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A Review of Development and Application of Solar Photovoltaic Powered Refrigeration System

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Abstract: This paper describes the review of previous studies on experimentation and simulation of solar PV panel-based vaccine refrigerator and performance evaluation in different part of the world. In India, there are many regional places where electrical power is not available therefore vaccine preservation is challenge and due to this, people are losing their life. Solar PV based solution would help us to resolve this challenge in India. In South Africa, electricity availability and refrigeration need is a challenge. In techno –economic assessment study, they carried out AC operated refrigerator and DC operated refrigerator with Solar PV based electrical supply and observed that AC refrigerator has relatively high-power consumption in comparison with DC refrigerator. In one of the review paper, they studied the lessons learned across many countries in solar refrigeration units sold by WHO and the outcome of study was for sustainable financing mechanism and incentives, long term maintenance and repair is required. Also, the system design to be carried out with solar experts as well as installations to be done by well trained technicians. The keys to success included the use of WHO PQS prequalified approved equipment supplied by qualified vendor and installation done by well trained technicians. Battery failure in Senegal from 1993 to 2002, @34 villages of the region of Senegal were equipped with photovoltaic powered systems in health centers. 9 of those installations included refrigerators. The proper planning and well training to the technical professional would help to maintain proper caring of all the installed units and those have resulted in a good condition after 5 years later. A PV system set up with a refrigerator having 25 mm PU foam insulation thickness, min. 320 W panel capacity along with 50 Ah battery capacity and with 50 mm insulation, 200 W panel is capacity is enough. In both combination, unutilized power is not used by the system in the peak sunny days. With the change in AC compressor motor to DC compressor, inverter is not required and load on the PV panel would be less. In case of AC refrigerator, power surges of magnitudes 250-425 W during cycling whereas in case of DC refrigerator, power surges of less than 75 W. With the previous learning on Solar refrigerators failure across many places in the world, recommendation is to plan properly initial and recurring investment for the future, also allow only professional system designers, Plan for perfect installation and repair services and closely monitor the cooling performance of the solar refrigerator. With the help of solar tracking system, the best possible power from PV system can be produced from sunshine to sunset.

Keywords: Solar Photovoltaic (SPV), Solar Cooling Technologies, Refrigerator, Vaccine Cold Chain, Renewable Energy

1. Introduction

This paper describes the study and review on development in solar refrigeration domain, its experimentation and performance evaluation of domestic refrigerator operated on solar photovoltaic powered vapour compression and thermoelectric refrigeration system to store vaccine and household stuffs [1]. In India, many remote areas where grid electricity not widely available, and due to non-availability of vaccine on needed time which resulting into loss of lives. Solar PV operated refrigerators would resolve these limitations [2]. The electricity produced by SPV panels could be used to operate refrigeration units [3]. An economic assessment of AC operated compressor refrigerator system installation cost is higher by 18% than DC operated compressor refrigerator [4]. In USA, solar refrigerators are introduced in immunization programs and strengthened accordingly for strong funding mechanisms and incentives for medical staff and workers as well as technicians were to carry out periodic maintenance, repair, and replacement parts of the refrigeration units [5]. The solar operated vapour compression refrigeration system requires power consumption which happens 34.14 kWh/day and photovoltaic array with a exposed surface area of 27.58 m^2 produce sufficient electricity to meet the power consumption [6]. Multiple working fluid in solar absorption system and adsorption system given different results with their advantages and limitations. Although the coefficient of performance of absorption cooling system is better than adsorption system [7]. Solar driven thermoelectric technologies is being used widely in refrigeration field. They are much better in technologies not only meet the need for refrigeration and air conditioning applications but also can fulfill the demand for energy conservation and environment protection [8]. It has been observed that solar refrigeration will play major role in meeting the requirements of people in the rural areas of developing countries like India for refrigeration needs. Many solar technologies have been proved to be technically feasible and compatible and have further scopes for development in our daily life [9].

2. Literature Review

In the study of performance evaluation of a solar powered photovoltaic operated household refrigerator, prototypes, and experiment as well as simulation steps of making a 165-litre domestic refrigerator into a solar powered refrigerator [1]. A refrigerator (165 L) capacity consists of wire condenser tubes at back sides and the compressor mounted at the bottom place has been used. R- 34a refrigerant was used in the system. The input power of the compressor is 110 W and it operates on 220 V, 50 Hz power supply. The rated r current is 0.95 A. A thermostat used to control inside temperature and compressor Cut In and Cut Off as per defined specification of Thermostat i.e. Switch On +1-9°C and Switch Off -2-18°C. Four 35 Wp Solar Photovoltaic panels were used to convert the solar energy into an electrical energy. The type of Solar Photovoltaic panels were Mono-crystalline silicon type and rated capacity 35 Wp with short circuit current 2.4 Amp and maximum power voltage 16.4 V. The panels were arranged a set of 2 in series and in parallel with other set of 2 panels in series. The objective of this arrangement was to have enough potential difference across 24 V battery bank to get properly charged. To provide the back up when no or less solar intensity, a battery bank is used. It consists of 2 nos. of 12 V-135 Ah lead acid batteries was connected in series. The battery bank was connected to compressor through inverter and transformer system which was used to convert the Direct Current from SPV system or the battery bank to AC current at required frequency and voltage to run the compressor. The household refrigerator and other equipment were kept in a separate room with all sides with fully made of Poly Vinyl chloride sheets and other insulating materials. The solar panels were placed in high sunlight coverage throughout the day, at an angle of 45° to the horizontal facing south direction. During experimentation, pull down test and warm up tests carried out at 42°C hot atmospheric conditions. The temperatures were dropped down when the compressor was running and rise during the cut-out period. A max. COP of 2.102 and pull-down time of 40 minutes were observed in the system during test. The current values of COP kept on decreasing as we approach to noon. The zero COP value denote the cut off the compressor [1]. It was technically feasible to convert a household 165-liter refrigerator to photovoltaic refrigerator under normal operating conditions. The normal operation test and pull-down cooling speed test indicates about 140 Wp photovoltaic capacity and 2 nos. 12 V-135 Ah battery banks which was the best possible configuration required for this converted unit system to work better under the normal ambient conditions. During the test was the system was capable to maintain a temperature in the freezer compartment as specified by the WHO (World Health Organization) for vaccine preservation (0-8°C). In India, there are different places where the electrical power supply is not continuously widely available therefore vaccine or food stuff preservation is always challenge due to which people are losing their lives. Solar photovoltaic powered energy-based refrigerator may resolve these challenges. By optimized design for re-sizing of PV panel, right battery capacity and well cabinet insulation thickness for a photovoltaic operated household refrigerator will meet this purpose [2]. By increasing number of panels which provides guarantee for the operation of refrigerator in the cloudy weather days, however it increases the cost of the system. Duty cycle (ON/ OFF percentage of refrigerator) remains constant irrespective of the SPV panel size and capacity. A 25 Ah battery capacity was insufficient for this system as it charges and discharges fast. It has been observed that by increased PU foaming thickness, the yearly power consumption is decreased, and the duty cycle also reduces. When we increased the PU foaming insulation thickness more than 75 mm the duty cycle and power consumption would reduce at a very low significant rate. It has been observed that a refrigerator with 25 mm PU foaming insulation thickness, minimum 320 W panel capacity along with 50 Ah battery power capacity is required. If the insulation level get increases up to 50 mm then the 200 W panel capacity is sufficient to operate the refrigerator. The study elaborates the performance of a modified direct cool conventional type of refrigerator to work with a system as a PV powered one [3]. The project carried out on conventional cooler. The modifications required to reduce useful gross volume capacity by 30% hence the energy consumption drop down to 1.53 kWh/day for the refrigeration purpose with 15 hours running of the compressor, during the conservation the load was @1.7 kWh with the system operating till 24 hours. A comparative study on technological and economical assessment of a converted DC household refrigerator and a conventional AC household refrigerator, both powered by solar PV was carried out in Ghana [4]. The experiment carried out on 92 L two identical domestic refrigerators. Both refrigerators connected to the PV power supply and measured the cooling performance and power consumption accordingly. Figure 1 indicates that the one side is set up for the AC refrigerator and the other side for the DC refrigerator.

For the AC operated refrigerator, solar panel of 250 Wp, battery of 100 Ah, SPV Charge controller of 25 A and inverter with 500 W capacity were installed. For the DC operated refrigerator, solar panel of 200 Wp, battery of 100 Ah and SPV charge controller of 20 A were installed. In the study of solar powered units installed across world and observed that so many technical and qualitative problems in those units. Using solar powered type of refrigeration system for vaccine storage where other resources of electricity are inadequate or costly [5]. Some lessons learned out of it with solar powered refrigeration system field experience and identified critical factors for successful introduction of solar units into immunization programs in the future including.

1) Long term funding policies and incentives scheme for health workers and technicians is required to support long term maintenance activity, repair and replacement units.
2) System design to be done by well-trained solar refrigeration professionals taking into considerations of the conditions of installation sites.
3) Installation and repair be carried out by well-professional Engineers and technicians.
4) Cooling performance is continuously monitored and stick with protocols are to be followed to track the data which indicates problems.

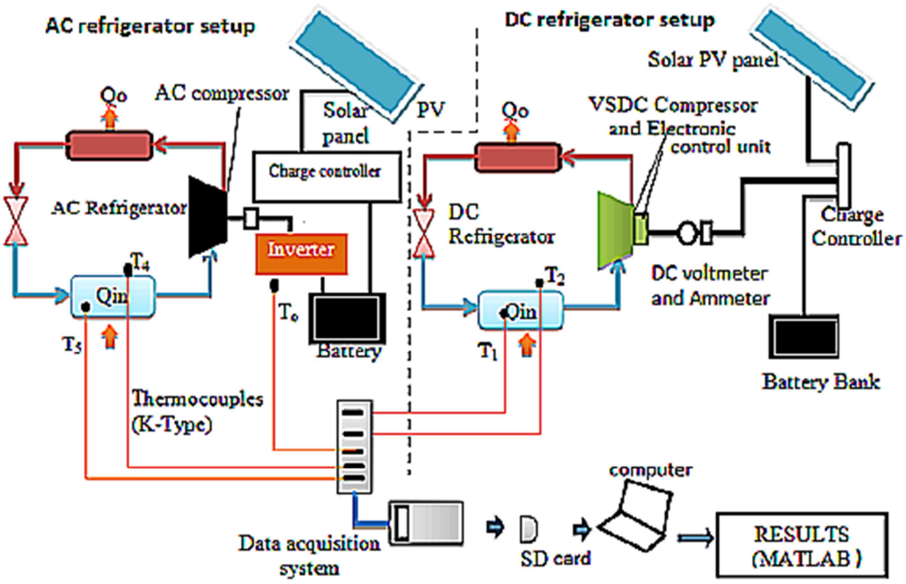

***Figure 1.** Experimental set up for AC and DC refrigerators.*

While reviewing the country experience and its challenges, it is noticed that since 2005, UNICEF has supplied 6500+ nos. solar photovoltaic powered vaccine refrigerators out of which 6048 nos. were battery based and 495 nos. were direct drive, with the highest numbers supplied to Africa. About 80 nos. solar powered refrigerators were supplied to Ghana in the late 1980s, but they had faced a high failure rate (close to 51%) immediately after installation. With Indonesia experience, in 1998 analysis team reviewed the data available on the status of solar 520 nos. solar refrigerators installed in 1991. Report shown a lack of spare parts and technical knowledge and competency was a major challenge. In Northern Nigeria, only 25 nos. of 74 nos. refrigerators were working healthy when inspected a few years later after installation in the early 2000s. However, the program identified for 32 nos. solar refrigerators candidates for recovery and was able to reinstate 28 nos. out of them. 75% of the repair required were related with either to the battery or the electronic operated battery controller. Success in Sierra Leone, after 8 years, around 75% which are > 700 nos. solar operated refrigerators were installed to replace gas absorption type of refrigerators are still in working condition. The keys to success included the use of WHO PQS prequalified approved equipment supplied by qualified vendor and installation done by well trained technicians. Battery failure in Senegal from 1993 to 2002, @34 villages of the region of Senegal were equipped with photovoltaic powered systems in health centers. 9 of those installations included refrigerators. A system was put in place whereby each health centers had to contribute a monthly payment towards maintenance. With all these above lessons learned, author has suggested to follow below recommendations.

1) Make proper planning of initial and recurrent investment.
2) Allow only professional system designer for system designing.
3) Monitor cooling performance of all the units.

A solar powered VCC refrigeration system has been used in this study. It is carried out for every hour basis simulation and performance of solar powered vapour compression refrigeration system [6]. The Vapour Compression Refrigeration system was investigated for different evaporation temperatures and months in Adana city situated in southern region of Turkey. First, the hourly cooling load capacities of a sample building during 23rd day of May, June, July, August, and September months were determined by using meteorological data such as hourly average solar intensity radiation and climatic temperatures. According to the obtained results for the 23rd day of July, the higher amount of the PV electrical power production for Te=-10°C occurs as 5.55 kWh at 1:00 PM. The daily highest compressor power consumption is the same as the daily total PV power production with amount of 47.85 kWh/day. A study carried out on a review of solar thermal refrigeration and cooling methods [7]. The different cooling systems have been studied i.e. solar photovoltaic cooling system, absorption cooling system with different cooling fluids etc. In solar photovoltaic cooling system, PV modules, the battery, the inverter, and the AC unit has been used for experiments. Due to the whole year availability of solar irradiance, solar energy can be easily collected all over the world. Although the solar photovoltaic operated system can provide electricity as well as meets the refrigeration needs, solar thermal refrigeration is much better effective. Solar thermal cooling technologies are being used over the world for industrial and office cooling applications. These cooling systems are more applicable in remote regions where conventional cooling is quite difficult and solar energy is always available. These systems are also more often suitable than conventional refrigeration systems because global warming free working fluids (instead of chloro-fluorocarbons) are used as refrigerants. This study briefed all the different working fluids of solar absorption cooling systems and adsorption cooling systems, providing different results with their advantages and constraints. Though the coefficient of performance of absorption cooling refrigeration systems is much better than that of adsorption cooling systems, the higher temperature issues can be easily handled with solar adsorption cooling systems. Moreover, solar hybrid cooling systems can provide more cooling capacity and better coefficients of performance by eliminating some of the problems encountered with individual working pairs. A study described a couple of technical and economical comparison of existing solar cooling systems, including both thermally and electrically driven. Focused on prospects for solar cooling – an economic and environmental assessment [11]. They have compared each technology including projections about future costs of solar electric and thermal systems.

3. Results and Discussion

A PV system set up with a refrigerator having 25 mm PU foam insulation thickness, min. 320 W panel capacity along with 50 Ah battery capacity and with 50 mm insulation, 200 W panel is capacity is enough. In both combination, unutilized power is not used by the system in the peak sunny days. With the change in AC compressor motor to DC compressor, inverter is not required and load on the PV panel would be less. In case of AC refrigerator, power surges of magnitudes 250-425 W during cycling whereas in case of DC refrigerator, power surges of less than 75 W. With the previous learning on Solar refrigerators failure across many places in the world, recommendation is to plan properly initial and recurring investment for the future, also allow only professional system designers, Plan for perfect installation and repair services and closely monitor the cooling performance of the solar refrigerator. With the help of solar tracking system, the best possible power from PV system can be produced from sunshine to sunset. With different working fluids in solar absorption system, COP of the cooling system is better than adsorption system. With wide use of solar driven thermoelectric technologies, need in refrigeration, air conditioning and power generated can be fulfilled. With solar cooling technologies, needy people in rural areas can meet their requirement for vaccine storage. Further potential in solar cooling technologies is needed on less energy conversion efficiency, the highest cost of solar collectors and thermally activated cooling technologies. The solar photovoltaic cooling system cost is highly depending on PV panel cost.

4. Conclusions

DC operated compressor will have less cost in comparison with AC operated compressor system, which improves the overall efficiency of SPV system. Higher insulation thickness is always useful to contribute better performance of cooling system and PV efficiency. Key learnings are identified to make successful project of vaccine refrigerator which are proper investment planning, professional system designers and well-trained technicians. Without Government financial subsidy with substantial figure, payback of SPV investment would be not viable. Further research is needed on economic and environmental assessment aspects.

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