Loss and Cost Evaluation of Typical Solar DC Distribution for Residential House

A

Thesis submitted

in partial fulfillment of the Requirements

for the degree of

Master of Technology

By

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CERTIFICATE

This is to certify that the thesis entitled "**Loss and Cost Evaluation Of Typical Solar DC Distribution for Residential House**", submitted by **Ajit Kumar Sahu** to Indian Institute of Technology, Bhubaneswar, is a record of bonafide Project/Research work under my (our) supervision and we consider it worthy of consideration for the award of the degree of Master of Technology of the Institute.

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(Supervisor)

DECLARATION

I certify that

a. The work contained in the thesis is original and has been done by myself under the general supervision of my supervisors.
b. The work has not been submitted to any other Institute for any degree or diploma.
c. I have followed the guidelines provided by the Institute in writing the thesis.
d. I have conformed to the norms and guidelines given in the Ethical Code of Conduct of the Institute.
e. Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.
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Signature of the Student

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Ajit Kumar Sahu
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V	Voltage
I	Current
P	Power
R	Resistance
L_m	Line inductance of bi-directional converter
w	Wattage rating
D	Duty cycle
t_{on}	Turn on time of bi-directional converter
t_{off}	Turn off time of bi-directional converter
V_l	Voltage across load
R_l	Load resistance
T	Time period of bi-directional converter
f	Frequency
V_L	Low voltage side voltage of bi-directional converter
V_H	High voltage side voltage of bi-directional converter
D.D	Depth of discharge
R_{ac}	AC resistance
R_{dc}	DC resistance
P_{loss}	Power loss
R_{fan}	Resistance of fan
$R_{television}$	Resistance of television
R_{mixer}	Resistance of mixer
ϕ	Power factor angle
V_0	Output voltage of buck converter
V_{DC}	DC source voltage
V_{AC}	AC source voltage

Abstract

The purpose of this project is to construct a prototype DC electrified house that can be usable in rural electrifications. More specifically, this project focuses on the development and construction of an efficient DC powered house by minimizing the losses in the conductor, cable length and total cost of the system and also to verify that both the cost and losses can be minimized with respect to conventional type solar powered AC system, as the inverter loss is omitted in the above system. In this project both simulation and hardware implementation both AC and DC powered houses are done. The results of this project serves as a proof that, the solar powered DC electrification is economically feasible compared to the conventional AC solar powered houses.

Chapter 1

1. INTRODUCTION

1.1 Overview

Energy is the basic need for people's living standard for the development of socio-economic and enhancement. The energy consumption increased day by day due to became more developed. But the conventional energy system has a negative impact in our environment and which is also in the verge of exhaustion.

The conventional distribution system for rural electrification is not that much fruitful to satisfy the electricity consumption for rural areas because rural villages are more far from the grid system [1]. Also the DISCOMS (corporations who is responsible for the distribution of electricity) do not give a priority for rural electrification since it does not directly lead to economic regeneration or increased productivity [4]. As per the census data of 2011 of the state of Odisha, 50.00 Lakh households are yet to electricity, mostly in the rural areas. The only way to provide electricity to these areas by renewable sources.

Among the available renewable sources like wind energy, solar energy, fuel cells, geothermal energy; solar energy is easily available and less costly than others. The output of the solar cells are DC, which is an advantage as it can be easily integrate to the storage elements (batteries)without any power conversion [5,7].These storage power used to compensate the energy deficiency or store the extra energy whenever it required.

We know that most of the household appliances are internally operated on DC like led bulb, television, computer; so by converting DC to AC by inverter which are again internally converted to DC there are some unwanted loss occur. The energy generated by these photovoltaic cells can supply DC power directly to the DC appliances without converting to AC. By this method the wanted losses are avoided which provide a better power quality [9].

In this project, we envisage an energy-efficient house model which uses low-DC voltage

Generated from PV sources to run household appliances. A novel scheme is proposed for efficient generation of power (<500 W) for home appliances with low voltage DC (24 V) for creation of an energy-efficient home for the future.

In conventional solar powered AC system there are two stages of energy conversion occur from source to load (i.e. 1st stage DC to 230 v AC and then again 230 V ac to low voltage DC inside the equipment), which can be easily neglected by providing low voltage DC (24 V, 12 V) to the equipment, in this manner both losses and safety can be checked [25, 27].

The feasibility of "low-voltage DC house for rural electrification" set within predefined boundary conditions is the subject of this report. The first part of the research has focused on simulation of a house with different types of load. The second part of the project concentrates on the hardware implementation of the above models.

1.2 Objective of the project

The objective of the project is to model and construct a DC house. This will include selection of the size of the house, load for each house section, selection of proper conductor for each load, wiring of the house by minimizing the loss and cost, proper sizing of the battery for DC house, cost and loss comparison between solar powered AC and DC system.

Here below the main objective is mentioned:

Work Plan 1:

[1] Design and simulation of MPPT controller, DC-DC converter, DC-AC Converter, Battery Charging Controller.

[2] Fabrication and Experimental Study.

Work Plan 2:

[1] Simulation study of solar and battery energy, to meet the energy demands during day time only.

[2] Experimental study of solar and battery energy, to meet the energy demands during day time only.

Work Plan 3:

[1] Simulation study of solar and battery energy, to meet the energy demands during day and night.

[2] Experimental study of solar and battery energy, to meet the energy demands during day and night.

Work Plan 4:

[1] Evaluation and analysis of the energy saving of PV based DC system in comparison to traditional PV powered AC system using simulation.

[2] Experimental validation.

Work Plan 5:

[1] Evaluation and analysis of the optimizing cost of the system considering its technical and operational feasibility as well as economic aspects

[2] Experimental validation.

1.3 Document overview

The second chapter outlined the various advantage and disadvantage of both AC as well as DC electrification. Then to minimize the line loss in the system which parameters' we should take care of and how to find the overall loss by taking simple DC circuit analysis.

In the third chapter, we will discuss about the various advantages of choosing 24 V for DC electrification and with that the safety requirement need to design the house.

Chapter four will consist of discussion about various parts of DC house 1.e. PV panels, charge controller, MPPT algorithm used and DC-DC converter .which will be briefly discus in the same chapter.

In the fifth chapter we will discuss the load section that is used for to model and design of this house. The simulation design of various load and how to calculate the various parameters are discussed.

Chapter six consist of result and analysis of both AC and DC house. This chapter will show the experimental result for both the cases and losses occurred in the line and devices. Then what size of battery needed to provide continuous power for six hour during night time and total cost to design the DC house.

1.4 Literature review

- Y. Arafat et al [2] have worked on “Feasibility Study of Low-Voltage DC House and Compatible Home Appliance Design”. The research area is focused on the design of efficient kitchen appliances for a low-voltage DC supply. The outcome of this investigation is that, the 48V DC system with optimized cable area most economical and viable as compared with the 230V AC system and also save energy.
- N. Soorian et al [3] have worked on “Appliances in a low-voltage DC house - Low power solutions in the kitchen area”. The research concluded that, Low voltage DC can certainly save money for their users, cables of optimized thickness will guarantee that the losses due to high currents are kept low in the kitchen.
- H. Kakigano et al [10] has proposed The losses in the ac and dc micro grid systems for residential complex with PV system . The analysis results show that the whole losses of the dc system are around 15 % lower than that of the ac system for a year. Any electrical energy storages are not considered in both systems. If the energy storage is included, the loss reduction effect of dc distribution becomes higher than this result.
- Kuei-Hsiang Chao et al [15] have proposed a stand-alone photovoltaic power generation system framework for small-scale air-conditioners, and formulated a DC link voltage regulation strategy based on a bidirectional buck-boost converter combined with the charge and discharge functions of a battery. The DC link voltage not only maintains its set command value, but also supplies sufficient power for small-scale air-conditioners under insufficient irradiation through the charge and discharge functions of the battery. When higher levels of solar irradiation are provided, the excess energy is stored in the battery.
- Mark Cabaj [16] has experimented the parallel DC-DC converters, were assembled and tested to verify that they function properly for this purpose. Once all main components were selected, each one was tested to verify their functionality for the DC House model. Some of these other tests included testing the solar panel, DC drives, Motors, Generators, charge controller with battery, DC power distribution panel, buck converter, and appliances.

Chapter 2

2. BACKGROUND

The main aim of this project is to propose a cost effective low voltage DC system for electrification in the rural area. The DC house provided power by solar energy which was back up by a battery system i.e. battery. This DC powered house in not connected to grid i.e. the sole power was provided by solar energy and battery storage system called standalone PV system.

Traditionally, power transmitted to an area through transmission line where the density of population is high from grid. But in some rural areas it is not possible to provide power from trough grid through transmission line because of certain constraints like the geographical location not allowed and if also the transmission cost is too high (i.e. transmission line, substations, transformers etc.).

As per the census data of 2011 of the state of Odisha, 50.00 Lakh households are yet to Use electricity, mostly in the rural areas. So to provide power to these small villages in remote location there is only one method, that is use of renewable energy in this areas. As we know that out of all renewable energy sources, solar energy is more feasible and cost effective alternative than other. So this project creates an opportunity to apply new technology which is able to fulfill the humanitarian gap that exist between the globalized world and them.

As we know that the cost effective depends upon the efficiency of converter/inverter. In early nineties, the power electronics is not that much developed so the conversion efficiency of these devices is very less. The cost and loss involved in this project mainly depends upon the efficiency of these converter and suitable chosen of load.

Today, the scenario has completely changed due to the advent of power electronics devices used in power sector. Now-a-days the efficiency of DC-DC converter is about 75-95 percentage whereas efficiency of inverter is 70-80 percentage.

2.1 overview of PV based AC system

Now-a-days most of the solar based house electrifications are AC based. In this system the power generated by solar panels are feed to DC-DC converters through MPPT algorithms and then the regulated DC voltage was further converted to 230 V AC which are feed to the household appliances [21]. But in this process there is unnecessary losses occurred in the inverting stage from DC to AC. As we know that the efficiency of the inverter is nearly equal to 80% at full load and even more at partially loaded condition [18, 28]. So by this process there is unnecessary loses are occurred inside the inverter. Below figure 2.1 shows the power flow diagram of a PV based house electrification.

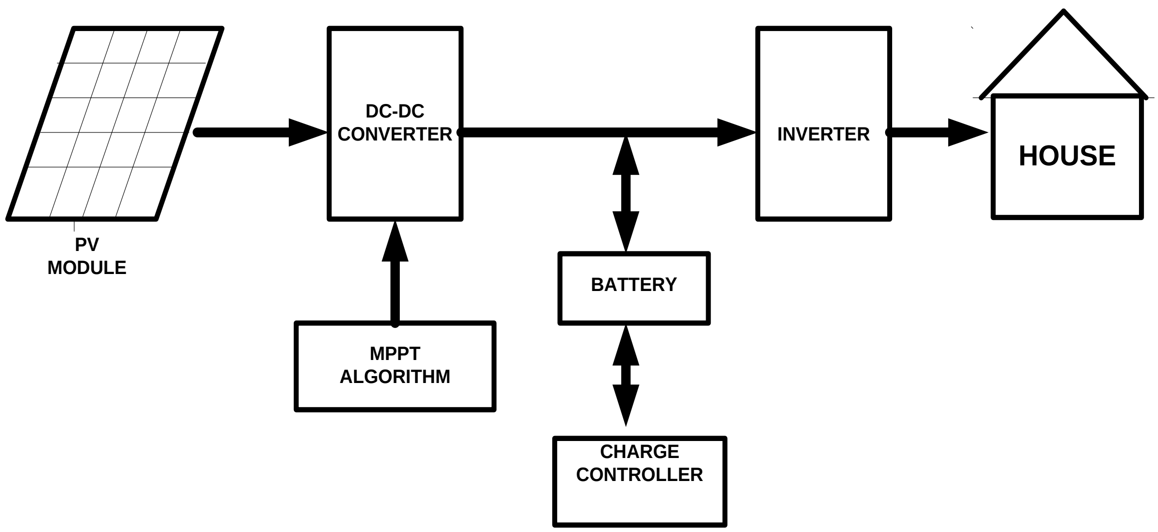

Figure 1: PV integrated AC house layout diagram

2.1.1 Advantages of AC house electrification

There are certain advantages of autonomous PV based AC houses; which are listed below [26]:

1. Due to high voltage i.e. 230 V the current carries by the conductors are less; which leads to lesser I^2R losses and cost saving.
2. More familiar with the AC system.
3. Easily available of the AC household appliances.

2.1.2 Disadvantages of AC house electrification

There are certain disadvantages of using AC for house electrification. These are [24]:

1. Complexity in power calculation.
2. Have to maintain 50 Hz frequency across all equipment's.
3. We have to take care of the reactive power.
4. Due to skin effect the conductor size may increases.
5. Due to inverter the total system efficiency decreases and cost increases.
6. Due to reactance comes into account; there is unnecessary voltage drop occur.

2.2 overview of PV based DC system

The DC House is designed to power a house in a village where there is no access to electricity. DC house allows unfortunate villages to improve their style of living. The DC power house will include various types of components like PV array, Battery charge controller with MPPT, Tubular battery and DC appliances. This autonomous DC house will be grid independent also called stand-alone system [21, 32]. Figure 2.2 mentioned below suggest the power flow through different stages of a DC house.

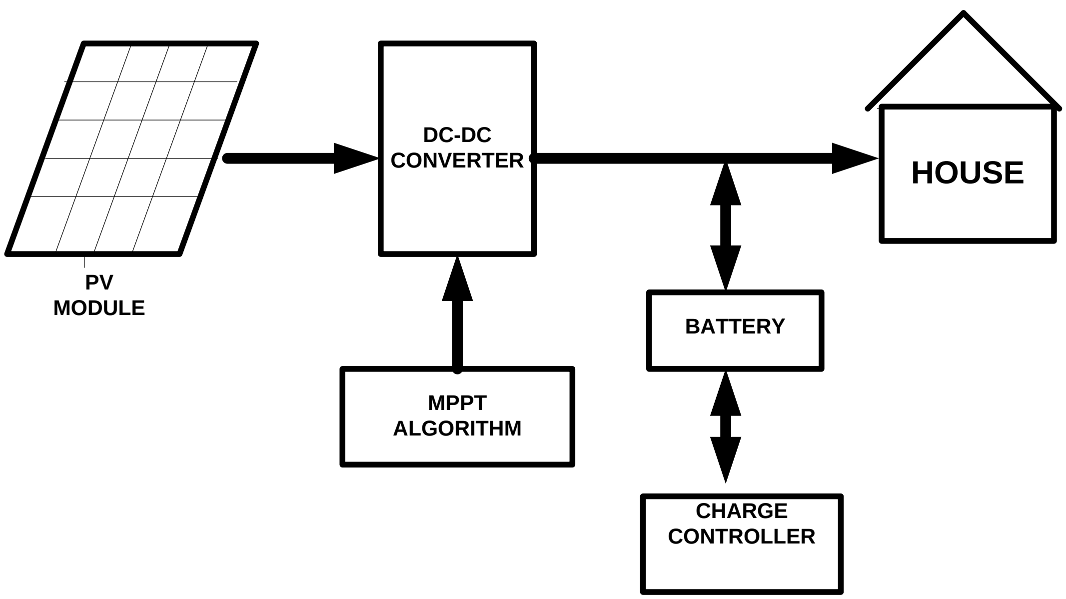

Figure 2: DC house layout diagram

The improvement in the area of power electronics have made a huge impact on DC powered rural electrification. There are many advantage for DC electrification; some of these are simple integration with the PV system (both operate on DC voltage), simple coupling with storage elements (i.e. Battery) and high power density. Many authors [11, 12] have investigated the feasibility of the implementation of DC in low and medium voltage systems. It can be concluded that if the if losses in DC-DC converter reduced, then the total system efficiency can be increased significantly. Generally the efficiency of the converter is varies between 80%-95% depends upon the manufacture.

2.2.1 Advantages of DC house electrification

There are many advantages of PV based DC house with respect to AC electrification .some of these are [6]:

1. Easily integration with the renewable sources of like solar energy.
2. Easily integration with the storage devices without any further energy conversion.
3. High power density.
4. Safety; Due to lesser voltage operation i.e. 24 V, 12 V.
5. No skin effect and no need to maintain frequency constant.
6. Less value of appliances rating than of AC appliances.
7. No need to convert voltage from one level to another i.e. DC-AC. So inverter loss omitted.

2.2.2 Disadvantages of DC house electrification

Although DC electrification have some disadvantages these are not major ones. Which are listed below [6]:

1. DC appliances are not as much familiar as AC appliances.
2. Conductor size increases due to high current carrying compared to AC system, As in house electrification we use low voltage i.e. 24 V, 12 V.
3. Losses in the conductor increases.
4. DC transient occur during switching.

2.3 Loss comparison

2.3.1 For AC system

In figure 2.3 shows a load connected across an AC voltage source V_s through a conductor of resistance R and inductance L. Let P_{ac} was the total power consumed by the load [8].

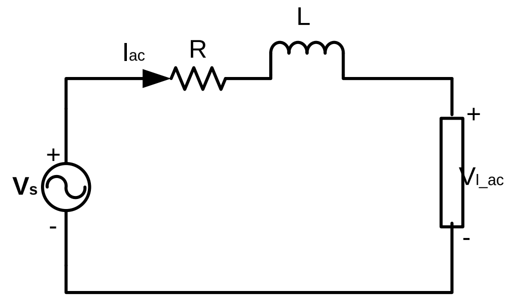

Figure 3: Simple AC circuit will source and load

So the total current drawn by the load can be written as:

$$I_{ac} = \frac{P_{ac}}{V_{l\_ac}.\cos\phi} \tag{2.1}$$

Where V_{l_ac} is the load voltage and $\cos\phi$ is the power factor for that system.

So total loss can be calculated as

$$P_{loss\_ac} = I_{ac}{}^2.R = \frac{P_{ac}{}^2}{V_{l\_ac}{}^2.\cos^2\phi}.R \tag{2.2}$$

2.3.2 For DC system

Let us consider a DC load connected across a voltage source V_{dc} through a conductor of resistance R, which is shown in figure 4. The power consumed by the load is P_{dc} when a current of I_{dc} flow inside the conductor [16, 30].

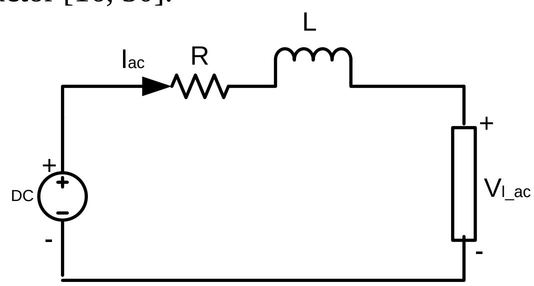

Figure 4: DC circuit with source and load

The load current I_{dc} in terms of P_{dc} can be written as:

$$I_{dc} = \frac{P_{dc}}{V_{l\_dc}} \tag{2.3}$$

So the total loss across the resistance P_{loss_ac} can be written as:

$$P_{loss\_dc} = I_{dc}{}^{2}.R = \frac{P_{dc}{}^{2}}{V_{l\_dc}{}^{2}}.\mathrm{R} \tag{2.4}$$

But we can write as $V_{l\_dc} = \sqrt{2}V_{l\_ac}$ without damaging the conductor insulation.

So by dividing the equation (2.1) from equation (2.3), we can get:

$$\frac{I_{dc}}{I_{ac}} = \frac{V_{l\_ac}}{V_{l\_dc}}.\cos\phi = \frac{\cos\phi}{\sqrt{2}} \tag{2.5}$$

Similarly by dividing the equation (2.2) from equation (2.4), we can get:

$$\frac{P_{loss\_dc}}{P_{loss\_ac}} = \frac{V_{l\_ac}{}^{2}}{V_{l\_dc}{}^{2}}.\cos^{2}\phi = \frac{\cos^{2}\phi}{2} \tag{2.6}$$

Form the equation (2.5) it was shown that the current density of in the DC system is higher than that of AC supply system. Similarly we can concluded from equation (2.6) that the power loss across the DC system is much lower than that of AC system.

The loss comparison between PV based AC system and DC system is given below [1]:-

Table 1: Losses comparison between AC house and DC house

	PV BASED AC SYSTEM		**PV BASED DC SYSTEM**	
SL NO.	**SYSTEM COMPONENT**	**LOSSES**	**SYSTEM COMPONENT**	**LOSSES**
1	DC TO AC	15%	DC TO DC	5%
2	BATTERY	8%	BATTERY	8%
3	OTHER LOSSES (rectifier, Standby and feeder)	12% of Average consumption per year or 20-30% of total loss per year	OTHER LOSSES	NIL

Chapter 3

3. DC DISTRIBUTION SYSTEM

This chapter will consider the construction criteria of the DC house. To construct a DC house it should obey the following conditions [29]:

1. The power transfer from source to load with minimum energy loss.
2. The voltage across each appliance must be nominal i.e. lesser voltage drop across conductor.
3. The cost of the PV based DC electrification must be comparable with the PV based AC electrification.
4. The control and install of the DC must be simple.
5. It must be safe to the user.

3.1 Power Transfer in DC Network

For the study purpose, the power transfer in a DC appliances can be easily verified with a DC source V_{dc} connected across a load of resistance R_l through a conductor of resistance R and inductance L. From the below figure 4 we can calculate the total power flow, voltage drop and loss across the conductor. Also we can find the parameters on which both the loss and voltage drop depends. According to this we can find the appropriate conductor length and size for each appliances [4].

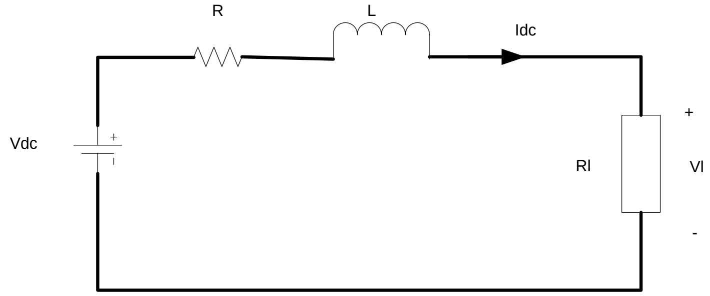

Figure 5: DC source connected to the load

Where,

R =conductor resistance

L =conductor inductance

V_{dc}=source voltage

V_l =load voltage

R_l =load resistance

From the above fig 4, the followings are calculated

$$\begin{aligned} P_l &= \frac{V_l^2}{R_l} \\ V_l &= I_{dc}.R_l \\ V_{l,dc} &= V_{dc} - V_l = I_{dc}.R \\ P_{l,dc} &= P_{dc} - P_l = I_{dc}{}^2.\mathrm{R} = \left(\frac{V_l}{R_l}\right)^2.R \end{aligned} \tag{3.1}$$

From the above equation (3.1) we concluded that the voltage drop and power loss is directly proportional to conductor resistance. Whereas, the resistance of the conductor is depends upon the thickness and length of the wire [24]. So to minimize voltage drop and I^2R loss we have to find out appropriate size of the conductor and minimal length from source to load.

3.2 Safety requirements for the DC low-voltage installation

For design and construction of low voltage DC house, it has to satisfy the NEN 1010 'Safety requirements for low-voltage installations' [1]. The important features of the of the NEN 1010 safety requirement fot the DC system installation are mentioned below:

The conditions which determine the wire diameter are [1, 31]:

1. The conductor should have high temperature tolerance.
2. The voltage drop will be in the limit.
3. Expected to sustain mechanical forces caused by short circuits.
4. Other mechanical forces to which conductors could be exposed.
5. Maximum impedance at which the short circuit protection still works.

3.3 Voltage level selection

In this section we are going to analyze the appropriate voltage level for the DC house electrification. The standard DC low voltage for house electrification are 48 V, 24 V and 12V. But the selection of voltage level depends upon various factor i.e. voltage drop, losses due to conductor resistance, safety of the user and economic to the user [9].

We know that from figure 4,

$$P_{loss} = I_{dc}{}^{2}.\mathrm{R} \tag{3.2}$$

And

$$I_{dc} = \frac{V_{dc}}{R} \tag{3.3}$$

So per unit loss can be written as;

$$\frac{P_{loss}}{P_L} = \frac{2.I_{dc}{}^{2}.\mathrm{R}}{P_L} = \frac{2.\left(\frac{P_L}{V_L}\right)^2 .R}{P_L} = \frac{2.P_L}{V_l^2}.R \tag{3.4}$$

Where P_L is the power consumed by the load and V_l is the voltage across the load.
Similarly we can write this,

$$V_{drop} = V_{dc} - V_l \tag{3.5}$$

And per unit voltage drop can be written as

$$\frac{V_{drop}}{V_l} = \frac{V_{dc} - V_l}{V_l} \simeq \frac{V_{dc} - V_l}{V_{dc}} \tag{3.6}$$

By putting the value of V_{dc} in the eq. (3.6), we can get that

$$\Rightarrow \frac{2.I_{dc}.\mathrm{R}}{V_l} = \frac{2.\left(\frac{P_l}{V_l}\right).\mathrm{R}}{V_l} = \frac{2.P_l}{V_l^2}.\mathrm{R} \tag{3.7}$$

From the eq. (3.4) and eq. (3.7), we get that both the per unit voltage drop and per unit loss directly proportional to the conductor resistance and inversely proportional to the square of voltage across the load. So for to minimize both the loss and voltage drop we have to wisely choose the DC voltage level for house electrification.

Among the all proposed voltage levels, the more feasible is 24v dc distribution system due to the following reasons [16]:

1. The availability of DC electrical appliances for this voltage range,
2. 24 V DC is frequently used as the chosen voltage level in PV and battery systems.
3. The losses and voltage drops across the cable for 24 V DC systems are less than that of 12V DC system.

4. The total energy losses in a year in 24 V DC system are less compared to 12V DC system.
5. The short circuit current of 24 V DC system is less as compared to 12V DC system.
6. 24 V DC is more safety compared to 48 V DC system.

The fact that voltages below 24 V DC are, under normal circumstances, touch safe. The fact that systems with a nominal voltage below 24 V DC do not need special measures to protect against direct and indirect touch. The requirement that conductors must be protected against over currants and short circuits [32]. The requirement that voltage losses in conductors should not cause malfunctioning of household appliances. (For 220 V AC installations the maximum allowed voltage drop is 5% of the nominal voltage).

Chapter 4

4. MAJOR COMPONENTS OF DC HOUSE

In this chapter we are going to discuss about the different parts of the DC house. To design a DC house the major components used are photovoltaic array, battery, battery charge controller and DC-DC converter with MPPT algorithm. Whereas in inverter used in the AC house model which is omitted in this case [13].

4.1 Photovoltaic array

The output of the PV array depends upon the irradiance level, environmental temperature and characteristic of the respective module. Before calculating the hourly output of PV module, the average hourly light intensity on horizontal surface should be converted to that on the PV module. Generally, Hay's model is used for this purpose. In figure 6 the electrical model of a PV module shown with a current source connected across a diode. Where R_{sh} is the shunt resistance of the module and R_s is the series resistance [14,17].

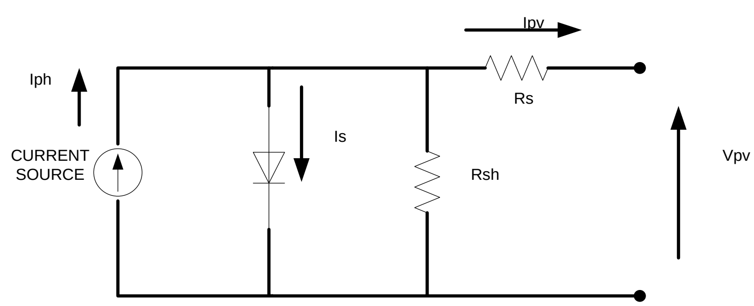

Figure 6: Equivalent circuit of PV module [18]

To get the required output voltage and power we have to connected connect number of PV cells in series or parallel manner.to enhance the voltage rating cells should be connected in series and for current rating it should be in parallel.in this project we connected four number of PV modules in parallel to fulfill our requirement.

Below equation (4.1) and (4.2) shows the voltage rating and power rating of PV array:

$$V_{PVA} = N_{PVS}.V_{PV} \tag{4.1}$$

$$P_{PV} = N_{PVP}.N_{PVS}.V_{PV}.I_{PV} \tag{4.2}$$

Where N_{PVS} is total number of series connected PV modules and N_{PVP} is the total number of parallel connected PV module.

Figure 7: Front view of TP-280 PV panels

Figure 8: Four panels connected in parallel

To conduct the experiment, we used four number of PV panels in parallel to provide the load demand. The practical value of all the parameters are given in a tabular form below:

Table 2: Data sheet for TP-280 PV panel

Nominal power output (W)	280
Power tolerance (W)	0-5
Module efficiency (ŋ%)	14.1
Voltage at P_{MAX} V_{MPP} (V)	36.1
Current at P_{MAX} I_{MPP} (A)	7.78
Open-circuit voltage V_{OC} (V)	44.5
Short-circuit current I_{SC} (A)	8.33
Actual Power output P_{MAX} (W)	201.6
Actual Voltage at P_{MAX} V_{MPP} (V)	31.8
Actual Current at P_{MAX} I_{MPP} (A)	6.35
Actual Open-circuit voltage V_{OC} (V)	39.2
Actual Short-circuit current I_{SC} (A)	7.03

Number of cells & size	72 cell and 156 mm
Operating temperature range (ºC)	-40 to +85

4.2 MPPT Algorithm

The output current-voltage characteristics of solar arrays are nonlinear, and the operating conditions of the optimum PV power gained from the PV array is affected by solar irradiation, cell temperature and loading conditions. Therefore, a maximum power point tracking control is needed to continually match the PV internal resistance with the loading effect, hence ensuring that maximum power is transferred to the load [24].

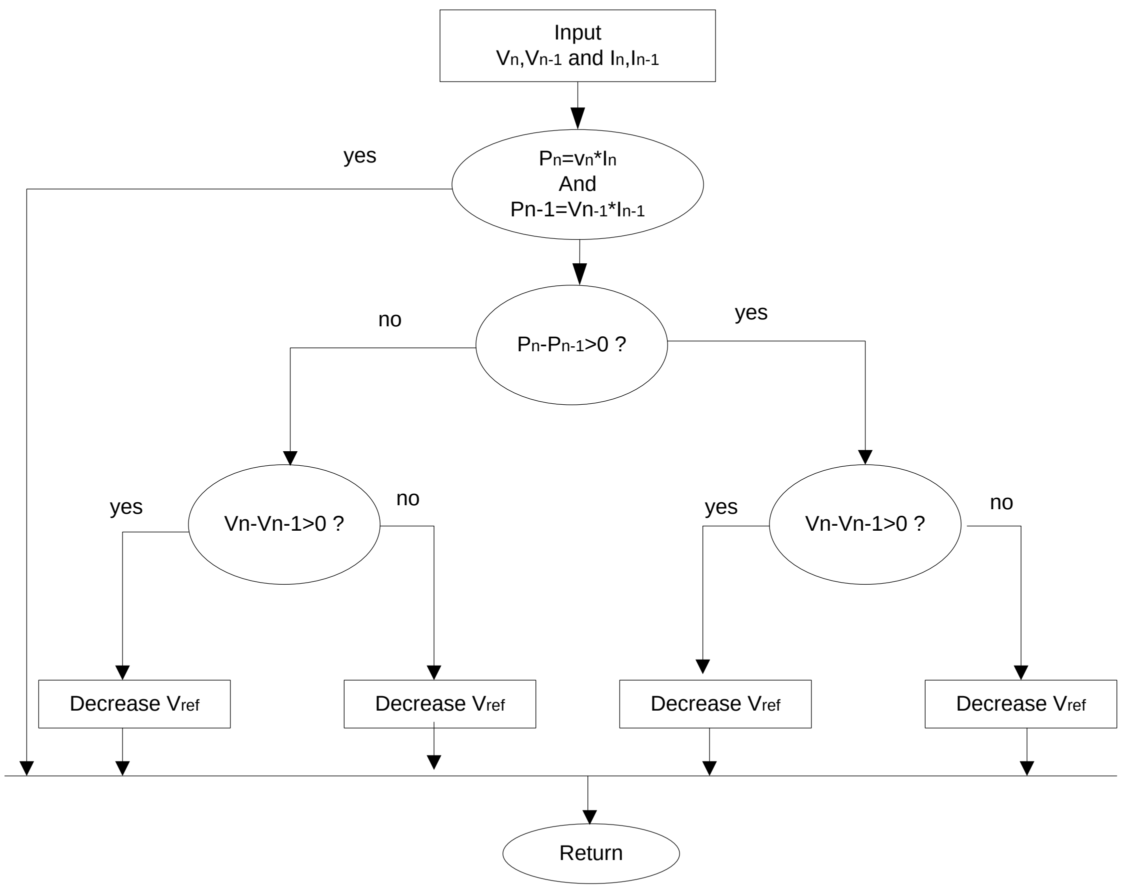

Figure 9: Flow chart for P and O MPPT algorithm [24]

To extract the maximum power from the PV panel, in this algorithm power at the two points of P-V curve compared and according to that the reference voltage adjusted.

4.3 Battery charge controller

For simulation study of the mentioned PV system, we use a bidirectional power converter for a stand-alone photovoltaic power generation system and system energy management where a lead-acid battery is used to regulate the power supply. The overall framework of the this system comprised a maximum power point tracking controller, bidirectional buck-boost converter, lead-acid battery, energy management system [15].

4.3.1 The Bidirectional Buck-Boost Converter

To provide and store power from stand-alone photovoltaic power generation systems during overproduction and underproduction for uninterrupted power supply, it provides the stored power as an auxiliary service during electricity shortages. This study proposes a bidirectional buck-boost converter (as shown in Figure 10) to manage the storage and supply of power between photovoltaic power generation systems and batteries. Due to the circuit structure of a bidirectional converter allows bidirectional power flows, two operation modes can be set for this converter depending on the direction of the power flow: boost and buck modes. The following section provides in-depth descriptions regarding the fundamental topology and component design of the proposed bidirectional buck-boost converter circuit.

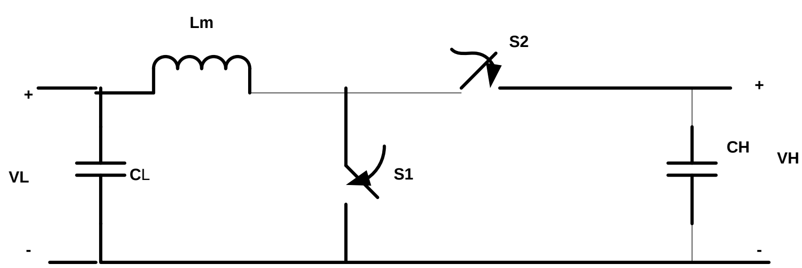

Figure 10: Framework for the bidirectional buck- boost converter circuit [15]

4.3.1.1 Boost Mode

This charge controller can operate in two modes depend upon the requirement i.e. Buck model during discharging and Boost mode during charging depends upon the switch position. In a single operation cycle, the converter’s duty cycle *D* is defined as the ratio between the on time to the time period of switch, as shown in below [17, 18].

$$D = \frac{t_{on}}{T} = \frac{t_{on}}{t_{on} + t_{off}} \tag{4.3}$$

Where t_{on} and t_{off} respectively represent the close and open durations of the switch in a single operation cycle.

A. Closed switch *S1* (0<t<DT)

When switch S_1 on the low-voltage side of the converter is closed, switch S_2 on the high-voltage side presents an opened state because of the complementary mechanism between the switches on the high-voltage and low-voltage sides. Consequently, the equivalent circuit of the system as shown in Figure 11. In this mode, the inductor *Lm* and low-voltage supply *VL* connect in parallel, causing the inductor voltage V_{Lm} and voltage V_L on low-voltage side to be equal. The circuit equation can be stated as:

$$V_{Lm} = V_L = L_m \frac{di_{Lm}}{dt} \tag{4.4}$$

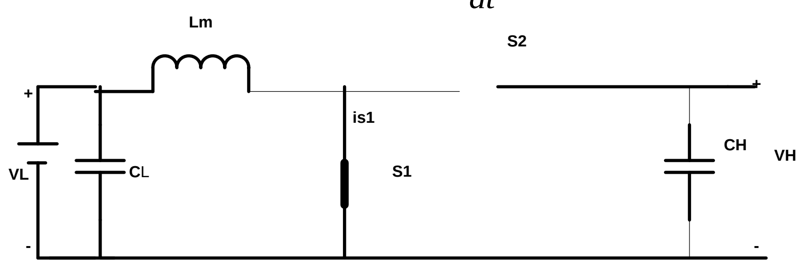

Figure 11: The equivalent circuit of the bidirectional buck-boost converter operating under boost mode and when the switch S_1 on the low-voltage side is closed [15]

The rate of change of in the inductor voltage I_{Lm} is constant. Therefore, the inductor current presents a linearly increased when the switch is closed. The change of the inductor current can be written as:

$$\frac{\Delta i_{Lm}}{\Delta t} = \frac{\Delta i_{Lm}}{DT} = \frac{V_L}{L_m} \tag{4.5}$$

From the above equation:

$$\triangle i_{Lm(\text{on})} = \frac{V_L}{L_m}.DT \tag{4.6}$$

B. Open switch S_1 (DT<t<T)

When switch S_1 on the low voltage side of the converter is in an kept open, while switch $S2$ on the high-voltage side be in closed state. The equivalent circuit for the converter is shown in Figure 12. The inductor voltage V_{Lm} *as a function of* i_{Lm} for this state can be expressed as

$$V_{Lm} = V_L - V_H = L_m \frac{di_{Lm}}{dt} \tag{4.7}$$

And

$$\frac{di_{Lm}}{dt} = \frac{V_L - V_H}{L_m} \tag{4.8}$$

When the switch S_1 is open, the change of the inductor voltage i_{Lm} presents a linearly decreased. This state can be express as

$$\frac{\Delta i_{Lm}}{\Delta t} = \frac{\Delta i_{Lm}}{(1-\mathrm{D})\mathrm{T}} = \frac{V_L - V_H}{L_m} \tag{4.9}$$

And from above equation, we get

$$\triangle i_{Lm(off)} = \frac{V_L - V_H}{L}(1-D)\mathrm{T} \tag{4.10}$$

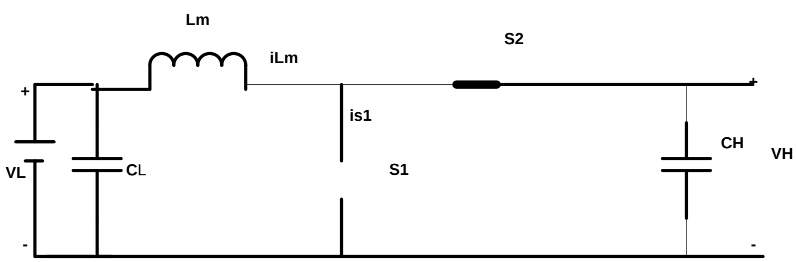

Figure 12: The equivalent circuit of the bidirectional buck-boost converter operating under boost mode and when the switch S1 on the low-voltage side is opened [15]

Under a steady-state operation, the change of the converter's inductor current i_{Lm} in a single cycle of operation must equal zero, that is:

$$\triangle i_{Lm(\text{on})} + \triangle i_{Lm(\text{off})} = 0 \tag{4.11}$$

Putting the values in above equation

$$\frac{V_L}{L_m}DT+\frac{V_L-V_H}{L_m}(1-\mathrm{D})\mathrm{T}=0 \tag{4.12}$$

By simplifying the above equation:

$$V_H=\frac{1}{1-D}V_L \tag{4.13}$$

Capacitance and inductance design for the converter under boost mode:

The value of the capacitor is:

$$C_H=\frac{D}{R_H f(\frac{\Delta V_H}{V_H})} \tag{4.14}$$

The value of the inductor is defined by:

$$L_{m,\min}>\frac{D(1-D)^2 R_H}{2f} \tag{4.15}$$

4.3.1.2 Buck mode

This section will state the consequences regarding the Buck mode operation of that bi-directional converter [15, 17].

A. Closed switch S2 (0<t<DT)

When switch *S2* on the high-voltage side of the converter is in closed state, whereas the switch *S*1 on the low-voltage side is kept open because of the complementary operation between the signals controlling both the switches on the low-voltage and high-voltage sides. Subsequently, the converter in this state becomes an equivalent circuit, as shown in Figure 13. The voltage on inductor *Lm* can be expressed as in terms of i_{Lm}:

$$V_{Lm}=V_H-V_L=L_m\frac{di_{Lm}}{dt} \tag{4.16}$$

Simplifying the above equation

$$\frac{di_{Lm}}{dt} = \frac{V_H - V_L}{L_m} \tag{4.17}$$

During this operation mode, the rate of change for the inductor current is a positive value, which stated as linearly increased. When the switch is closed, the change of the inductor current in (4.17) can be rewritten as

$$\frac{\Delta i_{Lm}}{\Delta t} = \frac{\Delta i_{Lm}}{DT} = \frac{V_H - V_L}{L_m} \tag{4.18}$$

So

$$i_{Lm(\text{on})} = \frac{V_H - V_L}{L_m}.\text{DT} \tag{4.19}$$

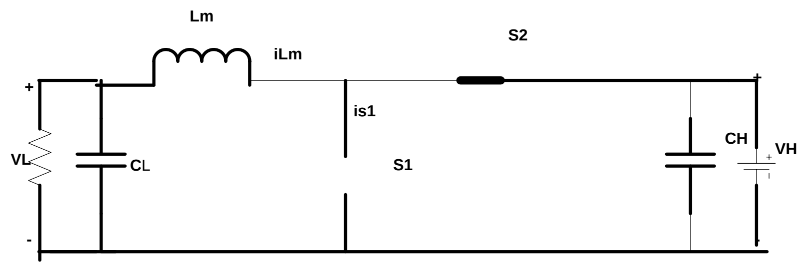

Figure 13: The equivalent circuit of the bidirectional buck-boost converter operating under buck mode and when the switch S2 on the high-voltage side is closed [15]

B. Open switch S2 (DT<t<t)

When switch S_2 on the high-voltage side of the converter is in open and switch S_1 on the low-voltage side presents a closed state. The equivalent circuit for this state of converter is shown in Figure 14, and the inductor voltage can be written as:

$$V_{Lm} = -V_L = L_m \frac{di_{Lm}}{dt} \tag{4.20}$$

So

$$\frac{di_{Lm}}{dt} = \frac{-V_L}{L_m} \tag{4.21}$$

In this operation mode, the rate of change of the inductor current is a negative value, thus, presenting a linear decreased. When the switch is closed, the change in the inductor current in can be rewritten as:

$$\frac{\Delta i_{Lm}}{\Delta t} = \frac{\Delta i_{Lm}}{(1-\mathrm{D})\mathrm{T}} = \frac{-V_L}{L_m} \tag{4.22}$$

From above equation

$$\triangle i_{Lm(\text{off})} = \frac{V_L}{L_m}(1-\mathrm{D})\mathrm{T} \tag{4.23}$$

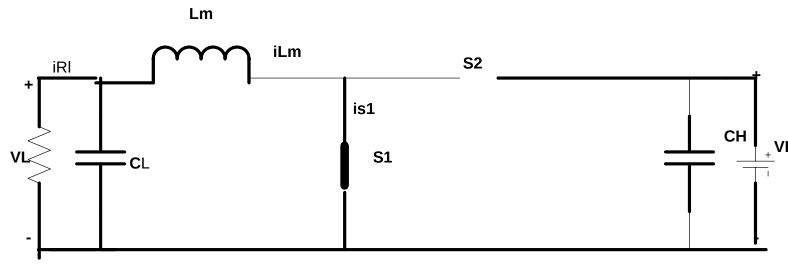

Figure 14: The equivalent circuit of the bidirectional buck-boost converter is operated under buck mode when the switch S2 on the high-voltage side is open

Under steady-state

$$\triangle i_{Lm(\text{on})} + \triangle i_{Lm(\text{off})} = 0 \tag{4.24}$$

Putting the values in the above equation

$$\frac{(\mathrm{V}_H - \mathrm{V}_L)}{L_m} DT - \frac{V_L}{L_m}(1-\mathrm{D})\mathrm{T} = 0 \tag{4.25}$$

Simplify the above equation we get

$$V_L = V_H . D \tag{4.26}$$

As shown in (4.26), 0<D<1. Therefore, under this operation mode, the voltage *VL* on the low-voltage side is smaller than the voltage *VH* on the high-voltage side.

The value of the capacitor and inductor in boost mode is:

The value of the capacitor is;

$$C_L = \frac{(1-D)}{8(\frac{\triangle V_L}{V_L})\mathrm{L}_m . f^2} \tag{4.27}$$

The minimum value of the inductor is defined by:

$$L_{\mathrm{m\_min}} = \frac{(1-\mathrm{D})\,\mathrm{R}_L}{2f} \tag{4.28}$$

To maintain the consistency of the inductor current flows for the bidirectional buck-boost converter when operating under boost and buck modes, (4.15) and (4.28) can be further simplified as follows:

$$L_{m\_boost} = \frac{\mathrm{D}(1-\mathrm{D})^2 {V_H}^2}{2P_H f} \tag{4.29}$$

$$\mathrm{L}_{m\_buck} = \frac{(1-\mathrm{D})\,{\mathrm{V}_L}^2}{2P_L f} \tag{4.30}$$

Where $P_L = \frac{{V_L}^2}{R_L}$ and $P_H = \frac{{V_H}^2}{R_H}$. Assuming that the *D* value is increased from 0 to 1 in increments of 0.005, these values can then be substituted into function $D(1-\mathrm{D})^2 {V_H}^2$ of (4.29) and function $(1-D)\,{\mathrm{V}_L}^2$ of (4.30). Furthermore, when D=1/3, function $D(1-\mathrm{D})^2 {V_H}^2$ achieves the maximum value solution, and this value is greater than $(1-D)\,{\mathrm{V}_L}^2$ in any duty cycle, indicating that is under any duty cycle.

$$\frac{\mathrm{D}(1-\mathrm{D})^2 {V_H}^2}{2P_H f} > \frac{(1-\mathrm{D})\,{\mathrm{V}_L}^2}{2P_L f} \tag{4.31}$$

When operating under boost or buck modes, the *D* value is substituted with 1/3 when designing the inductance value of the bidirectional buck-boost converter.

4.3 Battery

Battery are used in PV system for the purpose of storing energy when there in surplus in power generation i.e. during the day time and supply necessary power to the load when there is no irradiance i.e. during cloudy days and night time. There are other some reasons to use batteries in PV systems are to operate the PV array near its maximum power point, to power electrical loads at stable voltages, and to surge currents to the loads whenever there is a generation deficit occur.

The charging and discharging of battery controlled by battery charge controller that we discussed above [20].

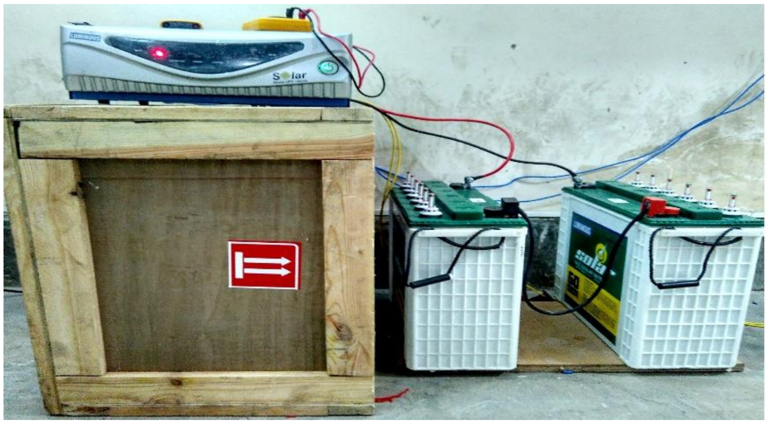

Figure 15: Battery with inverter

Generally in stand-alone PV systems lead acid batteries are used .other types of batteries like nickel-cadmium, lithium-ion batteries may be used, but lead acid type batteries are having some advantage over them. The capacity of a battery is measured in Ampere-hours or Amp-hours (Ah). In this house model we used two 100 Ah lead-acid batteries which are connected in series to test the whole system.

4.3.1 Battery size calculation

To minimize the total cost of the PV system we have to calculate the proper size of our battery bank, which will prove necessary power for a fixed period of time. For sizing the battery following steps are followed [22]:

1. Calculate the total wattage rating of the load.
2. Find the energy used in a day (i.e. total number of hours the loads are ON).
3. Now decide how many days' worth of energy you want to store in your battery bank.
4. Then find the total watt- hours (energy consumed).
5. Divide the total energy with your system voltage.
6. Then multiply it with percentage depth of discharge (D.D) on your batteries convert the Kw-hour result into amp hours (Amp-hour).

Ex: - For V volt system, consumes a total power of P watt. Then the size of the battery required to provide continues power for n number of hours in a day for N days is:

$$\text{Battery size} = \frac{P \times n \times N}{V \times D.D} \tag{4.32}$$

4.4 Buck converter

In the DC house some of the equipment's are operated on 12 V DC because of that to step down the voltage from 24 V to 12 V DC we need a buck converter. The DC-DC converters are used in this project are of rating 150 watt. The output voltage formula for buck converter is [15]:

$$V_O = D.V_{DC} \tag{4.33}$$

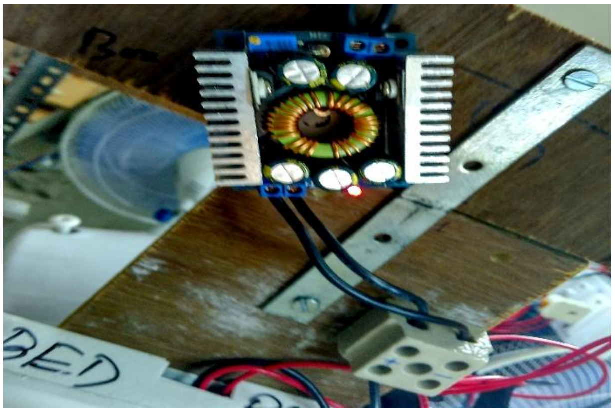

Figure 16: DC-DC buck converter

Chapter 5

5. LOAD SELECTION

In order to select the loads needed for the DC house it is important to consider the needs of the people living there and the humanitarian goals of the DC house project and weigh them against the constraints that an isolated generation system provides. First we should accurately define the limitations of our generation system, then develop a strategy to select the loads that can fit in those constraints. The following subsections discuss this issue

5.1 House model

These models are classified according to their load rating (depends on the total no of equipment used).MM_1 model has 5 LED bulbs, 3 fans a television and a mixer. The total load demand is under 500 watts.

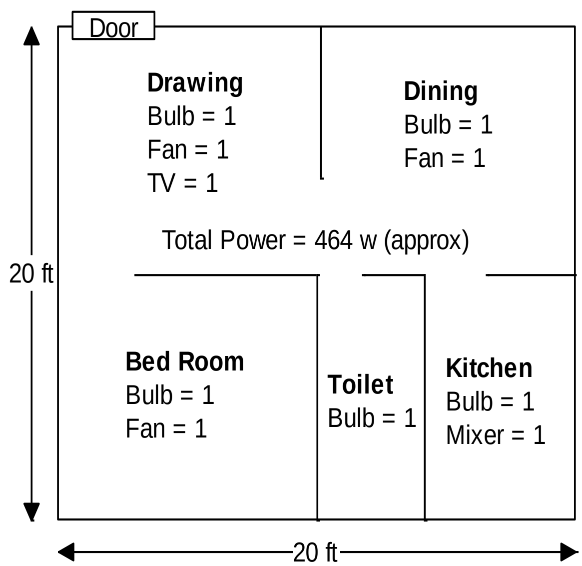

Figure 17: All loads for house model

Table 3: Rating of each load house

EQUIPMENT	QUANTITY	RATING
BULB	5	14
FAN	3	20
TELEVISION	1	25
MIXER	1	90

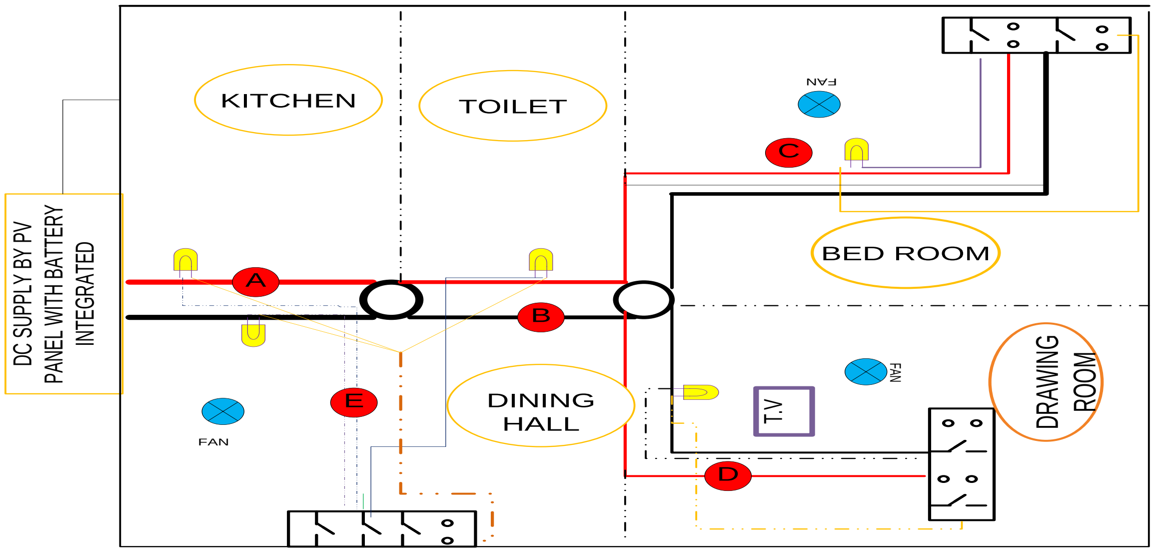

Figure 18: Total wiring diagram for house model

Figure 19: Hardware implementation of the DC house

5.2 Led bulb

The DC House model needs to have a source of light for night hours. The most efficient form of lighting is through the use Light Emitting Diodes (LEDs). LED is more efficient than Compact Fluorescent (CFL) and incandescent light bulbs. Six LEDs will be used to light up the DC House. However, the lumens emitted by these LED strips must be appropriate for the size of the model [20].

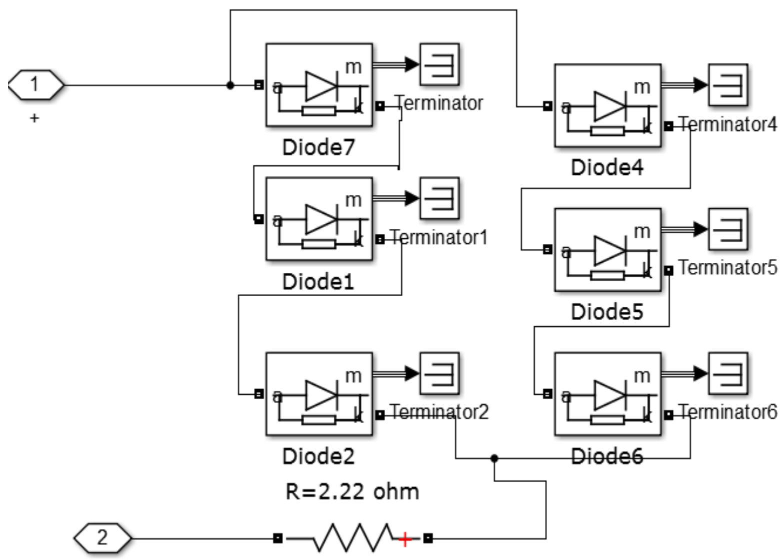

Figure 20: Simulation for LED bulb

The source voltage is 12 volts, the forward voltage drop of each LED is 3.2 volts, and resistor value is 2.22 Ohms. These assumptions would result in a branch current of:

$$I = \frac{12 - 3*3.2}{2.22} = 1.08 Amp$$

Next, the power dissipated by each LED and the resistor were determined.

$$P_{resistor} = I^2 \times R = 1.08^2 \times 2.22 = 2.59 watt$$

$$P_{led} = \frac{6}{2} \times 3.2 \times 1.08 = 10.368 watt$$

Then the Efficiency of the string could be calculated by determining the amount of power dissipated by the LEDS compared to the amount of power dissipated by the entire string. Where "n" is the number of LEDs in the string. The following equation for efficiency was determined:

$$Efficiency_{led} = \frac{n * P_{led}}{n * P_{led} + P_{resistor}} \tag{5.1}$$

Therefore this equation indicated that the more LEDs there are in a string, the more efficient the string is. This is because there will always be a power loss associated with the current limiting resistor, and this cannot be removed because it is necessary to limit the current through the string and thus would protect the LEDs from damage. It is possible however to increase the number of LEDs per string, which would make the power wasted by the resistor less significant, because it will always stay the same regardless of the number of LEDs in the circuit. The tradeoff however associated with increasing the number of LEDs the source voltage must be increased in the same manner.

5.3 Fan

The floor fan is a simple permanent magnet DC motor. Its maximum power draw is approximately 20-25 Watts. In order to correctly model this device. The power drawn by the DC fan nearly constant over a period of time. So to study the current waveform behavior the fan can be modeled as a simple resistor connected across load. The required resistor value can be calculated from below formulae. However for AC electrification the fan will modeled with a R-L series circuit [17].

$$R_{fan} = \frac{{V_{dc}}^2}{P_{fan}} = \frac{12^2}{20} = 7.2\Omega \tag{5.2}$$

5.4 Television

Generally most of televisions internal circuit required DC power. Which is internally convert 230 volt AC to required level DC. Because of that unnecessary losses are occurred in the internal circuit. Which can be easily available by simply operated in DC source. Generally DC operated televisions are consumed 23-27 watts [6].

So for simulation a television, we can simply put equivalent amount of resistor value which can be calculated below:

$$R_{television} = \frac{{V_{load}}^2}{P_{television}} = \frac{12^2}{25} = 5.76\Omega \tag{5.3}$$

5.5 Mixer

Mixer is a simple DC motor as like ceiling fan, with higher capacity than the fan. In this hardware we used a 230 watt mixer to study. But the no-load power drawn by the mixer is around 85-90 watt. so for simulation study here we taken an equivalent amount of resistor for this load.

$$R_{mixer} = \frac{{V_{dc}}^2}{P_{mixer}} = \frac{24^2}{85} = 6.77\Omega \tag{5.4}$$

5.5 Conductor design

Proper design of conductor is an important part of the study. To carry the load current from source to load with minimum voltage drop and power loss we have to take of the conductor size according to load type and distance from the source. Form the equation (3.6) the voltage drop and power loss greatly depends upon the length and area of thickness (mm^2) of the conductor. But before that a conductor should satisfy the below criteria [25, 29]:

The conditions responsible for chose a suitable conductor are:

1. Type of load it is designed for.
2. The thickness should appropriate to minimize the line loss and voltage drop.
3. High mechanical strength and sustainable to temperature rise.
4. Cost effective.

In the hardware implementation of the above say DC house we use 0.5 mm^2, 1 mm^2, 1.5 mm^2, 2.5 mm^2 and 6 mm^2 size of conductor. Total length of conductor for different appliances from source to load are listed below.

Table 4: Data sheet for conductor size for MM-1 model

<table>
<tr><th rowspan="1">ZONE</th><th>EQUIPMENT TYPE</th><th colspan="2">LENGTH
(in feet)</th><th rowspan="2">RATING OF CONDUCTOR
(watt)</th><th rowspan="2">CURRENT RATING
(AMPERE)</th><th colspan="2">WIRE SIZE</th></tr>
<tr><th colspan="2"></th><th>Positive</th><th>Negative</th><th>Positive</th><th>Negative</th></tr>
<tr><td>A</td><td>CONDUCTOR</td><td>5.0</td><td>5.0</td><td>164</td><td>6.90235</td><td>2.5</td><td>2.5</td></tr>
<tr><td>B</td><td>CONDUCTOR</td><td>6.0</td><td>6.0</td><td>104</td><td>4.37710</td><td>2.5</td><td>2.5</td></tr>
<tr><td>C</td><td>CONDUCTOR</td><td>10.0</td><td>10.0</td><td>39</td><td>1.64141</td><td>1.5</td><td>1.5</td></tr>
<tr><td>D</td><td>CONDUCTOR</td><td>9.0</td><td>9.0</td><td>65</td><td>2.73569</td><td>1.5</td><td>1.5</td></tr>
<tr><td>E</td><td>CONDUCTOR</td><td>3.0</td><td>3.0</td><td>60</td><td>2.52525</td><td>1.0</td><td>1.0</td></tr>
<tr><td rowspan="3">DRAWING HALL</td><td>BUB</td><td>4.5</td><td>4.0</td><td>14</td><td>0.58922</td><td>0.5</td><td>0.5</td></tr>
<tr><td>FAN</td><td></td><td></td><td></td><td>0.00000</td><td></td><td></td></tr>
<tr><td>TELEVISION</td><td></td><td></td><td></td><td>0.00000</td><td></td><td></td></tr>
<tr><td>BED ROOM</td><td>BULB
FAN</td><td>4.5</td><td>4.0</td><td>14</td><td>0.58922
0.00000</td><td>0.5</td><td>0.5</td></tr>
<tr><td rowspan="2">DINING</td><td>BULB</td><td>3.5</td><td>1.0</td><td>14</td><td>0.58922</td><td>0.5</td><td>0.5</td></tr>
<tr><td>FAN</td><td></td><td></td><td></td><td>0.00000</td><td></td><td></td></tr>
<tr><td>BATHROOM</td><td>BULB</td><td>6.8</td><td>3.3</td><td>7</td><td>0.29461</td><td>0.5</td><td>0.5</td></tr>
<tr><td rowspan="2">KITCHEN</td><td>BULB</td><td>5.8</td><td>2.3</td><td>14</td><td>0.58922</td><td>0.5</td><td>0.5</td></tr>
<tr><td>MIXER</td><td>5.0</td><td>5.0</td><td>85</td><td>3.57700</td><td>2.5</td><td>2.5</td></tr>
<tr><td>NEGATIVE WIRE IN DINNING HALL</td><td>CONDUCTOR</td><td>0.0</td><td>3.0</td><td>42</td><td>1.76767</td><td>0</td><td>1.5</td></tr>
</table>

Chapter 6

6. RESULTS AND ANALYSIS

In this chapter we are going to discuss varies aspects of AC electrification and DC electrification and how the DC electrification became a suitable alternative in all aspects whether it is total loss in the system or economical point of view. First of all we will discuss about the AC electrification and then compare it will DC and verify the result with respect to what size of battery required in both the case and total cost involved.

6.1 AC Electrification

For AC electrification there are two stage of energy conversion stages required. Firstly the solar generated DC power converted to AC sinusoidal and after that it is converted to DC inside the equipment. Due to two stage energy conversion there are unnecessary losses are incurred in the whole system. To full fill our project objective to continuous supply of power to load even when solar energy is not available we need required size of battery to fulfill this.

In this experiment we tested the AC system with solar energy available and without solar energy for a period of six hour. And the results are shown below:

6.1.1 AC Electrification with PV and Battery

In this case we use both PV panel and battery parallel to supply our load demand. We conducted the experiment during the day light for six hour and the results are shown in the below table (5).

From the above experiment we got that the total load operate at power factor at 0.9983 and consume a total power of 344.022 watt. Whereas during transformation from DC-AC there is total 82.82 watt loss incurred inside the inverter. The total power consumed and delivered by all the elements are shown in the graphical format in figure (6.1).

Table 5: Power taken by various equipment with both PV and battery connected

TIME	PV ARRAY			INVERTER				BATTERY			LOSS IN THE INVERTER (watt)
	V (Volt)	I (Amp)	P (watt)	V (Volt)	I (Amp)	P (watt)	p.f	V (Volt)	I (Amp)	P (watt)	
1	25.83	17.5	452.02	218.8	1.597	345.36	0.988	25.38	0.9	22.84	83.82
2	26.03	18.5	481.55	218.1	1.592	344.98	0.993	25.6	1.7	43.52	93.05
3	26.11	18.9	493.47	220.17	1.587	346.76	0.992	25.67	2.2	56.47	90.24
4	26.21	19.1	500.61	219.33	1.588	344.66	0.986	25.73	2.6	66.89	89.05
5	26.24	18.8	493.31	219.09	1.576	343.73	0.995	25.77	2.8	72.15	77.42
6	26.33	19.1	502.90	218.8	1.581	342.36	0.989	25.85	3.0	77.55	82.99
7	26.34	19.1	503.09	218.32	1.583	343.10	0.992	25.88	3.0	77.64	82.35
8	26.29	18.5	486.36	218.83	1.589	344.08	0.989	25.83	2.2	56.82	85.45
9	26.13	17.2	449.43	218.21	1.588	343.04	0.989	25.76	0.9	23.18	83.21
10	25.99	15.8	410.64	218.54	1.578	342.37	0.992	25.57	0.3	7.67	75.94
11	25.64	13.5	346.14	218.17	1.578	343.69	0.998	25.46	2.8	71.28	73.73
12	25.12	10.9	273.80	218.9	1.574	344.14	0.998	24.91	5.9	146.9	76.63
AVG						**344.02**	**0.998**				**82.8281**

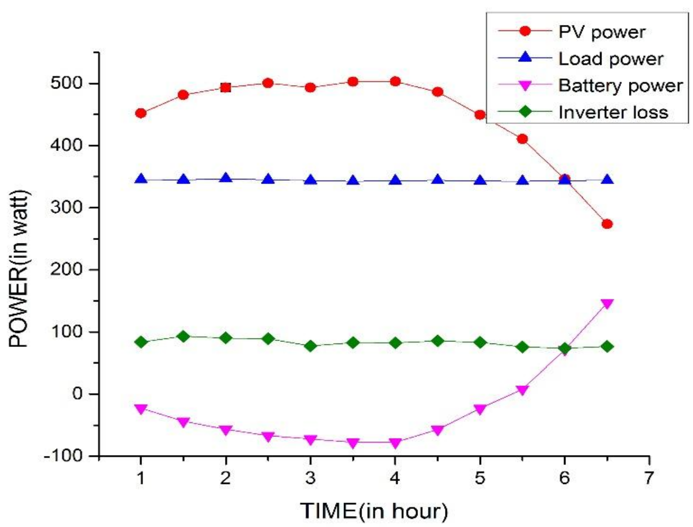

Figure 21: Power vs time curves various equipment and inverter loss

From the above graph it was shown that whenever there is a mismatch between total load demand and power supplied by the photovoltaic panel, the extra power was delivered by the storage element.

Below figure 6.2 shows the complete simulation study for AC system with the load voltage and current wave forms are shown below in figure 6.3 & figure 6.4 respectively.

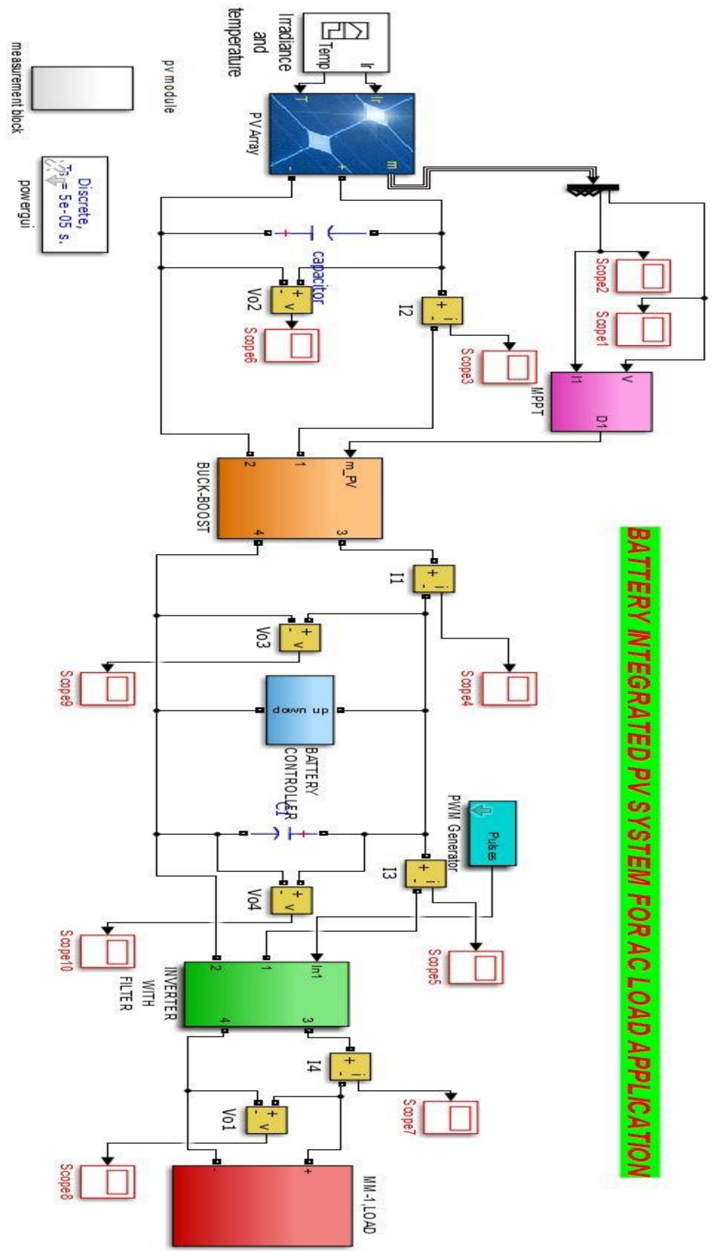

Figure 22: Simulation model for AC load

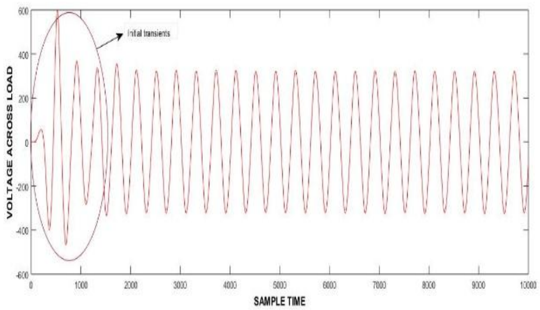

Figure 23: Load voltage waveform across load

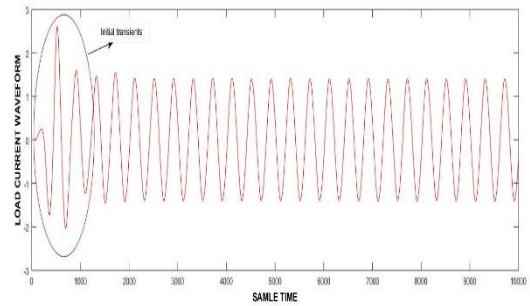

Figure 24: Load current wave form across load

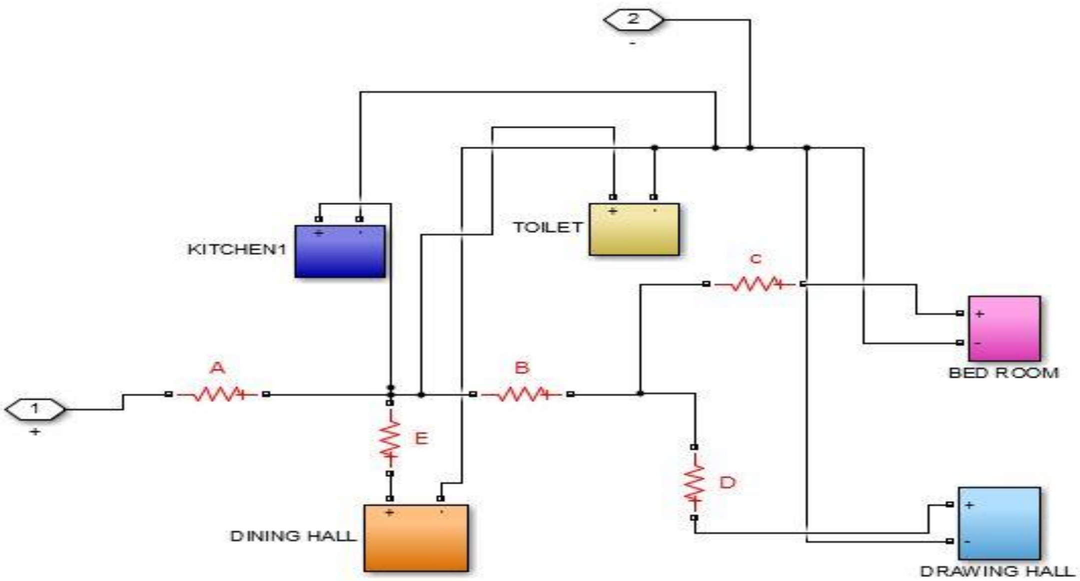

Figure 25: Simulation model of the load

The simulation study are done by modeling the loads as we discussed above. Figure 22 shows the complete simulation model for AC electrification. The current wave form have some initial transient in it which is steady after sometime.

6.1.2 AC Electrification without PV

In this case we conducted the experiment with all load on without solar power available. So the total power demanded by the all the appliances are provided by the battery source only. In The experimental data are i.e. the power delivered by the battery during a period of six hour are shown in table (6).

Table 6: Power taken by various equipment without solar power

TIME (hour)	INVERTER				BATTERY			INVERTER LOSS (Watt)
	I (Amp)	V (Volt)	P (Watt)	p.f	V (Volt)	I (Amp)	P (Watt)	
1	1.590	218.6	342.88	0.9864	24.22	16.9	409.318	66.43
1	1.592	219.7	343.05	0.9808	24.15	16.9	408.135	65.08
2	1.582	219.2	343.37	0.9901	24.06	17.0	409.020	65.65
2	1.578	218.6	343.53	0.9958	23.97	17.1	409.887	66.35
5	1.583	219.1	342.80	0.9883	23.87	17.1	408.177	65.37
6	1.587	218.5	343.54	0.9907	23.79	17.2	409.188	65.64
7	1.591	218.6	343.69	0.9882	23.70	17.3	410.010	66.32
8	1.579	218.6	343.62	0.9955	23.62	17.2	406.264	62.64
9	1.592	219.2	345.22	0.9892	23.50	17.3	406.550	61.33
10	1.584	219.3	345.40	0.9943	23.38	17.5	409.150	63.75
11	1.589	219.1	343.43	0.9864	23.23	17.5	406.525	63.09
12	1.587	218.8	344.19	0.9912	23.00	17.9	411.700	67.51
13	1.585	218.8	344.41	0.9931	22.82	18.0	410.760	66.35
AVG			**343.77**	**0.9900**			**408.821**	**65.042**

From the above experimental data it was shown that the average load power demand for six hour was 343.37 watt and loss incurred in the inverter during this period was 65.042 watt. The total experimental data are given below in the graphical format in figure 27.

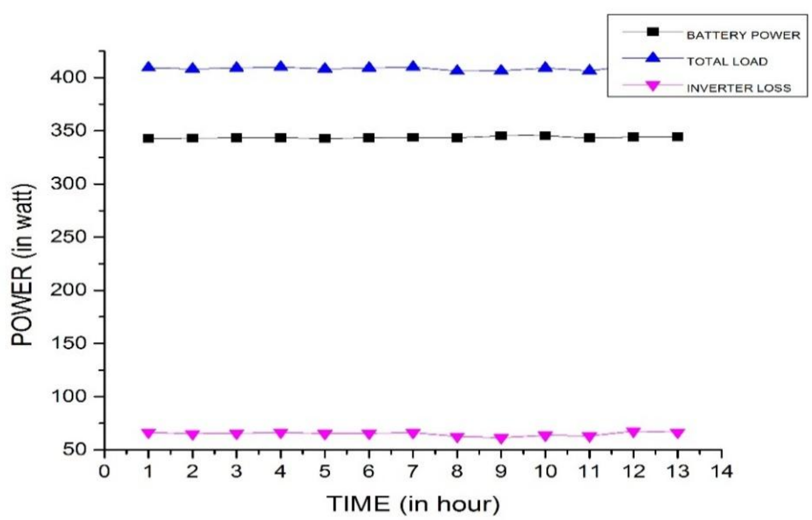

Figure 26: Power vs time curve for equipment without solar power

6.1.3 Battery size calculation for AC system

In this system the power taken on full load condition is 343.77 watt. To provide continuous supply of power for six hour in a day the optimum battery size required of depth of discharge 80% can be calculated from the equation (4.32).

$$Battery_{ac} = \frac{343.77 \times 6 \times 1}{24} \times \frac{1}{0.8}$$

$$= 107.428 \text{ amp-hour}$$

6.2 DC Electrification

In this section we are going to discuss about the various aspects of DC electrification i.e. with PV and battery integration and with battery backup power only. First we are going to calculate the losses in the various section of the conductor in both the cases and compare it with the traditional standalone AC system. This experiment is conducted with and without solar power for six hours to study the case.

6.2.1 DC electrification with PV and Battery

To provide required power to the all the DC load of MM-1 model PN panel and battery circuit are provide power parallel. The six hour experimental data are given in tabular format in table 7.

From the data the losses in the charge controller circuit is only 23.19 watt. Whereas the line losses are increased due to high current rating as voltage level is very lesser than AC supply.

Table 7: Power delivered by all equipment's with both PV and Battery on

TIME (Hour)	PV			BATTERY			LOAD			LOSS IN CHARGE CONTROLLER (WATT)
	V (Volt)	I (amp)	P (watt)	V (Volt)	I (amp)	P (watt)	V (Volt)	I (amp)	P (watt)	
1	27.54	19.3	531.52	26.53	10.9	289.177	26.5	8.2	217.30	25.04
1.5	28.75	16.9	485.87	27.66	8.6	237.876	27.62	8.2	226.48	21.51
2	29.17	16.5	481.30	28.27	7.9	223.333	28.23	8.2	231.48	26.48
2.5	31.75	12.1	384.17	29.06	4.1	119.146	28.88	8.2	236.81	28.21
3	33.9	9.2	311.88	29.11	1.6	46.576	28.67	8.2	235.09	30.21
3.5	35.48	7.1	251.90	27.33	0.4	10.932	27.27	8.2	223.61	17.36
4	35.41	7.1	251.41	27.28	0.2	5.456	27.22	8.2	223.20	22.75
4.5	28.9	5.5	158.95	25.98	3.2	83.136	25.8	8.3	214.14	27.94
5	28.6	5.4	154.44	25.57	2.9	74.153	25.46	8.3	211.31	17.27
5.5	28.8	4.8	138.24	26.16	3.8	99.408	26.06	8.2	213.69	23.95
6	27.7	3.1	85.87	25.05	5.6	140.28	24.96	8.3	207.16	18.98
6.5	27.27	2.3	62.72	24.91	6.6	164.406	24.82	8.4	208.48	18.63
AVG									**220.73**	**23.19**

From the above experimental data it is shown that the average loss in the controller circuit when both the PV and battery power on is 23.19 watt. The power delivered/consumed curve for all the sections are given in the graphical format in figure.

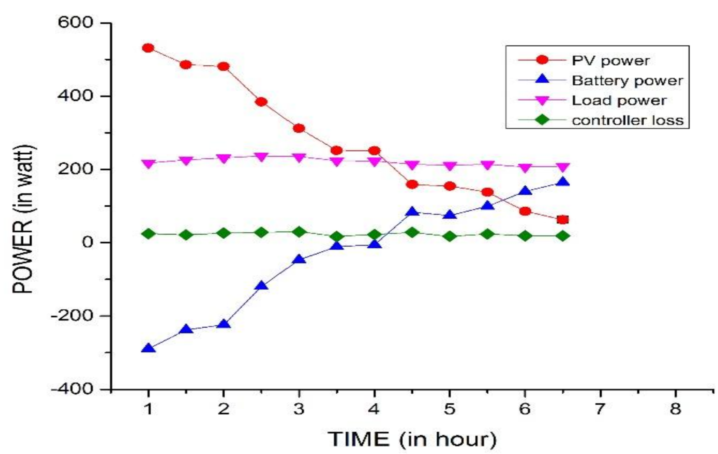

Figure 27: Power vs time curve for all the equipment's when both PV and Battery on

The simulation for the battery powered DC house with solar power are shown in figure 6.7. The load voltage wave form have some initial transients on it for some time which is later steady irrespective variation of PV array temperature and irradiance level shown in figure 6.8.

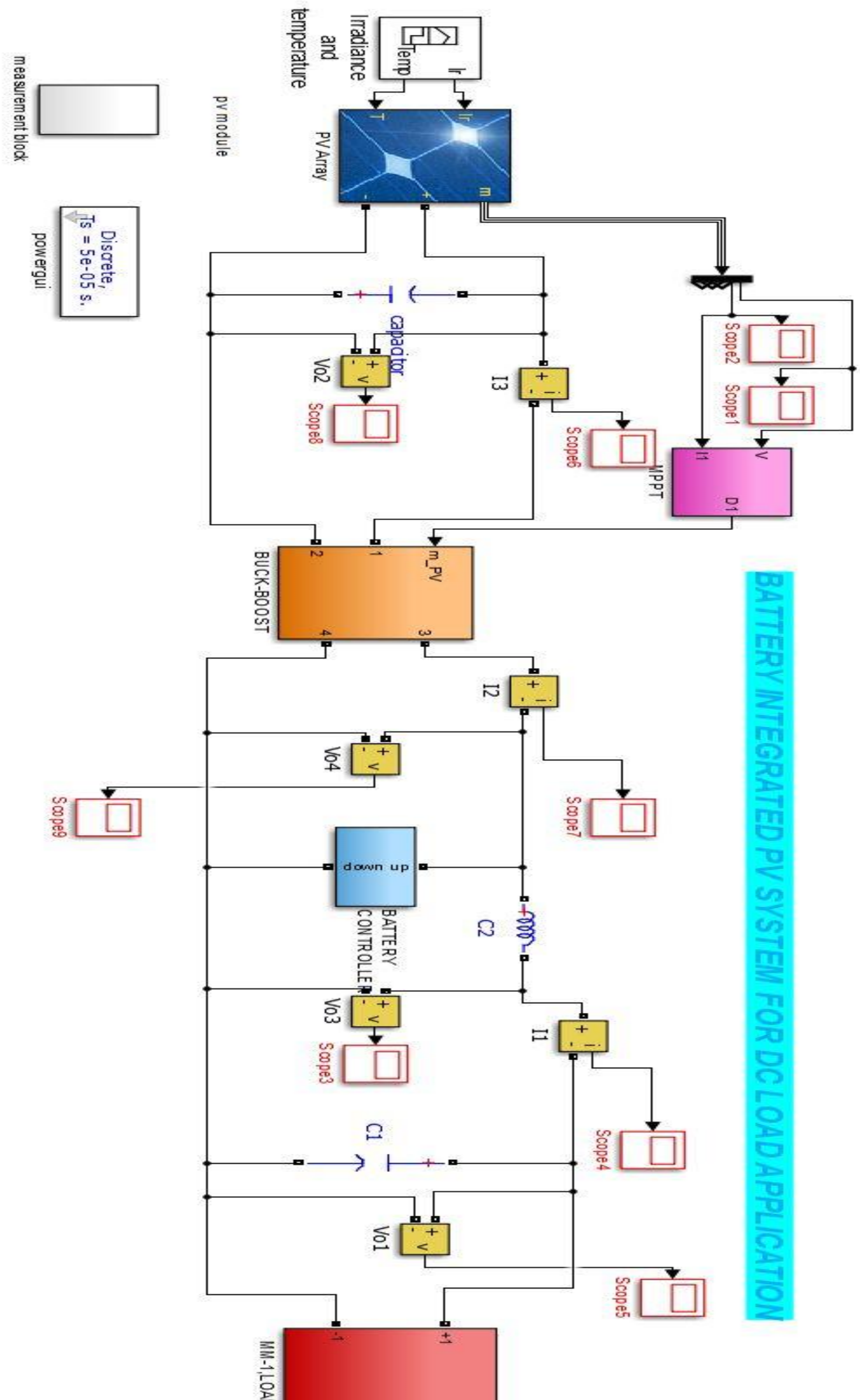

Figure 28 : Simulation model for DC load

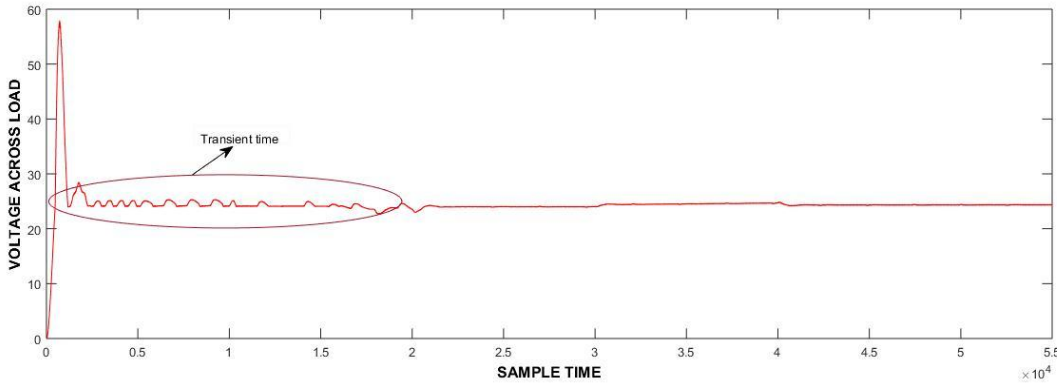

Figure 29: Voltage wave form across MM-1 model

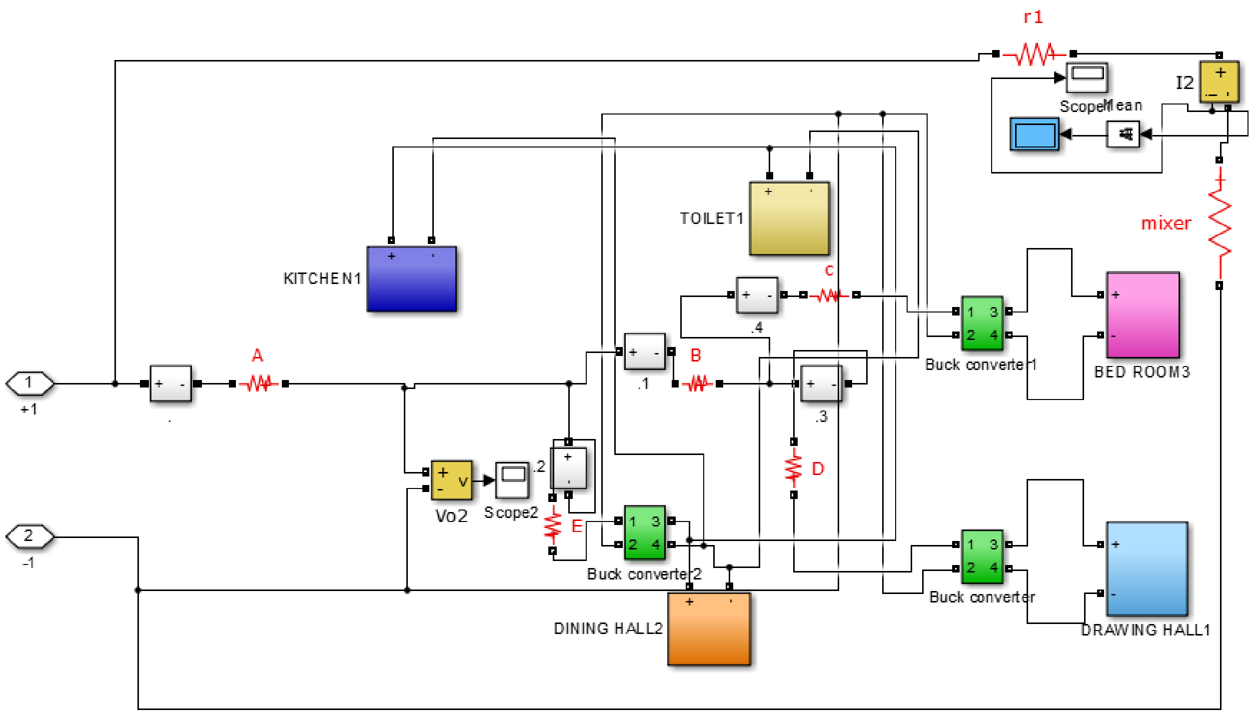

Figure 30: Complete load model for MM-1 with DC supply

Figure 6.9 shows the simulation of MM-1 model house with DC supply which is comprise a DC-DC buck converter to step down the voltage from 24 V DC to 12 V DC for the loads that operates on 12 V supply.

6.2.2 DC electrification without PV

When there is no Irradiance available i.e. during night, cloudy days the DC house consume power from the storage device. Here the experiment done for a period of six hour and the current and voltage data's are shown in the tabular format in table 8.

Table 8: Power delivered by all the loads with only battery power on

TIME (Hour)	BATTERY			CHARGE CONTROLLER			CHARGE CONTROLLER LOSSES (Watt)
	V (Volt)	**I (Amp)**	**P (Watt)**	**V (Volt)**	**I (Amp)**	**P (Amp)**	
1.0	25.77	8.1	208.73	24.57	8.1	199.01	9.72
1.5	25.70	8	205.60	24.52	8.1	198.61	6.98
2.0	25.65	8.1	207.76	24.48	8.2	200.73	7.02
2.5	25.62	8.1	207.52	24.44	8.1	197.96	9.55
3.0	25.55	8.1	206.95	24.39	8.2	199.99	6.95
3.5	25.47	8	203.76	24.37	8.2	199.83	3.92
4.0	25.41	8	203.28	24.33	8.1	197.07	6.20
4.5	25.36	8.1	205.41	24.27	8.1	196.58	8.82
5.0	25.29	8.1	204.84	24.22	8.2	198.60	6.24
5.5	25.22	8.1	204.28	24.19	8.2	198.35	5.92
6.0	25.17	8.1	203.87	24.15	8.2	198.03	5.84
6.5	25.08	8.1	203.14	24.11	8.2	197.70	5.44
Average			**205.43**			**198.54**	**6.88**

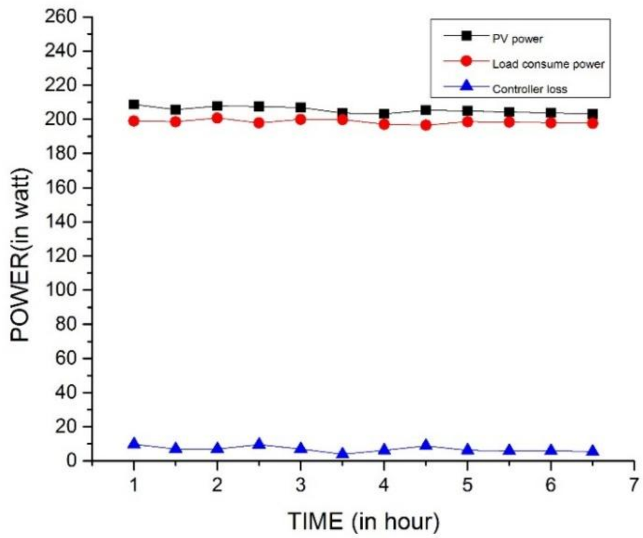

Figure 31: Power vs time curve for all the equipment's when only Battery on

6.2.3 Battery size calculation for DC system

When there is no solar power available the battery should provide the require amount of power to the load i.e. 198.54 watt. Our aim is to provide uninterrupted power for a six hour for that the optimum size of the battery circuit can be calculated from equation (4.32).

$$Battery_{dc} = \frac{198.54 \times 6 \times 1}{24} \times \frac{1}{0.8}$$

$$= 62.043 \text{ amp-hour}$$

6.3 Comparison

We conducted the above experiment for MM-1 model with all the loads are ON. From the experimental data for both AC and DC supply the total loss in both the cases are compared below with the total cost involved in design the house.

6.3.1 System cost comparison

The system cost comparison involved the individual cost of all the equipment's that are used for design and construction of houses. The equipment's involved to design the house model are conductors, bulb, fan, inverter, battery, charge controller switches and sockets. The table mentioned below consists for cost involved in making of house.

Table 9: Total cost involved in both house modeling

ITEM TYPE	QUANTITY	TYPE (mm^2)	AC EQUIPMENT (Rupee)	DC EQUIPMENT (Rupee)
CONDUCTOR	39.7 ft.	0.5	46.77	46.77
	6 ft.	1.0	11.10	11.10
	41 ft.	1.5	122.30	122.30
	32 ft.	2.5	152.29	152.29
	15 ft.	6.0	166.11	166.11
BULB	9		1800.00	2070
FAN	3		2000.00	2200.00
TELEVISION	1		13120.00	13120.00
MIXER	1		8199.00	8199.00
SWITCHES	9		99.00	99.00
PLUG	5		120.00	120.00
MCB	1		450.00	450.00
BATTERY	2		18400.00	18400.00
INVERTER	1		8930.00	0.00
CHARGE CONTROLLER	1		0.00	9499.00
BUCK CONVERTER	3		0.00	2253.00
TOTAL			**53616.57**	**56908.57**

From the above data shows that the total cost involved in construct a DC house is slightly higher than that of AC house due to that extra converter. But as we know that the total power loss is much lower than that of AC house, so it can be cost effective and the battery required for DC system design is around 65 amp-hour rating where as in case of AC the rating of the battery is around 110 amp-hour.

6.3.2 Power loss comparison

As we know that the rating of AC equipment and DC equipment are varied from each other. Because of that the current drawn by each is varied so the line losses are varied depends upon the current rating. Below we discussed about various loss in each section of the house.

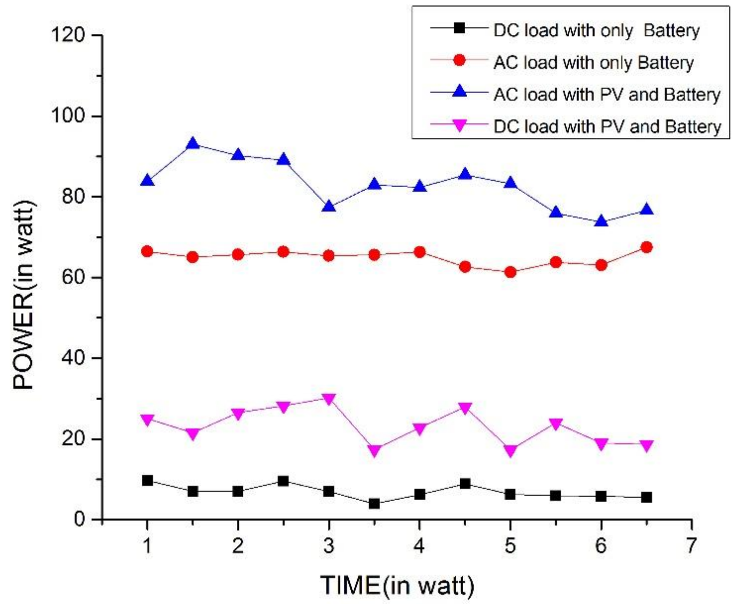

Figure 32: Inverter and charge controller loss curve for both the system under both the cases i.e. with PV and without PV

6.3.3 Conductor loss

The line loss in the conductor depends upon the physical parameter of the conductor i.e. thickness and length. As we know that our AC system operates on 230 V AC whereas DC system design for 24 V DC, due to this low voltage rating the current drawn by equipment's are varied so line losses. In the below table the line losses are calculated for both the AC and DC system taking the skin effect factor for AC resistance as 1.2.

Table 10: Conductor loss calculation in both AC and DC system for MM-1

ITEM	TYPE	FOR AC SYSTEM			FOR DC SYSTEM		
		AC resistance	Current rating (ampere)	Loss (watt)	DC resistance (ohm)	Current rating (ampere)	Loss (watt)
A	CONDUCTOR	0.0248	1.2	0.0358	0.020726	4.5	0.419
B	CONDUCTOR	0.0298	0.8	0.0191	0.024872	3.2	0.2546
C	CONDUCTOR	0.0829	0.3	0.0074	0.069088	1.1	0.0835

D	CONDUCTOR	0.0746	0.5	0.0186	0.062179	2.1	0.2742
E	CONDUCTOR	0.0373	0.4	0.0059	0.03109	1.3	0.0525
DRAWING HALL	BULB	0.0696	0.057	0.0002	0.058	1.1	0.0701
	FAN	0	0.095	0		1.6	0
	TELEVISION	0	0.115	0		2.01	0
BED ROOM	BULB	0.0696	0.057	0.0002	0.058	1.1	0.0701
	FAN	0	0.095	0		1.6	0
DINNING HALL	BULB	0.0576	0.057	0.0002	0.048	1.1	0.0580
	FAN	0	0.095	0		1.6	0
KITCHEN	BULB	0.0924	0.057	0.0003	0.077	1	0.0770
	MIXER	0.0248	0.412	0.0042	0.0207	3.4	0.2392
BATHROOM	BULB	0.1086	0.03	$9.77*10^{*5}$	0.0905	0.53	0.0254
TOTAL				**0.09225**			**1.6249**

The experimental data for losses in the various conductor are discussed above. It was seen that the conductor losses in both AC and DC systems are negligible as compared to other losses. But the loss in the AC system is less compared to that of DC system.

7. CONCLUSION

This project demonstrated how a DC system was designed, modeled, and characterized steady state using the both hardware implementation and Simulink toolbox in MATLAB. This characterization provides a strong basis for future design decisions when the DC House is eventually constructed. This includes: the circuit configuration, and the bus voltage level (24 v) that produces the best efficiency for the best price. The Simulink model requires a relatively large initial investment in time to properly model all devices, however once complete can be easily tweaked to test for additional transient or steady state characterizations.

Chapter 3 shows the various advantages of DC electrification over AC in terms of conductor and losses. Chapter 4 outlined and justified the load selection for the DC house. This was done via thorough research of typical home loads and requirements such as lighting, motor load, and entertainment. These devices had to be fully justified for their inclusion in the DC house, so that a realistic load selection could be achieved. Additionally, developing a strong understanding of how each device operates was necessary to create an accurate model of their performance in the Simulink model.

Chapter 5 demonstrate the different section of DC house which was used to construct the MM-1 model. Chapter 6 shows the result and analysis drawn from the both the distribution system. The cost involved in the total system calculate with losses.

It is concluded that the initial cost involved for construct and design of DC house is slightly higher than that of AC system, although not much difference. But the total loss involved in the DC system is less than that of conventional PV based AC system

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