ORIGINAL RESEARCH ARTICLE

Photovoltaic solar heat pump system

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ABSTRACT
In recent years, a new PV-SAHP system has proposed a solution to the problem of overheating of solar panels in solar photovoltaic power generation systems. It uses the PV-heat pump water heater system to cool the solar panels and heat the heat pump in order to expect simultaneous improvement of photoelectric conversion efficiency and heat pump energy efficiency ratio.

KEYWORDS: photovoltaic solar heat pump system, photovoltaic power generation, heat pump water heater, efficiency

1. Introduction

Over the past few decades, energy problems have become increasingly prominent, has become a major problem plaguing all mankind. The solar energy can be renewable, pollution-free, huge reserves, is recognized as the ideal energy. So the study of solar energy utilization has been carried out, and in recent years the heat of this problem is also rising. Today, the use of solar energy has begun to take shape, solar water heaters have been very popular, solar photovoltaic power generation is also toward high efficiency, low cost direction.

This paper first elaborates the research and development of solar photovoltaic power generation, air source heat pump water heater and solar heat pump, and puts forward the existing problems and solutions in the system. In the third part of the introduction of photovoltaic power generation - heat pump water heater joint system works. Through the comparative analysis of the efficiency of the system, loss, economic benefits and so on, we can clearly see the advantages of the joint system.

2. Solar photovoltaic power generation, heat pump water heater development

2.1. Solar photovoltaic power generation

In 1893, the French scientist, Becqurel found that the light can make the semiconductor material between the different parts of the potential difference. This phenomenon was later called 'photovoltaic effect', referred to as 'photovoltaic effect.'

In 1954, American scientist, Chabin and Piersson made a practical monocrystalline silicon solar cell for the first time at Bell Labs in the United States, creating a practical photovoltaic power generation technology that converts solar energy into electricity.

Since the 1970s, the rapid development of modern industry, energy problems gradually exposed. So, people will look to the renewable energy. Solar energy per second to reach the ground up to 800,000 kwh of space, if one can be one of the million into electricity, the annual power generation will be tens of times the energy consumption of the Earth. Thus, since the 80s of last century, the number of solar cells gradually increased, the growing market. After the 20th century, 90 years, the rapid development of photovoltaic power generation. By 2006, the world has built more than 10 megawatt-class photovoltaic power generation system, six megawatt-class networked photovoltaic power plant.

According to the '2013-2017 China PV industry market outlook and investment strategic planning analysis report' [2] survey data show that in 2011, the global PV installed capacity of about 27.5GW, compared with 18.1GW last year, or up to 52%, the cumulative global installed capacity of more than 67GW. Nearly 28GW of the world's total installed capacity, nearly 20GW of the system installed in Europe, but the relative slowdown in growth, including Italy and Germany, the global market growth accounted for 55% of the capacity, respectively 7.6GW and 7.5GW. In 2011, the demand for photovoltaic industry in the Asia-Pacific region, represented by China, Japan and India, increased by 129% year on year, with capacity of 2.2GW, 1.1GW and 350MW respectively. In addition, in the increasingly mature North American market, last year the new installation capacity of about 2.1GW, an increase of up to 84%.

China is the fastest growing global PV installed country, the installed capacity of photovoltaic power generation in 2011 than in 2010 increased by about 5 times in 2011, battery production reached 20GW, accounting for about 65% of the world. As of the end of 2011, China has a total of about 115 battery companies, the total capacity of 36.5GW.

If the problem of high cost of photovoltaic power generation can be resolved, the solar power industry will have infinite potential, which for the energy crisis is also of great significance.

2.2. Heat pump water heater

In the early nineteenth century, the French scientist Sadi Karnot presented the 'Carnot cycle' theory for the first time in 1824, which became the origin of heat pump technology. 1852 British scientist Kelvin (L. Kelvin) proposed that the refrigeration device for heating, the inverse Carnot cycle for heating the heat pump design.

1911 Switzerland Zurich successfully installed a set of water as a low heat source of heat pump equipment for heating, which is the early water source heat pump system, is also the world's first set of heat pump system. Heat pump industry in the 20th century, 40 years to the early 50s have been rapid development of household heat pump and industrial building heat pump began to enter the market, heat pump into the early stages of development.

With the same solar photovoltaic power generation system, heat pump in the last century 70 also ushered in the development of the golden age. Heat pump new technology emerging, the use of heat pump is also constantly open up, widely used in air conditioning and industrial areas, in energy conservation and environmental protection plays a major role.

Now the most common market is the air source heat pump water heater. As the name suggests, air source water heater that is to absorb the heat in the air to heat the device. Compared to the direct use of electric heating, air source heat pump in general can reduce energy consumption to 1/4 [3]. Because of its low power consumption, compared with solar water heaters affected by the weather smaller, has a unique advantage.

2.3. Solar heat pump system

Solar heat pump system refers to the solar energy heat pump system. The solar heat pump system overcomes the shortcomings of the ordinary air-cooled heat pump system in the high latitude area due to frost failure caused by the system efficiency is low or even unable to run, and improve the system's evaporation temperature and improve the system performance. SAHP system is divided into two types: (1) indirect solar heat pump system solar collector system and heat pump cycle are independent, both through the heat exchanger to achieve energy exchange; (2) direct expansion solar heat pump system, the solar energy set Heaters and heat pump evaporators combined into one, heat pump fluid flow in the solar collector, directly absorbed into the collector surface of the solar energy [4].

2.4. PV solar heat pump (PV-SAHP) system and research status

The efficiency of solar photovoltaic power generation decreases as the temperature of the panel increases. When the panel temperature is high, it is necessary to cool down. A single method of cooling consumption of electricity, income is little or even more harm than good, the actual production and life rarely cool. And the traditional cooling method makes the heat on the battery board in vain.

At the same time, the COP value of the heat pump water heater rises with the increase of the ambient temperature. If the PV panel as a heat source of heat pump water heater, making the temperature of the photovoltaic panels remain at a low level. This will not only give the battery cooling, to ensure power generation efficiency, but also improve the heat pump water heater energy efficiency. Photovoltaic panels will become a collector, power generation integrated photovoltaic evaporator.

The concept of photovoltaic light and heat utilization was first proposed by Kern and Rusell [5], followed by a large number of studies on similar PV / T systems. In recent years, the University of Science and Technology of China proposed the combination of photovoltaic cells and direct expansion solar heat pump, constitute PV-SAHP system. Liu Weiliang [6] PV-SAHP system for theoretical modeling and experimental measurement of two aspects of the study. He Hanfeng [4] According to the changes of weather conditions, the dynamic parameters of the system were analyzed, and the economy of the system was considered. Pei Gang [7] by changing the system parameters, studied the PV-SAHP system performance changes.

3. PV-SAHP system principle

3.1. Heat pump water heater cycle

The refrigerant is vaporized in the evaporator and then enters the compressor for adiabatic compression. The pressure and the temperature are increased and the condensate is allowed to enter the tank to heat the water. After the heat-cut process, the temperature and pressure are reduced, again into the evaporator cycle.

For the analysis of the heat pump cycle (Figure 3.1), it is necessary to determine the evaporation temperature and the condensation temperature, which are and. Ideally, the temperature of the hot water, is the ambient temperature. In fact this cannot be done, the working fluid and cold and heat source temperature cannot be the same, need to keep 5 heat transfer temperature difference.

When the heat dissipation temperature and exothermic temperature are known, the table can be obtained 3 ~ 4 process and 5 ~ 1 process pressure and the enthalpy of each point.

$$(COP)_H = \frac{Q}{W} \quad (3.1)$$

In the refrigeration cycle of Figure 3.2,

Heat supply $q_1 = h_2 - h_4$

Compressor power consumption $w = h_2 - h_1$

$$(COP)_H = \frac{h_2 - h_4}{} \quad (3.2)$$

$$(COP)_H = \frac{h_2 - h_{4'}}{h_2 - h_1}$$

After the supercooling treatment,

(3.3)

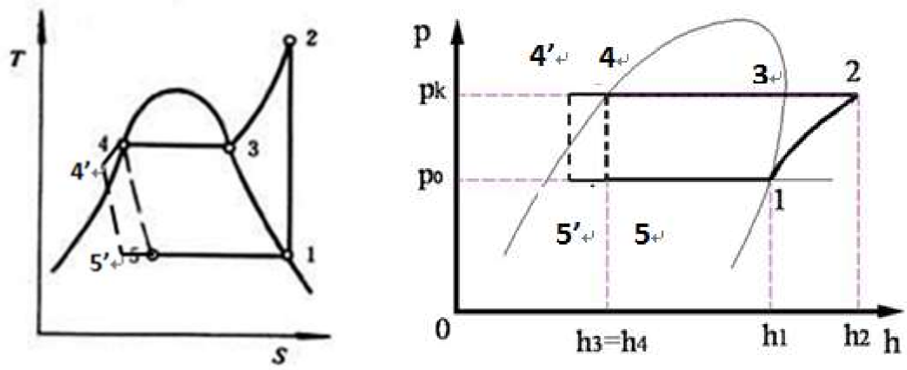

Figure 3.1 Temperature and enthalpy diagram of the heat pump cycle

3.2. Photovoltaic Evaporator

PV evaporator is the core of photovoltaic solar heat pump components, is based on the solar cell, the integration of the evaporator part of the heat pump, through the flow of refrigerant to take off the heat plate.

3.2.1 Photovoltaic Battery [8]

Photovoltaic cells use the photovoltaic effect. The sun shines on the semiconductor p-n junction to form a new hole-electron pair. In the role of the electric field to form a current. At present, the ground photovoltaic system is a large number of silicon-based silicon solar cells can be divided into monocrystalline silicon, polysilicon, and amorphous silicon solar cells.

In this paper, monocrystalline silicon cells as the object of study. The cover material of the battery is a double-layer vacuum glass and is covered with foamed glass as a thermal insulating material. Solar cells can receive solar energy can be expressed as follows:

$$q_p = I(1-\gamma_c)\tau_c\alpha_p \qquad (3.4)$$

Where:

I - radiation intensity (W / m2) irradiated onto the panel

γ_c- Coverage reflectivity

τ_c- - cover transmittance

α_p --The proportion of solar energy absorbed by the battery

Part of the incident solar energy directly into electricity, power generation

$$q_e = \eta_p q_p \qquad (3.5)$$

The photoelectric conversion efficiency of photovoltaic cells in the formula. The study shows that the temperature decreases with the increase of temperature

$$\eta_p = \eta_{rc}[1-\beta_p(t_p - t_{rc})] \qquad (3.6)$$

Among them:

η_{rc} -- Standard efficiency of photovoltaic cells at temperature

β_p -- the temperature coefficient of photovoltaic efficiency.

3.2.2 Analysis of heat dissipation

In the absence of a refrigeration unit, after the simplified, the formula for the heat dissipation of the panel can be written as

$$Q_l = U_l(t_p - t_a) \qquad (3.7)$$

Among them

t_p - PV cell temperature

t_a - Ambient temperature

U_l - Heat loss factor, consisting of the following three items

$$U_l = U_{iso} + h_{rad} + h_{out} \qquad (3.8)$$

Where

U_{iso} --Heat Transfer Loss Coefficient of Thermal Insulation Materials

h_{rad} -- Linearized thermal radiation loss factor

h_{out} -- External air convection heat loss factor

These three coefficients can be derived from the following methods

$$h_{out} = 2.08 + 3.0u_w \qquad (3.9)$$

Where the wind speed.

$$U_{iso} = (\frac{\delta_{iso}}{k_{iso}} + \frac{1}{h_{out}})^{-1} \qquad (3.10)$$

The symbol of which respectively represent the thickness and thermal conductivity of the thermal insulation layer.

Symbol take the calculated value in the literature.

The values required for this calculation are shown in the table below.

3.3. Photovoltaic solar heat pump system

According to the derivation of 3.1 and 3.2, the thermal equilibrium equation of the PV evaporator is as follows

$$q_p - q_e - q_l = q_2 \qquad (3.11)$$

Symbol indicates the cooling power of the heat pump evaporator. In this paper, select the heat pump refrigerant R134a. If the condensation end temperature is constant, the subcooling temperature is maintained at 5 ℃,, and is completely determined by . At this point the value of each parameter of the heat pump is a one-way function.

4. Ideal system analysis of the system

According to Equation 3.11, it can be seen that the photovoltaic evaporator will eventually stabilize at a certain temperature, depending on the cooling power of the heat pump evaporator, under the combined action of solar radiation, heat pump heat, and heat dissipation of the panel itself. In the analysis of this paragraph, take the final stability of the PV evaporator as an independent variable, the analysis system of the various parameters. These analyzes are based on the following assumptions:

1. The area of the PV evaporator is 1m2.

2. The condenser end of the working temperature of 65, for heating 60 shower with hot water. Ambient temperature is 25.

3. There is no pressure loss in the process of flowing in the pipeline.

4. Compressor is a strict reversible entropy of the compression process.

Solkane 6.0 software was used in the analysis. The software can calculate the parameters of each point in the cycle and the system's cooling power, heating power, compressor power and energy efficiency ratio after specifying the type of working fluid and the main parameters of the cycle.

4.1. $(COP)_H$

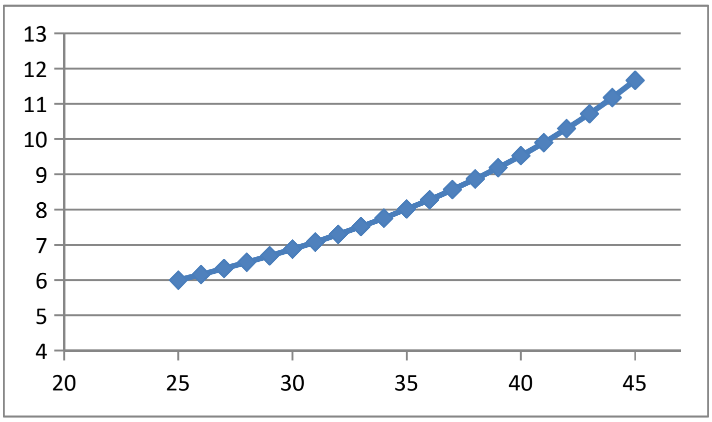

Figure 4.1. The law of varies with

The same as the Carnot reverse cycle, the higher the temperature of the PV evaporator, the closer to the hot end temperature, the higher the energy efficiency ratio.

4.2. PV cell power generation and system net power generation

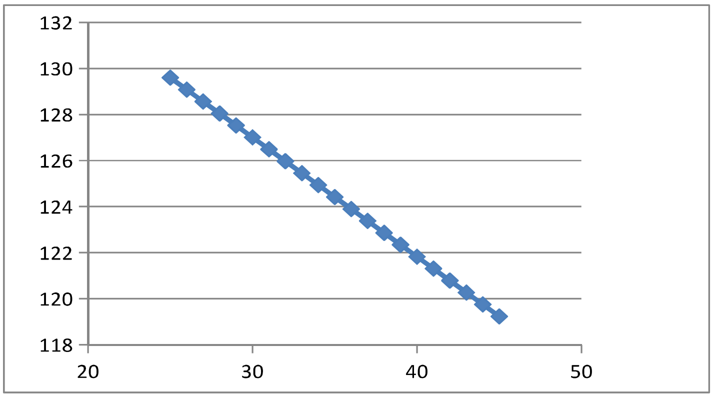

Figure 4.2 changes with the law

The relationship is derived directly from equation 3.6, which is a linear negative correlation.

The net power generation is calculated as follows

$$q_{e,net} = q_e - w_c \qquad (4.1)$$

Where the compressor power consumption, .

After processing, the relationship is as follows:

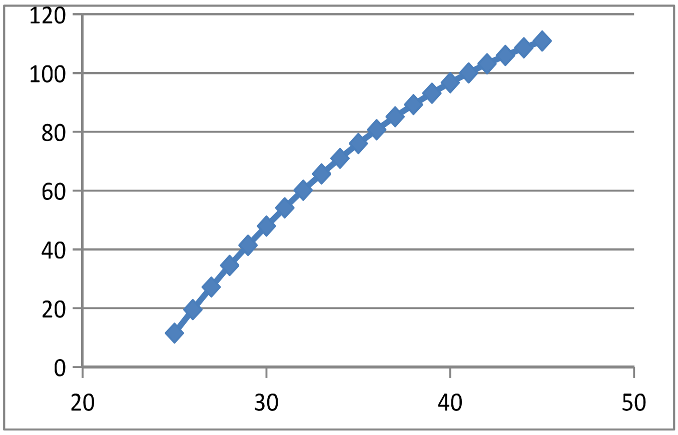

Figure 4.3 (w) with the law of change

It can be seen that as the temperature increases, the net power generation is increased, which is the opposite of the change in battery power. The reason is that with the battery temperature rise, the output power of photovoltaic cells will indeed decline, but the effect of heat pump to save electricity is more obvious.

4.3. Heat

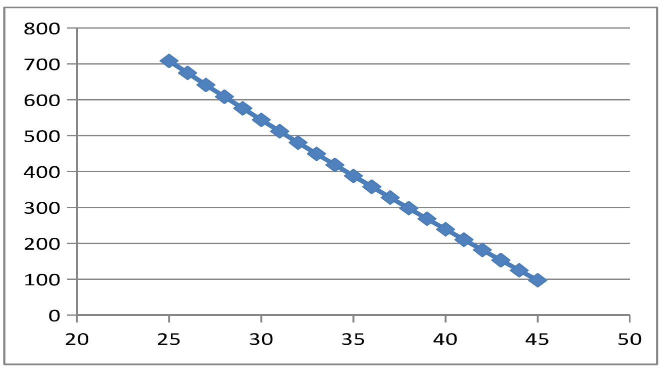

Figure 4.4 (w) with the law of change

The higher the temperature of the battery, the lesser energy the system can deliver to hot water, which is easy to understand because the high temperature of the panel indicates that most of the heat falling on the battery is used to keep the battery warm and not being taken away by the evaporator.

4.4. Net income

The net income of the system, is calculated as follows

$$E_{ex,net} = q_{e,net} + E_{x,Q} \qquad (4.2)$$

Where, on behalf of hot water to get the heat, and

$$E_{x,Q} = \left(1 - \frac{T_0}{T_3}\right) q_1 \qquad (4.3)$$

of the ambient temperature of 298K, hot water temperature 333K.

Make the curve as shown below

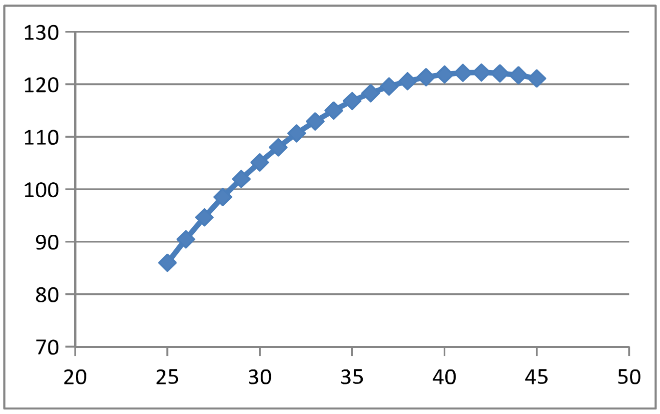

Figure 4.5 (w) with the law of change

It can be seen that near 42, net income is taken to the extreme value. The reason is that the net power generation and heating with the law of change is the opposite, there is a point so that the net income to take a great deal.

4.5. Analysis

When the PV-SAHP as a system, with the PV evaporator temperature changes, most of the parameters are monotonous changes. This shows that the battery power generation efficiency changes, but compared to the heat pump energy efficiency changes caused by the change is still very small, so the power output from the point of view, the cooling effect to the panel is not obvious.

At the same time should also be noted that there are other benefits to the cooling of the battery, such as slowing the film and other components of the oxidation rate, extend the battery life.

5. Economic Benefit Analysis

Currently on the market commonly used water heaters are electric water heaters, solar water heaters, air source water heater several. This part uses a reasonable estimate, from the economic point of view, these devices and photovoltaic solar heat pump for comparison. In order to facilitate comparison, it is assumed that the functions of these devices are to use 2 hours per day, 100L 10 water to 60, and equipment investment through the network quotation platform.

5.1. Electric water heater

Electric water heater price of about 1,000 yuan. The cost per year is

$$M = 365 * p * cm(t_2 - t_1) \qquad (5.1)$$

Where p is the price of 0.5 yuan / degree. Into the calculation of the annual cost of 1064.6 yuan.

5.2. Solar water heater

At present, the price of 100L ordinary solar water heater is about 2,000 yuan. Assuming that there are 8 months a year can be completely solar heating, other times need electric auxiliary heating, is similar to the calculation of 5.1 type, the annual cost of 354.9 yuan.

5.3. Air source water heater

Compared to the above two, the price of air source water heater higher, take the current average of 4,000 yuan. As the air source water heater energy efficiency ratio with the ambient temperature changes, take the annual average of 4, the annual cost of 266.1 yuan.

5.4. Photovoltaic solar heat pump

In the analysis of Chapter 4, the heat pump conditions (ambient temperature 25, solar radiation intensity 1000 W / m2) are specified. In fact, only about four months of the weather can reach this level throughout the year.

In the case mentioned in Chapter 4, select as 30 for analysis. At this time COP 6.88, heating power of 544.1W /m2, and functional requirements of heating power to 2916.7W, so the need to purchase the battery plate 5.4 m2. The current price of monocrystalline silicon cells is about 450 yuan /m2, coupled with inverter and other ancillary equipment, the part of the investment is about 3600 yuan. Plus heat pump investment of 3,500 yuan, the total cost of 7100 yuan.

Assuming 340 days the battery can work properly, generating 6 hours a day, according to the analysis in Chapter 4, the average power generation power of 120W / m2, calculated by the year can generate electricity 1321.9 degrees. Year 4 months COP value of 6.88, the rest of the time to take an average of 4, you can get the annual compressor power consumption 458.0 degrees, so the annual net power generation 863.9 degrees, income 432.0 yuan.

5.5. Analysis

The above results are tabulated

Installation	Equipment investment	Annual fee
Electric water heater	1000 yuan	1064.6 yuan
Solar water heater	2000 yuan	354.9 yuan
Air source heat pump	4000 yuan	266.1 yuan
Photovoltaic solar heat pump	7100 yuan	Income 432.0 yuan

After comparison, it can be seen that if the stability of PV-SAHP system is good enough, the investment of air-source heat pump can be recovered in 4 years, 6.5 years and 4.4 years, respectively, compared to electric water heater, solar water heater and air source heat pump. Taking into account the photovoltaic system can transform solar energy, the contribution of energy conservation cannot be ignored.

6. Conclusion

This paper analyzes the principle, energy efficiency and economy of PV solar heat pump system. As the selected model is ideal, and the reality will be some deviation, but for the inspection of PV-SAHP system output and feasibility of a certain guiding significance.

Compared to other forms of heating, PV-SAHP due to the higher temperature of the photovoltaic evaporator and more energy-efficient, and can output the energy of this high-grade energy. Compared to a single photovoltaic cell, the system can be electric dual-use, to improve the efficiency of photovoltaic conversion. The current constraints of its development is still the price of equipment, if the cost of the problem is resolved, the comprehensive utilization of solar energy is of great significance.

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