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반사판을 이용한 고정식 집속형 복합 Panel에 대한 연구

김규조, 김승환, 유형철, 김완태, 허창수
인하대학교 전기공학과

A study on the fixed-concentrating hybrid panel using reflector

Kiu-Jo KIM, Seung-Whan KIM. Hung-Chul YOO, Wan-Tae KIM, Chang-Su Huh
Inha University Electrical Engineering

Abstract - The most effective methods of utilizing solar energy are to use the sunlight and solar thermal energy such as hybrid panel simultaneously and to use concentrator. From such a view point, systems using various kinds of photovoltaic panels were constructed in the world. However there have not been a type of panel using concentrator and hybrid simultaneously.
If the sunlight are concentrated on the solar cell, cell conversion efficiency increase and the temperature of the solar cells increases. As the temperature of the solar cells increases, so cell conversion efficiency decreases. Therefore, for maintaining cell conversion efficiency at these conditions, it is necessary to keep the cell at low temperature. In this paper, after designing a concentrate rate for concentrating, we proposed model for cooling cell and using waste heat. and we compared with conventional panels after calculating the electrical and thermal efficiency using energy balance equation.

1. INTRODUCTION

Solar energy intensity is so low that the spending costs to convert solar energy into available energy are too much than other energy resources and because the conventional solar energy converting devices utilize sunlight and solar thermal energy separately, intensity of the solar energy is lower.

So a hybrid panel is investigated to improve these problems, but the converting efficiencies don't reach the theoretical results than expected. The cell converting efficiency is improved by increasing photo current. this is done by just concentrating the sun light. but concentrating the sun light makes the temperature of solar cells high and contributes to the cell efficiency low. However, if a proper cooling structure and use of waste heat are applied to the system, we can have the most proper converting efficiencies.

In usual solar cells, because about the 70% of energy supplied from the sun light is radiated to the air as heat, it decreases the total converting efficiencies. Therefore, in case of concentrating solar cell, using of solar thermal energy is very important source of energy in improvement of total efficiency. And rising of temperature by concentrating is very effective in terms of not only increasing the total converting efficiencies but also using the appliances of solar converting systems. To develop of these devices we have to study optical converting efficiency and thermal efficiency and need an optimal condition and design

The conventional panels have the problem of which a receiving area is as same as a loosing area, this causes increasing heat losses. but by concentration, we can reduce the losses in a way of preventing the radiation of absorbed energy. And proper cooling duct engineering techniques for controlling the temperature rising and bonding characteristics improvements for transferring heat are required also.

We choose the hybrid-fixed concentrator because of considering appliance to small and middle type systems. thus, we proposed the way of increasing the converting efficiencies of the solar cells by concentration and proposed the way of improving the efficiencies totally by using waste heat.

2 ESTIMATION OF CONCENTRATION RATIO

From figure 1 it is clear that, if θ_n is the reflected ray meeting the nth mirror element with respect to the absorber surface, then the slope of the reflected ray meeting the absorber at point A should be equal to $(2\theta_n - \delta - 90°)$. Hence the slope of the first mirror element can be in the range $90° > \theta_1 > 45° + \delta$ for the given of δ.

If $\tan\theta_1 = \alpha_1$ and $\tan(2\theta_1 - \delta - 90°) = \beta_1$, the generalized relationship between the angle of inclination of the mirror element and the reflected ray under consideration can be expressed as

$$\alpha_1 = \frac{\beta_1 + \tan\delta}{1 - \beta_1 \tan\delta} + \sqrt{1 + \left(\frac{\beta_1 + \tan\delta}{1 - \beta_1 \tan\delta}\right)^2} \quad (1)$$

The width of the first mirror element is determined by calculating the co-ordinates of the point of intersection C of the lines drawn from points A and B at angles $(2\theta_1 - \delta - 90°)$ and θ_1, respectively. Hence BC is the width of the first mirror element and can be calculated from

$$W_1 = \frac{X_1 - X_0}{\cos\theta_1} \quad (2)$$

where X_0 is the X-co-ordinate of the lower edge of the mirror elements, and

$$X_1 = \frac{1}{\alpha_1 - \beta_1}(\alpha_1 X_0 + \beta_1 X_0) \quad (3)$$

is the X-co-ordinate of the upper edge of the first mirror element.

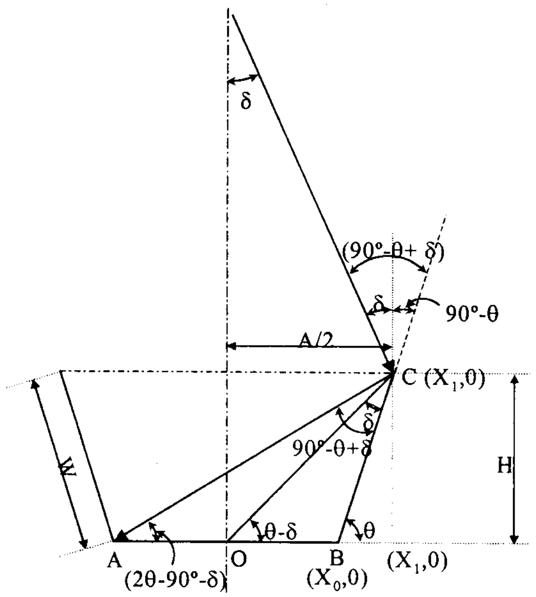

Figure 1. A design of a V-trough type concentrator

Based on similar geometrical-optical consideration to those applied for the first mirror elements, the following generalized expressions for the angle of inclination θ_n, width W_n, and the position in terms of the X Y-co-ordinates of the nth mirror element can be derived:

$$\alpha_n = \frac{\beta_n + \tan\delta}{1-\beta_n \tan\delta} + \sqrt{1+\left(\frac{\beta_n + \tan\delta}{1-\beta_n \tan\delta}\right)^2} \quad (4)$$

where

$$\beta_n = \tan(2\theta_n - \delta - 90^\circ) \quad (5)$$

with

$$W_n = \frac{X_n - X_{n-1}}{\cos\theta_n} \quad (6)$$

where

$$X_n = \frac{1}{\alpha_n - \beta_n}(\alpha_n X_{n-1} + \beta_n X_0 - Y_{n-1}) \quad (7)$$

$$Y_n = \beta_n (X_n + X_0) \quad (8)$$

are the X Y-co-ordinates of the extreme upper edge of the nth mirror element, and ϕ_1=0.

The concentration ratio is

$$C = \frac{\underline{aperture\ width}}{absorber\ width} = \frac{2X_n}{2X_0} \quad (9)$$

In this paper, the concentration ratio is less than 2(named as low concentration), we designed a V-trough type concentrator which has a single reflector to simplify the manufacturing processes.

We showed the changes of concentration ratio by inclination of reflector in figure 2. With referring to this results, we determined the inclination degree of reflector as 75.5 and the concentration ratio as 2.

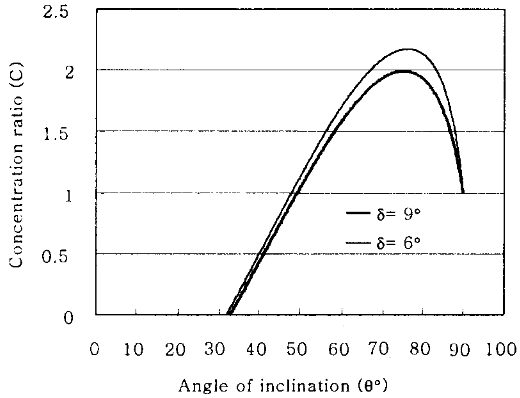

Figure 2 Variation of concentration ratio with acceptable half angle and angle of inclination

3. THE FIXED-CONCENTRATED HYBRID PANEL

First, we installed concentrator and consisted of the system in one body including solar cells for generating electrical energy, absorber for absorbing heat and thermal fluid for transferring heat to load. And we designed that the sun light come to solar cell through the cover glass.

Figure 4 shows the proposed model of a fixed-concentrated hybrid panel. We need to explain the model we designed in detail in terms of functional characteristics.

1. The cover glass works as a function of protecting the panel from contamination and preventing the heat generated to send out. consequently total heat losses are reduced.
2. Reflectors concentrate the sun light which comes through the cover glass on the surfaces of solar cells and absorber whose function convert the solar energy into electrical and heat
energy. Thus, the insolation incident per unit area becomes more higher.
3. The solar cells convert the sun light concentrated into electricity practically.
4. The heat acquired from the solar cells when the temperature rise is transferred to thermal fluid.
5. Thermal fluid is used for warming water and heating.

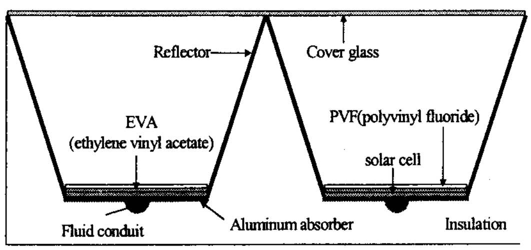

Figure 4 Cross section of proposed model

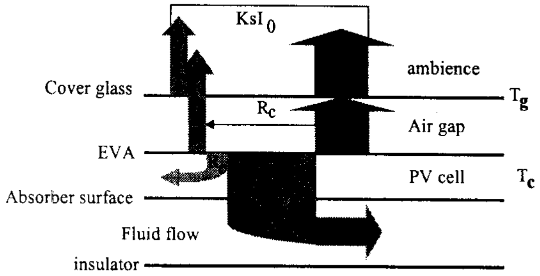

Figure 4 Energy flow model

4. ENERGY BALANCE EQUATION AND ESTIMATION OF EFFICIENCY

We referred to the energy conservation equation fo yielding efficiency. We assumed following to apply this equation. First, side and back energy losses of panel are ignored, Second, practically the sun light reflected by collector is absorbed by cover glass orreflected again bur this quantity is too low, so neglected. Third, the total sunlight is arrived on the collector by a reflector. Fourth, temperature of heat which is transferred from the surfaces of collector to thermal fluid is at a constant temperature. these four assumptions are applied.

Figure 4 shows a model of energy flows. applying the energy conservation equation to each panel derives next equations.

① Energy arrived on cell

If we suppose that absorptance through the surface of cover glass and concentrator and reflection of insolation between each of surfaces are ignored, the energy absorbed per unit area on the absorber is expressed as follows,

$$R_c[W/m^2] = K_s I_0 \tau_g r_r \tau_e \alpha_c \quad (10)$$

where, K_s = the concentration ratio

I_0 = insolation incident on inclination surface

τ_g = the transmittance of the cover glass

r_r = the reflection ratio of the reflector

τ_e = the transmittance of EVA and PVF

α_c = cell absorptivity to sunlight

② Heat energy loss from collector to cover glass

The heat energy is partly transferred from the solar cells to the cover glass,

$$R_{cg}[W/m^2] = \varepsilon_c \sigma (T_c^4 - T_g^4) + U_{cg}(T_c - T_g) \quad (11)$$

where, ε_c = emissivity of cell

σ = Stefan-Boltzmann constant

U_{cg} = the heat-transfer coefficient between cell and the cover glass

T_c = average cell temperature, K

T_g = average glass temperature, K

Table 1. Radiative properties of the analysis model

	glass	reflector	PVF	EVA	cell	absorber
τ	0.90	-	0.94	0.93	0.10	-
r	-	0.95	-	-	-	-
ε	0.05	-	0.10	-	0.01	0.50
α	0.05	-	-	-	0.90	0.50

③ Heat energy loss from the cover glass to ambience

The heat energy transferred from the solar cells is released through the cover glass finally. The heat losses are, respectively:

- radiative heat loss : $\varepsilon_g \sigma (T_g^4 - T_a^4)$
- convective heat loss : $U_{ga}(T_g - T_a)$

where, ε_g = emissivity of glass

U_{ga} = the heat-transfer coefficient from cover glass to ambience

T_g = average ambient temperature, K

Thus, the total energy loss to the ambient is,

$$R_{ga}[W/m^2] = \varepsilon_g \sigma (T_g^4 - T_a^4) + U_{ga}(T_g - T_a) \quad (12)$$

④ Electrical energy generated by solar cell

The electrical energy generated from a solar cell is expressed as follows:

$$R_e = \eta_0 K_s I_0 \tau_g r_r \tau_e \alpha_c pf (1 - \Delta (T_c - 298)) \quad (13)$$

where, η_0 = reference cell efficiency at reference temperature(1000 W/m^2, 25℃)

pf = cell packing factor defined as the fraction of the cell envelope area occupied by the cell

Δ = change in cell efficiency per unit cell temperature change, K^{-1}

⑤ Energy transferred to thermal fluid

Consequently, in terms of energy loss, $R_{cg} = R_{ga}$ and we can calculate the energy transferred per unit area to thermal fluid by the energy balance equation. this energy is,

$$R_w = R_c - R_{cg} - R_e = R_c - R_{ga} - R_e \quad (14)$$

finally, the electrical and thermal efficiencies are expressed. as follows:

$$\eta_e = \frac{R_e}{I_0}, \quad \eta_t = \frac{R_w}{I_0} \quad (12)$$

5. THE NUMERICAL ANALYSIS

Table 1 represents the heat-radiation characteristic to components of the proposed panel. To confirm the property of the proposed panel, we compared with PV/T(photovoltaic/thermal hybrid collector), PV(photovoltaic module) and SC(thermal collector).

We calculated efficiencies using the numerical substitution method and each parameter is T_c and T_g. Environmental data, T_a and I_0 are determined as 25℃ and 800 W/m^2. The results are about properties of optical and thermal efficiency to temperature change. If the proposed panel is performed in a practical situation, temperatures of each layer will be changed complexly and continuously.

5.1 Properties of electrical efficiency

As shown in figure 5, electrical efficiencies of each panel are 15%(on the proposed panel), 8%(on the PV/T panel) and 9%(on the PV panel) where the temperature of a solar cell is at 30℃.

We can see the fact that the value of PV is higher than PV/T. It's because of optical losses through the cover glass. And with these results, we knew that a construction of modules effects to the electrical efficiency and confirm that the electrical efficiency is enhanced by concentrating the sun light.

5.2 Properties of thermal efficiency

As shown in figure 6, thermal efficiencies of each panel are 76%(on the SC), 53%(on the PV/T) and 105%(on the proposed panel), where T_a=25℃, T_c=50℃, I_0=800 w/m^2 are, according to these results, we confirm that a construction of modules effects to thermal property. thus, thermal efficiency is increased by concentrating the sun light as same as electrical efficiency

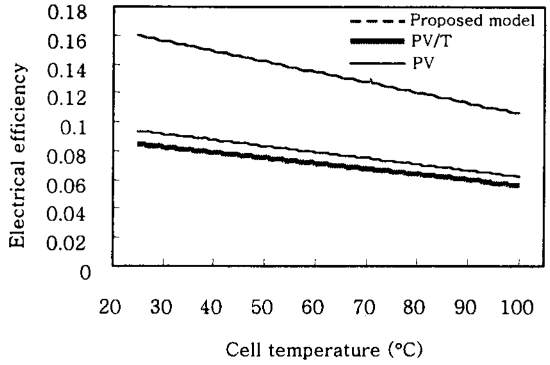

Figure 5 Dependence of photovoltaic efficiencies on cell temperature

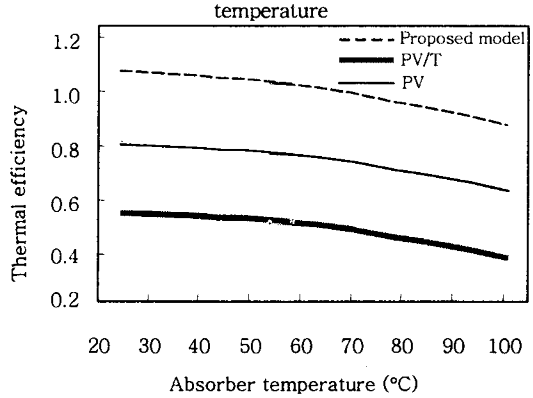

Figure 6 Dependence of thermal efficiencies on absorber temperature

6. CONCLUSION

We designed the fixed-concentrating hybrid panel using reflector and estimated electriclal and thermal efficiencies through the numerical analysis for comparing with PV/T, PV and SC.

As the result of the estimation, the proposed panel is much effective in terms of electrical and thermal energy than PV/T, PV and SC. Thus, the fixed-concentrating hybrid panel using reflector is a very effective way of both generating electricity and getting heat energy in a small area. Further, It appears that applications of the concentrated hybrid panel is an important contribution to the most effective way of solar energy spread.

More studies about systems using and applying to the hybrid concentrating panel are needed.

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