Research on Hot Water System of PVT Coupled Heat Pump High-speed Service Area Based on TRNSYS

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Abstract: The high-speed service area is located outside of the urban energy system. If there is no efficient energy saving technology, it will lead to a large amount of energy consumption. As an important ancillary facility along the expressway, the service area has a large demand for hot water due to the high density of human flow. Renewable energy should be fully utilized to make domestic hot water. In this paper, a water-cooled photo-voltaic thermal (PV/T) coupled heat pump hot water system model is proposed. The TRNSYS model for the system operation is built, and an operating experimental platform is set up to verify the model experimentally. The comprehensive performance of typical days in winter and summer was evaluated, and it was found that the average COP of the system was as high as 7.9 and 8.1 respectively. The photoelectric conversion efficiency is as high as 17.5% and 19.5%, respectively. This system has good technical adaptability in the high-speed service area, providing certain guidance for building the green and ecological high-speed service area.

1. Introduction
In recent years, the energy crisis and environmental pollution have become more and more serious, and the efficient use of new energy has gradually become the research focus of domestic and foreign scholars. As an important infrastructure along the highway, the high-speed service area consumes huge amounts of domestic hot water, so searching for an efficient and reasonable hot water system has become an important part of the energy-saving work in the service area.

As a kind of clean energy, solar energy is an effective way to solve energy problems. The utilization technology of solar photovoltaic and thermal integration (PV/T) is developing rapidly, and the temperature change of photovoltaic cell modules seriously affects its photoelectric conversion efficiency. In order to solve this problem, researchers have proposed a solar photovoltaic / thermal integration system through a lot of experimental research, and coupled it with the heat pump system. Liping Ouyang [1] established dynamic heat transfer models of PVT hot water system with different connection methods, and the optimal connection method was determined by calculating the power generation, actual heat collection, and actual comprehensive power generation as the optimization goals. Yuanwei Zhang [2] and others determined the optimal circulation flow rate of the heat pipe PV/T system through testing and research on the heat pipe PV/T system and the PV system. In this paper, a new type of PVT coupled heat pump hot water system is proposed, and the TRNSYS model of the system is built,
and the technical adaptability of the system on typical days in winter and summer is analyzed, so as to provide some guidance for the design of PVT hot water system in high-speed service area.

2. System introduction
Part of the solar radiation received by the PV/T heat collector is converted into electrical output by the photovoltaic effect of the cell module, and the other part is lost in the form of heat through convection and radiation, and the rest of the heat is absorbed by the cooling fluid in the PV/T heat collector. This part of the heat absorbed by the fluid is heated by the heat pump system and then sent to the hot water storage tank for domestic hot water. Compared with the ordinary heat pump system, this system takes the heat converted by solar radiation as the low heat source of the heat pump, which improves the evaporation temperature and pressure of the evaporator, thus improving the COP of the heat pump. Figure 1 shows the schematic diagram of a water-cooled PV/T coupled heat pump hot water system.

![Figure 1 Schematic diagram of water-cooled PV/T coupled heat pump hot water system](image)

3. TRNSYS model building
In order to facilitate the simulation calculation, the following assumptions are made for the TRNSYS model of the water-cooling system:

(1) It is considered that water is a single-phase, homogeneous, constant physical property and incompressible fluid, which flows in a steady, one-dimensional and steady state;
(2) It is considered that the water tank is full of water and the water is fully mixed during operation, and there is no temperature stratification;
(3) The heat loss of the pipeline is ignored and the heat loss of the water tank is constant and the water tank does not age with time;
(4) The system only adds water at night, and the water temperature is equal to the ambient temperature at that time.

The TRNSYS model is as follows:
4. Experimental verification of simulation model
The actual picture of the experiment in this paper is as follows. The experimental devices of the system consist of a water-cooled PVT collector, a buffer water tank, a hot water storage tank, a circulating water pump and a test system (temperature test, irradiance test, power test). The experimental location is Jinan, Shandong Province and the experimental time is from December 7th to December 10th, 2020. The experiment was pre-operated one day in advance, and the recording started from the next day. Test items include hot water storage tank temperature, solar irradiance, and PVT power generation. The experimental data was recorded every 15 minutes.

Figure 3 Physical picture of the water-cooled PVT coupled heat pump hot water system test bench

Both the experiment and the simulation set the hot water temperature of the hot water storage tank to 50°C. The experiment tested the temperature of the hot water storage tank, the solar irradiance and the PVT power generation. The temperature of the water tank and the photoelectric conversion
efficiency of PVT are compared with the simulation results. And the results of the comparison are as follows:

![Figure 4 Comparison of experimental and simulated results of hot water storage tank temperature](image1)

![Figure 5 Comparison of PVT photoelectric conversion efficiency experiment and simulation results](image2)

### Table 1 Comparison table of experimental results and simulation results

| Parameter                                | Experimental average (°C) | Simulation average (°C) | average error (%) |
|------------------------------------------|---------------------------|-------------------------|------------------|
| Temperature of hot water storage tank    | 46.2                      | 48.5                    | 4.74             |
| Photoelectric conversion efficiency (%)  | 14.64                     | 15.05                   | 2.73             |

As shown in Figure 4 and 5, the average errors between the simulation and experimental data of hot water storage tank temperature, PVT photoelectric conversion efficiency are 4.74%, and 2.73% respectively. Therefore, it can be considered that the simulation results have high accuracy, and the TRNSYS model has certain credibility.

5. Analysis of simulation results

The temperature of the buffer water tank, the temperature of the hot water storage tank, the comprehensive thermoelectric conversion efficiency, and the system heating performance coefficient of the typical days in winter and summer are simulated through the software. The simulation time is 9:00-19:00. The designed values of hot water consumption and hot water temperature are 3m³/d and 50°C respectively. The simulation results are as follows:

![Figure 6 Temperature change of water tank on typical days in winter](image3)

![Figure 7 System performance change on typical days in winter](image4)
It can be seen from Figure 6 that the temperature of buffer water tank is between 20-31 °C on typical day in winter, which can better meet the requirements of evaporation end of water source heat pump. The temperature of heat storage water tank rises rapidly to 50 °C and maintains at about 50 °C from 9:00 when the system starts operation. It can be seen from Figure 7, the heating performance coefficient of the system can reach up to 8.9 on a typical day in summer, which reaches the peak at about 12:00 on a typical day. The average values of heating performance coefficient and system’s comprehensive thermoelectric conversion efficiency are about 7.9 and 75% respectively. The PVT photoelectric conversion efficiency is about 17.5%. In summary, the system has a good winter operation effect and significant energy saving effect.

It can be seen from Figure 8 that the temperature of the buffer water tank is between 25-35°C on a typical summer day. The temperature of heat storage water tank rises rapidly to 50 °C and maintains at about 50 °C from 9:00 when the system starts operation. It can be seen from Figure 9, the heating performance coefficient of the system can reach up to 9 on a typical day in summer, which reaches the peak at about 12:00 on a typical day. The average values of heating performance coefficient and system’s comprehensive thermoelectric conversion efficiency are about 8.1 and 78% respectively. The PVT photoelectric conversion efficiency is about 19.5%. In summary, the system runs well in summer. Compared with ordinary air source heat pump, hot water systems (COP is about 4-5) have better technical adaptability.

The PVT system has a high power generation efficiency in summer, up to 5kw. By accumulating the data, it can be obtained that the annual power generation of the system is 22,800 kwh, which has good economic benefits.

6. Conclusion
High-speed service area domestic hot water system consumes a lot of energy. This paper proposes a PVT coupled heat pump hot water system that can directly supply hot water, introduces the structural composition and working principle of the system and establishes the TRNSYS simulation model of the system. The model verification is carried out by using the experimental data of winter typical days. The results show that the established simulation system can better fit the actual working status and has a certain degree of credibility.

Using TRNSYS to simulate the operating conditions of winter typical days and summer typical days. The results show that the system is operating well, and the average heating performance coefficients of the system in winter and summer typical days can reach 7.9 and 8.1 respectively. The average values of the photoelectric conversion efficiency of the system in winter and summer on typical days can reach 17.5% and 19.5% respectively. And the annual power generation capacity of the system can reach 22,800 kwh. This system has great potential for energy saving.
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