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Energy Efficient Hybrid Solar System for Cold Storage in Remote Areas

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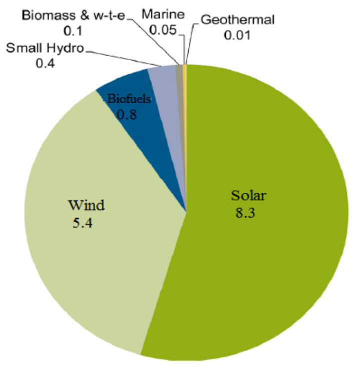
***Abstract*—Stand-alone PV systems have shown to be reliable and cost effective for cooling & refrigeration and have attracted the users. For a specific application with an estimated requirement of cooling in cold storage, low power air conditioning system using PV modules has been designed, fabricated and developed. The paper also deals with our experiences encountered including the successful operation of the refrigeration system during off the sunshine hours continuously for 7 or 8 hours. The calculations of the specific cooling costs show the promising economic effectiveness and reliability of the designed PV refrigeration system. Keeping in view of the technical performance and economic parameter, it demonstrates that this small-scale technology can contribute to solving problems of cooling like small area refrigeration including the transportable and small cold storage container with integrated PV energy supply systems. These systems can be erected on or around a cold storage to obtain the cooling needs while grid electricity cuts frequently or especially in remote desert areas.**

***Keywords*— Hybrid system; Solar-Refrigeration; Solar cooling; solar hybrid cooling system; solar cold storage**

I. INTRODUCTION

India receives sunshine and has clear sky conditions for approximately 300 days in a year. There are several important reasons for considering solar energy as an energy resource to meet the needs of developing countries like India. First, the solar energy received by earth is more than 10,000 times the current use of fossil fuels and nuclear energy combined. The amount of harmful green house emissions are reducing by using solar energy in place of carbon footprint based fuels [1]. Secondly, the growing demand for energy throughout the world has caused great importance to attach to the exploration of new sources of energy [2]. Thirdly, energy is a critical need of many countries but they do not have widely distributed readily available supplies of conventional energy resources. Fourthly, most of the developing countries like India have good availability of solar radiation. Therefore, today most of public markets invest on solar energy based equipments shown in figure 1. In the inverter air conditioning system, the electric circuit controls the capacity supplied by the air conditioner via modifying the motor speed to change the capacity of the compressor. 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. This system operates on solar energy in day time and uses grid energy in night or cloudy days.

In this paper, an application of solar energy for air-conditioning in multipurpose cold storage through our selected design has been presented and discussed. It goes with the concept of converting solar energy into electrical energy which in turn changes into mechanical energy that helps the circulation of air and cooled by DC inverter based vapor compression air conditioner in most instances. Keeping in view of the technical performance and economic parameter, it demonstrates that this small-scale technology can contribute to solving problems of cooling like small area refrigeration including the transportable and small cold storage container with integrated PV energy supply systems [3-5].



Source: UNEP, Bloomberg New Energy Finance
Fig. 1 Public markets new investment in renewable Energy by sector, 2014.

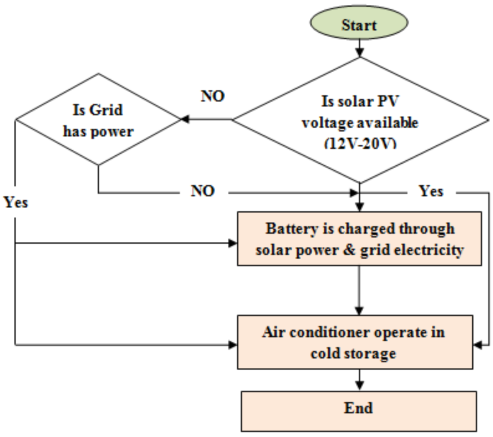


Fig. 2 Flow chart for power switching in DC inverter air conditioning system

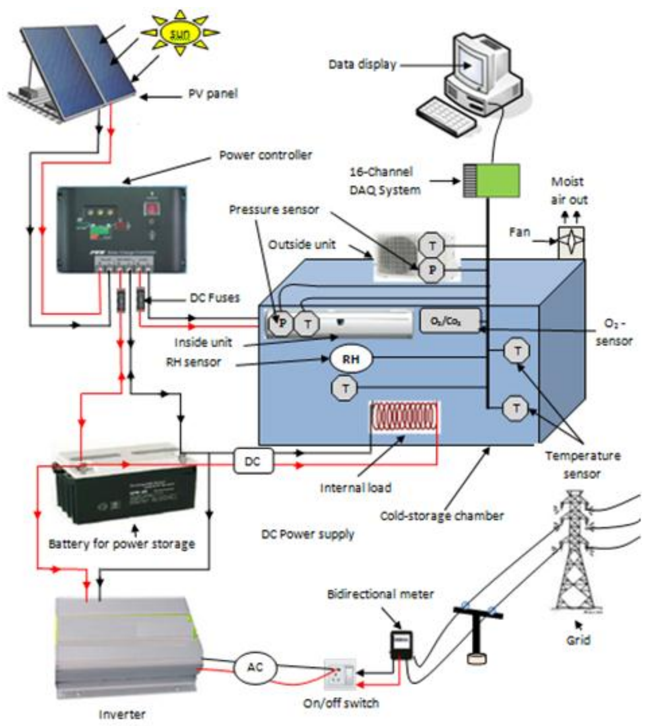


Fig. 3 PV air conditioning in hybrid cold storage with net metering

II. SIZING FOR HYBRID COLD STORAGE

For the application of PCM to improve temperature stability during power loss in cold store, a vertical cabin dimensions 6m H x 4m W x 4m D and a storage volume of 96000 L was used. Anodized aluminum panels filled with PCM (A ethylene glycol solution with a melting point of -23°C) were placed against the walls of the cold cabin in the arrangement. The PCM panels were placed vertically against the entire walls to minimize the amount of usable storage space lost. This PCM panels was covered entirely with poly urethane foam panels. This will reduce the heat transfer from outside to inside the cabin. The PCM will absorb the energy as evaporator coil cools and stores the energy by changing its phase. During power cuts or off peak time the PCM will releases its energy and maintains the cold cabin at constant require temperature for -8°C for about 7-8 hours depending upon the outside condition. Thus a small difference in temperature can be used for storing energy and releasing the stored energy. Phase change material use Ethylene Glycol mixed with water in ratio 1:4. A DC operate fan was mounted on upper right side of cold cabin for remove moisture air from cold storage [5-10].

Volume of hybrid cold storage = Length (L) × Breadth (L) × Height (H) = L.B.H m^3

Capacity of hybrid cold storage = (Vol. × 1000) = (Vol. × 1000) liters

III. DESIGN FOR SOLAR OPERATING A.C SYSTEM

Solar hybrid cold storage has five main parts. Description about these parts are explain blow:

A. DC inverter air conditioning

An air conditioning system includes a refrigerant circuit, which includes a compressor for receiving a refrigerant vapor and for compressing the refrigerant vapor, and a condenser for condensing a portion of the compressed refrigerant vapor into a liquid refrigerant. The refrigerant cycle also includes an expansion valve for reducing a pressure of the condensed liquid refrigerant, and an evaporator for evaporating the condensed liquid refrigerant. The compressor is driven by a DC electric motor which controls a rotational speed of the compressor via an inverter present in cold storage, and a temperature of the inverter is decreased by the refrigerant circuit. The system also includes an electric circuit for determining whether a temperature of the inverter in cold storage is greater than a first predetermined temperature, and an electric circuit for controlling a rotational speed of the compressor. Specifically, when the temperature of the inverter in cold storage is greater than the first pre determined temperature, the electric circuit decreases the rotational speed of the compressor [11-12].

The schematic of an inverter air conditioner is the same schematic of a normal air conditioning with adding an inverter and inverter control unit which reduce the electricity used by reduce or stop the electric motor is shown in figure 4. An inverter air conditioner controller has a DC/AC inverter that changes DC power into AC power with a desired An air conditioning system includes a refrigerant circuit, which includes a compressor for receiving a refrigerant vapor and for compressing the refrigerant vapor, and a condenser for condensing a portion of the compressed refrigerant vapor into a liquid refrigerant. The Figure 4 shown in operation of the DC inverter air conditioning system can be better explained with the aid of the flow chart. The operation of the DC inverter air conditioning system depends on whether the inverter temperature (T) in cold storage is greater than a first predetermined temperature (T_1). When the temperature (T) of an inverter in cold storage is greater than the first predetermined temperature (T_1), this will enforce the controller of the DC inverter to reduce the rotational speed of the compressor. However, when the temperature (T) of the inverter in cold storage is greater than the second predetermined temperature (T_2), which is greater than the first predetermined temperature (T_1), this will switch off the compressor. It this way mention the temperature (T) in cold storage between the first predetermined temperature (T_1) and the second predetermined temperature (T_2) [13-14].

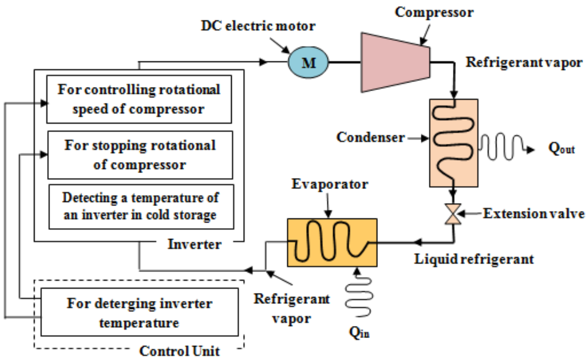


Fig. 4 Schematic of a DC inverter air conditioner

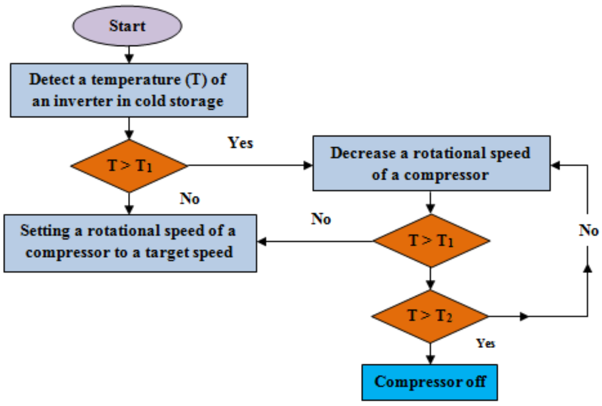


Fig. 5 Flow chart of an operation of the DC inverter air conditioning system

B. *Charge controller*

The charge controller regulates the flow of electricity to protect the batteries from overcharging and over discharging. In this system, a charge controller is used which is needed to extract maximum power point to draw maximum available power. It reduces complexity of system [14].

C. *Battery pack*

In our system arrangement the battery works as a secondary energy source when grid electricity as well as solar light is not present. In our design a lead-acid battery (liquid electrolyte) has been used which is configured for 12 volts. It is important when it comes to getting the right batteries and maintaining them. Economical and maintenance factors are the common issue to select suitable battery. The battery storage must have enough capacity to handle the energy demands by the system especially during periods of very low solar radiation. Rainy day, cloudy weather and at night are examples for the period of low solar radiation [14].

D. *Grid-Connected Inverters*

Grid-connected inverters are supply-driven, they provide all the power supplied from a D.C source to the grid or mains. Therefore, in grid-connected systems, the solar inverter is the connecting link between the solar battery and the A.C grid [14].

E. *PV module selection*

Photovoltaic which is combination of two words; photo for light and voltaic for electricity, converts the energy of sunlight directly into electricity. The conversion from the sunlight into electricity is occurred because of the PV effect. A complete PV system comprises two subsystems. First subsystem is the PV panels that convert sunlight into electricity. In between the first subsystem (controller) and air conditioner, there will be second subsystem which is a set of devices and structures that enables the PV electricity to be properly applied to the load. This third subsystem is known as “balance of system” or inverter [15].

IV. CALCULATION

The charge controller specification is 12 V and rate charging control 24 Amp. Air Conditioner model used in multipurpose hybrid cold storage is Voltas 1.5 Ton DC 18V DY Split A.C. A voltage regulator is designed to automatically maintain a constant voltage level

$$COP_{cooling} = \frac{Desired\ output\ or\ cooling\ capacity(W)}{input\ power(W)}$$

The acceptable COP for the system recommended by the supplier should be 3.25.

$$Input\ power(W) = \frac{desired\ output\ (W)}{cop_{cooling}}$$

$$Input\ power(W) = \frac{5200\ W}{3.25} = 1600\ W$$

Input power required 1600 W.

We need 1600 W with 8 working hour per day

Work ×working hours in day = work hours per day

1600×8 = 12800 W.hr/day = 12.8 KW.hr/day

Let 1 unit cost in Punjab =Rs 6.00.

One day cost =Rs 76.8.

One month cost=Rs 2304.00.

Minimum hour for sunlight per day = 7 hr/day

$$Total\ load\ capacity = \frac{work\ per\ day}{Min.\ hour\ for\ sunlight\ per\ day}$$

$$Total\ load\ capacity = \frac{12800\ W.\ hr/day}{7\ hr/day} = 1828.57W = Approximat\ 2000\ W$$

We need photovoltaic solar system with capacity 2000 W.

The available size of panel with the standard 500 W output

$$Number\ of\ panels = \frac{Total\ capacity}{The\ output\ for\ one\ panel} = \frac{2000\ W}{500\ W} = 4\ Panel$$

Therefore we need 4 panels at 500 W each.

$$Load\ size(Amp.) = \frac{Total\ capacity(W)}{compressor\ voltage(V)} = \frac{2000\ W}{12\ V}$$

=166.67 A.

Assuming drop voltage 30%

166.67×30% = 50 A.

The minimum efficiency of battery 85%

The actual amperes of battery is (85%×166.67) – 50

= 91.67 ~ 92A. h.

The actual capacity of one battery: 92 A. h, working hours: 8 h.

$$\text{The actual Amp.} \frac{92 \text{ A.h}}{8 \text{ h}} = 11.5 \text{ A.}$$

The running current of air conditioning unit is

8.7 A – 11.4 A with starting current of 34.2 Amp.

With total power stored 2000 W, 12 Volt and 167 Ah.

The inverter specifications are: DC input 48 V, AC output 220 - 240 V, output power 5 kW and the charge controller 12 Volts each and charge rating 24 Ampers with over load and short circuit protection [16-17].

V. EFFICIENCY FOR HYBRID COLD STORAGE

The work *W* is consumed by mechanical compressor to produce the cooling power *Qc*. Refrigeration machine efficiency is defined as the cooling power *Qe* divided by work input W [11].

- Refrigeration machine efficiency

$$\eta_{Pow-cool} = \frac{\text{cooling power}}{\text{work input}} = \frac{Q_e}{W}$$

The efficiency of solar panel is defined by the ratio of power (*W*) *kW* to the product of solar panel surface area A_S (m^2) and the direct radiation of solar beam I_P *(kw/m2)*. $I_P=1kw/m^2$ is commonly used for calculation of nominal efficiency [9].

- Efficiency of solar panel

$$\eta_{sol-pow} = \frac{W}{I_{p \times A_s}}$$

$$= \frac{\text{output power of solar panal}}{\text{solar panal surface areaa} \times \text{intensty of solar radiation}} = \frac{W}{Q_s}$$

Where Qs = cooling surface.

- The total efficiency of inverter based solar hybrid cold storage system is

$$\eta_{sol-cool} = \frac{Q_e}{Q_s} = \frac{\text{cooling power}}{\text{cooling surface}}$$

VI. CONCLUSIONS

This paper has presented photovoltaic solar energy processing with applications in the DC inverter technique use in hybrid cold storage air conditioning area. This system can be applied in multipurpose solar hybrid cold storage. The investigation shows that the use of DC inverter air conditioning system can be considered as the most cost effective technology. The application of this technology linked to the India weather will be more reliable, efficient and effective during the summer season when electricity demand is more. The combination of PVT system with DC inverter air conditioning system is the way to improve using of energy efficiently. The performance of the air conditioning system is significantly good. The net metering is also taken into consideration this system will become more economically viable. Net metering enables the user to sell the excess energy back to the utility grid. Thus it gives economic benefit and reduces the impact on the environment by reducing pollution.

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