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The Efficiency Analysis of Solar PV/Thermal Hybrid Systembetween Storage-Type and Separation-Type

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Abstract*—Solar PV/thermal hybrid system combines the solar PV panel and solar hot water unit for solar energy application. The storage-type PV/thermal hybrid system added a water tank below the PV panel directly to cool the surface of PV panel is different from the separation-type PV/thermal hybrid system with a water tank on the top of the PV/thermal hybrid system. By altering the irradiation at the same PV panel inclination, the experience data of storage-type and separation-type solar PV/thermal hybrid system can be got, including the surface temperature of solar PV panel, the hot water temperature, the current and voltagegenerated by PV panel. Photovoltaic efficiency and hot water efficiency can be calculated by submittingcurrent and voltagegenerated by PV panel into efficiency formula. Total efficiency of PV/thermal hybrid system transformed by photovoltaic efficiency and hot water efficiency can be analyzed and compared with the storage-type and the separation-type. Storage type PV/thermal hybrid system will show the better performance.

***Keywords*-Solar, PV/thermal, storage-type, total efficiency.**

I. INTRODUCTION

Natural energy includeshydraulic power, wind energy, geothermal energy, solar energy,etc. Solar energy is the most recommended among just because its inexhaustibility and non-polluting. As a result, the world implements it vigorously. The research of solar PV system and the facility popularization are actively pushedin many countries. In the recent years, solar PV electricity generation capacity has increased dramatically and turned into rapid-growing industry around the world.

Currently, solar energy is the most foremost renewable energy because of its purity and infinite reception. Many large-scale industries and companies pay more attention to energy technology. They understood that solar energy may become the trend of energy generation in the future. Besides, Taiwan is located on the subtropical zone and is sufficient of sunlight. It is likely for us to develop and use solar energy. However, being limited to materials factor, the conversion efficiency of solar energy is not so good. To improve the conversion efficiency must be main topic of the solar conversion technology.

As the increase of the national income and living standard, air conditioners are populated in general families and offices. Power overload happens every summer. Electricity consumption of air conditioners is exactly proportional to sunshine amount, so the period of power overload is during the strongest sunshine season. Solar PV panel has been considered as the best renewable energy that is very developable and ecological in the future. The related application technologies mature gradually. If generating power of solar energy can promoted and applied directly to meet the extra electricity consumption in summer, power consumption peak will be soothed. It can make a positive contribution to domestic energy demand and electricity power supply.

Oil price slid rapidly many times since the 80s, though, solar energy application products were still high-priced so as to lose the competitiveness. Solar energy development was always swung by oil price fluctuations between governments and corporations. That blocked the steady progress in the science and technology field. At the same time, it showed that using solar energy generally impacted by fossil energy supply, politic conditions and war, making the developing process complicated.

Many scholars referred to the research that solar PV panel can be cooled down by water to improve its efficiency [1~3]. Wang et al. [2] sealed the whole PV panel with silicone, and put it into the liquid to cool it down. Krauter [3, 4] set a water tank above PV panel with multiple water pipes releasing water through the upper surface of the panel to cool it down. The surface temperature of the panel decreased from 60℃ to 40℃ at the irradiation of 900W/m2.

Combining solar PV panel with solar heat collector is another concept to improve the overall efficiency [5~7].Hollick [5] laid solar PV panels above a wave board painted with dark-color that could easily to absorb irradiation wavelength. The wave board absorbed the irradiation energy as sun shined. The PV panel above the board could converse sunlight to electric, and the water flowing under the wave board could absorb the heat from the PV panel. This is the combination of solar photoelectric conversion by PV panel and solar hot waterby heat conversion, what we called PV/thermal (or PV/T) system. Tonui and Tripanagnostopoulos [6] made use of air to cool PV panel and indirectly transferredheat to liquid, constructing a PV/thermal solar energy collector. They investigated the meritsor faults of PV/thermal system at different operation conditions under the PV panel. Tsai and Huang [7]

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investigated the storage-type solar PV/thermal hybrid system to adjust the irradiation amount of halogen light. When the light irradiate on the solar PV panel, voltage and current of PV panel can be measured with I-V curve measurer and drawn an I-V curve to analyze the efficiencies.

Solar PV test equipment has constructed to adjust the irradiation amount of halogen light. When the light irradiate on the solar PV panel, voltage and current of PV panel can be measured with I-V curve measurer and drawn an I-V curve to analyze the efficiencies. This experiment was carried out with differentirradiation and the same inclination angel of PV system to compare the total efficiency and the surface temperature of the solar PV panel.During the photoelectric conversion process of solar PV panel, the waste heat on the surface will affect conversion efficiency. A storage-type PV/thermal hybrid system added directly a storage tank below the PV panel directly to cool the surface of PV panel was designed to distinguish from the separation-type PV/thermal hybrid system. As the solar PV panel generates waste heat, cooling water in the tank will take it away. With this, the solar PV panel efficiency can be improved, its lifetime can be maintained, and the hot water can be reused. Total efficiency transformed by electronic power efficiency and hot water efficiency of PV/thermal hybrid system can be analyzed and compared with the storage-type and the separation-type.

II. METHOLOGY

A. Energy conversion efficiency formula of PV/ thermal hybrid system

There is proportion gradient in the hot water sink due to the temperature difference. The water with lower temperature at the bottom of the sink flows to the bottom of the collector through pipelines. It forms a continuous heating natural circulation mode. The mode is “natural circulation solar water heater”.

If the heat storage sink is not set above the heat collector, pump must be equipped to pressure, forming the above-mentioned circulation heating system. This way is “obliged circulation solar water heater”. The water of the later usually runs faster than the water of the former. As a result, the heat collection efficiency is better. Nevertheless, it wastes more power, and is more likely to leak water at the adapter and the seams of the pipelines because of the long-term pressurization condition.

The idea about the surface heat generated at the irradiating solar PV panel can be cooled, and the waste heat can be used to become hot water, formsthe structures of PV/thermal hybrid application. This hybrid system can not only cool the surface of the solar PV panel to lengthen the lifetime, but can recycle the waste heat without pump pressurization. Then the solar energy can be applied the most effectively.

The experimental data of PV/thermal hybrid system at different irradiation can be measured, including I-V curve, surface temperature distribution of PV panel, and water temperature inside the water tank below the PV panel. Photovoltaic efficiency and hot water efficiency can be calculated by the efficiency equations. And, the best design parameters to promote the total efficiency of the PV/thermal hybrid system can be got from these experiments.

The efficiency in the program can be calculated as follows. Photovoltaic efficiency of the PV panel, η_e ,can be defined as:

$$\eta_e = \frac{P_{max}}{I(t)\cdot A_c} \cdot 100\% \quad (2\text{-}1)$$

Where the $I(t)$ is the irradiation amount, and A_c is the surface area of the PV panel. Hot water efficiency of the solar PV/thermal hybrid system, η_w, can be defined as:

$$\eta_w = \frac{m_w C_w (T_t - T_i)}{\sum [I(t)\cdot \Delta t]\cdot A_c} \cdot 100\% \quad (2\text{-}2)$$

Where the m_w and C_w are the weight and the specific heat of the water in the tank. Δt is the interval of each experiment. T_i and T_t are the average water temperature of the tank before and after each experiment. The total photo-electric conversion efficiency, $\eta_{e,total}$, can be defined as:

$$\eta_{e,total} = \eta_e + \eta_p \cdot \eta_w \quad (2\text{-}3)$$

Where *the* η_p is the solar electric/heat energy conversion that is changed into the PV panel electric/heat conversion efficiency. According report to Ji et al. [8] and Huang [9], heat energy has lower conversion energy level than electric energy, and itsη_p is about 0.38. Namely, the hot water efficiency is about 38% of the photovoltaic efficiency. That is,

$$\eta_{e,total} = \eta_e + 0.38 \cdot \eta_w \quad (2\text{-}4)$$

B. Experimental setup of PV/ thermal hybrid system

Experimental setup shows as figure 1, 2. I-V curve is obtained by solar I-V measuring instrument of accuracy ±1% reading value. Light source of halogen lamp is controlled by the angle inclination adjustment. Thermocouple of accuracy ±0.1℃ and infrared thermal imager of accuracy ±2% are used to measure the water temperature of water tank and the surface temperature of PV panel respectively. Figure 2-1 shows the experimental setup of the experimental equipment of separation-type solar PV/thermal hybrid system. Water tank is set at the top of the solar system to recycle waste heat. Figure 2-2 shows the experimental setup of the experimental equipment of storage-type solar PV/thermal hybrid system. Water tank is set below the PV panel to receive the waste heat directly, as shown in figures.

The purpose of the experiment is to know how to reuse the waste heat during the photoelectric conversion of the solar PV panel. The affect parameters are set as follows:

- The interval Δt of each experiment is set to be one hour.
- Tilt angel will be set to be 30°.
- There are four radiation values, 600,700,800 and 900 W/m^2.

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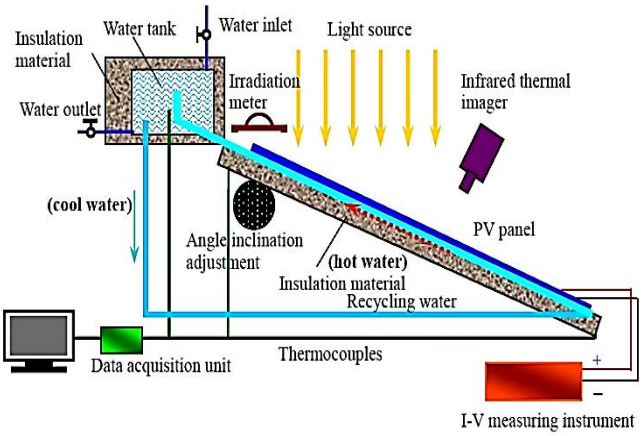

Fig 1.Experimental setup of the experimental equipment of separation-type solar PV/thermal hybrid system.

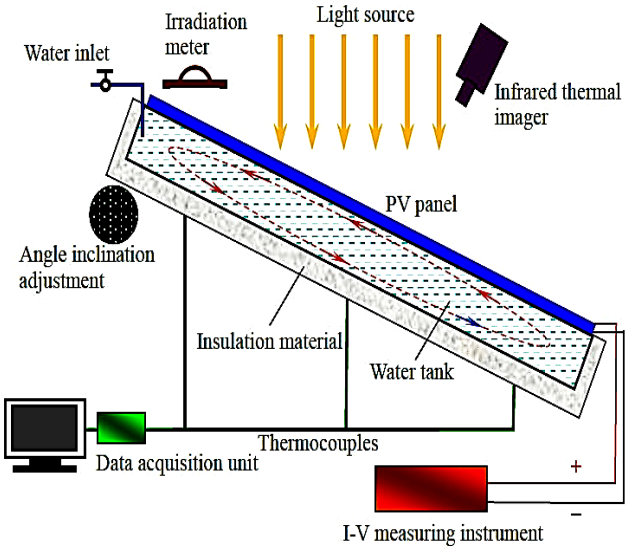

Fig 2. Experimental setup of the experimental equipmentof storage-type solar PV/thermal hybrid system.

III. RESULTS

A. The temperature difference of cooling water

The solar PV/T hybrid system is to use halogen light simulating sunshine and to adjust four kinds of radiation amount, 600,700,800 and 900 W/m^2 with tune CD. And then record the statics to analyze and compare with each other.

As shown in each figure 3, when tilt angel is set to be 30degree, each of the separate solar PV/thermal hybrid system and storage solar PV/thermal hybrid system grows with the increase of the radiation amount. The water temperature of the storage solar PV/thermal hybrid system is higher than one of the separate solar PV/thermalhybrid system. Because the sink of the storage solar PV/thermal hybrid system is under the solar PV panel, it can directly absorbs waste heat without pipeline. So the storage solar PV/thermal hybrid system absorbs waste heat faster than separate solar PV/thermal hybrid system.

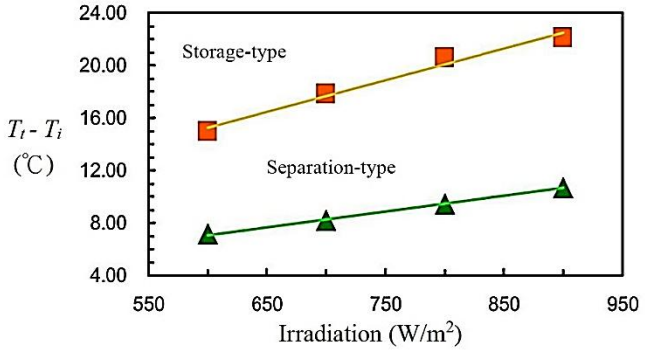

Fig 3. The temperature difference of cooling water between separation-type and storage-type solar system.

B. Surface temperature analysis with IR thermal imager

After measuring a set of data and capturing the I-V curve we needed, the halogen light would be turn off. However, there were still some heat remained, and it would affect the shooting of the thermal imaging instrument. As a result, we covered the halogen light with a mask. Shooting the image we needed with the thermal imaging instrument, then we analyze and compare with the solar PV panel surface temperature of the cooling system at each radiation amount with analysis software for thermal imaging instrument.

This experiment was carried out with different radiation amount irradiating on the solar PV panel. As shown in figure 4(a), when the radiation amount is 600W/m2 and the tilt angel is 30°, the highest surface temperature of the separate solar PV panel is 56.4 °C. We can see clearly through thermal image that the region with the highest temperature is located on the surface of the separate solar PV panel. With the farther distance to the surface of the solar PV panel, the surface temperature drops gradually. When the radiation amount increases, as shown in picture 4(a) ~ 4(d), the center surface temperature of the solar PV panel averagely rises 2 °C~6 °C.

As shown in figure 5(a), the highest surface temperature of the storage solar PV panel is 45.2°C. We can see clearly through thermal image that the region with the highest temperature is located on the surface of the storage solar PV panel. With the farther distance to the surface of the solar PV panel, the surface temperature drops gradually. When the radiation amount increases, as shown in figure 5(a) ~5(d), the center surface temperature of the solar PV panel averagely rises 3 °C~13 °C.

Figure 6 is Surface temperature of PV panel between separation-type and storage-type solar PV/thermal hybrid systemat 600 W/m2~900 W/m2 radiation data. The temperature of storage solar PV/thermal hybrid system is lower than the one of separate solar PV/thermal hybrid system. It means that the cooling efficiency of storage solar PV/thermal hybrid is better than the one of separate solar PV/thermal hybrid system.

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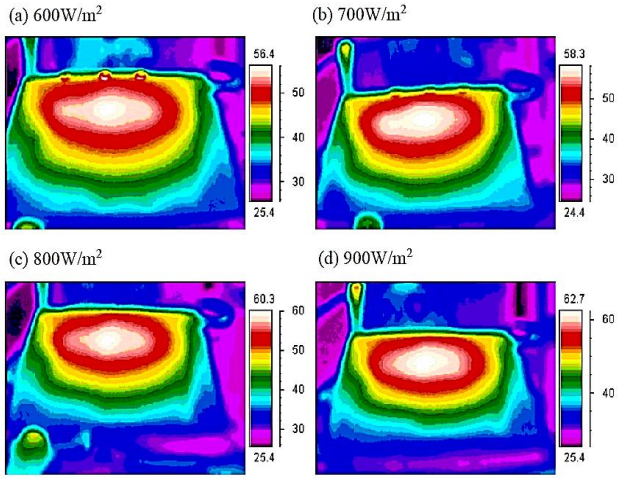

Fig 4. Imaging pictures of surface temperature of PV panel in the separation-type solar PV/thermal hybrid system.

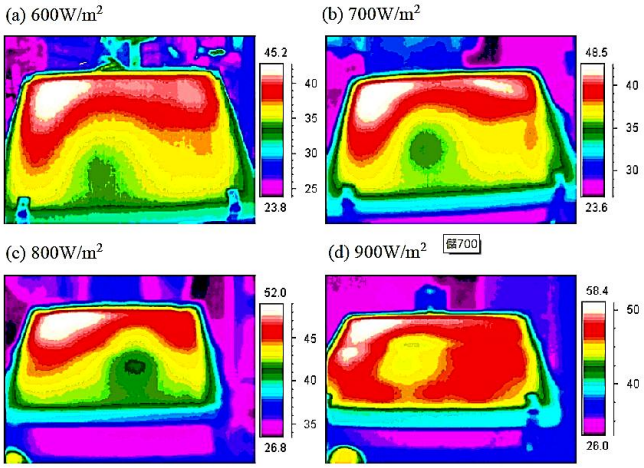

Fig 5. Imaging pictures of surface temperature of PV panel in the storage-type solar PV/thermal hybrid system.

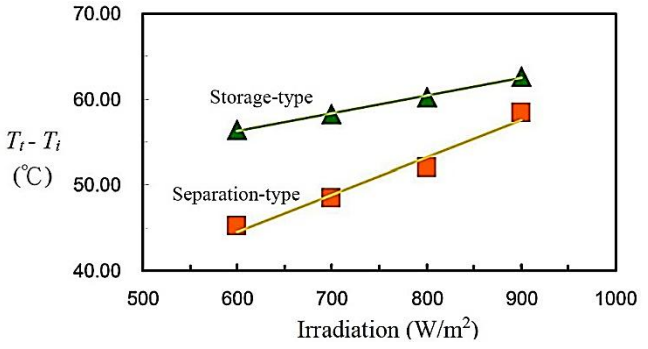

Fig 6.Surface temperature of PV panel between separation-type and storage-type solar PV/thermal hybrid system.

C. Total Efficiency Analysis

As shown in figure 7, the cooling system temperature change under the PV panel is calculated into the formula (2-2) to get the water heating efficiency. We can see through the picture that the water heating efficiency of storage solar PV/thermal hybrid system drops as the radiation amount reduces. The water heating efficiency of storage solar PV/thermal hybrid system is about 37% to 39%, though; the one of separate solar PV/thermal hybrid system is 34%. In comparison, the water heating efficiency of storage solar PV/thermal hybrid system is 3~5% higher than the one of separate solar PV/thermal hybrid system.

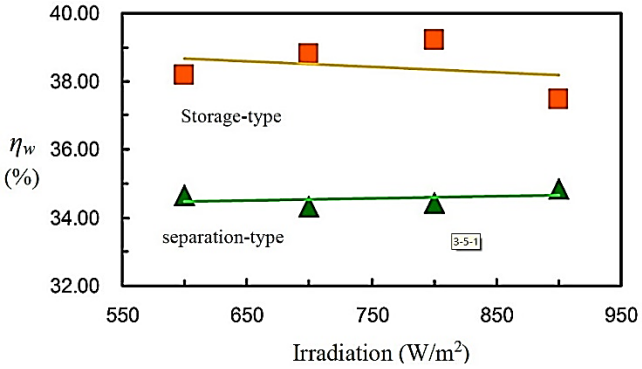

Fig 7.Water heating efficiency between separation-type and storage-type solar PV/thermal hybrid system.

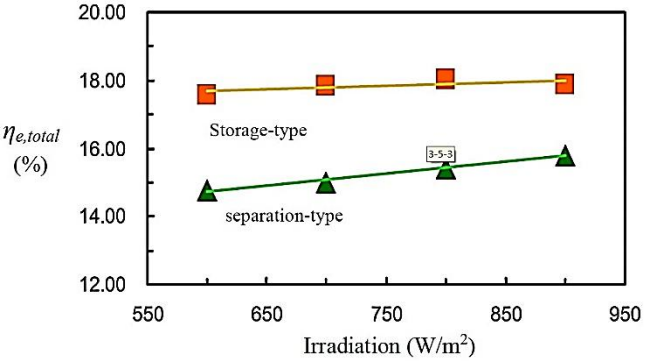

Fig 8. Total efficiency between separation-type and storage-type solar PV/thermal hybrid system.

The statics of the solar PV panel is calculated into the formula (2-1) to get the solar PV panel efficiency. We used halogen lamp as the radiation light in the experiment, so the photoelectric efficiency $\eta_e$is only a quarter of its rated efficiency (the photoelectric efficiency at the sunlight, whose radiation amount is 1000W/m^2).Solar photoelectric efficiency without PV/thermal hybrid system is just about 3%.

The final total efficiency can be calculated into the formula (2-3) to gettotal efficiency. As shown in figure 8, the efficiency of storage solar PV/thermal hybrid system and the one of separate solar PV/thermal hybrid system rises with the increase of the radiation amount, and these two curves were getting closer.

The total efficiency of storage solar PV/T hybrid system is 17% to 19%, and separate solar PV/T hybrid system is about 15%. In comparison, the total efficiency of storage solar PV/T hybrid system is 3% to 5% better than the one of separate solar PV/T hybrid system. Learning from figure 9, the total efficiency of storage solar PV/T hybrid system is 6 times better than the one of separate solar PV/T hybrid system.

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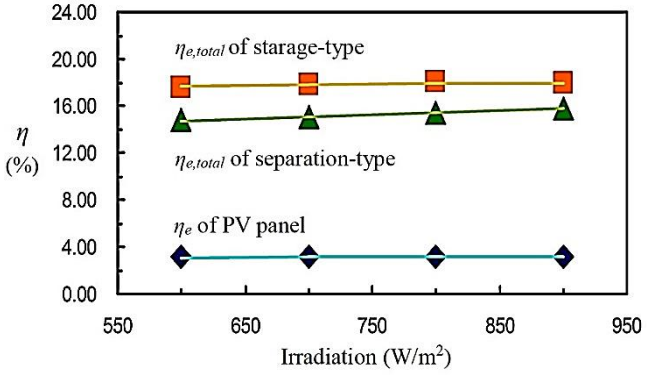

Fig 9. Total efficiency between separation-type, storage-type solar PV/thermal hybrid system and pure PV panel.

IV. CONCLUSION

The purpose of this experiment is how to reuse the waste heat produced by photoelectric conversion of solar PV panels. Under simulated sun light and outdoor solar irradiation, the total efficiency of storage solar PV/T hybrid system is 1.13 to 1.19 times better than one of separate solar PV/T hybrid system. The total efficiency of storage solar PV/T hybrid system is 4.93 to 5.67 times better than one of simple solar PV panel.

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