DEVELOPMENT AND IMPLEMENTATION OF A BATTERY AND SOLAR POWERED DC COMPRESSOR BASED COLD STORAGE FOR OFF GRID RURAL AREAS ENSURING FOOD SECURITY

A Thesis Submitted to the Department of Electrical and Electronic Engineering of BRAC University

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DECLARATION

We hereby declare that our research titled "Development and implementation of a battery and solar powered DC compressor based cold storage for off grid rural areas ensuring food security", a thesis submitted to the Department of Electrical and Electronics.

Engineering of BRAC University in partial fulfilment of the Bachelors of Science in Electrical and Electronics Engineering, is our own work. The work has not been presented elsewhere for assessment. The materials collected from other sources have been acknowledged here.

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ABSTRACT

Preserving perishable goods as soon as they are harvested is the main concern for the farmers in the rural areas of Bangladesh for lack of cold storage facilities and absence of electricity supply. To supply ample facilities in the rural areas of the country this project is aimed to provide cold storage facilities incorporating renewable energy (Solar energy) and batteries; it will give a total off grid solution to the problem storing perishable goods and ensure food security. The prototype of the cold storage consists of solar Photovoltaic (PV) panels, batteries, charge controller, freezer and a DC compressor. The DC compressor, which is replaced by the AC compressor in the freezer, is the most vital component of the system as it runs the freezer taking DC output from the PV panels. The power supplied from the PV panels simultaneously runs the DC compressor and charges the batteries through the charge controller. The batteries give backup and runs the DC compressor at night in nonappearance of the sun. The system has been developed and implemented at the rooftop of BRAC University building 1 and all the tests have been done there. This thesis paper includes the system's overall performance test, results and analysis of the results. Moreover, the battery backup time in absence of sun for a long time has been analyzed. In all, the system has the complete solution for supplying cold storage facilities in off grid areas and give an environment friendly solution of the storage problem.

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Acronyms

PV	Photovoltaic
MPP	Maximum Power Pointer
HVD	High Voltage Disconnect
PWM	Pulse Width Modulation
BLDC	Brushless DC
AC	Alternative Current
DC	Direct Current
LED	Light Emitting Diode
SOC	State of Charge
POT	Potentiometer
LCC	Life Cycle Cost
LCOE	Levelized Cost of Energy
PP	Payback Period
CARC	Control Application and Research Center
COP	Coefficient of Performance

Chapter 1

Introduction

1.1 Background

Energy crisis is one of the main concerns in the contemporary word as its scarcity and demand is increasing day by day with industrial evolution, population growth and modern civilization. In particular, in the third world countries meeting energy and power demand is the main concern at present. Likewise, in Bangladesh the present scenario of energy and power supply is insufficient and the nation has to undergo through various hindrance and obstacles in the development sector. Bangladesh has the lowest availability of electricity i.e. 321 kWh per annum whereas electric generation capacity was 10289MW in January2014 [1]. According to the statistics, only 62% of the population has the access to the national grid [1]. Hence to meet the energy demand, renewable energy is a convenient source in the country.

Available conventional energy sources in Bangladesh which are coal, natural gas and oil are cost ineffective, hard to reach and not environment friendly. As a result, non-conventional energy like solar energy is the most expedient and reasonable alternative renewable energy source to produce electricity in off grid areas of the country. Solar energy taken from sun using photovoltaic panels is the most used technology in the world at present, which is cost effective, efficient and existing in abundance. Bangladesh's geographical location is between 200 30' and 260 45 latitude [2]. .March-April has the maximum sun radiation and December- January got the minimum. Moreover, the sun is available throughout the year and the energy we get from it 180*109 MW/year [2]. Daily solar radiation is between 4 and 6.5 kWh/m^2[3,4].For this profusion of solar energy, it can be used to meet up the electricity demand of the country. However, it is being used in small scale for example, supplying electricity for lights, fans and operating television in the households of rural areas. Figure 1.1 shows the daily solar radiation for each month in Bangladesh.

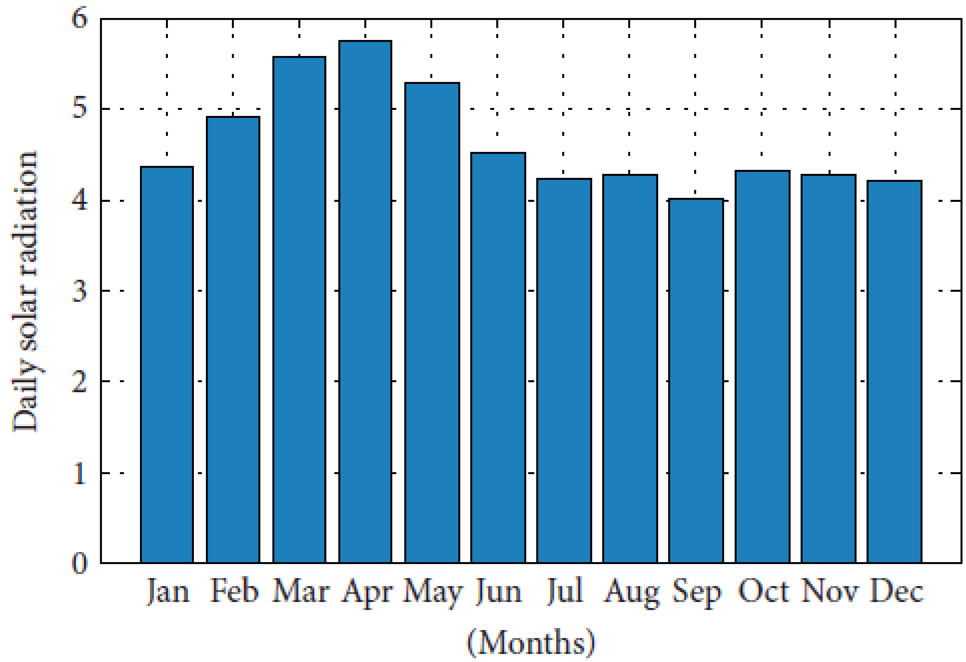


Figure 1.1: Daily Solar radiation in Bangladesh [5].

1.2 Objectives

Reserving perishable agricultural goods as soon as they are harvested is the main concern of the farmers in a tropical country like Bangladesh. They lose their nutritious values and are deteriorated if they are not stored in a cold place. As most of the rural areas in Bangladesh lack electricity supply, preservation of these goods has become problematic. Farmers mostly use chemicals to preserve the perishable crops which are harmful for the people and also the food loses its nutritious value. Salting is also being used from ancient time for food preservation. However, it is not that feasible and the food is tend to decease easily. Therefore, freezing is the most advantageous solution in terms of food preservation. As electricity availability and its price is the main concern in rural areas, freezing is a difficult option. BRAC University Control & Application Research Center (CARC) has come up with a feasible and economical solution inaugurating the project “Development and implementation of a battery and solar powered DC compressor based cold storage for off grid rural areas ensuring food security”which incorporates solar power to run the freezer. This off grid system is designed in such a way that it takes energy from the sun and runs the DC Compressor of the freezer which is the replacement of the AC compressor. At day time the sun runs the compressor through the charge controller and simultaneously charges the batteries. The batteries run the compressor at the absence of the sun. This off grid renewable energy system can reduce the difficulties of storing perishable goods for the farmers, preserving medicines in the hospitals, and storing fishes for the fishermen in rural areas and reduce their daily electricity expenses. Moreover, its greater accomplishment would be providing freezing system in off grid areas in Bangladesh where electricity has not been introduced yet.

Being a developing country, it is hard to meet the demand of electricity especially in remote areas. As a result, the agricultural system lacks behind in case of preservation of crops where there is no grid supply. This disadvantage leads to the spoiling of the harvested crops and the nation has to undergo through food crisis. Moreover, it also affects the economy of the country as deterioration of the crops triggers price hike. To come to a feasible solution, it is necessary to introduce such a technology that it will preserve the crops and also meet electricity demand in low cost. The solar cold storage uses solar energy transforming it into electricity. It is a complete off grid system and is missioned to meet the electricity demand in rural agricultural areas in the country. After harvesting the crops, the farmers can store them in the cold storage and prevent them from perishing. As it is a complete off grid system, the electricity cost is saved and also it will give 24 hours facility with the backup system in the rural areas. Hence, the loss of fresh agricultural goods can be diminished permanently. Successful implementation of the project will lead to several advantages. It will reduce the dependency on electricity and proper use of renewable energy will help the country to go green with solar power. In addition, one of the main objective of the project is to make it cost effective; efficient use of solar power by developing a total automated solar powered cooling system. Therefore, the project is aimed to spread this new technology all over the country in order to have an economical and beneficial solution to electricity supply.

1.3 Literature Review

With the emergence of solar technology, solar powered freezer is being used all over the world from past few years. Diverse technologies of solar powered cooling system have been introduced worldwide where the main idea of the cooling system is similar. Basically it involves the idea of converting solar energy into electrical energy. Bharj [6] developed hybrid project for cold storage using both grid and off grid system. When the solar power is unavailable the system is designed to take power from the grid. The system consists of a solar PV panel, a battery, an inverter, a controller, cold storage chamber, DC vapor compression refrigeration system and Data Acquisition System. It operates on solar energy in day time and grid energy at night time and cloudy days. The PVT and DC inverter refrigeration system has an estimated efficient result in India. Another project by Freni and Messina [7] is solar powered absorption chiller system for cold storages. Based on the absorption and desorption of a solar collector. The prototype operates with a 24-hours intermittent cycle and consists of a solar collector, an air cooled condenser and an evaporator. At day time when the sun is available, the collector allows methanol desorption from activated carbon and the methanol vapor is condensed by the condenser then passed into the receiver. After that, the methanol collected into the receiver is passed to the evaporator through an automatic valve. At night the activated carbons absorbs methanol from the evaporator.

In addition, Ameen[8] evaluates and describes the development of solar-powered freezer for remote areas where electricity is scares commodity. This paper focusses on the storage of medicine and vaccines at a temperature of minus 10’C with a storage capacity of 9.1kg. The whole comprises of a freezer unit along with an array of photovoltaic panel and lead acid battery. The system employs conventional vapor compressor refrigeration cycle technology however, uses R-12 as the refrigerant. The length of the capillary tube was modified and optimized at 11.18ft and 0.144lb for efficient operation. Moreover, investigation was also made to evaluate the effectiveness of charging the battery and running the freezer by the solar panel. Hence based on their findings further modifications were made and performance test were carried out which was also highlighted by the methodology used in the optimization procedure.

Beside, Ewert et al. [9] designed a solar powered refrigeration system focused on combining the vapor compression technique and a special controlling system. The refrigeration system has several parts of component working together. A variable speed DC compressor is used and it runs directly using the DC current of the photo voltaic (PV) panel. The compressor circulates the refrigerant through an insulated chamber to extract the heat from it. There is a thermal reservoir inside the insulated enclosure. This insulated enclosure has a special type of phase changing material. When the heat is extracted this phase changing material gets frozen and later when the sunlight is not available is can work as a hit sink and keep the temperature inside the insulated enclosure cool. A special type of control system is used in order to make the most efficient use of the solar powers. This technique monitored the available solar power and then compared it with the compressor speed and then varied the compressor speed with respect to the power available. This also ensured that power loss is very low. A capacitor is used to provide Additional start-up current to the compressor. Lastly, Pedersen and Mate [10] have developed a refrigeration system where it can operate directly from solar PV panels without batteries. They used ice packages instead of batteries for backup system where the ice can give hold up time up to 2.5 days. They have used a DC Compressor with refrigerant R600a and a special built-in controller for solar power including adaptive speed control. In all, based on the projects described above and by doing the comparative study we have developed our system which is more convenient in our country to provide viable solution to the electricity problems in rural areas.

1.4 Motivation

In consideration and comparison of all the projects described in the literature review section, a system has been designed and developed which is a totally off-grid solution. This system has been developed in such a way so that its efficiency is better than the other existing systems in the world. As inverter system causes power loss, we used DC compressor. Powering the system with PV panels and batteries at night is the most reasonable option to run the DC compressor. Most of the solar cooling projects include AC compressor and inverter system which inverts the DC current input taken from the PV panels to AC. However, this system is inefficient and energy is wasted while DC current is converted into AC by the inverter. Whereas, DC compressor is more efficient in terms of power efficiency and power consumption. Also, its speed and voltage is easily controllable. The DC compressor used in this project Danfoss BD 35F, has a controller unit with it which gives safety options, troubleshooting and software control system. Hence, running the freezer with the DC compressor and PV panels is a better option than any other existing system used in solar freezer. The schematic diagram of the proposed solar based cooling system is shown in Figure 1.2.

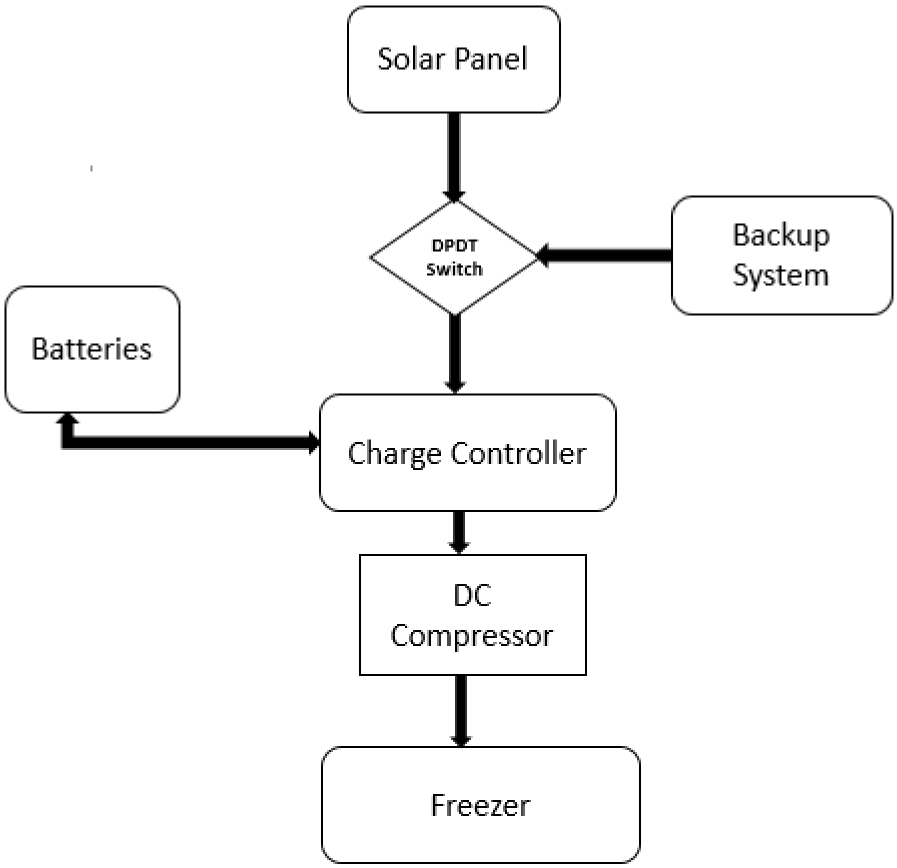


Figure 1. 2: Block Diagram of the whole system

Figure 1.2 shows the system takes energy from PV Panel or powered source (DC Compressor) and passes it to the charge controller. The charge controller dissipates the energy to the DC Compressor and also charges the battery instantaneously. At night the batteries give backup and when there is no power supply from the PV panel or batteries, the powered source is kept for the ultimate backup.

1.5 Justification

Lack of humidity and scorching sun is a combination that rotten the vegetables stored outside after cultivation. This leads to the idea of storing them in cold place in a cost effective way. Also the lack of electricity supply is the main concern. Grid supplied cold storage is expensive and unaffordable for the farmers. Moreover, many rural areas of Bangladesh do not have electricity supply. Keeping these in consideration, a system needed to be developed that will be cost effective as well as off grid. Solar being an excellent source of renewable energy, it has been used in this project making it a total off grid system using batteries as backup. By virtue of that the farmers will be relieved from the pressure of storing the vegetables and crops without paying for electricity. In Bangladesh, solar powered cooling system has not been introduced yet. This project is the first attempt incorporating solar power into freezing system. Successful implementation of this project can meet the demand of electricity of the farmers and also improve the economy of the country. DC powered solar freezer would give the farmers a sustainable refrigeration system and prevent their crops from perishing. Moreover, it will consume less power, it is cost effective and can run the freezer efficiently.

1.6 Overview of the Content

The following chapters portray the work that has been accomplished, the field tests, energy calculation, payback calculation and suggested future plans. The first chapter gives the overall introduction of the system and literature survey on cold storages. The second chapter gives an overview of the whole system and the components. The third chapter shows the experimental setup, filed test data, result and analysis. The fourth chapter focuses the energy efficiency of the system and the financial feasibility analysis. The fifth chapter gives an overview of the entire thesis and also the challenges faced and future work that is yet to be done

Chapter 2

Overview of the Solar Powered Freezer

2.1. Introduction

The solar powered freezer is aimed to incorporate an off grid freezing system to give power supply in the rural areas for freezing agricultural crops, household goods, fishes and medicines. The proposed solar powered freezer consists of four solar panels, six rechargeable batteries, one pulse width modulation (PWM) charge controller, one DC Compressor and one freezer. There will also be a backup system which will be controlled by the Double Pole Double Throw (DPDT) switch. The backup system will be discussed in the Chapter 5 i.e. "Future Plan of the Project". The schematic diagram of the proposed solar powered refrigeration system is shown in Fig 2.1.

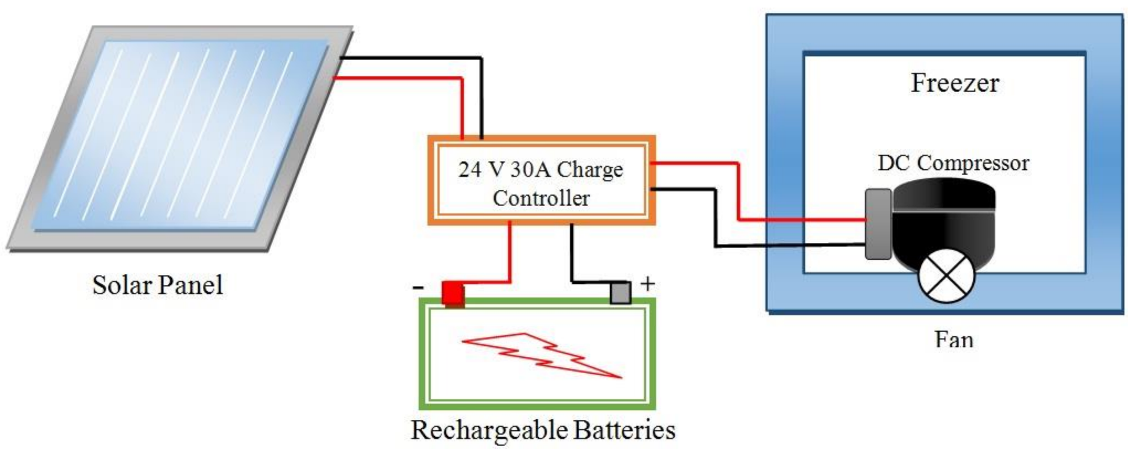


Figure 2.1: Schematic diagram of the whole refrigeration system.

Solar panel connection: The four solar panels are connected in parallel. All the positive connection are shown by red wire and the negative with black wire. Figure 2.2 shows the wire connection of whole solar system.

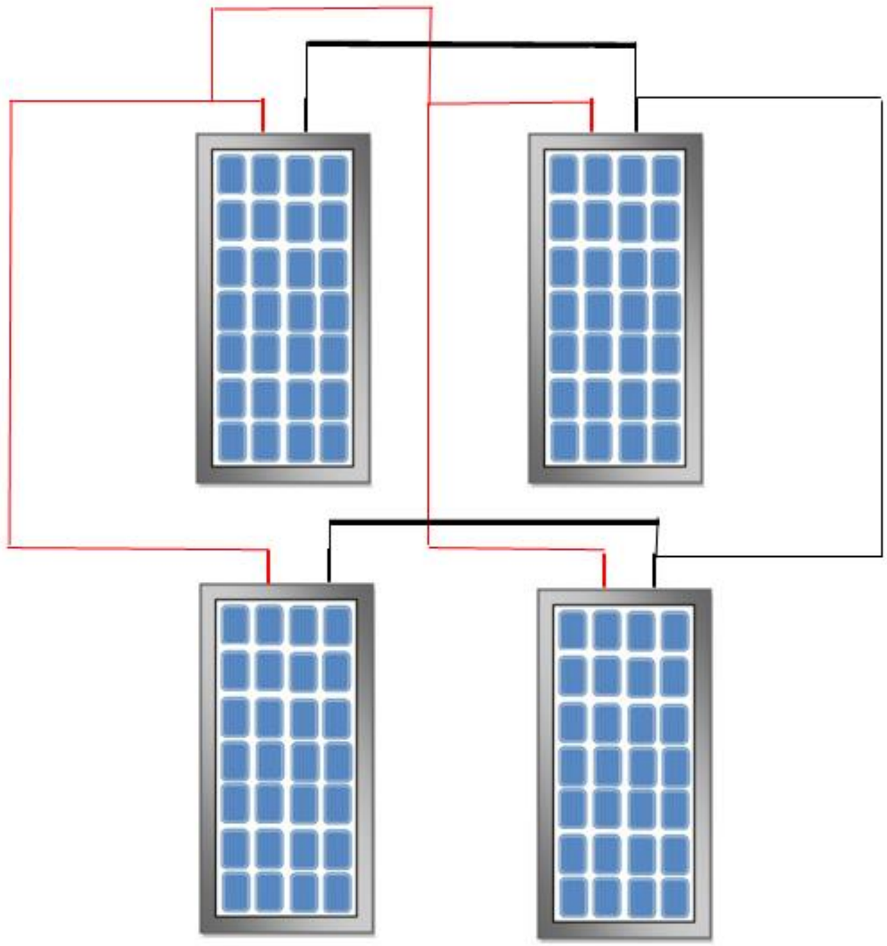


Figure 2.2: Solar Panel Wire diagram.

Battery Connection: The 12V 20Ah two batteries are first connected in series. Likewise, three sets of batteries in series make 24 V 20Ah battery each set. The three sets of batteries are connected in parallel giving the whole battery system 24V 60Ah. Figure 2.3 shows the battery connection of the system.

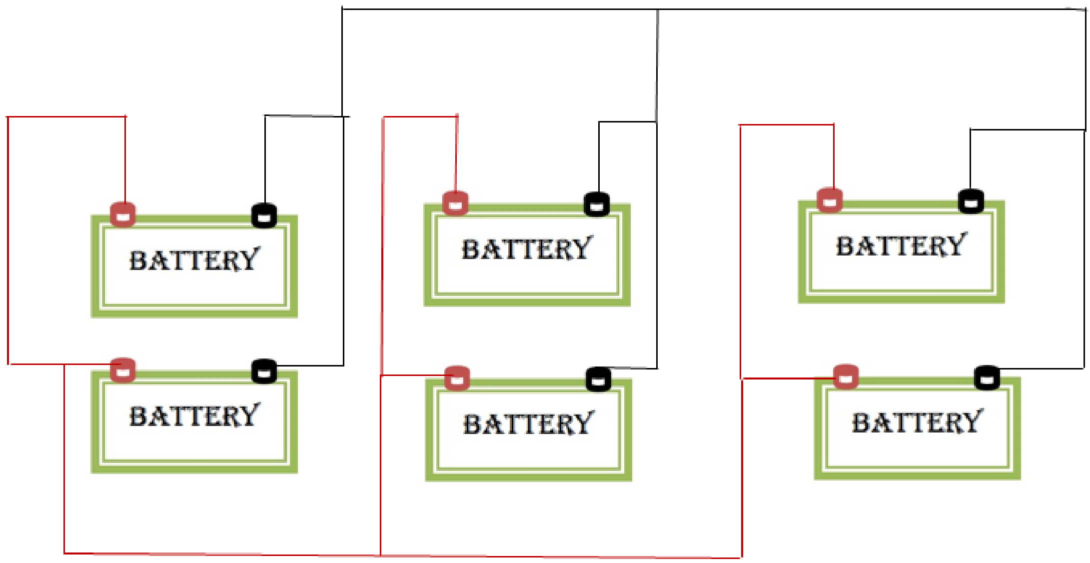


Figure 2.3: Connection Diagram of the batteries.

2.2 Description of Individual Components

2.2.1 Solar Photovoltaic Panels

In the era of industrialization, going green with solar is the best solution. Solar panels have been used worldwide and it is easy to store and relatively safe to use in commercial purposes. Solar photovoltaic panels are being used worldwide for producing electricity or heat. The technology of absorbing sun's ray to energy has added many aspects of using the solar as renewable energy. Its each module is rated as DC output and generally produces 100-365 Watts, which is a massive source of power. In our system four 200 watt 24V Mono crystalline solar panels purchased from Electro Solar Bangladesh. Its rated short circuit current is 6.2A and Maximum Power Pointer (MPP) current 5.7A. In total there are 800 Watt solar panels and the four panels are in parallel connection. The panels are tilted in 10 degree angle facing south. A single unit of solar panel is presented in Figure 2.4.

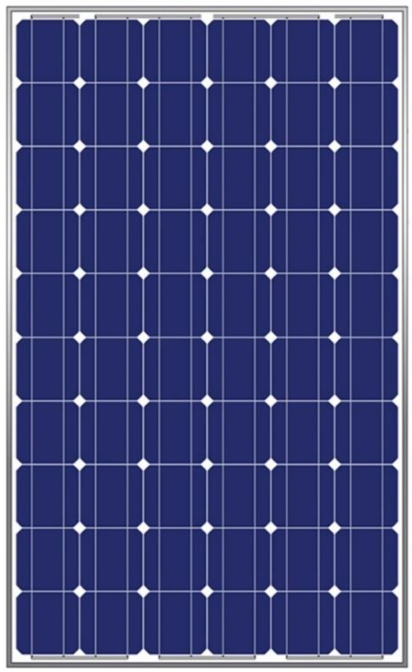


Figure 2.4: A single unit of Mono crystalline Photovoltaic Panel.

2.2.2 Charge Controller

Charge controller is used to limit the current and voltage that is expected from the solar panels into the range required for the load. The charge controller having Pulse Width Modulation (PWM) technique of 24V and 30A rated has been used in our system from Electro solar company to support the 12-24V DC Compressor. PWM charge controllers pulls down the solar voltage to the necessary voltage required in the load. Its High Voltage Disconnect (HVD) is 27.5 V. The charge controller is shown in Fig. 2.5.

Figure 2.5: 24V-30A Charge Controller

2.2.3 Batteries

In the system, we have used batteries as back up when there is not enough sunlight (i.e., cloudy day and night). The rating of a battery is 12 V and 20Ah. Two 12V batteries has been connected in series and made 24V set of batteries. Three sets of 24V batteries have been connected in parallel. The total energy in the battery is 60Ah where each sets gives 20Ah energy. Each battery dimension is 16.5 X 17.5 X 12.6 cm. the battery used for the proposed system is shown in Figure 2.6.

Figure 2.6: 12V-20Ah battery

2.2.4 DC Compressor

The compressor used in our thesis project is a “DC Compressor” which is the “heart” of the entire system. DC compressor has Brushless DC (BLDC) motor which is more efficient because it has less power consumption than brushed motors. Though conventional AC compressors have better performance, their power consumption is higher than the BLDC compressor. Moreover, there is an external control unit in DC Compressor by which some external features like fan, variable resistors to control speed, LED troubleshooting option and software speed controlled features are available. In contrast, these features are not available in AC compressors. Table 2.1 represents a comparison between DC compressor and conventional AC compressor.

Table 2.1: Differences between AC and DC compressor

AC Compressor	DC Compressor
No External Controlling Unit	External controlling unit exists
Operating voltage 220 V- (50/60 Hz)	Operating Voltage 12 or 24 V
Operating current 0.6 amps	Operating current 1.5 A
Thermally protected from inside	External unit ensures protection.

We chose “Danfoss BD35F” compressor which is a German made specially designed and developed for the purpose of direct solar application, due to its “soft start” mechanism which requires low starting current of around 4 amps to initially start the compressor (motor). Moreover, the compressor uses the refrigerant “R134a” which matches with our freezer refrigerant type. The operating voltage range of the compressor is from 10V-45V and can be used for both 12V and 24V systems. The compressor is a reciprocating type which uses 78W at maximum condition. It is to note that unlike conventional AC Compressor, this specific compressor comes with built in variable speed control, over heat thermal protection, battery protection, motor start error protection and fuse which are all embedded in the “Electronic Unit circuit” for an intelligent and efficient operation. The rated speed of the compressor is 2000rpm with the maximum of 3500rpm. This compressor supports both mechanical and electronic thermostat for ease of use and also has support for software (Tool4Cool) controls through the electronic unit for further ease of use in controlling operating temperature, compressor speed etc. In 24v system the compressor cut-out and cut-in voltage is 22.8v and 24.2v respectively. The compressor also supports LED notifications for ease of trouble shooting and diagnosis. Hence, this compressor truly stands above the crowed and is an ideal choice for solar applications and research. Figure 2.7 and 2.8 shows the DC Compressor and its controller unit.

Figure 2.7: Danfoss BD 35F DC Compressor

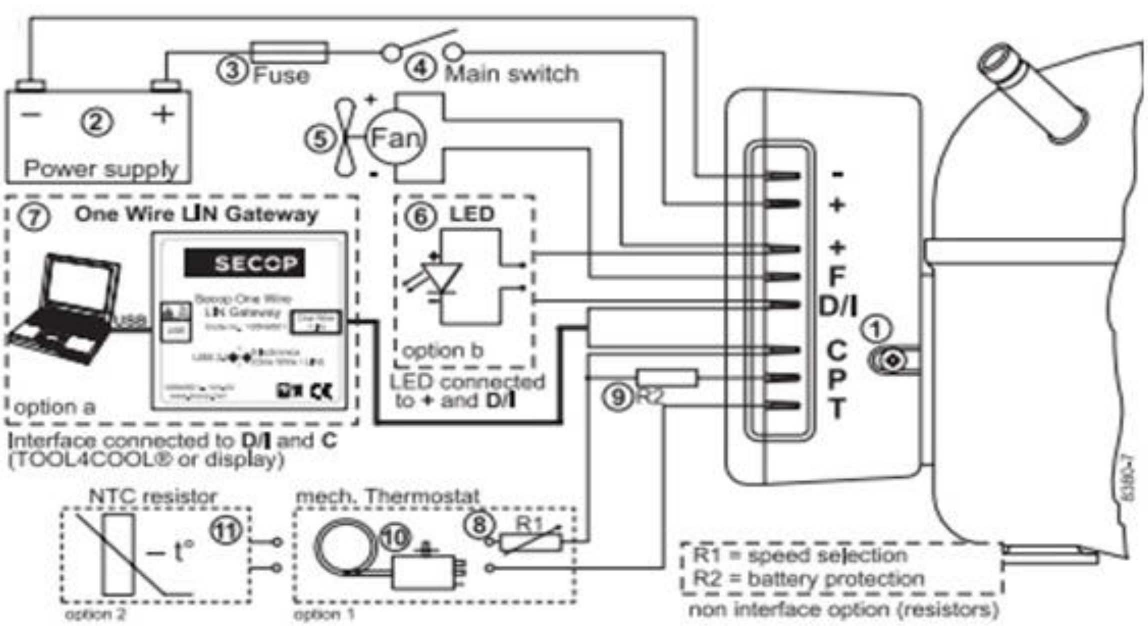


Figure 2.8: BD 35F Controller unit features [11].

2.2.5: Freezer

Walton FC-1B3 deep freezer has been used in this project. Its refrigerant is R134a which matches the DC compressor's refrigerant. The capacity of the freezer is 125 liter and 7.5 cft gross volumes. The freezer can freeze up to -18 degree Celsius. The freezer has been shown in Figure 2.9.

Figure 2.9: Walton FC-1B3 freezer

Chapter 3

Experimental Setup, Field Test Data and Result

3.1 Experimental Setup

A digital multi-meter with temperature sensor has been put inside the freezer to measure the temperature hourly. A clamp meter has been used to measure the compressor current. Two ammeters have been series with the solar panel and battery connection which shows their current. Two digital multi-meters are used to measure the voltage of the solar panel and battery respectively. Figure 3.1 shows the experimental setup of the system.

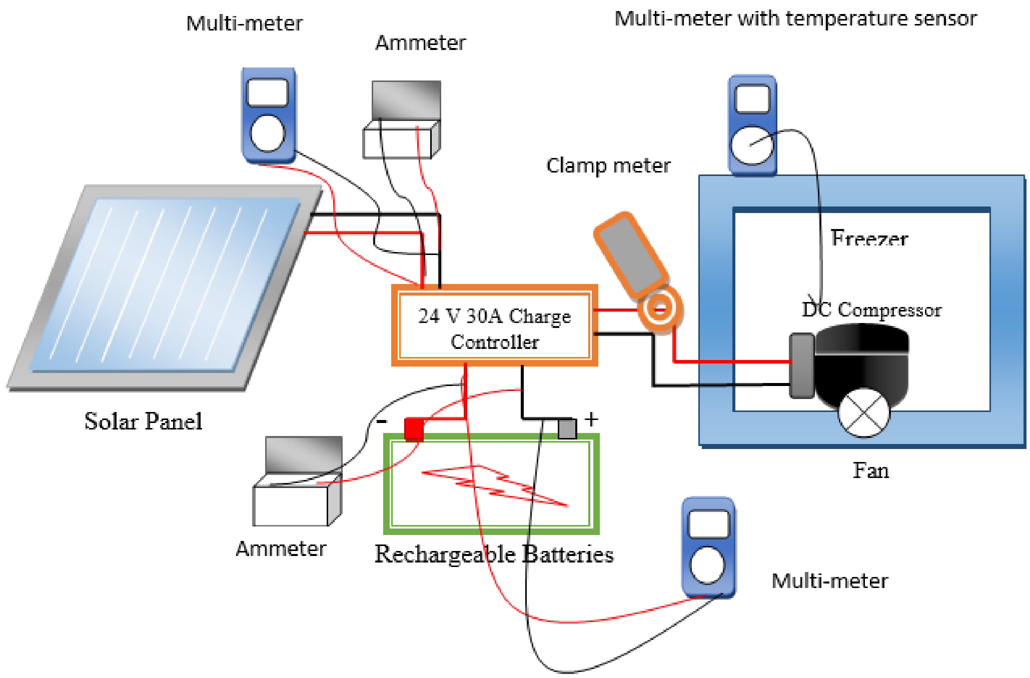


Figure 3.1: Experimental setup of the system

3.2 Experimental Tests

A several type of experimental field tests (i.e. No load and load tests, battery back-up test, speed control tests) were conducted for this project. The main objective of these tests was to see how the DC compressor performs with the solar powered cooling system. No load and Load test were conducted to see how much the temperature inside the freezer changes with respect to time. The battery backup test was conducted for the system to see how much the battery can give back up in terms of hours under normal circumstances so that in case of emergency when the sun is not available power can be adjusted through some backup system and also the amount of battery power needed to back up for emergencies can be found. Lastly, the compressor variable speed test was done to compare between different speed test results to see how the system can be run more efficiently. And also to analyze the power consumption changes during different speed test, so that in future the system can be modified to run according to the power available and have less energy loss.

Figure 3.2: Field test experimental setup

3.2.1 No Load test

No load test is the freezer's performance test with the DC compressor to see how the temperature inside the freeze changes with time. This test was done with putting a little less than half liter water glass inside the freezer so that it can be understood when ice has formed. The freezer was started running at 9.00 am in the morning. The starting temperature inside the freezer was 24 °C. The duration of the test was 10 hours. The test was finished at 5.00 pm. The temperature had dropped to -8 °C. There was Solid ice formed in the inside part of the freezer body. Table 3.1 shows experimental results for no load test. The graphical representation of inside temperature of the freeze with respect to time is shown in Figure 3.2. Figure 3.3 is picture of the ice that was formed inside the freezer.

Table 3.1: No Load test result for proposed solar powered Freezer

TIME	Temperature (° C)	Battery and Load Voltage (V)	Load Current (A)	Solar panel Voltage (V)	Solar panel Current (A)	Battery Current (A)
9.00 am	24	24.6	1.2	30.5	4.1	2.9
10.00 am	7	24.7	1.5	31.2	5.3	3.8
11.00 am	0	25.1	1.2	35.5	5.5	4.3
12.00 pm	-2	24.8	1.1	34.2	5.6	4.5
1.00 pm	-4	24.6	1.1	38.4	4.8	3.7
2.00 pm	-6	25	1.3	36.5	4.5	3.2
3.00 pm	-7	25	1.1	33.4	3.4	2.3

4.00 pm	-7	24.9	1.2	31.9	3.6	2.4
5.00 pm	-8	24.9	1.3	26.2	2.7	1.4
6.00 pm	-8	25	1.4	0.3	0	-1.4
7.00 pm	-8	24.9	1.1	0	0	-1.1

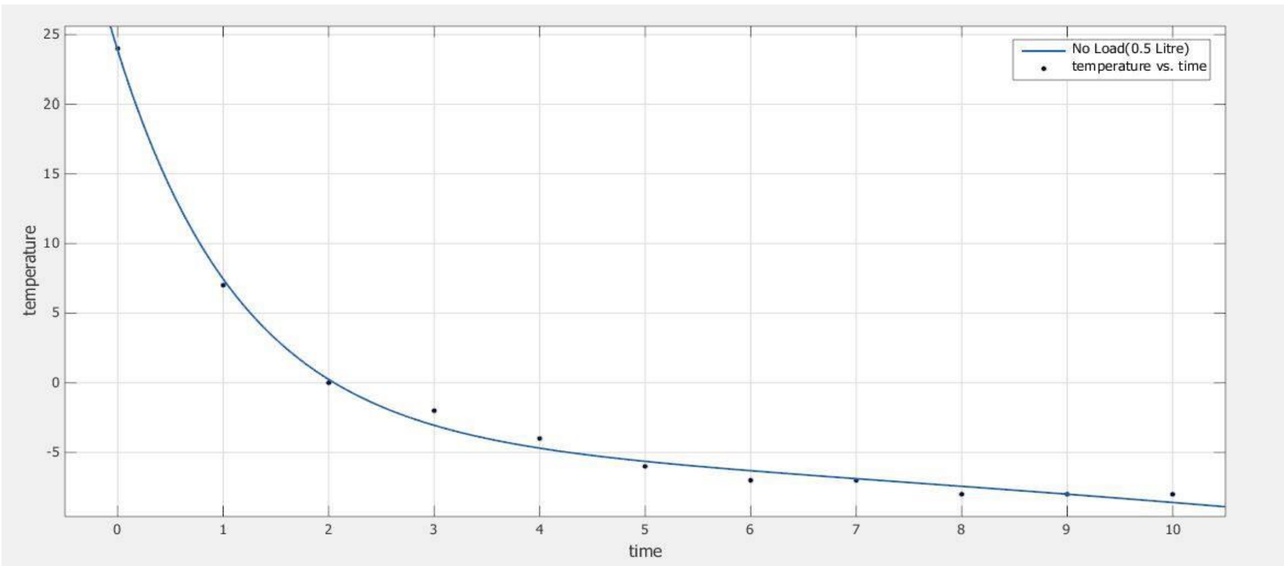


Figure 3.3: Temperature changing along with time for No Load condition

EQUATION: f (x) = a*exp(b*x) + c*exp(d*x)

Coefficients (with 95% confidence bounds):

a = -4.239

b = 0.07066

c = 28.1

d = -0.8508

Figure 3.4: Ice formed inside the glass after 10 hours

3.2.2 Load test

The Load test was done for analyzing the freezer's performance. Only water was used as a load for this project. 10.5 liter, 20.5 liter and 30 liter were the different amount of load that was used. Same procedure was followed throughout for the entire load test. Whole the test was done under normal circumstances. Throughout the test compressor was running at rated speed. The average ambient temperature of the environment was around 27-28 °C and The average sun intensity was around 3.6 kW/m^2 per day.

3.2.2.1 Load test with 10.5 litter water

The freezer was started at 9.30 am. Ambient temperature inside the freezer was 27 °C. The freezer ran till 6.30 pm making the runtime 9 hours in total. The temperature dropped from 27 °C to 3 °C. Table 3.2 represents different data's that were recorded during the test. Figure 3.4 shows the graphical representation of the freezers temperature changes with time. Figure 3.5 is a picture of the field test.

Time	Temperature (°C)	Battery and Load Voltage (V)	Load current (A)	Solar panel Voltage (V)	Solar panel Current (A)	Battery Current (A)
9.30 am	27	27	1.3	29.42	3.9	2.6
10.30 am	13	26.5	1.3	28.65	3.6	2.3
11.30 am	11	26.8	1.3	28.91	3.1	2.8
12.30 pm	9	26.7	1.4	29.33	4.6	3.2
1.00 pm	8	26.3	1.3	29.67	6.1	5.8
1.30 pm	8	26.5	1.3	29.68	5.3	4.0
2.30 pm	6	25.9	1.3	28.48	5.7	5.4
3.30 pm	7	25.4	1.2	26.85	4.1	2.9
4.30 pm	5	26.3	1.5	26.04	3.3	1.8
5.30 pm	4	25.5	1.4	0.7	0	-1.4
6.30 pm	3	25.1	1.1	0.3	0	-1.1

Table 3.2: 10.5 liter test result for proposed solar freezer

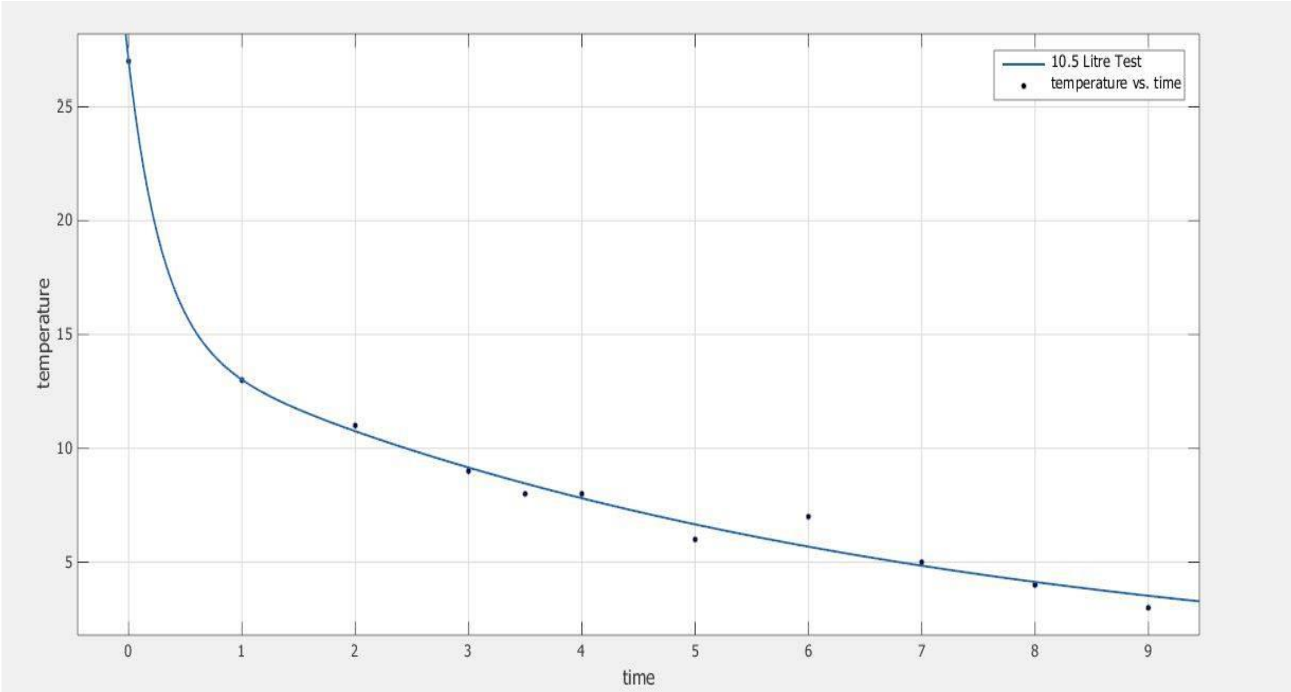


Figure 3.5: Temperature changing with Time for 10.5 liter load.

EQUATION: f(x) = a*exp (b*x) + c*exp (d*x)

Coefficients (with 95% confidence bounds) :

a = 12.24

b = -3.357

c = 14.76

d = -0.1591

Figure 3.6: Water chilled after the 10 hours t

3.2.2.2 Load test with 20.5 litter water

Second test was with 20.5 liter, the same procedure is followed like the previous load test. The test was started at 9.00 am in the morning while the temperature inside the freezer was 27 °C. Total duration of the test is 9h 30 min. the temperature inside dropped from 27 °C to 15 °C. Table 3.3 shows the result data of the 20.5 liter test. In figure 3.6 the graphical representation of freezer's performance with respect to time is shown.

Table 3.3: 20.5 liter load test result for proposed solar freezer

Time	Temperature (°C)	Battery and Load Voltage (V)	Load Current (A)	Solar panel Voltage (V)	Solar panel Current (A)	Battery Current (A)
9.00 am	27	27.1	1.3	29.78	3.7	2.4
10.00 am	25	27.3	1.3	29.64	3.6	2.3
11.00 am	23	27.1	1.4	29.04	3.5	2.1

12.00 pm	21	26.7	1.4	30.15	4.9	3.5
1.30 pm	19	26.7	1.3	28.92	5.6	4.3
3.00 pm	17	26.7	1.3	28.77	5.5	4.2
4.00 pm	16	26.6	1.3	26.51	4.3	2.0
5.00 pm	16	25.8	1.5	26.03	2.6	1.1
6.30 pm	15	25	1.3	0.6	0	-1.3

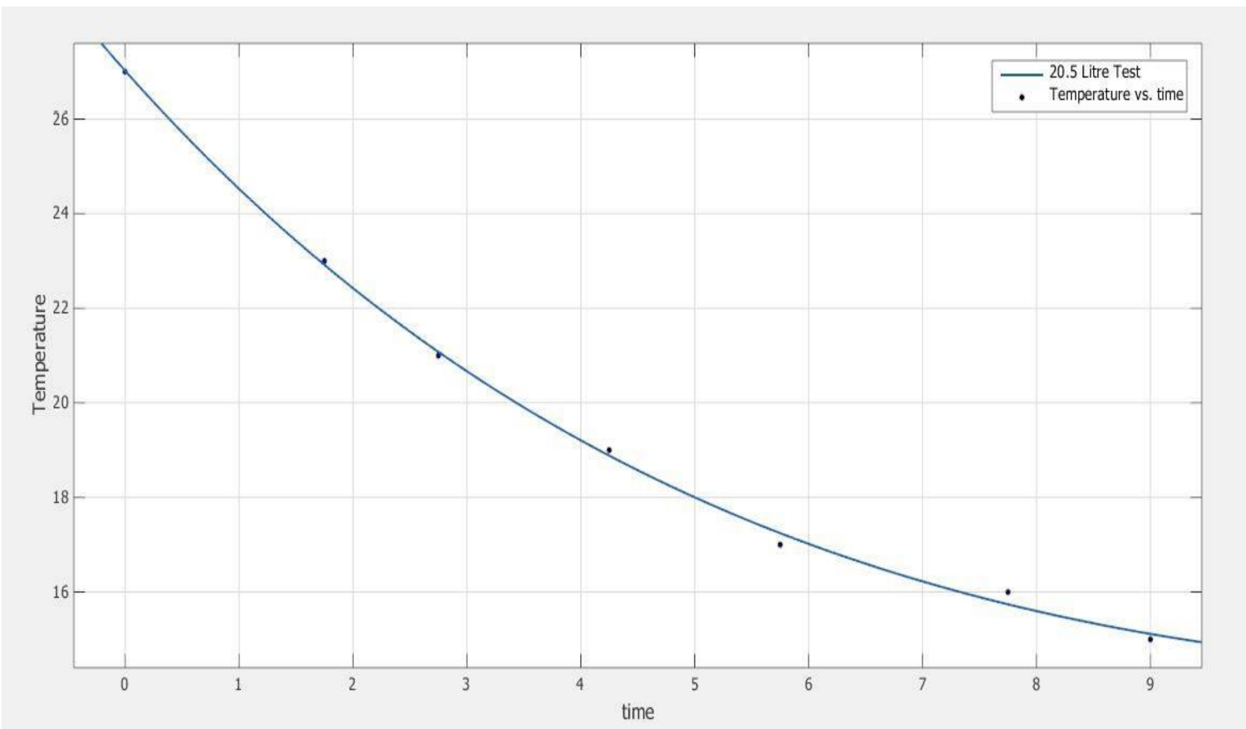


Figure 3.7: Temperature changing with Time for 20.5 liter load.

EQUATION: f(x) = a*exp (b*x) + c*exp (d*x)

Coefficients (with 95% confidence bounds) :

a = 19.39

b = -0.1529

c = 7.632

d = 0.03241

3.2.2.3 Load test with 30.5 litter water

Last test was done with 30.5 liter load. The freezer was started operating at 9.00 am with 25 °C inside temperature. The test was done for 7 h 30 min. The temperature dropped to 14 °Cat 4.30 pm. Table 3.4 shows the result of the test and figure 3.7 shows the graphical representation of the result.

Table 3.4: 30.5 liter test result for proposed solar freezer

Time	Temperature (°C)	Battery and Load Voltage (V)	Load Current (A)	Solar panel Voltage (V)	Solar Panel Current (A)	Battery Current (A)
9.00 am	25	27 V	1.3	36	3.6	2.3
9.30 am	22	27 V	1.3	37	3.9	2.6
10.00 am	20	27 V	1.2	38	3.8	2.6
10.30 am	19	26.8	1.2	40.6	4.5	3.3
11.00 am	18	27.1	1.4	40.6	5.6	4.2
11.30 am	17	27.3	1.5	40.6	6.1	4.6
12.00 pm	17	26.8	1.0	40.5	5.9	4.9
12.30 pm	16	26.8	1.0	40.5	6.3	5.3
1.00 pm	16	26.8	1.0	40	7.8	6.8

1.30 pm	16	27.2	1.4	40.7	7.6	6.2
2.00 pm	16	26.9	1.3	40.4	6.2	4.9
2.30 pm	15	27	1.1	40.3	5.3	4.2
3.30 pm	15	26.8	1.0	39.9	4.6	3.6
4.00 pm	15	27.3	1.0	36.1	3.0	2.0
4.30 pm	14	26.4	1.1	36.4	2.1	1.0
5.00 pm	13	26	1.2	24.4	0.7	-1.2
6.00 pm	12	25.3	1.1	0.3	0	-1.1

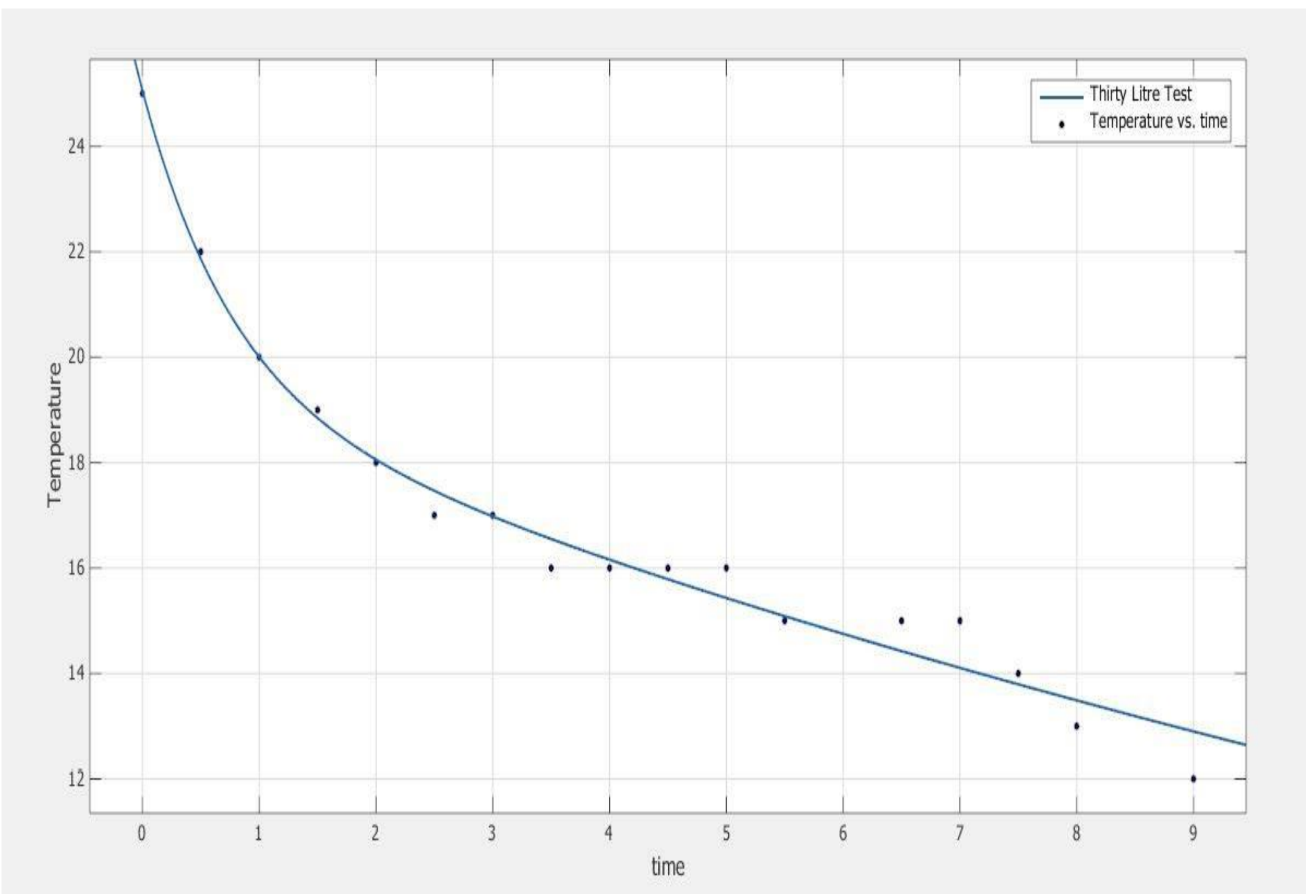


Figure 3.8: Temperature changing with time for 30.5 liter load

EQUATION: f(x) = a*exp (b*x) + c*exp (d*x)

Coefficients (with 95% confidence bounds):

a = 5.783

b = -1.308

c = 19.28

d = -0.04466

From all the load tests data and graphs, it can be said that as the load increases it takes more time to decrease the temperature. Since the specific heat for water is 4200 J/ kg so when the loads are increasing then it is supposed to consume more and more energy and hence time increases.

3.2.3 Battery Backup Test

The battery backup test was conducted for our system. The purpose of this test was to see how many hours the batteries can run the freezer without any external support and then use the value to project the value for more powerful system. Six lead acid batteries are used for this test. Each battery has 12 V and 20 AH. As we know that lead acid batteries can be used up to 50 % of discharge without any damage [12]. So, the test started at 100 % state of charge (SOC) of the batteries and the time to reach 50% SOC was recorded. The test was done in six days. For this test the battery was directly connected to the compressor through the charge controller. The solar PV panel connection was opened and it was made sure that batteries do not receive any charge during this period. Before the test the batteries were fully charged and the open circuit voltage is measured at 26 V. This is considered the 100% SOC for our batteries. We considered 24.2 V as the 50 % SOC as it is the standard for a 24 v battery. We can see the result of the battery back-up test in Table 3.5. Figure 3.8 shows the battery state of charge decreasing rate along with time.

Table 3.5: Battery backup test results for proposed solar freezer

Day	Time	Open circuit Voltage	State of charge
Day 1	11.00 am	26 V	100 %

	5.00 pm	25.55 V	87.5 %
Day 2	10.00 am 5.15 pm	25.55 25.26 V	 79.44 %
Day 3	11.30 am 5.00 pm	25.26 V 25.03 V	 73. 05 %
Day 4	9.30 am 5.00 pm	25.03 V 24.58 V	 63.33 %
Day 5	1.30 pm 5.00 pm	24.68 V 24.52 V	 58.88 %
Day 6	10.00 pm 3.30 pm	24.52 V 24.21 V	 50.2 %
Total time :	35 hour / (1.5 days)		Discharge = 50 %

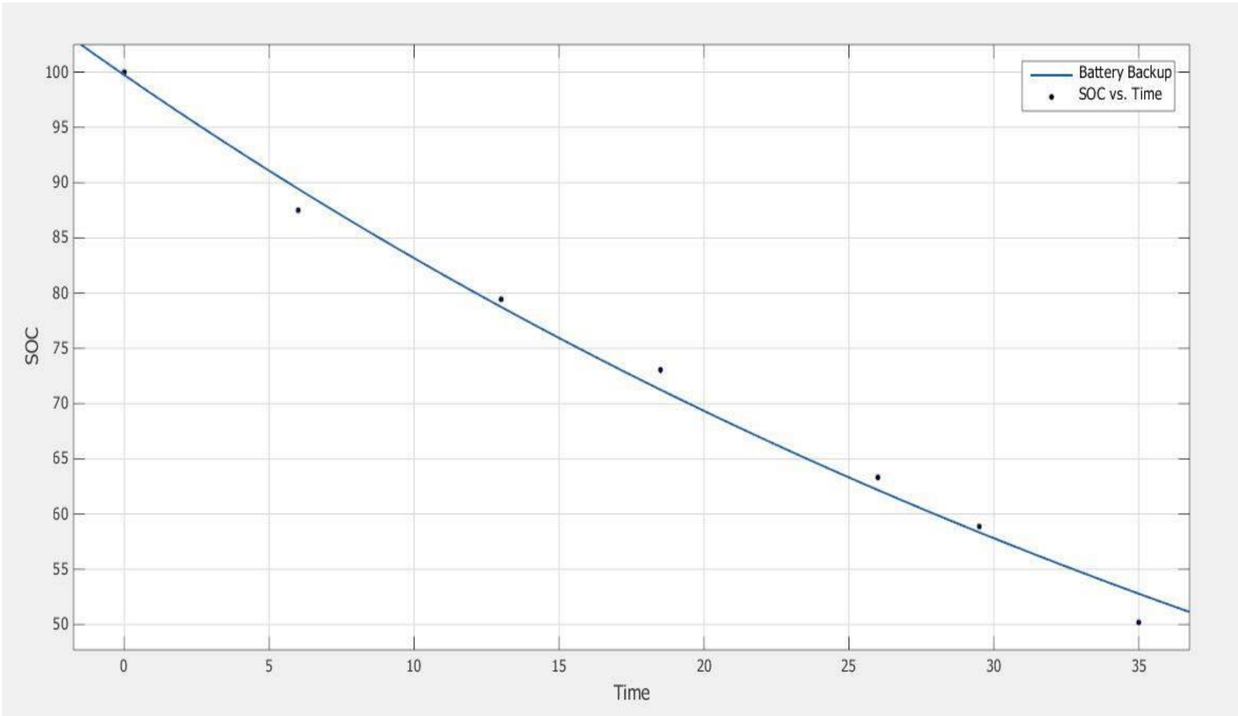


Figure 3.9: Battery SOC (state of charge) decreasing along with time

EQUATION: f (x) = a*exp (b*x)

Coefficients (with 95% confidence bounds):

a = 99.74

b = -0.01817

From the test we found that, if we run our freezer at the rated 2000 rpm the battery can give back up for 35 hour which is almost 1.5 days without any disruption. The compressor current was 1.3A in average. We can conclude that if we want to use 200 Ah 24 V batteries we can easily make a relation with our system and find estimated Time to be around 3 days considering 20 % loss for practical reasons.

3.2.4 Test with variable compressor speed

The objective of this test was to see how the freezer performs when the speed of the compressor is changed. The Danfoss BD 35F compressor is a variable speed compressor. The instruction for varying the speed is given in the data sheet of the compressor. In order to change the speed the Compressor a Potentiometer (POT) is connected between terminal C and T of the controller unit. Figure 3.9 shows the electron unit connection diagram for Danfoss BD 35F compressor. The value of the resistors used, current passing through the resistors and corresponding speed are given below in Table 3.6.

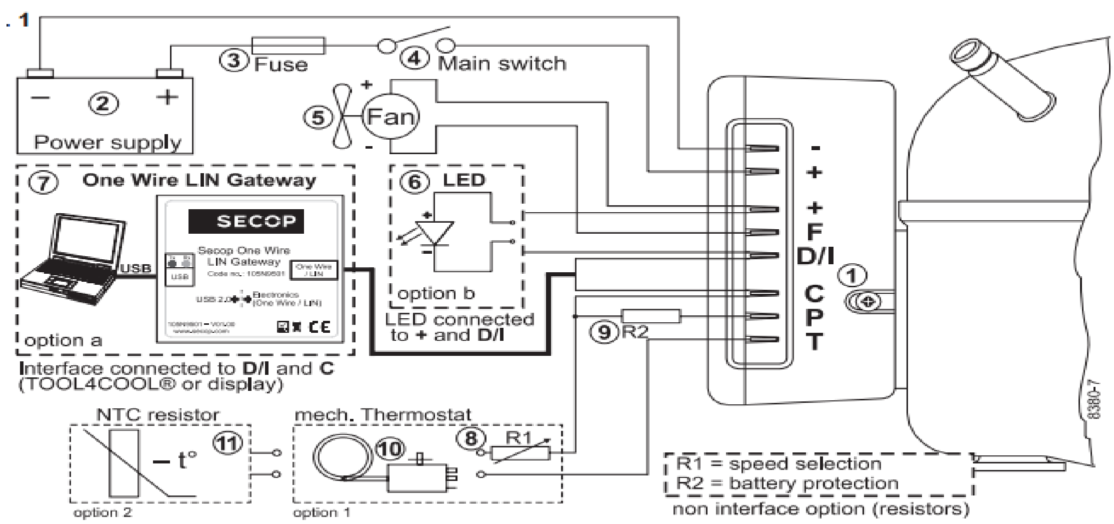


Figure 3.10: Variable Resistor Connection in the Compressor's Controller unit

Table 3.6: Compressor speed with corresponding resistor

Resistor (Ω)	Motor speed (rpm)	Controller circuit current (mA)
0	2000	5
277	2500	4

692	3000	3
1523	3500	2

For testing how the freezer performs in different speed. The ambient temperature of the freezer was set at 25°C and the time to reach to 0 °C was measured. Firstly the 3500 rpm speed test was conducted. The compressor current was 2.3A and it took 70 minutes to reach to the expected point. Then 2500 test and 2500 rpm test followed. Table 3.7, 3.8 and 3.9 shows the test result data for 3500, 3000 and 2500 rpm speed test. Figure 3.10 shows the bar chart of compressor response to different speed with respect to time.

Table 3.7: Compressor variable speed test result for 3500 rpm

Time	Temperature (°C)	Compressor current
10.20 am	25° C	2.3 A
10.50 am	11° C	
11.00 am	9° C	
11.15 am	4° C	
11.30 am	0° C	

Table 3.8: Compressor variable speed test result for 300 rpm

Time	Temperature (°C)	Compressor current

12.30 pm	25° C	1.7 A
1.00 pm	13° C	
1.30 pm	8° C	
2.00 pm	5° C	
2.30 pm	0° C	

Table 3.9: Compressor speed test result for 2500 rpm

Time	Temperature (°C)	Compressor current
3.00 pm	25° C	1.5 A
3.50 pm	14° C	
4.35 pm	10° C	
5.00 pm	7° C	
5.20 pm	6° C	
6.30 pm	0° C	

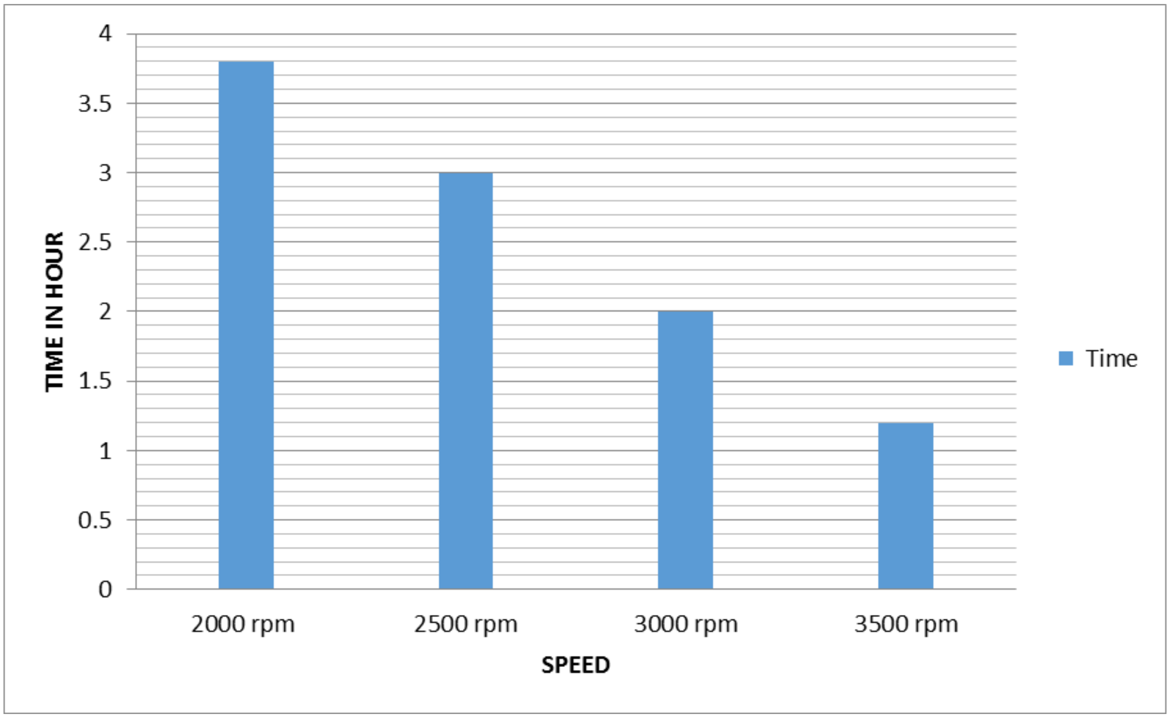


Figure 3.11: Compressor response to different rpm along with time.

From the bar chart we see that as the compressor speed increases the time to reach the desired temperature decreases. This is happening because as the compressor speed increases the BLDC motor rotation in side SC compressor increases and it causes the compressor to circulate the refrigerant gas (R134a) at a higher rate so in result we see that the time to cool down the temperature decreased.

Chapter 4

Energy and Feasibility Analysis

4.1 Energy Analysis

Along with the industrial and transport sector, the residential sector also belongs to the large energy consumer in Asia where cooling appliances like refrigerators and freezers have a substantial share in the residential electricity use. Bangladesh being a fairly warm climate regionand its good soil composition makes it an ideal agricultural industry with large harvest each year. However, due to this "warm climate" storing the harvest is a huge challenge with big energy and financial demands. Hence, energy consumption of household cooling appliances has attracted considerable attention in recent decades both in privet and government sectors.

4.1.1 Working Principle of Refrigeration

Nowadays, refrigerators are common in most household. They are used to store perishable goods and to protect food from bacterial growth which can be achieved in very low temperatures. For this purpose, heat from the low temperature region inside the cooling compartment has to be removed which was absorbed from warm food by conduction or convection process through the wall of the cabinet. According to the second law to thermodynamics, heat flows in the direction of decreasing temperature. This means heat transfer from a lower temperature inside the freezer to a higher ambient temperature cannot occur naturally. Therefore, it requires some kind of heat pump with additional energy input which is achieved by one of the refrigeration systems i.e., vapor-compressor system. The following Figure 4.1 shows the schematic diagram of the refrigeration system.

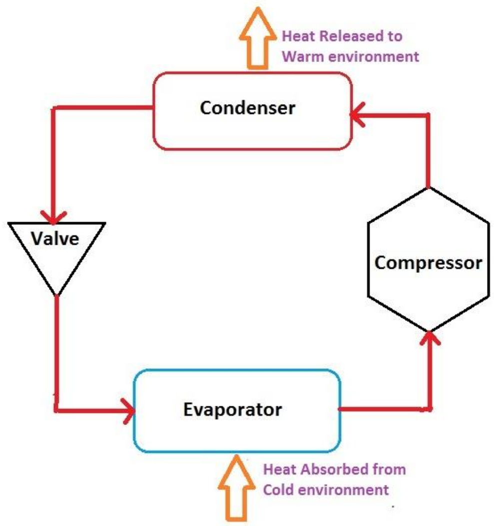


Figure 4.1: Schematic diagram of the refrigeration system.

4.1.1.1 Vapor-Compressor Refrigeration System

The vapor-compressor refrigeration system is the most widely used refrigeration system in practice. The purpose of the "compressor" here is to transfer the heat from a low-temperature inside the compartment of the freezer to a higher outside ambient temperature by compressing the refrigerant that changes its state of aggregation and is released through the discharge end of the compressor at a very high pressure. The refrigerant is again sucked backed by the compressor through its suction pipe at a lower pressure. Usually an AC compressor is used for this refrigeration cycle. However, the developed system uses a "DC compressor" for the following reasons:

- The operating voltage range of the compressor is from 10V – 45V and can be used for both 12V and 24V systems. As a result, voltage requirement makes it ideal for solar applications.
- The compressor is a reciprocating type which uses 78W at maximum condition, hence consumes less power to operate.
- Moreover, the compressor comes with built in variable speed control ,over heat thermal protection, battery protection, motor start error protection and fuse which are all

embedded in the “Electronic Unit Circuit” for an intelligent and efficient operation. The rated speed of the compressor is 2000rpm with the maximum speed increase to 3500rpm which helps to decrease the freezing time considerably.

- This compressor supports both mechanical and electronic thermostat for ease of use and also has support for software (Tool4Cool) controls through the Electronic unit for further ease of use in precisely controlling freezer temperature and compressor speed. The following Figure 4.2 shows the schematic diagram of the Vapor-compressor refrigeration system with DC compressor

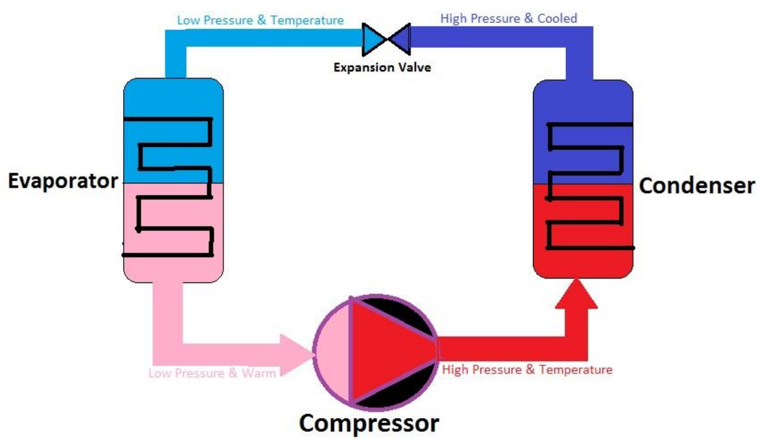


Figure 4.2: Schematic diagram of Vapor-compressor refrigeration system with DC compressor.

4.1.2 Effects of Different Factors on Refrigeration Energy Consumption

Ambient temperature, refrigerator compartment temperature and the load level plays a significant role on the compressor run time, consequently having a large impact on the energy consumption of the overall system.

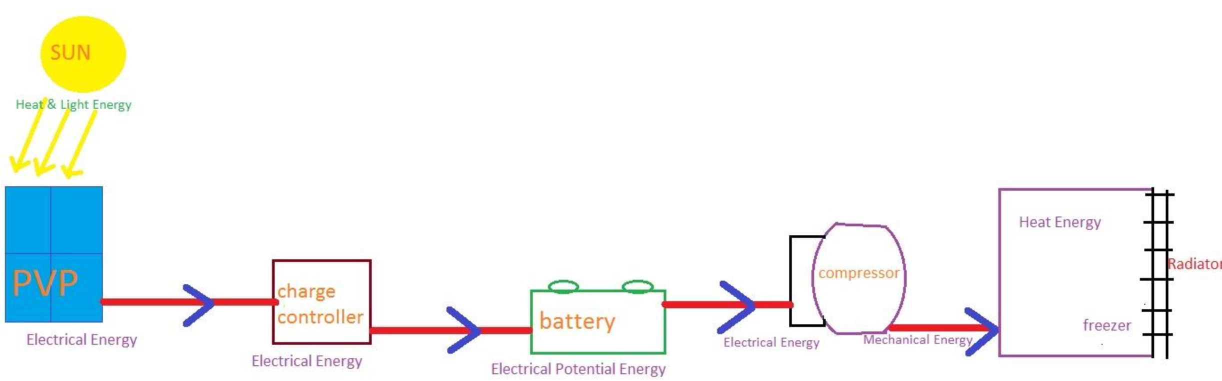
- The Ambient temperature greatly affects the time required to reach the desired temperature and is closely related to the freezer energy consumption. The more the ambient temperature is the more it requires time to cool down the freezer. Hence, the compressor has to run for a longer period of time to reach that desired temperature mark than usual; consequently consuming more energy than usual. This is clear from basic physics, with higher temperature difference between the inside and outside of the freezer;

the system has to work for a longer time to extract heat. Furthermore, high ambient temperature decreases the efficiency of the compressor, hence consuming more energy to give the same output work.

- The refrigerators compartment temperature plays a vital role as well. Position of the thermostat pointer plays the key role. If the thermostat is reset to a lower temperature, the energy consumption rises and vice versa. Hence the compressor run time depends on the particular thermostat position and consequently the energy consumption varies accordingly.
- The Load levelising is also a matter of concern for the energy consumption. The compressor run time also depends on the filling level of the freezer. For a completely filled compartment the system has to extract a huge amount of heat energy from the given load to reach the desired compartment temperature hence increasing the compressor run time drastically, consequently increasing the energy consumption. In practice two-third filling of the freezer is observed for optimum use.

4.1.3 Energy Flow Diagram of the Developed System

The following diagram shows the step by step energy conversion of the whole system. Energy from the sun is mainly of two types: thermal and light. However, light energy is converted to electrical energy by the photovoltaic panel. This electrical energy is then used to drive the compressor where the compressor converts it to mechanical energy. Later the freezer converts it to heat energy. The excess electrical energy is converted to electrical potential energy by the battery.



4.1.4 Energy consumption scenario in different systems

Two “similar” systems is considered with two distinct difference (inverter and compressor) between them while other components remaining the same. Due to this two distinct difference the energy consumption of the systems differs.

4.1.4.1 AC compressor refrigeration system with inverter

The AC compressor inverter system is a typical solar refrigeration system which takes direct current from the solar photovoltaic panels and inverts it to alternating current with the help of an “inverter” to drive the AC compressor. Power is delivered from the solar panels through the inverter, where the inverter itself consumes power to operate, hence consuming a percentage of the input power. Nowadays, inverters has efficiency of more than 90% with the better ones up to 98% of efficiency which generally are very expensive for a household solar system and will increase the initial cost of the system significantly. Moreover, the efficiency of the inverter decreases with increasing power load. The system uses 800W of photovoltaic panel, hence a 1kW inverter with 95% of efficiency is selected for the system for safe operation. The wattage rating of the “replaced” AC compressor is 112W and the required voltage is 220V AC at a frequency of 50Hz. The current drawn is 0.6A with the calculated power factor pf=0.85 (from PF formula). Real power consumed by the compressor is 112W and the Coefficient of Performance i.e. COP of the Panasonic AC compressor is 1.14 [13]

4.1.4.2 DC compressor refrigeration system with direct solar energy consumption

The DC compressor refrigeration system is a distinctive system which takes direct current from the solar photovoltaic panelsand drives the DC compressor directly with the help of a charge controller. The developed system uses a Danfoss BD35F compressor with a 24V 30A MPPT charge controller. The variable speed DC compressor consumes 78.5W at maximum rpm. The developed system is a 24V system where the compressor draws a constant current of 1.2Amps at the rated speed. As it is a direct current system the power factor is not considered and the COP of the DC compressor is 1.48[14]

4.1.5 Power and Efficiency of the systems

For the inverter system, the output power from the inverter to drive the AC compressor is 112W at 95% efficiency; hence the calculated actual real power input to the system is 117.9W (A). The power input to the compressor is 112W, hence the calculated actual power output by the system is 127.7W (B). The calculated efficiency i.e. the COP of the system is 1.083 (C) which is rather low for a cooling system. For the developed system, the dc compressor is the one which consumes all the power; hence, its COP is approximately equal to that of the system i.e. 1.48. The "COP" of 1.083 means 1 kWh of electrical energy is required to remove 1.083 kWh of heat energy from the system; on the other hand the developed system is capable of removing 1.48 kWh of heat energy for the same 1 kWh of electrical energy. As both system uses the same 60Ah battery to store electrical energy, its impact in the efficiency calculation is the same for the both system, hence battery calculation is not considered.

A) Efficiency of Inverter = output power of inverter / input power of inverter.
B) COP of Compressor = output heat energy / input electrical energy.
C) Efficiency of Whole system = actual output power / actual input power.

4.1.6 Advantage of developed DC refrigeration system

The developed system has a greater system "COP" than that of the AC inverter system; hence significantly more heat energy can be removed from the system for the same input of electrical energy.

- Does not use inverter, hence minimizing useless power consumption of the whole system.
- The absences of invert helps avoid imperfect sinusoids from poor conversions, hence retains the longevity of the electrical equipment and most importantly the compressor life.
- Variable speed control allows the dc compressor to run at a higher speed, hence decreasing compressor run time.
- The dc compressor is intrinsically more efficient than the ac compressor, hence making it ideal for solar application.

- The maintenance is easier due to the built-in safety features and intelligent error detection of the compressor.
- The developed system can be easily and precisely controlled according to ones needs due to its digital control unit.

4.2 Feasibility Analysis

Feasibility analysis determines if the project is feasible financially to implement in practical fields. For our case, the feasibility analysis includes Life Cycle Cost (LCC), Net Present Value (NPV), Levelized Cost of Energy (LCOE), Payback Period and battery sizing. For our analysis, we considered three different types of system i.e. the conventional AC freezer, solar freezer using inverter technology and lastly our solar powered freezer using DC compressor.

4.2.1 Assumptions for Feasibility Analysis

For Feasibility analysis three different systems have been considered:

1. Type A: Conventional AC freezer run from national Grid Electricity
2. Type B: Solar powered Conventional AC freezer using inverter. It is off grid.
3. Type C: Solar powered freezer using DC compressor which is totally off grid and DC.

The following general assumptions have been made based on the context of Bangladesh.

1. Electricity is produced by gas, coal, hydro turbine, steam turbine and diesel power plants. Average cost of electricity per unit (kWh) is 14.29 [ref: Power Cell Bangladesh].
2. Annual recurring cost for type A is 1400 Tk. For type B and type C, it is approximately 4930 Tk each.
3. The initial investment costs of type B and type C are 1, 26,240 Tk and 1, 15,500 Tk respectively.

Different economic factors with assumed values are listed in Table 4.2.2 to analysis the financial feasibility analysis of the proposed solar power refrigeration system.

Table 4.1: Economic factors to determine feasibility of the system

Economic Factors	Units
Operation and maintenance cost	5%
Inflation rate	5%
Discount Rate (DR)	7%
General Escalation (GE)	3%
General Inflation rate ($\mathcal{E}$)	5%
Cost of the Energy (COE)	14.29 Tk/kWh
Interest Rate (*i*)	7%
System Life time (n)	20 years
Labor cost in Installation	3000 Tk

4.2.2 Project Feasibility Factors and Results

Different economic factors are demonstrated in Table 1 considering the present market conditions.

Type A is the general freezer that is available in the market. It runs by AC electricity. Type B also uses AC compressor but inverter technology has been incorporated with it to convert the DC current coming from the solar panels and batteries into AC current. It is not available inside Bangladesh. It has to be imported from outside the country. So prices of components have been considered according to the market price of that country [15]. The initial cost for this system is 1, 26,240 Tk.

For type C, the proposed solar panel is four 200 watt 24V panels. Our DC compressor required 24V system so the panels have been connected in parallel. The cost of solar panel per watt is 55

Tk. Life time of the system has to be considered according to the component which has the maximum life time. In our case solar panels have a life time of 20 years. So all other components have been considers for a life time to 20 years. Solar panels cost a total of 44,000 Tk. Hamko 12V 200Ah batteries cost 13,500 tk each and has a life cycle of 5 years. Considering other components the initial cost of type C system gets to 1, 15,500 Tk. The energy consumption of type A and type B are similar as both uses AC compressor and it is 1.2 kWh/day. Whereas, Type C consumes 0.45 kWh/day.

4.2.2.1 Life Cycle Cost (LCC) Analysis

LCC is the method of determining the cost of an entire system considering the initial investment along with other maintenance and operation costs that might occur in future for a sustainable system during a certain period of lifetime (generally 20 years). It generally consists of the initial investment, operation and maintenance cost and component replacement costs during the whole period. LCC not only helps assess future resource requirements but also helps to compare between different relevant alternatives. Comparison makes it clear which one is better. It helps evaluate the long run cost which indicates whether the system is affordable. The LCC of our system is calculated using the following equation-

$$LCC = C_c + \sum_{n=1}^{N} C_{O\&M}^{n} + \sum_{n=1}^{N} C_{r}^{n} \qquad \text{(i)}$$

Where, N is life time of the system, C_c is the capital cost of the system, $C_{O\&M}^{n}$ is the annual operation and maintenance cost of year n, and C_{r}^{n} is the replacement cost of the system. Table 4.2.2.1 shows calculated LCC of different systems.

Table 4.2: Comparison of LCC between different systems

Cost of the items	**Price (in Tk)**
Capital Cost	

	Type A	**Type B**	**Type C**
Deep Chest Freezer	20000	44000	13000
800 W PV Array	-	44000	44000
Solar Charge Controller	-	4400	3500
Battery	-	27000	27000
Inverter		2400	-
AC/DC Switch	-	1440	-
DC Compressor	-	-	25000
Installation cost	-	3000	3000
LCC Capital Cost	**20000**	**126240**	**115500**
Operation & Maintenance Cost			
O & M Cost 20 yrs	20000	126240	115500
LCC O & M Cost	**20000**	**126240**	**115500**
Nonrecurring cost			
Battery in 15 years	-	63000	63000
LCC Nonrecurring Cost	**21000**	**98595**	**98595**
Cost of Electricity	**125180**	**0**	**0**
Total 20 yr LCC	**186180**	**351075**	**329595**
Total Energy (kWh)	8760	8760	14235*
LCC Cost/ kWh (Tk/ kWh)	**21.25**	**40.08**	**23.15**

[Note: * The energy consumption of type A and type B are similar as both uses AC compressor and it is 1.2 kWh/day. For type C energy consumption is 0.45 kWh/day. So type C is consuming

62.5% less energy than type B. For type B total energy is 8750 kWh. So for type C it will be 14235 kWh for the total period of 20 years.

Based on the calculation of LCC, We see that LCC of type C is much closer to type A. And type B LCC is very much higher than the other 2. The purpose of this project is to provide the remote area people with cooling facility where there is no electricity and to contribute to the solution of electricity production shortage. Not to mention it will totally reduce the greenhouse gas production which could have taken place in the process of electricity production.

4.2.2.2 Payback Period (PP)

Payback Period i6s the time required for the investor to recover the investment. For the payback period calculation we applied the following formula:

$$PP = \frac{C_c}{A_s} \qquad \text{(ii)}$$

Here C_c is the capital Cost and A_s is the annual savings.

The following table shows the payback period for type B and type C

	$C_c(tk)$	$A_s(tk)$	**PP (years)**
Type B	126240	6259	**20.17**
Type C	115500	10170	**11.36**

Chapter 5

Conclusion and Future Work

5.1 Conclusion

For proper utilize of solar energy for the off grid areas of the country, this initiative to start the project in a large scale has been taken and it has future prospectus of solving the storage of perishable goods in the rural areas of Bangladesh. For successful implementation and outcome of the project, a comprehensive research work and comparative study has been done to find out the most reasonable and effective technology that could have been pursued. Moreover, various experimental tests have been performed to analyze the overall performance of the project. Not only performance analysis but the financial feasibility analysis (i.e., Life cycle cost (LCC) and Payback period (PV) analysis) gives the overview of the project's efficiency and the financial perks of using the solar energy instead of the electricity in the next twenty years.

The solar cold storage project that has been developed incorporates solar PV panels, a DC compressor (Danfoss BD 35F) and batteries. The DC output from the PV panels controlled by a charge controller simultaneously runs the DC compressor and charges the batteries. As the project does not include any inverter technology there is no power loss in the system hence its efficiency is higher and feasibility is reliable. Moreover, users can change the Compressor motor rpm according to their needs using DC compressor. Some experiments have been done to check the consistency of the system i.e., the performance test, Battery backup test, LED troubleshooting test and the Compressor speed test. In the performance test the time taken to go to a certain temperature has been observed for different loads. (For example 0.5 liter, 10.5 liter, 20.5 liter and 30 liter) Following that, analysis and comparison has been done of the results. Moreover, the battery test showed how many days 200Ah battery can give back up. The projected value is 3.84 days which is very reliable. The compressor speed test includes compressor performance in variable speed controlled by variable resistor. The time taken to reach the 0 degree in different speed has been analyzed in this test. As for the feasibility analysis which included LCC and PP, our system has very less LCC and PP compared to another similar solar refrigeration system (referred to as type B using inverter). This proves that our system is feasible for application purpose.

5.2. Challenges and Future Work

There have been some difficulties and challenges that we have to overcome while doing the project. Firstly, there had been difficulty to decide on choosing the DC compressor i.e. which DC compressor would be preferable for this project as it is the main component of the system. After an ample research, we decided on Danfoss BD 35F and imported it from China. Secondly, the solar radiation has not been the same consistently. Hence the ambient temperature had been different in different performance test days which affected the system's performance. Moreover, there had been continuous fluctuation in the solar current for which a precise way to measure the solar current had to be settled.

The project has a vision of enhancement in a large scale as solar cold storage to preserve large amount of easily spoilt daily goods. The possible future works of the project has been discussed below:

- Firstly, expansion of the micro project into a large cold storage is the prior future plan. In order to do that, the numbers of PV panel need to be increased which will produce higher wattage based on the demand of the load. In addition, the number of DC compressors need to be increased as per the capacity of the cold storage. Hence, the cold storage would be more convenient for bigger quantity of goods.

- Also, the heat produced from the solar panels can be used in a productive and usable way. From a typical solar panel operating in its maximum power point, only 10-15% incident sunlight is converted into electricity [16]. The rest is converted into heat which is emitted into the environment. The heat transfer capability of the PV panels depends on the thermal resistance and configuration of the materials used in solar cells. This solar thermal energy can be used in various productive ways. For instance, the heat can be used in heating water which would give hot water at the same time running the cold storage. (what is the use of hot water I mean where we can use this, just mention one purpose of this hot water) Thus, the solar thermal energy can be used in a useful way.

- Furthermore, the main component of the project which is the DC compressor has a vital feature i.e. its speed control technology. Uniquely, it can operate in variable speed which is a major advantage in controlling the temperature cooling time as per need. In future, a speed optimization device is yet to design which will control the speed of the compressor according to the ambient temperature. Hence, algorithms need to be developed according to the operation required for controlling the compressor's speed.

- Lastly, a temperature control technique needs to be developed that will control the temperature inside the storage and make the compressor on and off as required for the goods. This will help to control the compressors on/off state by controlling for a range of temperature. This feature will give the option to control the freezer's temperature manually according to the temperature needed for different goods. For instance, if the controller has required temperature of 5 °C the compressor will off at that temperature and again start when the temperature gets higher suppose 8 °C inside the cabinet. Thus, it will provide a way to control the temperature inside the storage which subsequently it will lessen the energy consumption.

References

[1] https://en.wikipedia.org/wiki/Electricity_sector_in_Bangladesh

[2] Shiblee, N.H., Solar Energy in Urban Bangladesh: An Untapped Potential, ChE Thoughts 2 (1), 8-12, 2011. [December 2015]

[3] S. K. Nandi, M. N. Hoque, H. R. Ghosh, and S.K.Roy, "Potential of wind and solar electricity generation in Bangladesh," *ISRN Renewable Energy*, vol. 2012, Article ID 401761, 10 pages, 2012.

[4] World Automotive Achievements-Solar Powered Rickshaw, http://www.speedace.info. [March, 2016]

[5] M S Kaiser and A R M Siddique, "Optimal Hybrid Option Analysis for a Remote Location in Bangladesh," International Journal of Advanced Renewable Energy Research, vol-2, issue-2, pp-777-783, 2013.

[6] Dr. R. S. Bharj, Surender Kumar and Rajinder Kumar, "Study on Solar Hybrid System for Cold Storage," International Journal of Research in Management, Science & Technology (E-ISSN 2321-3264) Vol. 3 , No. 2, April 2015

[7] Angelo Freni, Giulio Santori, Alessio Sapienza and Giuesppe Gulli, "Solar Powered Solid Adsorption System for Cold-Storage Applications,"16th CIRIAF National Congress, At Assisi, Volume: ISBN 978-88-6074-755-6, April 2016

[8] Ameen, A. "Development of a solar-powered freezer" Journal ID: ISSN 0001-2505, Volume 100, Part 2; PB: 1372 p

[9] Michael K.Ewert and David J. Bergeon, "Solar powered refrigeration system," Us 6,253,563 B1, Jul. 3, 2001

[10] Mr. Per Henrik Pedersen and Mr. Janos Mate, "Solar powered direct drive refrigerators with hydrocarbon refrigerants"

[11] BD35F-B, Bus-optimized, Direct Current Compressor, R134a, 12/24V DC & 100-240V AC 50/60Hz. http://www.secop.com/fileadmin/user_data/SEPS/datasheets/bd35f-b_101z0205_r134a_12-24vdc_05-2016_desd100x402.pdf [December 2015]

[12] "Battery Maintenance 101", https://www.emarineinc.com/Batteries-Maintenance-101. [October 2016]

[13] “Panasonic Industrial devices and solutions,” https://industrial.panasonic.com/ww/products/motors-compressors/compressors/refrigerant-r134a-induction-compressors-lbp/qb-series/QB51C99GAX0 [December 2016]

[14] “BD35FDirect Current Compressor, R134a, 12 - 24V”,

http://www.discoverysailing.us/bd35 [August 2016]

[15] “Green energy Innovation” http://www.geinnovations.net/Solar-Freezer.html [October 2016]

[16] “Heat Generation in PV Modules”, http://pveducation.org/pvcdrom/modules/heat-generation-in-pv-modules [November 2016]

Appendix:

Assumption and consideration for feasibility Analysis:

Total Energy/Day (For AC compressor)**: 1.2 kWh / day**

Total Energy/Day (For DC compressor)**: 24V*1.3*14.4 = 0.45 kWh/day**

Cost of the Energy (CoE) : **14.29 tk/ kWh [power cell Bangladesh]**

Unit Price of the PV cell : 55tk/unit

Maintenance Cost (O & M) : 5% of Total investment annually.

Discount Rate **(DR)** : 7%

General Escalation **(GE)** : 3%

General Inflation rate **(Ɛ)** : 5%

Interest Rate **(i)** : 3%

Nonrecurring factor : **0.565** (DR=7% & GE 3%; x = 15 yrs)

$$nonrecurringfactor = \left(\frac{1+GE}{1+DR}\right)^x$$

Labor cost in Installation : 3000 tk

System Life time **(n)** : 20 years

Battery Life time : 5 years **{per unit price= 13500tk (12V, 200Ah)} (return value for 2 batteries = 6000 tk)**

LCC:

LCC Capital Cost = All initial costs Added
= **115500** tk
LCC Maintenance Cost = y% of Total Investment or Capital cost
= (**115500** * 0.05) tk
= (X * 0.05 * 20) **[life time 20 years]**
= 115500 tk
LCC Nonrecurring Cost = Battery cost (3 times of purchasing cost) + **0.565 times** Battery cost
= [{(27000*3)-(6000*3)} + 0.565* {(27000*3)-(6000*3)}]
= **98595 tk**
Cost of Electricity = 20 yrs * 365 days * (1.2 * 14.29) (for Conventional AC freezer)
= **125180 tk**
Total Energy = life time * 365 days * term kWh/day

= 20 * 365* 1.2
= **8760 kWh**

Total 20 yr LCC= LCC Capital Cost+ LCC Maintenance Cost + LCC Nonrecurring Cost + Cost of electricity
= 115500+115500+98595 = 329595 tk

Payback Period (PP):

$$PP = \frac{C_c}{A_s}$$

C_c = Capital cost = 115500 tk (for type C)

A_s = Annual savings

For Type C annual energy production is 14235/20 = 711.75 kWh

So A_s = 711.75*14.29 = 10170 tk (for Type C)

Power and Efficiency calculation

Actual input power = 112W / 95%
=117.9W
Actual output power= 112W * 1.14
=127.7W
COP of the whole system =127.7W / 117.9W
=1.083