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Performance study of a solar photovoltaic air conditioner in the hot summer and cold winter zone

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Abstract

This paper presents the experimental results of a solar photovoltaic air conditioner system to study the heating and cooling performance of system in the hot summer and cold winter zone like Shanghai, China. Four working modes have been investigated: cooling in summer and heating in winter, both for daytime and nighttime. The design of the system is described. Results are reported in terms of COP_{solar} based on solar radiation, Solar Fraction (SF) and Solar Direct Consumption Ratio (SDCR) respectively. It is found that the COP_{solar} for cooling of present system was around 0.32, which is higher than solar thermal driven cooling machine, while the heating COP_{solar} for heating was around 0.37, which is lower than the thermal efficiency of conventional solar thermal collector. The energy flow chart has been drawn based on measured results of typical weather condition in Shanghai. The energy losses in different devices of the system have been evaluated. This work has demonstrated that consistent and reliable air conditioning can be achieved by present system in winter as well as in summer and thereby can be used as a good solution to reduce the peak load of electrical grid in the hot summer and cold winter zone of China or the area with similar weather conditions around the world.

Keywords: Photovoltaic; Air conditioning system; Heating and cooling; Hot summer and cold winter zone

1. Introduction

The increasing demand for energy in developing countries and global environmental concerns are opening up new opportunities for utilization of renewable energy resources (Salameh, 2003), especially solar energy. The photovoltaic technologies are attracting more and more attention because the solar cell converts sunlight into electricity without heat engine (Parida et al., 2011; Ma et al., 2013) and its price is decreasing significantly in recent years. There are two main types of solar PV application technologies (Kaundinya et al., 2009): stand-alone photovoltaic system (Cherif and Dhouib, 2002; Modi et al., 2009) and grid-connected photovoltaic system. Grid-connected systems are relative simple which consist of photovoltaic panels, inverters, power conditioning units and grid connection equipment. These systems seldom have batteries. The grid-connected PV system supplies the excess power, beyond consumption by the connected load, to the power grid. In stand-alone photovoltaic systems, as the demand from the load does not always equal to the solar panel capacity, battery banks are generally used. Based on electrical current used, the stand-alone system can be subdivided into alternative current system and direct current system.

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Nomenclature

PV-AC	Photovoltaic Air Conditioner
C_b	capacity of the battery bank
C_{inv}	rated capacity of the inverter
dc	direct current
COP	coefficient of performance
COP_{solar}	coefficient of performance based on solar energy input
DOD	depth of discharge
E	electrical energy (A h, kW h)
I	current (A)
n_{rainy}	the number of continuously rainy day
P	power (W)
PF	power factor
Q	heating/cooling energy (MJ, kW h)
SDCR	Solar Direct Consumed Ratio
SF	Solar Fraction
SOC	state of charge
t	time
T	temperature (°C)
U	voltage (V)

Greek letters

η	efficiency

Subscripts

c	cooling
daily	daily
dc	direct current
ac	alternative current
b	battery bank
h	heating
in	air flow in
irr	irradiance
inv	inverter
input	input
l	load
max	maximum
out	air flow out
pv	photovoltaic
r	remainder
solar	solar energy

Solar energy has already been widely used as an energy source for heating (Esen, 2000; Esen and Yuksel, 2013) and cooling (Henning, 2007; Kattakayam and Srinivasan, 2004; Axaopoulos and Theodoridis, 2009; Fumo et al., 2013). As there is a high coincidence of the solar radiation and the building cooling load in summer, the solar powered cooling machine can provide the indoor environment with maximum cooling capacity. The solar powered cooling technologies can be divided into two categories. The first group is thermally driven technologies, which use solar collectors to provide thermal energy to drive a cooling process, such as absorption, adsorption and desiccant cooling (Henning, 2007). The second group is photovoltaic cooling technologies, which uses electricity generated by photovoltaic cell to drive the conventional vapor compression chiller. Even though photovoltaic cooling technologies are not complicated, applications had been hindered due to the high investment cost of solar photovoltaic cell and related conditioning equipments for years. In recent years, with fast drop of the cost of photovoltaic cell, more attention has been attracted on these technologies. One important application of the solar cooling is air conditioning. The advantages of Photovoltaic Air Conditioner (PV-AC) include simple structure of the system, reliability in operation, and quick response to the variation of load. Further, since conventional domestic air conditioner (split type or windows type) can work as heat pump, PV-AC can also provide heating in winter under some climate conditions. In many cases, since the heating/cooling load is not always the same as power production from photovoltaic array, the excess power generated during the daytime can be stored in the battery of the stand-alone system or sent to the grid in grid-connected system. Nowadays, the proportion of air conditioning energy consumption in the building energy consumption is increasing. The large-scale application of PV-AC systems might be a good solution to reduce the pressure of the electric network during electrical grid peak periods.

Since cooling is always needed in daily life, solar PV powered refrigeration in small capacity has been investigated in previous work (Kattakayam and Srinivasan, 2004; Axaopoulos and Theodoridis, 2009). However, with the expand application of photovoltaic system, interests in solar air conditioning are increasing. More recently, Fumo et al. (2013) compared a solar thermal cooling system that uses an absorption chiller driven by solar thermal energy, and a solar photovoltaic cooling system that uses a vapor compression system (electric chiller) driven by solar electricity (solar photovoltaic system). Tobin et al. (2012) developed a PV powered direct current air conditioner with ice storage to lower diesel-generated energy usage in forward operating bases and to help reducing electricity costs. In the initial experiment, the glycol air handler was producing 4.5 kW of cooling power. Because the oil was unable to cycle through the refrigerant lines nor smoothly to return to the compressor, the compressor lifetime was severely shortened and not much results were obtained.

Though some useful results have been reported in previous work, it can be observed that most researches were based on theoretical analysis, and experimental studies on PV-AC are scarce. Also, most of the working conditions studied in previous work are under standard conditions,