An investigation into the passive cooling of photovoltaic cells under concentrated illumination

Chien-Hsiung Tsai
Professor, Department of Vehicle Engineering,
National Pingtung University of Science and Technology
Ext.7459 chtsai@mail.npust.edu.tw

In Taiwan, 98% energy demand depends on import supplies. However, the prices of fossil energy keep going up because the resources are limited. Therefore, more and more reusable energy resources have to be developed. At present, the governments focus actively on the renewable energy projects, which include mainly the wind energy, solar energy, biomass energy and fuel cells. In recent years, in order to increase electrical energy generated by a photovoltaic system, the researches of the high concentration photovoltaic (HCPV) system technology which has high efficiency have been developed quickly. HCPV system is mainly composed of concentrating device, high-efficiency solar cell, and tracking system(as shown in Fig.1). The difference in structure between HCPV solar cells and traditional solar cells is the usage of concentrated-light module to enhance the optic-electric transition efficiency. However, the temperature of the module will be risen under the conditions for the high-concentrating sunlight in the HCPV system, which is a big problem that influences the efficiency of the solar cell. Many researchers have shown that the photovoltaic cell energy-conversion efficiency decreases with increasing temperature of the module. Therefore, cooling of photovoltaic cells is one of the main concerns when designing concentrating photovoltaic systems.

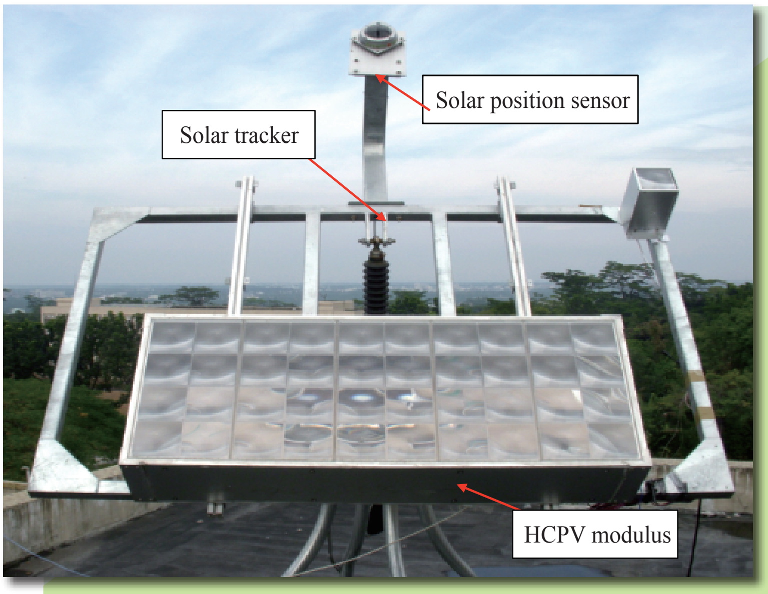

Fig. 1 the HCPV modulus at the NPUST

In addition, TamizhMani et al. establish an empirical equation to describe the module temperature and the ambient conditions, which include ambient temperature, irradiance, humidity, wind speed and wind direction. However, the measurement recording methods have to take a long time monitoring and cannot be observed the flow patterns within the HCPV module.

Recently, some researches regarding the problems of heat dissipation have been performed using CFD software. Chou et al. presented a finite element model (FEM) simulations which showed that the thickness of the heat sink plate plays an important role in the thermal management of the HCPV solar cell package. Gray utilized the finite volume method (FVM) to examine the flow characteristics and temperature distribution around a 2-D HCPV chamber as a function of the various elevation angles of the module. However, these results seem to over simplify the actual physical phenomena, i.e. the three-dimensional effects of geometry and wind speed etc.

In an attempt to address the limitations described above, this study conducts 3-D CFD simulations using the Reynolds Averaged Navier-Stokes equations and the RNG k-ε turbulence model to investigate the flow patterns and the temperature distribution within the HCPV module. The simulations commence by investigating the correlation between the elevation angles of the module and the maximum temperature within the module under a no-wind environment. The simulations focus on the effects of the module elevation angles, and the various wind speed. In addition, the authors have described in details on the asymmetry of flow field within the module.

Influence of the elevation angles of the HCPV module on the temperature distribution and the flow-field phenomena under the no-wind conditions

In order to enhance the HCPV module conversion efficiency, the HCPV unit has a two-axis tracking system, which consists of two main moving parts: the both of vertical and horizontal directions (Rumyantsev et al.). Tracking mechanisms are fully automatic managed by analog sun sensors. Therefore, the elevation angle of the HCPV module changes throughout the day. In this study, a series of simulations were performed in which the ambient temperature was 25°C, and the elevation angles were assumed to four different angles under the no-wind conditions, namely 0°, 30°, 60°, and 90°.

Influence of the elevation angles of the HCPV module on the temperature distribution

Figure 2~3 present the temperature distribution and the streamline patterns of the middle surface within the HCPV module for each of the four considered elevation angles. Note that in performing the simulations, the irradiance density for each single-cell concentrator on the bottom of the module was assumed an 850 W/m2. The results show that fluid motion within HCPV module due to variations in temperature creates the gradients in the air density. Furthermore, comparing Figure 2 and 3, it is evident that a higher temperature distribution is produced on the top of the HCPV module because of the natural convection as the elevation angle changes from 0° to 90°. As shown in Figure 4, the diagram compares the maximum temperature within the module of the horizontal installation with those of the vertical installation as function of the elevation angles. Both of the installed types show that the maximum temperature decrease as the angles is increased. Comparing the two sets of results, it is evident that for all elevation angles other than θ = 0°, the vertical installation results in a lower temperature of the HCPV module. In order words, the vertical type is more effective in thermal dissipation than the horizontal type. The main reason is that the vertical installation has strong effect of the free convection.

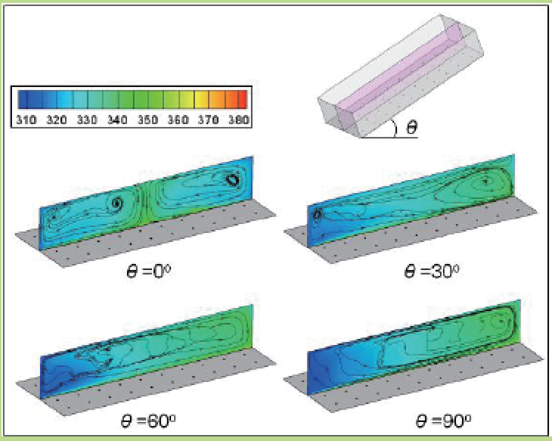

Figure 2. Temperature distribution and surface streamline patterns under different elevation angles for vertical installation. (unit: °C)

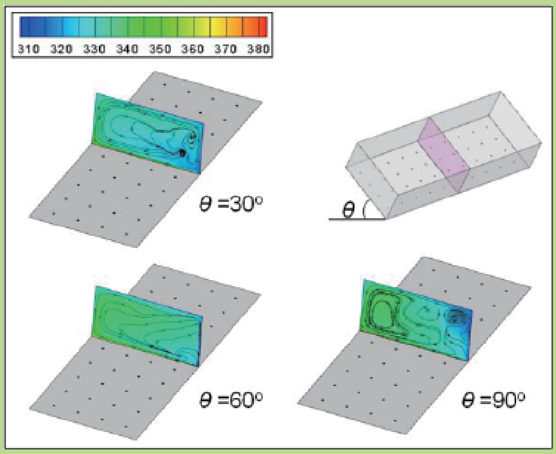

Figure 3. Temperature distribution and surface streamline patterns under different elevation angles for horizontal installation. (unit: °C)

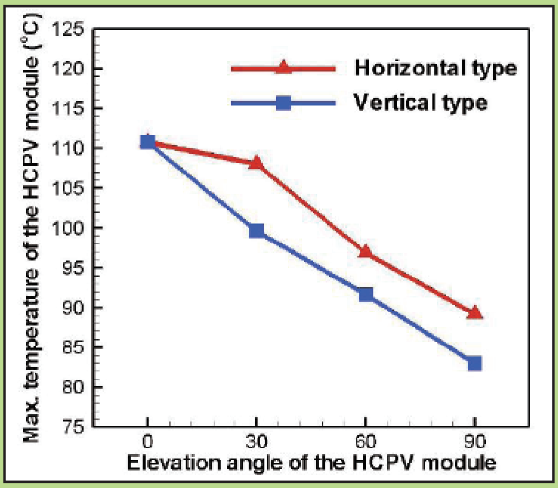

Figure 4. Effect of the installation type on maximum temperature for HCPV module as function of the elevation angle of the module.

Influence of the wind speed on the temperature distribution of the HCPV module

The results presented above have considered only for the no-wind conditions. However, in practice, the HCPV module is exposed to wind from a variety of speeds and directions (depending on the local environmental conditions, the time of year, and so on). Accordingly, in studying the similar heat dissipation problems for the module, it is not enough to consider one wind speed alone. In this study, the elevation angle of the module was first assumed to zero degree to simplify the physical problem. From an inspection of the data presented in Figure 5, it is clearly seen that the strong wind speed yields a reduction in the maximum temperature of the module. The main reason for help HCPV module heat dissipation is either the natural convection within the module or the forced convection produced by wind flow. However, note that the heat dissipation of HCPV module is significantly dependent upon the wind speed when the wind speed is smaller than 1m/s.

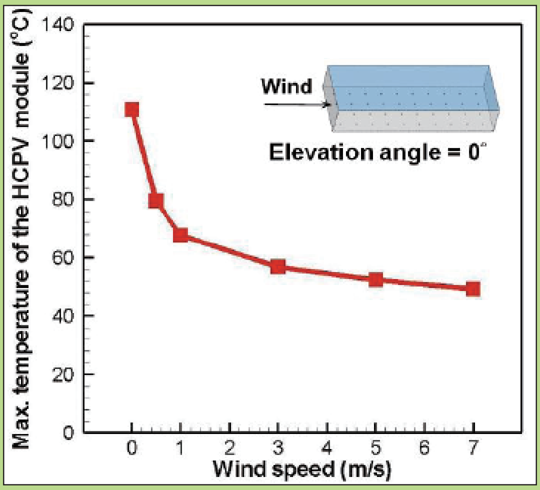

Figure 5. Variations for maximum temperature of HCPV module versus the wind speed.

ACKNOWLEDGEMENTS

The current authors gratefully acknowledge the financial support provided to this study by the National Science Council of Taiwan under Grant NSC99-2221-E-020- 030, and the Institute of Nuclear Energy Research under the Grant 982001INER056.

REFERENCES

TamizhMani, G., Ji, L., Tang, Y., Petacci, L., Osterwald, C. (2003): "Photovoltaic module thermal/wind performance: long-term monitoring and model development for energy rating". NCPV and Solar Program Review Meeting.

Chou, T.L., Shih, Z.H., Hong, H.F., Han, C.N., Chiang, K.N. (2007): "Investigation of the thermal performance of high-concentration photovoltaic solar cell package". International Conference on Electronic Materials and Packaging.

Gray, A. (2007): "Modeling a passive cooling system for photovoltaic cells under concentration". ASME-JSME Thermal Engineering Summer Heat Transfer Conference, Vancouver, Canada.

Rumyantsev, V.D., Andreev, V.M., Sadchikov, N.A., Bett, A.W., Dimroth, F., Lange, G. (2002): "Experimental installations with high-concentration PV modules using Ⅲ-V solar cells". Proceedings of PV in Europe - From PV Technology to Energy Solutions Conference, Rome, Italy, pp. 521-525.