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AIR CONDITIONING USING SOLAR PHOTOVOLTAIC ARRAY

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Abstract

The vapor compression refrigeration (VCR) and air conditioning systems are widely used for cooling, refrigeration, air conditioning, heating purposes and consumes more than 33% of the world energy. Solar energy is available abundantly as renewable energy source in summer when requirement of comfort is in peak demand. The electrical energy is replaced with solar energy by properly selecting solar panels, battery, inverter, charge controllers for storing fruits and vegetables in rural areas due to uncertain pattern of grid electricity. In the paper, solar power VCR system is designed and simulated with Simulink to estimate the performance in terms of irradiance and temperature. It is found that with rise in irradiance, current and power outcome increases. The solar system is CO_2 free with substantial saving of ₹ 29700 whereas conventional VCR system produces 5292 kg of CO_2 during life time of solar PV system.

1. Introduction

The conventional fuels are depleting fast so the researchers in the world are focusing attention on the renewable sources like solar and wind. The sun, prime source of energy is available for utilization in different applications such as refrigeration, air conditioning, heating, ventilation, and air conditioning. The solar energy is freely available as clean source of energy for environment over fossil fuels. As per the Indian weather data and ISHRAE handbook, it is found that the sun is available almost for 1500 to 2000 sunshine hours per year. The average intensity of solar radiation

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in India is almost 4-7 kWh/m^2. The solar power simulation of VCR system using phase change materials is 219% rise during on time, 139% growth during compressor off time and 3.5% rise in compressor power and 5.5% decrease in COP.

2. Literature Review

They studied performance of photovoltaic system from zero load to maximum load and found conversion and energetic efficiency of 8% and 11% respectively [1-2]. They conducted experimental observations on 0.2 TR (1TR= 3.5167 kW) and found that actual coefficient of performance (COP) is 0.58 and theoretical COP as 0.74 neglecting pump work and losses in refrigeration system [3]. They reviewed innovative technologies in solar photovoltaics and integration of solar power into conventional fossil fuel electrical grids [4]. The spectrum of the wavelength of radiation lies between 0.29 to 4.75 μm. They found that actual work consumption of compressor range from 5.33 kW to 6 kW with COP varies from 3.28 to 3.74 and efficiency fluctuates from 17% to 35% [5]. They captured waste heat (de-superheating) from condenser and used for household purposes like water heating, bathing, washing cloths and utensils along with cooling in evaporator for general purpose for storing fruits and vegetables. In combined heating and cooling VCR system, they saved overall cost of the system and space with R134a refrigerant [6]. They studied solar power refrigeration systems and calculate energy and exergy potentials for photovoltaic systems and found that photovoltaic efficiency as 8.4% and 8.2% while exergy efficiency was 11.4% and 11.2% respectively at zero load and maximum load. The experiments are conducted for parabolic dish solar collector (Scheffler solar dish) as heat generator for operating vapor absorption refrigeration systems. They run refrigerator with electricity and solar power for 7 hours and found that 0.43 kW power was saved [7]. They studied performance of VCR system for different compressor speeds with rate of cooling was 0.231, 0.485, 0.667 and 0.800 °C/min for different compressor speeds varying for 2000, 2500, 3000, 3500 rpm respectively [8]. They studied waste heat availability using PVT collectors to heat pump coupled with the ground source heat exchanger and validated experimental results using simulation [9]. The focus for research was to find the techniques for reducing the power consumption of inverter driven refrigerators in household and commercial domain. They investigated performance of refrigerator from 10 to 40 °C in voltage range of 310-325 V [10]. They studied the fitment of solar collectors under various collector array geometries and study the energy and exergy analysis using TRNSYS dynamic model and validated with the actual experimental data. They found that energy efficiency was ranging from 20 to 50% whereas exergy efficiency was always lower than 1.5% [11]. They studied performance of cascade refrigeration system with the help of solar and electrically operated VCR system with COP of 6 and 700 W/m^2 solar intensity at room temperature of 35 °C and water temperature of 7 °C which resulted in 50% less energy consumption for cascade systems than electrically operated VCR cycle [12]. They found that for solar collector area of 100 m^2, phase change heat storage and heat pump solar absorption refrigeration system produced 9 kW refrigeration capacity throughout the day for the specified conditions [13]. They studied plant consisting of heating system, cooling system and storage tanks with phase change material in solar cooling plants and working substance as synthetic oil for heat transfer fluid with operating temperature from 100 to 400 °C [14]. They developed solar refrigeration for transportation construction using vapor compressor and adsorption system. The solar photothermal adsorption refrigeration system was developed to achieve temperature of -1.83 °C [15].

3 Materials and Methods

In rural areas where grid connection is problem, refrigerated storage is most important method for fruits and vegetables. The solar refrigeration is having better energy efficiency which operates on 12 V or 24 V. The solar refrigerators are ecofriendly and reduce energy demand on grids but solar refrigerators are having high initial cost due to solar panels which depends on local climate and sun inclination where the batteries are used to store energy in day time which can be used in night. In renewable energy sources, deep cycle battery is used for constant current for longer time. The lead acid batteries are used commonly due to less price whereas Lithium batteries are used for longer life and higher efficiency [16-17]. The VCR system consists of evaporator, compressor, condenser, and expansion valve with R134a as refrigerant for producing the cooling effect. The refrigerating effect produced is depends on evaporator pressure and temperature. The compressor is attached to motor which runs with batteries. The condenser selected is an air cooled with round tube and plate fins for rejecting heat from refrigerant. The capillary tube is used as an expansion valve to reduce the pressure from condenser to evaporator. The solar power VCR system is designed for evaporating temperature of 7.4 °C, condensing temperature of 54 °C, degree of superheating at entry to compressor of 5 °C and degree of subcooling at the exit of condenser as 7 °C. A specific amount of sun energy only can convert into electricity as most panel efficacy is in order of 20% and efficiency depends on solar intensity. The solar panels used are monocrystalline, polycrystalline, and thin film. Silicon material is used for monocrystalline solar cells. The efficiency can range from 17% to 22% for most of the applications [18-19]. The polycrystalline panels are more efficient over monocrystalline. The substances such as silicon, Cadmium telluride, copper indium gallium selenide, and dye-sensitized solar cells are used for coating material. In household appliances, normally monocrystalline panels are used where as thin film solar cells are applicable in industries [20-22].

3.1 Charge Controller and Inverter

The charge controller is located between solar panel and battery bank for regulating electric energy generated through solar panels into the battery. The charge controller protects battery from overcharging and increases life and efficiency of battery. There are two types of charge controllers used in PV power systems such as Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT) controllers. The solar inverters are significant for converting direct current (DC) from solar panel into alternative current (AC) for specific applications. There are various types of inverters such as square wave, modified sine wave and pure sine wave. It is observed that modified sine wave outcome is not appropriate for LASER printers and precise electronic equipment's and motors [23].

3.2 Solar System Calculations

To run VCR system using solar, it is necessary to calculate the energy available for off grid system. Thus, for daily energy consumption, selected the battery, solar panels, charge controllers, and inverters as follows. The batteries are selected for daily power consumption, system voltage (12V/24V/48V) and depth of discharge. The size of solar panel depends on daily energy consumption and the number of peak sun hours. Thus, solar panels are selected for mean irradiance of 1000 W/m^2. The charge controller is selected for 50 Amp. PWM and the inverter is selected for 1100 VA, AC to DC pure sine wave Microtek inverter. Table 1 shows theoretical calculations performed for solar system components.

4 Solar photovoltaic array simulation

The solar PV array was simulated using Simulink in MATLAB with PV Module 1STH-215-P including five parallel strings and one series connected module per string. The Simulink model developed is representing actual solar PV system. The PV model is validated for different values of irradiance and temperature. Figure 1 shows Simulink model for solar PV array for current, voltage and power with respect to time for 1600 W/m^2 irradiance and 25 °C temperature as constant inputs to solar PV array. It was found that current and power increases up to certain point and then decreases drastically but voltage increases linearly in solar PV array. It was found that maximum power can be developed from selected solar module at 25 V.

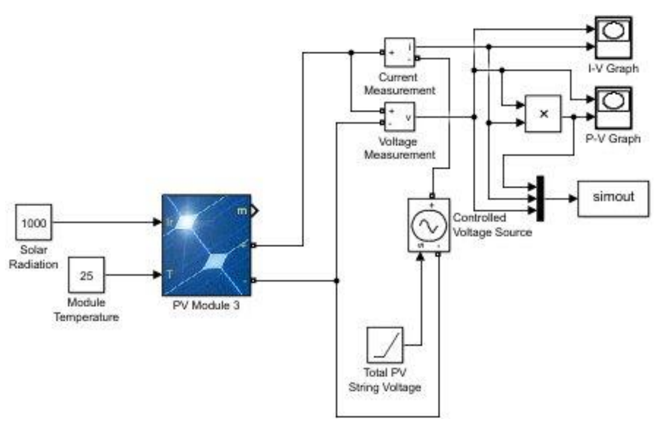

Figure 1. Simulink model for solar PV array

The solar power values are obtained for different values of irradiance from 0 to 2000 W/m^2 at a constant temperature of 25 °C. It was found that solar power and irradiance are directly proportional to each other**.**

Table 1. Selection of solar system components

Daily energy consumption	Power (W)	Time (Hours)	Energy consumption (W-hr)		
	151	5	755		
Battery size	Daily energy consumption (W-hr)	System voltage (V)	DoD	Battery (AH)	
	755	12	0.5	125.83	
Solar panel	Daily energy consumption (W-hr)	Peak sun hours	System efficiency	Solar panel (W)	
	755	4.5	0.7	239.68	
Charge controller	Solar panel Watt (W)	System voltage (V)	Safety factor	Current rating (A)	
	239.68	12	1.3	25.965	
Inverter	Continues Watt (W)	Surge Watt (W)	I/P voltage (V)	O/P Volt (VAC)	O/P freq. (Hz)
	800	1200	12	230	50

5 CO2 Emission Reduction for Solar Power and Cost Reduction

The solar power is an environmentally friendly source which does not produce any carbon emissions as against conventional power plants. It is found that electricity generated from thermal power plant using coal as fuel which emits approximately 0.98 kg of CO_2/kWh. If daily electricity consumption of VCR system is 0.75 kWh, Then, CO_2 emitted per day is 0.75 x 0.98 = 0.735 kg. Thus, total CO_2 produced in the life span of 20 years of the solar PV system is 0.735 x 30 x 12 x 20 = 5292 kg. For daily energy consumption of VCR system pf 0.75 kWh with ₹ 5.5 per unit, cost of electricity is 0.75 x 5.5 = ₹ 4.125. For 20 yearly, amount saved will be 4.125 x 30 x 12 x20 = ₹ 29700 with almost zero maintenance cost.

6 Conclusions

The intention in research work was to design, develop and simulate solar PV system which can run VCR system for remote areas for storing vegetables, fruits, chocolates due to grid problems. The required dimensions of solar system are selected based on calculated daily energy consumption, battery size, solar panel, charge controller, and inverters. Simulink model of solar

PV array was developed to simulate the performance with respect to irradiance and temperature. From Simulink it was investigated that with increase in irradiance and current, power output increases. The voltage where maximum power can be developed was found out from simulation for solar PV array at specific irradiance and temperature. The CO_2 emitted in conventional power plants is approximately found to be 5292 kg against solar PV system along with the monthly electricity bill reduction.

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