Report on

Solar PV-Diesel Hybrid Mini Cold Storage for Rural Off-grid Areas of Bangladesh

July 2017

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Background of the Project

Bangladesh is predominantly an agricultural country with more than 70% of the population is living in the rural areas living on agriculture [1]. Fertile land and moderate climatic condition enables the farmers to produce three crops a year. Rice, wheat and maize are the main crops are produced besides significant production of different vegetables throughout the year. Many of the vegetables like potato need storing for 6-8 months to maintain a reliable supply throughout the year. Some other perishable vegetables like tomato, brinjal, parble, papaya etc. are also produced in large volumes and are seldom stored in the cold storages for lack of storage facilities. Usually, the volume of the vegetable produced in a particular season is quite high and the peak harvesting season has duration of 1-2 weeks. This harvesting pattern shows excess vegetable supply in the market during the peak season, and the market gluts. Oversupply during this time causes the price of the product to crash down and the farmers are compelled to sell their products at a lower price that cannot recover even their production cost. Developing a storing facility for a short period of time (1 to 2 weeks) may help the farmers to supply their produced goods at a constant pace. This will reduce the oversupply during the period of harvesting.

In this paper we are proposing a new concept of cold storage that is appropriate for the remote rural areas and can be driven by solar PV. As already mentioned above, we have targeted the storage time to be 1-2 weeks depending on the type of the crop – but not beyond that. A cold storage that can store frozen fish or meat needs to maintain low temperature at subzero levels and the process is usually energy intensive. Such a model will be expensive to operate in the rural areas, as reliable energy supply to the cold storage seems to be the main hurdle. It is a well understood problem that a solar PV based cold storage cannot run during the night hours without battery or alternative generator backups. However, size of the power backup facility will increase the capital and running cost of the cold storage. Hence, an optimized design is important.

Although the usual storage temperature for perishable products like tomato is 8-10° C [3], they can be kept in a cold storage for about 2-3 weeks where the temperature does not exceed 7-8 °C, provided the products are freshly extracted from the field. Although 2-3 weeks may not look like a very effective storage time, it has a significant impact on the market price as over supply can be avoided to a great extent.

Here we propose for a cold storage that will mainly run during the day time by consuming power from the roof top solar PV panels. The usual run time of a cold storage does not exceed 25%. The cold storage will be designed in such a way that the temperature inside the cold storage will go to a minimum of 5-7^{0} C during the day time and will gradually increase to a maximum of 12-15^{0} C during the night hours when there is no energy supply. This will require a critical insulation design for the cold storage and also material charging and delivery management considerations. As for example, new materials are to be entered inside the cold storage in the morning of a sunny day and the cold storage should never be allowed to be opened during the night hours to avoid loss of cooling. A backup diesel generator will remain stand by in case of emergency. In a typical cold storage, the capital cost account for more than 70% of the cold storage cost whereas the rest, around 30%, include the fuel and maintenance cost. We accept that the cost of PV energy will be at least 3.5 times more expensive than the conventional grid power. But such a high cost of energy will not increase the storing cost by a big margin as the significant portion of the cost comes from the capital investment. The cost of storing should be such that it can offset the loss due to rotting and compensate for the increased market price that is expected. In Bangladesh, price of tomato varies by more than Tk. 5-10 per kg and that of potato varies by more than Tk. 5-7 per kg between the peak and off peak period. The calculations presented in the later sections show that an average enhancement in the price of Tk. 1.0 per kg/week can make the scheme economically viable.

So far the renewable energy resources in Bangladesh are concerned; solar PV has been accepted as the most potential and technologically proven resource. Solar PV is widely used in Bangladesh due to its continuous declining price in the world market and soft loan scheme introduced by Infrastructure Development Company Limited (IDCOL) of Bangladesh. Bangladesh has the success story of installing the highest number of Solar Home Systems in the world, reaching more than 3.5 million and growing at a rate of more than 50,000 per month. However, up to October 2016, about 4.1 million SHSs have been installed under the program in the remote areas, where electrification through gird expansion is challenging and costly. Isolated standalone PV system for off grid rural areas has received considerable attraction of the rural people. People at rural areas are now convinced that solar PV system helps to make their life a better one. So, application of PV in rural Bangladesh is not new and local technologies have developed to install and maintain PV based systems. Hence, a scheme of solar PV-based cold storage will be a promising idea for short term storage facility for the farmers.

In this report we are presenting a complete study on Solar PV based cold storage for the off grid areas of Bangladesh, which will cover mostly technical studies of the whole work. It will also represent some of the financial analysis of the cold storage, regarding energy management. Since it is a Solar-PV Diesel Hybrid system, energy flow from both Diesel generator and the Solar PV system has been observed.

Design principle- main challenges

A cold storage uses the basic heat pump mechanism. A regular cold storage uses a mechanical heat pump to pump out the heat from the storage goods stored inside the cold storage. The mechanical heat pump is run by an electric motor or even by an internal combustion engine. However, most of the case it is driven by an electric motor.

The main challenge in this project is to provide electrical power to an electric motor to drive a load like a hermetic scroll compressor of the heat pump. A scroll compressor is usually driven by a single or three phase induction motor. In an induction motor the starting current usually 4 to 5 times higher than the running current, depending on the load nature. To provide this multiple times of high current we need to select a large number of solar panels to provide this current. This will make a financial burden to the whole system. This is one of the challenges in the system. Second big challenge is to drive the system in cloudy weather or in gloomy weather or even at night. In a cloudy weather sudden appearance of the cloud will hamper the power generation of the Solar PV system. This will shut down the system suddenly. In a gloomy weather there will be no output power from the Solar PV system as well. During these periods, if required, we need to run the system. Hence a Diesel backup generating system is required for that purpose. The third big challenge is to run the three phase AC induction motor with the solar panels, which generates DC power. Since, AC and DC are completely different electrical system. The schematic of the whole system is shown in Fig. 1.

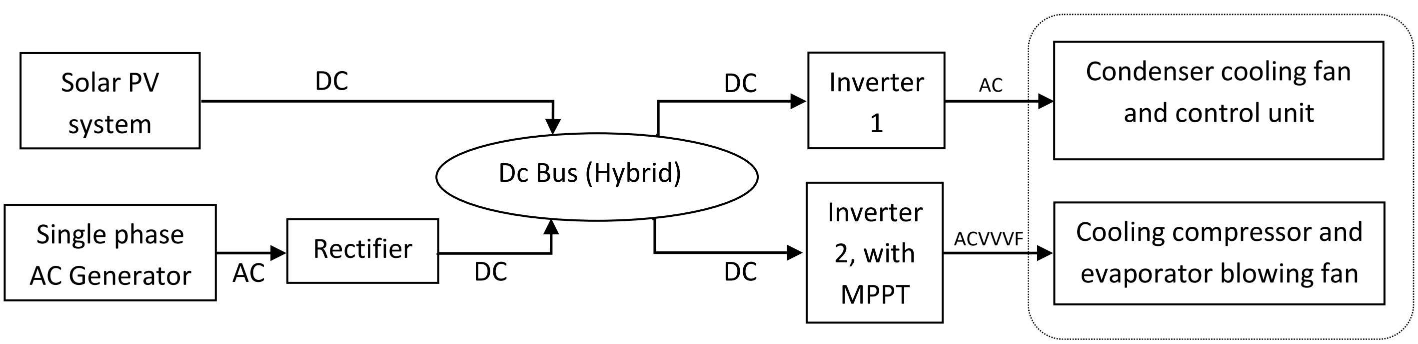


Fig. 1: Schematic of the proposed Solar Diesel hybrid cold storage

From this figure we can see that we have created a DC bus. Solar panels feed this DC bus directly. However, rectification has been done to rectify the AC output of the backup generator. The main challenge of the DC bus is to keep the voltage of the bus close to each other. However, diode has been used at the output of the both sources to avoid feeding back to each other. This DC bus is the feeder of two inverters. Each inverter has been chosen to feed with DC input. However, an inverter produces 3–phase, 3-wire Delta output; there is no neutral in this power electronic device. But the controlling unit of the cold storage requires a Line to neutral voltage, where a neutral point is present. Three single phase transformers have been used to create a 3 phase 4-wire system with correct voltage rating. This has been clarified more at the design steps of this report. The inverter with MPPT controller provides power for the compressor of the cold storage. Since, compressor has a 3-phase, high power (3 kW) induction motor; its starting current is about 35-39 A. A variable voltage, variable frequency (VVVF) drive is a standard device to reduce this starting current of the 3 phase induction motor. Moreover, it makes the run smooth at the starting. Another property of this inverter is its MPPT controller. According to the power (voltage x current) harvesting from the solar panel, it controls the frequency of the output voltage so that it can drive the motor at lower power than its rated power. This is done automatically by this inverter.

The second inverter has been used to provide power for the control unit throughout the day. Since the system has no battery backup system, it uses the solar power to run this inverter. A low power, independent source control circuit has been used to operate this inverter. Moreover, this circuit initiates alarm to startup the generator manually. A detail of this part is written at design step section.

The total system is a Solar PV Diesel Hybrid system, where the system can run with Solar PV system alone, it can also be run by partial sharing of power from the Solar PV and from the diesel generator. A single diesel generator can also run the total system.

Design steps

The design steps starts from the size selection of the proposed cold storage. The following items are considered in the design steps of the cold storage.

1. Selection of the size of the cold room
2. Calculate the size of the cooling system
3. Electrical energy required for the cooling system
4. Electrical system required for the cooling system
5. Voltage level of the system
6. Size of the solar panel
7. Choice of Voltage level of the solar panel
8. Selection of converter for DC to AC conversion
9. To maximize the energy harvest from the Solar PV system a semi-automatic system has been attached with the system.

1. Selection of the size of the cold room:

"A small scale, 37.43 m 3 (5.90 x 2.35 x 2.70), which is standard size of a 20 feet container, prototype cold storage will be designed, built, and tested in the laboratory to evaluate the performance of the system"-mentioned in the proposal. Keeping this word in mind, a cold room of (4m x 3m x 3m) 36 m^3 has been selected, which is available in the market. The company build cold room will confirm the industry standard. A four inch thick polyurethane insulation has been used in the cold room. The insulation is sandwiched by two thin sheets of metal. A standard hinge door flashing outside has been used in this clod room.

2. Calculate the size of the cooling system

To calculate the size of the cooling system, we need to calculate the cooling load at first. To calculate the cooling load we need fix some basic parameters from the beginning.

1. Size of the cold room.
2. Insulating material and its thickness
3. Minimum required temperature inside the cold room
4. Maximum daytime temperature outside the cold room
5. Criterion of the storing items
6. Maximum weight of the storing item
7. Pattern of storing schedule

These are shown in table I.

Table: I

1.	Size of the cold room.	(4 m x 3m x 3 m) 36 m^3, outside dimension
2.	Insulating material and its thickness	Polyurethane, 10 cm thick
3.	Minimum required temperature inside the cold room	5^0 C
4.	Maximum daytime temperature outside the cold room	45^0 C
5.	Criterion of the storing items	Specific heat of the storing goods- green chili, carrot, cabbage etc.
6.	Maximum weight of the storing item	4000 Kg
7.	Pattern of storing schedule	At one time, three equal steps

Cooling Load Calculation of the proposed Cold Storage

Here we need to fix some parameters at the very first stage. Like, insulation thickness -100 mm, insulating material, Polyurethane. Storing criterion, that is we can store 1000 kg of vegetables in one day, or it can be stored in two days, or even three or four days.

For cooling load calculation, we need to calculate the following parameters.

1. Transmission of heat through building.
    a. Transmission of heat through side walls.
    b. Transmission of heat through ceiling
    c. Transmission of heat through floor
    d. Transmission of heat through the door of the cold storage
2. Heat removal from the stored product
3. Respiratory heat generation from the stored product
4. Heat removal from the components inside the cold storage, like bins.

1. Transmission of heat through building:

To calculate the heat gain by the cold storage from outside world, first we start from the interior dimension of the cold storage. Since the outer dimension is 4 x 3 x 3 m^3 interior volume of the storage is $2.8m \times 2.8m \times 3.8m = 29.79m^3$

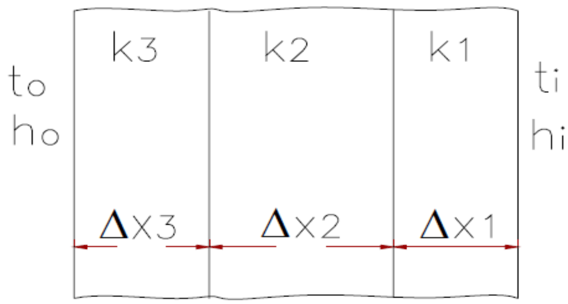
Surface area of walls $2 \times [(2.8m \times 3.8m) + (2.8m \times 2.8m)] = 36.96m^2$

Surface area of ceiling $2.8m \times 3.8m = 10.64m^2$

Surface area of floor $2.8m \times 3.8m = 10.64m^2$

Heat transmission through Walls:

Considering wall consist of 0.326mm (0.000326) steel, 100mm (0.1m). Polyurethane and 0.326mm steel. Heat Equation is $Q = UA\Delta t$



U = conductance per area, Btu/ (hr-F-ft^2)

h = convective heat transfer coefficient, Btu/(hr-ft2-F)

k = thermal conductivity, Btu/(hr-ft-F)

A = area normal to heat flow, ft^2

Δt= Temperature difference(F) (t_i-t_o).

ΔX= thickness of wall

Using these parameters of the equation we can calculate heat transmission by using the following equations.

$$U = \frac{1}{R} = \frac{1}{\frac{1}{h_{in}} + \frac{\Delta x_1}{k_1} + \frac{\Delta x_2}{k_2} + \frac{\Delta x_3}{k_3} + \cdots + \frac{1}{h_{out}}}$$

$$= \frac{1}{\frac{1}{4} + . \frac{0.000326}{12.035} + \frac{0.2286}{0.26} + \frac{0.000326}{13.754} + \frac{1}{15}}$$

$$= \frac{1}{1.196} Kcal/m^2 hr°C$$

$$= 0.836 Kcal/m^2 hr°C$$

This is the heat transmission coefficient of the cold storage. We can use this coefficient for the ceiling and for the floor also. Heat transmission rate for the side walls can be calculated as

$$Q = 0.836 \times 36.96 \times (40 - 5)°C$$
$$= 1081.45\ kcal/hr$$

Hence, heat transmission rate through ceiling can be calculated as:

$$Q = 0.836 \times 10.64 \times (40 - 5)°C$$

$$= 311.33\ kcal/hr$$

This value is also applicable for the floor.

So heat transmission rate for the total building

$$\boldsymbol{Q_{building}} = 1081.45 + 311.33 + 311.33 = 1704.11\ kcal/hr$$
$$= 7130.00\ KJ/hr$$
$$= 171120.00\ KJ/24hr$$

Heat transmission through door of the cold storage:

However, transmission of heat through the door is not present in this calculation. Door opening causes the exchange of heat between inside air and outside air. This can be calculated using the following equation,

$$\boldsymbol{Q_{air}} = \text{room volume} \times \text{air changes per hour} \times \text{air density} \times \text{enthalpy change}$$

= 29.79× 0.0417 × 0.85 × (40-5)

= 38.70 kcal/hr

$= 3886.10\ KJ/24hr$

So the total heat transmission of the cold storage is ($Q_{building}$ + Q_{air}).

2. Heat removal from the stored product:

$$\boldsymbol{Q_{product(1st\ Day)}} = mS\Delta t$$
$$= 1000 \times 0.96 \times 35 = 33600\ Kcal/24hr$$
$$= 140582.4\ KJ/24hr$$

Here, we have considered Green chili, whose specific heat is 0.96.

3. Respiratory heat generation from the stored products (vital heat):

A respiration heat occurs for reaction between the sugar and oxygen.

$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + 2667KJ$$

Here is the equation for Respiration Heat,

$$Q_{res-rate}(kj/hr - kg) = \frac{10.7f}{1000}(\frac{9T}{5} + 32)^g$$
$$= \left(\frac{10.7 \times 3.5104 \times 10^{-4}}{1000}\right)(\frac{9 \times 20}{5} + 32)^{2.7414}$$
$$= 0.396612\ kJ/hr - kg$$

Here, T is a temperature, taken as average 20°C. and f and g are respiration coefficients of various commodities. For Green chili, f=3.5104 × 10-4 and g=2.7414 [*Source*: Becker et al. (1996b).]

$$Q_{respiration} = m \times Q_{res-rate}$$
$$= 4075 \times 0.396612\ KJ/hr$$
$$= 1616.20\ KJ/hr$$
$$= 38788.65\ KJ/24hr$$

Since respiratory heat generation from the stored product is not so high we are considering the full load (4075 Kg) of the cold storage from the beginning. A small change in the cooling load calculation is acceptable.

4. Heat remove from the components used inside the cold storage, bins:

Occupied number of bins in the storage =163

Features	54 cm x 35 cm x 25 cm	
Volume	50 litre(approx.)	
Load	25 kg	
Weight	1.725 kg*163=281. 18kg	
Material	HDPE specific heat 0.57Kcal/kg °C	

$\boldsymbol{Q_{bin}} = ms\Delta\theta = 281.18 \times 0.57 \times 35 = 5609.44\ Kcal/24Hr = 23469.90\ KJ/24hr$

5. Miscellaneous

Misc.	*Watt*	*Kj/Watt*	*Hour*	*Total(KJ/24hr)*
Light	20	3.6	2	144
Fan	180	3.6	2	1296
	workers	*KJ/hr*	*Hour*	
Person	1	1000	1	1000

$$\boldsymbol{Q_{miscellaneous}} = 2440\ KJ/24hr$$

Hence combining all these components we can write;

$$\boldsymbol{Q_{1st\ Day}} = \boldsymbol{Q_{building}} + \boldsymbol{Q_{air}} + \boldsymbol{Q_{bin}} + \boldsymbol{Q_{miscellaneous}} + \boldsymbol{Q_{product}} + \boldsymbol{Q_{respiration}}$$

$$= 171120.00 + 3886.10 + 23469.90 + 2440 + 140582.4 + 0.00$$

$$= 341497\ KJ/24hr$$

Considering 10% heat loss as a factor of safety, $Q_{total} = 375646\ KJ/24hr$

First Day:

At first 1000kg of chilies are kept inside the cold storage. Same amounts of Chilies will be stored in the subsequent days up to 4th day. By taking 12 working hour per day of compressor and since a ton of refrigeration absorbs 12,660 kJ per 24 h: $\frac{375646}{24\times 3600} = 4.348$ kW of peak refrigeration required.

	Q building	Q air	Q bin	Q misc	Q respiratory	Q product	Q total KJ/24hr	Q overall 10% head	heat removing required (kW)
1000	171120	3886	23469	2440	0	140582	341497	375646.7	4.348
2000	171120	3886	0	2440	38788	140582	356816	392497.6	4.543
3000	171120	3886	0	2440	77576	140582	395604	435164.4	5.037
4000	171120	3886	0	2440	116364	140582	434392	477831.2	5.53
Full	171120	0	0	0	116364	0	287484	316232.4	3.66

Here, we have considered that in the first day we will load 1000 kg and this pattern will continue up to fourth day. In the first day there is no respiratory heat. There will be no heat load for the bins from the second day. In the fifth day there will be no heat from the product. Only respiratory heat will be generated from the products. Maximum heat load has been found in this pattern is 5.53 kW. The cold storage has the cooling load of 8 kW. So it is our perfect choice in the design.

3. Electrical energy required for the cooling system

From the calculation of the previous section it has been found that the system requires at most 8 kW heating load capacity to make the cold storage workable. Keeping this in thoughts, the system has been acquired. The electrical energy requirement of this system is around 3.5 kW, considering co-efficient of performance (COP) around 2. This electrical power is used by the compressor, control unit, condenser fan, and evaporator fan.

4. Electrical system required for the cooling system

As mentioned in the previous section, an MPPT controller has been used to maximize the power harvesting from the solar panels. The available MPPT controller for this specific load has a minimum input voltage of 500 V DC and has a maximum input voltage of 800 V DC.

5. Voltage level of the system

The MPPT controller dictates the voltage level in our system. This is a market available controller, whose voltage level is from 500 to 800 V. Hence the choice of voltage level is around 550 V to 620 V.

6. Size of the solar panel

We need 3.5 kW of electrical power to run the system. Considering 60 % of effective power from the solar panel, we have taken a 6 kW_P Solar panel system.

7. Choice of Solar panel voltage

Open circuit voltage of each solar panel is more than 36 V. this will give us 540 V in 15 series panel. However, thirty 200 W_P panels will provide 6 kW power.

8. Selection of DC to AC conversion

A DC to converter system has been thought to provide sufficient AC output for the control circuit of the cold storage, which operates the magnetic contactors, sensors, microcontrollers etc.

9. To maximize the energy harvest from the Solar PV system a semi-automatic system has been attached with the system.

A regular inverter has been thought to provide AC power for the control circuit. An MPPT inverter has been used to maximize the power harvested from the Sun. The DC bus creates in the system creates a simple solution of load sharing between the PV system and the generator system.

Specification of the component used

The following information is from the fabricated Solar PV-Diesel Hybrid Mini Cold Storage

Cold room information:

Cold Room Information	Room Size (m)	4*3*3 m3
	Inside Room Temperature	+5 ℃
	Suitable for Storage Goods	Vegetable
	Machine Weight	500 kg
	Cold Room Panel Thickness	100 mm
	Insulation Material	Polyurethane(PU)
	Double layer Material	0.326 mm Color Steel
	Power supply Refrigerant	380V-50Hz-3P
	Cooling way	R404a
	Working Conditions	Air cooling
	Max. Ambient temp. Evaporating	+45 ℃
	Evaporating temp.	-12 ℃
	Condenser temp.	+40 ℃
	Humidity	85 %
	Noise	55dB

Cooling System Information

Compressor	Brand Name Type	Copeland(America)
	Compressor	Scroll type
	Product Model Power	ZB21KQ
	Refrigerating Capacity	1.62 kw(3HP) 6.2 kw
Evaporator (Cooling fan)	Brand Name	Keweily
	Type	Ceiling-evaporator
	Model	DL-40
	Power	2*0.09 kw
	Refrigerating Capacity	8 kw
	Quantity	1 set
Condenser	Brand Name	CBFI
	Type	Air Cooling
	Model	FNF-10.2/50
	Quantity	1 set
	Power	2*0.12 kw
	Heat exchange capacity	10.2 kw

Electrical system Information:

Solar Panel	Brand Name		Solarland
	Model		SLP 250-24
	Input Power		200 watt*30 units
	Voltage at P_{max}		37.1 V
	I_{SC}		5.39
Inverter 1	Brand Name		LS (Korea)
	Model		SV015iG5A-4
	Rating		1.5 kW
	Input Power		Three Phase 380-480[V]
Inverter 2 (equipped with **MPPT Controller**)	Brand Name	SJ series	
	Model No.	PDS23-4T004	
	DC input	Max Input Voltage	800V DC
		Recommended Voltage, at MPP	500-700V DC
		Recommended PV Array Power	4.8-6.4 KW
	Alternate AC input	Voltage	Three phase AC 380/400/415440/V (+/-15%)
		Max Amps(RMS)	10.5A
		Power and VA Capability	5.9 KVA
	Output	Voltage, Rated	Three phase AC 380/400/415440/V (+/-15%)
		Max current (RMS)	9 A
		Power, Rated	4 KW
		Frequency	0-50/60Hz
Generator	Single phase	7 kVA	220 V AC, 50 Hz
Transformer	Single phase	30 % tapping	3 kVA 220 V AC

Development of the cold storage

Cold room and its cooling system

The cold room of the cold storage is 36 m^3 in size from its outer dimension. 10 cm thick polyurethane foam has been used inside the cold room. This insulating material has been sandwiched by two thin metal sheets. A hinge door has been used at the entry of the cold room. This door is opposite to the evaporator side. The actual picture of the cold room is given below. Cooling system of the cold storage is composed with Condenser, Evaporator and a Compressor.

Picture of the of the actual Cold storage fabricated at the roof top of United International University

According to the specification of cold storage, mentioned in the previous section, compressor of the cooling system draws 1.62 kW power, whose refrigerating capacity is around 6.2 kW. Evaporator draws the power of 2*0.09 kW whether the refrigerating capacity is 8Kw. The type of Condenser is air-cooling. The required power of the condenser is 2*0.12 kW and heat exchange capacity is 10.2 kW.

Solar panel for the desired output

The required solar power is around 4 kW to run the system, which is designed according to cooling system. However, using a good factor of safety we have considered it as 6 kW. To harvest this 6 kW power from solar panel, and make it applicable to the electrical system of the cold storage 15, 200 W_P panels are connected in series. Since each panel voltage is 37.1 V, they will produce 556 V during sunshine. Moreover this series will produce 5.4 A current with 3 kW_P power. Hence, similar circuit of 15 solar panels is made to generate 6 kW_P power, with 10.8 A current. This structure is shown in the picture below.

Picture of the solar panels used in the cold storage

MPPT inverter for the cooler compressor in the cold room

An inverter equipped with MPPT controller has been used to harvest maximum power from the solar panel and make it usable for the three phase compressor motor. The main feature of this inverter is that it can convert DC input to AC output with variable frequency of variable power. Hence the compressor motor can run with lower power at lower frequency. We may lose some efficiency. Nevertheless, we can harvest some solar power from the panels during sudden fall of sun shine or during the period of partial cloudy weather using this inverter. A very careful connection with compressor motor is required here to match the phase sequence of the motor. Otherwise there is chance of damaging the compressor, due to reverse direction of the scroll.

Picture of the inverters used in the cold storage

Regular inverter with transformer

The cold storage has three motor systems. The main and the big motor are inside the compressor. The other two motor systems are inside the condensing unit and in the evaporator unit. Each unit has two motors with blowing fans; which can easily be seen. These motors and the control unit run independently in the whole system. They require a 3 phase 4 wire AC electrical systems. An inverter produces 3 three phase delta system, neutral wire is absent there. To create neutral wire, which is essential for the system other than the main motor, three single phase transformers are used. Transformers are delta connected at the input side and the outputs are wye-connected, which creates a neutral wire for the system. The regular inverter has the option to change input and output voltage level. Using this option the DC input of this inverter is around 550 V and the output is around 400 V 3 phase AC (line to line).

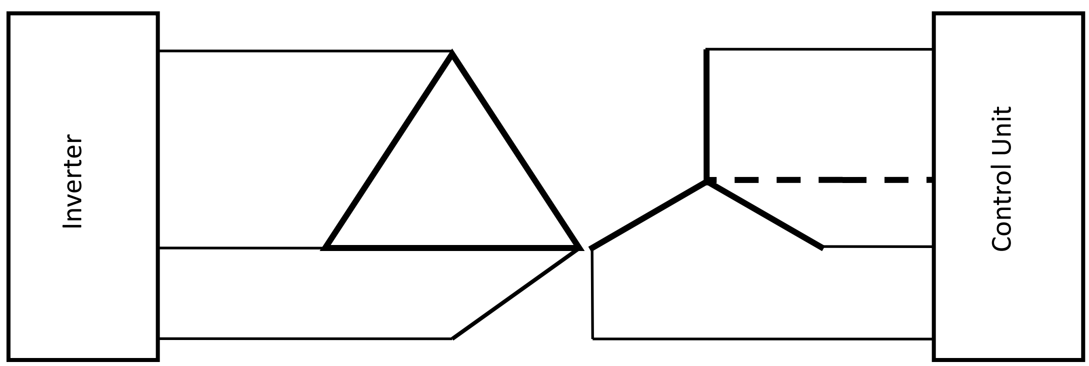


Fig.: The 4 wire electrical circuits used in the cold storage

Generator and its indigenous circuit for the control circuit

The electrical system of this cold storage is designed to operate from 500 V to 650 V dc, depending on the sunshine. A backup diesel generator is present in the system from the very beginning of the project proposal. A three phase generator is required to generate voltage level like 500 to 650 V dc. A three phase generator is available from 10 kVA and onward. So it is an over design in the system, and as well as it creates financial burden to the system. A simple single phase 5 kVA transformer is used to make 500-600 Vdc in the system. The circuit diagram is shown below. This DC voltage is made parallel with the DC voltage of the Solar panel. A capacitor bank at the output of the rectifier has been used to make DC voltage ripple free and provide rush current for the compressor motor.

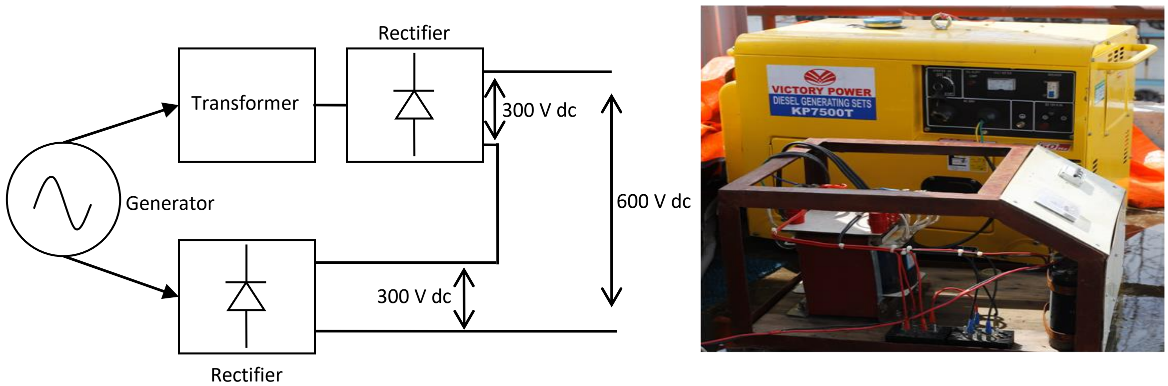
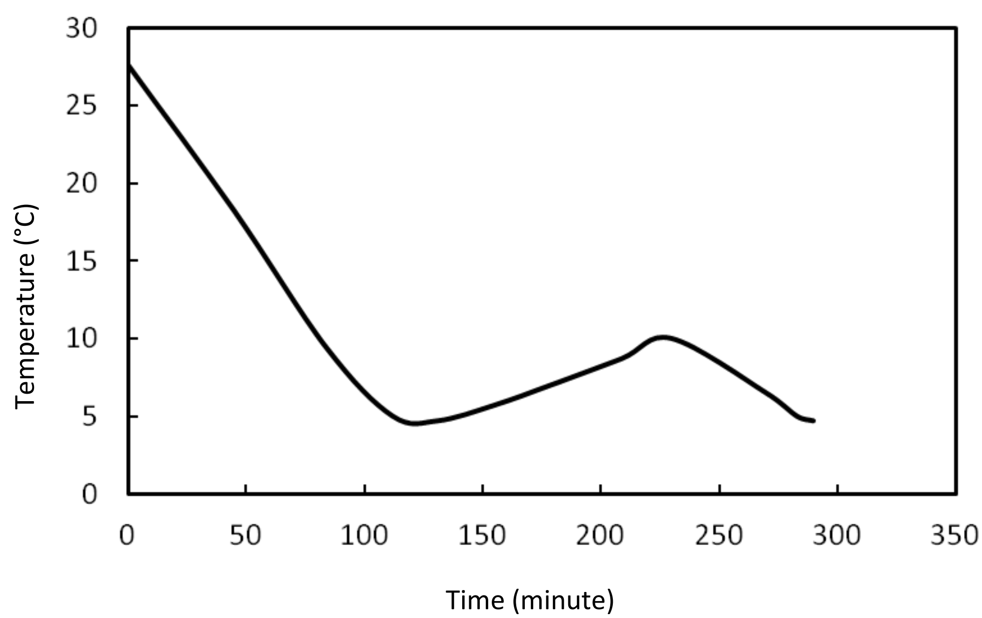


Fig: Electrical circuit and picture of the of the electrical equipment used in the cold storage

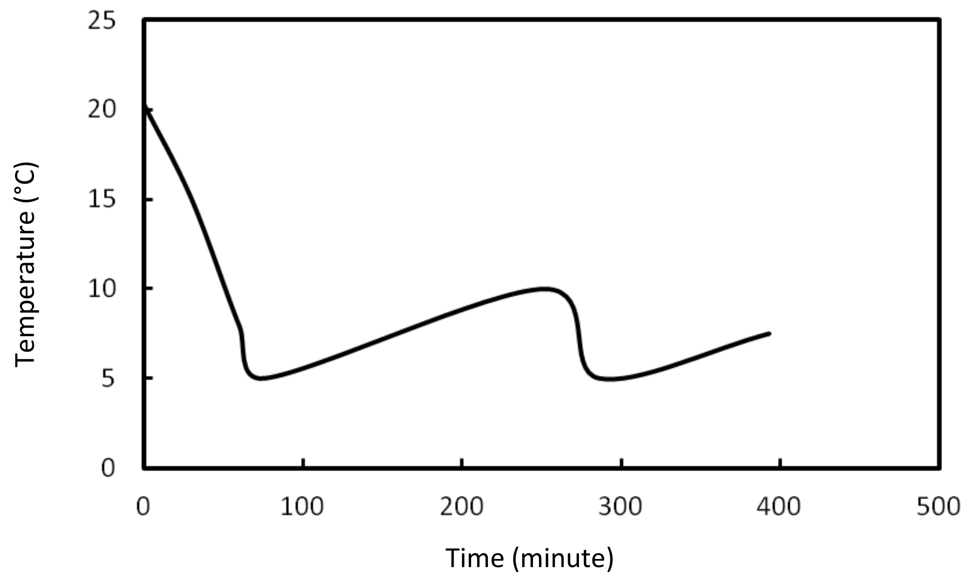
Test run of the cold storage, final technical data, and its analysis

The cold storage has been operated in a sunny day, in a partial sunny day, where sudden fall of sunshine has been found by running clouds, or even at gloomy day. The DC bus, explained in the previous chapters, shows a simple load sharing by the electrical loads. The system can run by the solar panel itself. It can run by the generator also. If it starts by the generator, solar panels in the system can share the electrical loads at the same time. This confirms the maximum utilization of the solar power generated by the panels. The system has been developed by an intelligent way. It will generate an alarm signal, if there is not enough sunshine but the temperature inside the cold room has increased and the cooler compressor needs to be switched on. Using all these features in the system, data has been taken in different dates and weather condition. Here, it should be noted that the minimum temperature of the cold storage is 5 °C. At this temperature the system stops its compressor. It starts its compressor again when the cold room inside temperature reaches to 10 °C. Both these setting can be changed by the controller of the system.

These are presented in the following figures. Temperature has been measured in two conjugative days. The building cooling load has been found less in the second day, which has been assumed in the preliminary stage of its design. The cooler compressor starts. The falling



Temperature inside the cold storage as function of time (At first day)



Temperature inside the cold storage as function of time (At second day)

slope indicates the fall of temperature inside the cold storage. And the rising slope indicates the small increment of temperature inside the cold storage during off time.

This is the figure of temperature profile for the second day. Here temperature falls very sharply compare to the first day. Less than 100 minutes has been found in the second day. Moreover, it has taken more time (approx 40 mins) to rise up to the starting time (10 °C) of the compressor. These two figures confirm the less use of compressor, the main power consumer of the system, in the following days.

Discussion on the project

A technically viable solar PV based Diesel hybrid cold storage has been made and run at the United International University premises. The system can run from the solar power and as well diesel generator power. It runs by both of them simultaneously. Load sharing of power confirms the maximum utilization of solar power. The following costs have been found during the establishment of the system.

	Head	BDT
1	Cold room	850000
2	Solar Panel	330000
3	Electrical system	350000
4	Structure	250000
5	Generator	75000
6	Bins, mats, jars etc	50000
7	Misc	50000
	Total	1955000

This system has no arrangement of battery backup. Hence the cost of battery is not present, which cuts the investment cost. However this is a pilot project. This cost can be minimized in the subsequent cold storage. The structural cost can be minimized if the panels are placed at the ground level in the rural areas. Since we can estimate the cold room size and its technology we may reduce its cost also. There will be no need of electrical system design for the next one. This will also reduce the price of the cold storage.

Conclusion

A "Solar PV-Diesel Hybrid Mini Cold Storage for Rural Off-grid Areas of Bangladesh" has been fabricated and run successfully by us. Some very new findings have been found in the actual scenario. The cooling load of this system was estimated as 2 kW, which is found around 6 kW. Hence 8 kW cooling system has been used. To run this cooling system, around 3.5 kW electrical systems have been used. To harvest sufficient energy to run this system a 6 kW solar panels are used. To run the system during gloomy weather a 7 kVA diesel generator has been chosen instead of 4 kVA. A complete calculation of cooling load and its summary has been presented in this report. All these new findings are important to design, fabricate, and operate a cold storage for the off grid rural areas of Bangladesh. Hope these will be helpful for our country man.