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RESEARCH ARTICLE

DESIGN ANALYSIS OF SOLAR POWERED PHOTOVOLTAIC REFRIGERATOR

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ABSTRACT

The research work is design analysis of solar powered photovoltaic refrigerator. The refrigerator in view is vapor compression system employing R134a or tetra fluoro methane as working fluid. The energy source to power the circulation of the working fluid is solar energy comparable with the conventional power from the national electricity grid. The solar power modules encompass photovoltaic panel to convert solar energy to unsteady direct current, a charge controller to stabilize the unsteady direct current, a battery as storage system or power bank to store electrical energy and an inverter to convert direct (DC) to alternating current (AC). The alternating current that is produced drives the AC compressor of the PV refrigerator. Design calculations for the PV refrigerator were performed with customized MS Excel spreadsheet.Comparative analysis of the operating temperatures of the evaporator of the PV refrigerator and the conventional vapor compression system with power source from national grid was made. At time interval 0 to 25 minutes in step of 5 minutes, the temperature difference for the two versions of refrigerating systems was 2^0C. Hence, the two versions of refrigerating system have more or less the same coefficient of performance (COP). But, the problem is that the PV refrigerator is the best option. The reason being that PV refrigerator operates on solar energy; a renewable form of energy, emission free and more environmentally friendly.

INTRODUCTION

Refrigeration could be defined as the process of conditioning a space or an environment to the required temperature to produce heating effect (heat pump) or cooling effect (refrigeration and air conditioning). The latter scenario which is the central focus of this work (refrigeration) is for preservation of perishable foods or a product. The current trend today is two types of refrigeration system are in place vapor compression and vapor absorption refrigeration system powered by electrical power from national grid. [Alamsyah, 2003] Rightly affirmed that the dividing line for the choice of the two variants is the coefficient of performance (COP). The new entrant, the solar powered photovoltaic refrigerator is in a state of continuous research and development and more so the best campaign for the sole reason that power source is renewable and in terms of level of emission more environmentally friendly [Sayigh, 1979].

LITERATURE SURVEY

[3]Delved into the possibility of using solar voltaic powered vapor compression system, continuous and intermittent liquid absorption or solid adsorption system.

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It is believed that these models would be more versatile systems in the rural and the remote areas. Domier, built and tested solar icemakers using strontium chloride and ammonia as the working fluids. A field trial in Delhi was partially successful, but there is the need for further development [Bansal, 1997]. A solar diffusion absorption refrigeration was built and tested. The generator design was successful in that the solution pumping rate was near optimum over the full range of generator's operating temperatures. Along the line, difficulties with hydrogen flow rate was encountered, resulting in poor evaporation rate of the generated ammonia. In essence, the overall COP was less than 0.05 [Hinotani, 1986]. A group of researchers simulated the performance of solar powered solid adsorption refrigerator with variouscollector design parameters and environmental parameters. It is believed that this body of work will lend itself to further studies in the design optimization of solar cooling system [Li, 2002].

Research Significance: The existing models and designs of solar refrigeration system had been discussed. The solar absorption and adsorption system are prone to low COP due to low working pressures. Hence, the inability to achieve sub-zero evaporator temperatures. More so, the construction and fabrication procedures demand specialized skills, comparable with the photovoltaic refrigerator driven by AC compressor. The solar absorption and adsorption system have low availability due to the high cost of the compressors.

Hence the AC drive photovoltaic refrigerator is the best campaign for cheap and efficient solar refrigeration system. The central focus being that it relies on renewable energy and the emission level is very low when compared with vapor compression system relying on national grid as power source. It is worthy to note that the low level of emission makes the system more environmentally friendly.

MATERIALS AND METHODS

Materials: The conventional vapor compression refrigeration system relies on national electrical grid for power to drive the compressor. The photovoltaic refrigerator uses the electrical power supplied the photovoltaic cells having been converted from direct current (DC) to alternating current (AC) to drive the compressor. In all cases, the compressor circulates the working fluid known as refrigerant to extract heat from insulated enclosure known as evaporator. The major components of PV refrigerator are: solar PV panel, charge controller/inverter and refrigerator set. The components of the system are as outlined:

Solar PV Panel: The PV panel cells being semiconductor such as silicon converts sunlight into electrical energy by photovoltaic effect.

Storage Battery: The direct current from the PV cells are stored as electrical charges in the battery. The stored energy are made available when needed.

Charge Controller/Inverter Unit: The charge controller regulates the voltage produced from the PV cells before the charges are stored in the battery. It functions also as a medium to prevent the battery from being over-charged or over-discharged. Hence, it supplies the right amount of energy to the battery for prolonged life. The inverter converts the low DC voltage to useable AC voltage. See Figures 1 and 2.

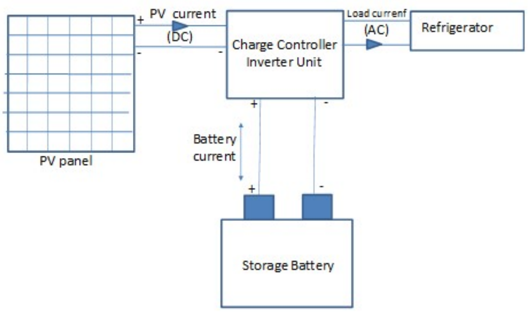
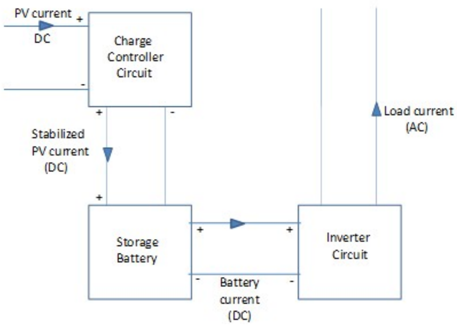


Figure 1: Configuration of Solar PV Powered Refrigerator



Other vital components required to build the PV refrigerator are as follows:

B Applicable Models for Vero Boards: This is a preformed circuit board made from copper strips and mounted on insulating bonded paper. It forms a more permanent circuit with more reliable connections than the one built from breadboard.

- **Resistors:** This regulates the flow of electrical current in the circuits.
- **Capacitors:** Capacitors are means of storing electrical energy in a circuit. They serve to stabilize energy flow of the system as well as band filters for passage of specific amount of current and voltage of specified waveform and frequency.
- **Diodes:** Diodes are used as signal rectifier, signal limiters, voltage regulators, switches, signal modulators, signal mixer, signal demodulators and oscillators.
- **Transistors:** Transistors regulate voltage or current flow in electrical circuits and act as button or gate for electronic system.
- **Transformer:** This acts in any circuit as voltage or current regulator. It could be a step-up or step-down transformer.

B Design Considerations

Sizing the PV Solar Module/Panel: According to[9], the daily energy demand (E_L) from the PV is expressed as:

$$E_L = \frac{E_S}{\eta_{Overall}} \quad (1)$$

$$\eta_{Overall} = \eta_{PV} \times \eta_B \times \eta_{INV} \quad (2)$$

$$E_S = W_C \times H \quad (3)$$

$$H = \frac{2}{3} \times t_H \quad (4)$$

Where:

E_S—estimated daily energy demand.
$\eta_{Overall}$--overall efficiency of the system.
η_{PV}--PV panel efficiency.
η_B--battery efficiency.
η_{INV}--inverter efficiency.
W_C--power rating of the compressor.
H—average daily hours of operation of the refrigerator.
t_H--total hours per day.
The PV floor area (A_{PV}) as expressed by [10] is as follow:

$$A_{PV} = \frac{E_L}{l_{av} T_{CF}} \quad (5)$$

Where:
l_{av}--average daily energy (solar isolation) input per year.
T_{CF}--temperature correction factor.
The PV peak power (W_{PVP}) at peak solar isolation (PSI) is given as (Alamsyah et. al, 2003):

$$W_{PVP} = A_{PV} \times PSI \times \eta_{PV} \quad (6)$$

The total system direct current (I_{DC}) needed to power the system is as expressed (Assad, 2010):

$$I_{DC} = \frac{W_{PVP}}{V_{DC}} \quad (7)$$

Where:
V_{DC}--system DC voltage.

PV panel modules must be connected in series and parallel arrangement to meet the desired voltage and current of the system. The number of PV modules in series (N_{ms}) is given by the expression:

$$N_{ms} = \frac{V_{DC}}{V_r} \quad (8)$$

Where:
V_r--rated voltage of one module.
The number of PV modules in parallel (N_{mp}) is as given:

$$N_{mp} = \frac{I_{DC}}{I_r} \quad (9)$$

Where:
I_r--rated current of one module.
Accordingly, the total number of PV modules/panel (N_m) is given as:

$$N_m = N_{mp} \times N_{ms} \quad (10)$$

Sizing the Battery: The empirical relation for sizing the storage capacity of the battery in kWh (S_{BC}) is given as [Wenham, 1994; Mahmood, 2006]:

$$S_{BC} = \frac{N_A \times E_S}{DOD \times \eta_B} \quad (11)$$

Where:
N_A—battery life.
DOD—maximum permissible depth of discharge of the battery.
The storage capacity of the battery in Ampere-Hour ($S_{BC}^{'}$) is expressed as:

$$S_{BC}^{'} = \frac{1000 \times S_{BC}}{V_B} \quad (12)$$

Where:
V_B--direct current voltage of one the batteries.
The total number of batteries needed (N_B) is given as:

$$N_B = \frac{S_{BC}^{'}}{S_{1\,BC}^{'}} \quad (13)$$

Where:
$S_{1\,BC}^{'}$--capacity of one of the batteries
The current requirement of the charge controller (I_{CC}) is expressed as:

$$I_{CC} = N_{a,mp} \times I_{SC} \times SF \quad (14)$$

Where:
$N_{a,mp}$--Actual number of PV module in parallel.
I_{SC}-short circuit current of the module.
SF-Safety factor.

The power requirement of the inverter (W_{INV}) in order to efficiently drive the compressor of the refrigerator is as expressed:

$$W_{INV} = 1.25 \times W_C \quad (15)$$

The input parameters to this mathematical models are as in Tables 1 to 3.

Table 1. Input Data to the Mathematical Models

S/N	Input Parameters	Symbols	Unit	Value
1	Power rating of the compressor	W_C	kW	0.07
2	Total hours per day	t_H	h	24
3	PV panel efficiency	η_{PV}	—	0.12
4	Battery efficiency	η_B	—	0.85
5	Inverter efficiency	η_{INV}	—	0.8
6	Averade daily energy input over a year	l_{av}	$kWhm^2$/day	4.23
7	Tempeture correction factor	T_{CF}	—	0.97
8	Peak solar isolation	PSI	kW/m2	1
9	System DC voltage	V_{DC}	V	12
10	Rated current of one module	I_r	A	2.78
11	Rated voltage of one module	V_r	V	12
12	Period of autonomy	N_A	day	0.052
13	Maximum permissible depth of discharge of the battery	DOD	—	0.8
14	DC voltage of one of tl the batteries selected	V_B	V	12
15	Capacity of one of the batteries selected	$S_{1\,BC}^{'}$	Ah	7.2
16	Safety factor	SF	—	1.25
17	Short circuit current of the module	I_{SC}	A	2.89
18	Actual number of PV modules in parallel	$N_{a,mp}$	—	1

Table 2. Refrigerator Set Specification

Manufacturffer	Samsung
Model	SRG-118
Capacity	113 Liter
Dimension	Width 453 mm
	Depth 495 mm
	Height 835 mm
Weight	26 kg
Power source	220 V
Rated Input	70 W
Refrigerant	R-134a

Table 3. Solar PV Panel Specification

Manufacturer	RUBITEC SPLAR
Type	HU50
Power	60 W
Current at typical power	2.78 A
Voltage at typical power	18 V
Open circuit voltage	21.5 V
Cells	34
Dimensions	840 mm x 540 mm x 30 mm
Weight	6.1 kg

RESULTS AND DISCUSSION

Results: The computational analysis of the mathematical models is as displayed in Table 4. The comparative analysis of evaporator (freezer) compartment temperatures for vapor compression refrigerator power from the national grid and the one powered by solar PV cells is as displayed in Table 5.

Table 4. Output Data for the Design

	Output parameter	Symbol	Unit	Formula	Value
1	Average hour of operation of the refrigerator per day	H	h	$H = \frac{2}{3} \times t_H$	16
2	Estimated daily energy demand	E_S	kWh/day	$E_S = W_C \times H$	1.12
3	Overall efficiency of the system	$\eta_{Overall}$	—	$\eta_{Overall} = \eta_{PV} \times \eta_B \times \eta_{INV}$	0.082
4	Daily energy demand	E_L	kWh/day	$E_L = \frac{E_S}{\eta_{Overall}}$	13.67
5	PV floor area	A_{PV}	m^2	$A_{PV} = \frac{E_L}{I_{av} T_{CF}}$	3.33
6	PV peak power	W_{PVP}	kW	$W_{PVP} = A_{PV} \times PSI \times \eta_{PV}$	0.4
7	Total system direct current	I_{DC}	A	$I_{DC} = \frac{W_{PVP}}{V_{DC}}$	0.03
8	Number of PV modules in series	N_{ms}	—	$N_{ms} = \frac{V_{DC}}{V_r}$	0.67
9	Number of PV modules in parallel	N_{mp}	—	$N_{mp} = \frac{I_{DC}}{I_r}$	0.012
10	Total number of modules/ panel requied	N_m	—	$N_m = N_{mp} \times N_{ms}$	0.008
11	Storage capacity of the battery in kWh needed	S_{BC}	kWh	$S_{BC} = \frac{N_A \times E_S}{DOD \times \eta_B}$	0.09
12	Storage capacity of the battery in Ampere hour needed	S'_{BC}	Ah	$S'_{BC} = \frac{1000 \times S_{BC}}{V_B}$	7.14
13	Total number of battery needed	N_B	—	$N_B = \frac{S'_{BC}}{S'_{1\,BC}}$	1
14	Current requirement of charge controller	I_{CC}	A	$I_{CC} = N_{a.mp} \times I_{SC} \times SF$	3.61
15	Power requirement if rhe unverter	W_{INV}	kW	$W_{INV} = 1.25 \times W_C$	0.088

Discussion of Finding: In order to avoid over-sizing and under-sizing the components that are involved, design factors such as efficiency rating, correction factor and safety factor were stringently kept in view. This is to ensure components design that are adequate, reliable and economical system design. The PV set is only one module. One battery is required to produce autonomous 1.25 hours (0.052 days) duty assuming the PV panel is disconnected in the process. The design consideration of the charge controller is fixed the rating at 12 volts and 3.61 amperes. The transformer to be employed is step down type with 230 V rating at the primary side and 12 V at the secondary. The performance efficiency of the solar powered refrigerator ties closely with vapor compression refrigerator whose power supply is from national electricity grid. This is subject to the fact that the evaporator (freezer) temperatures at different intervals of times in step of 5 minutes 2^0C for both models of refrigerators. Hence, the novel idea is that there is no temperature effects through PV panel or the national electricity grid.

CONCLUSION

Detailed design concepts for solar powered PV refrigerator to be used in Port Harcourt environment has been presented. It is more or less the best campaign to vapor compression system power from the national grid. It is considered an ideal refrigerator for the middle class family in the rural and remote areas with intermittent electricity. The design concepts portray minimal emission and environmental effects when compared with the model of refrigerator powered from national grid.

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