18
Supercapacitor Current (A)	-0.01	20.25	-17.17

From Table 38:

- Solar Irradiance: EMS experiment is highest solar power received but heavy usage on load demand. The EMS successfully reduced the minimum irradiance data collected -22.07 W/m^2 to -0.31 W/m^2.
- Battery voltage: reduce peak (from 61.32V to 53.16V) and average voltage (from 55.45V to 49.84V) to make sure health is safe from overcharging.
- Battery Current: reduce the average current from -5.27A to -3.31A; Peak current increase from 11.14A to 23.07 due to high power from solar and current demand to charge the supercapacitor. The discharged current also reduced from high -22.07A to -20.89A which is reduced by 5.5%. The EMS manage to protect the battery from deep discharging.
- Supercapacitor voltage: average voltage reduce from 55.45V to 48.53V due to full utilisation of the supercapacitor to cover battery; peak voltage reduced from 60.53 to 55.43 because it is controlled by EMS; lowest voltage is 14.18 which is fully utilised in EMS.
- Supercapacitor current: average current reduced from -0.97A to -0.01A (charging and discharging is balanced); peak current increased from 9.15A to 20.25A because of its control by EMS; lowest voltage is -9.97A to -17.17A due to full utilisation of supercapacitor to cover the battery.

CHAPTER V: CONCLUSION AND FUTURE WORK

5.1 Conclusion

The solar cabin system was able to supply sufficient power to a typical rural area house, as the demand was less than the solar cabin system capacity and its backup battery storage. The support from the backup battery could supply enough power during the night even if the system was not fully charged during the day.

In this research two load profiles were used i.e. Load Profile 1.0 using the profile in 2008 and Load Profile 2.0 using the latest load profile in a rural area in 2017. The difference between two load profiles such as the equipment utilised in the house, operating hours, total usage per day and the maximum current used per hour. The total power used per day from load for Load Profile 1.0 is 2594Wh in 16 hours and Load Profile 2.0 is 8728.1Wh for 24 hours. It is known from Load Profiles that the output shows a difference only on the load current usage in the house which does not affect the main objective of this thesis.

The main objectives of this thesis have been achieved. The EMS is successfully implemented in the solar cabin and provides significant results. The results show the efficiency is increased from 82.02% for solar cabin system without the EMS to 95.9% for the solar cabin system with EMS. The results are more efficient compared with other researchers with similar projects showing 95.2% and 84.4%. The result of the solar cabin at 95% with EMS is in line with the standards review in literature for efficiency.

The EMS consists of a real-time monitoring and controlling system in the solar cabin, creating a data storage system in the solar cabin using LabVIEW software and replacing DataTaker for collecting data. By using Rule-Based Fuzzy Logic to improve the effectiveness and efficiency of the hybrid battery-supercapacitor energy storage system, the classic logic for the control system was simplified. The EMS controls the charging and discharging of battery and supercapacitor and the whole system automatically.

The results on hybrid energy storage system show that the hybrid combination of supercapacitors and battery has tremendous benefits with many significant improvements. The peak supercapacitor current for experiment with EMS recorded 20.25A, increased more than 100% compared with the hybrid energy storage system without the EMS. The peak current increased because the supercapacitors managed to supply the high demand peak current and surge currents. The supercapacitors were able to supply peak power requirements in a short period and the battery can store more energy and supply to the continuous load power at a nominal rate over a longer period.

Hence the system reduced the current stress in the batteries, improved its lifetime and ultimately cut-down operating and maintenance cost of the system. The supercapacitors act as a buffer in this study by relieving the battery from high power demands. This combination is ideal for use in a rural area because of the reduced maintenance cost by extending battery performance and lifetime. The performance of the battery voltage and current show an improvement in battery performance. The discharge current rate is reduced to 5.5% thereby preventing deep charging from the load.

The DC to DC converter is placed between the battery and supercapacitor successfully as a major component in EMS. The DC to DC controls the charging and discharging of the supercapacitor based on fuzzy logic algorithm settings. The DC to DC converter also serves as a protection for the storage devices.

The classical logic requires a deep understanding of the system, exact equations, and precise numerical value and conditions with intermediate values which are based on true or false state. The fuzzy logic controller is a better way that enables the easy modelling of complex systems.

From the summary in Table 38, the main objective of the EMS, to reduce the high current discharge and fully utilise the energy at solar cabin, is effectively done. The EMS is theoretically able to extend the battery lifetime. It has been found from these results that the supercapacitor is able to withstand high currents.

Fuzzy logic is effective in managing hybrid energy systems, especially in multi controls and functions are performed on them. LabVIEW enables to build a fuzzy system without the need for text-based programming codes. The designer can use the Fuzzy System Designer and the Fuzzy Logic VIs to design and control fuzzy system.

Nevertheless, the complete research had not been entirely smooth all over, and as expected it had faced few challenges to accomplish the research. The limitations encountered while conducting the research are listed as follow:

1) Less knowledge on handling the supercapacitor. The supercapacitor can discharge very high current and all safety steps need to be taken before running the experiment.

2) The solar cabin designed based on Load Profile 1.0. When using latest load profile 2.0, the battery and supercapacitor need to supply more power to the system and affect the performance of the energy storage. The solar PV output power still remains the same 2kW but the power demand increased. When the power demand is more than the power supply, the battery and supercapacitor are not able to fully charge before night.

3) There are many research papers published based on the integration of hybrid energy storage with the management system. Unfortunately, these researches focus more on small scale systems and simulation with low current but the solar cabin runs on 48V and more than 20A current. All integration and management system with the high current needs to be developed with limited budget and resources.

5.2 Recommendation and Future Work

This project seeks to reduce the cost of implementing and operating a solar energy based renewable energy system by extending the battery life and assessing the amount of storage required for households. Future work needed to add to this project is to use an Artificial Intelligent (AI) i.e. genetic algorithm (GA) and Support Vector Machine (SVM) as a regression engine to predict load requirement after the system has been optimised using a Genetic algorithm. The Support Vector Machine (SVM) would be needed to get classification performance above 95% and determine an appropriate kernel for the support vector machine (SVM) in the renewable energy management system for the rural electrification domain.

This output from the GA has a benefit in that allows it us to significantly reduce the size of the system as compared to the scale of the current stand-alone PV system. Furthermore, by utilising the SVM, prediction of the load is possible. Data collection from the voltage sensors and current sensors of the PV modules, battery and supercapacitors, the time of the day and so on will used as data classification. SVM can be trained to predict the future load demand.

Battery monitoring was recommended to be added to the system because it can indicate hours of battery based runtime and determines battery bank state of charge. Battery monitoring can also improve the overall system performance of 24V and 48V battery banks. Battery string imbalance is determined using innovative mid-point sensing technology providing time to address the issue before performance significantly impacted.

From this research, it can be directly implemented to the real house for actual usage and applications. The implementation to the rural house can give benefit to the user to get quality electrical supply similar as from grid connected power supply.

In addition, the usage of Load Profile 2.0 increases the power demand compared to Load Profile 1.0. The solar cabin needs to increase its capacity. The solar PV needs to be upgraded to the latest technology of solar PV and also to increase the output power. For example, the current solar cabin system uses the 100W solar panel. The solar cabin can be upgraded to 350W per solar panel, and the solar cabin system capacity increased to 7000W.

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