Enhanced Transient Modeling of Hybrid Photovoltaic Air (PVT) Module

R. Kiflemariam[*1], F. Zevallos[1], M. Almas[1], and C. Lin[1]

[1]Department of Mechanical and Materials Engineering
Florida International University, Miami, FL
*Email: rkifl001@fiu.edu

Abstract:

2D transient heat conduction model was created in COMSOL Multiphysics to study the performance of photovoltaic-thermal (PVT) water system. The model captures the variation of important environmental and system parameters such as outside temperature, solar irradiation, air velocity and temperature. The model has a good agreement with experimental data for the photovoltaic cell temperature, air temperature inside the air channels and back surface temperature.

Keywords: Thermoelectric generator, Photovoltaic thermal (PVT), air cooling, COMSOL

1. Introduction

Solar Photovoltaic (PV) is an important means of generating electricity from solar energy. It employs the use of semiconductors that convert solar energy into direct current electricity. A PV cell absorbs photons of sunlight which displace electrons from atoms of the cell creating holes and movement of electrons .The process results in generation of electricity. Solar cells are interconnected to form a module. The modules are in turn connected in series or parallel to from solar arrays at some specified voltage and current. It is one of the cleanest, noiseless and green renewable energy generation methods. In addition, the systems have high credibility with 20-30 years life span expectation and very low maintenance system [1]. Solar photovoltaic/thermal units which are also known as hybrid photovoltaic/thermal (PV/T or PVT) solar units are systems that could simultaneously produce solar photovoltaic energy and thermal energy. The Photovoltaic cells produce electricity from the solar electromagnetic radiation and the solar thermal collectors absorb the heat energy from the sun making use of the remaining energy and at the same time cooling the PV module. The removal of the waste heat from the PV cells increases the efficiency of the cells. The combined panel in PV/T system reduces the physical space demanded as compared to separate photovoltaic and solar thermal systems and cost of equipment through the use of common frames and brackets [2]. A flat-plate PV/T water collector physical model was proposed by Bergene et al. [3] to evaluate the overall performance. Zondag et al. [4] investigated one-dimensional (1D), two-dimensional (2D) and three-dimensional (3D) numerical models, which allowed numerical models to forecast the performance of a PV/T hybrid system.

There are some previous studies which applied COMSOL Multiphysics to model PVT modules. Kalogirou et al studied the air cooled building integrated PV panel using time dependent partial differential equations in COMSOL[5]. Fontenault and Miravete presented a 2D steady state COMSOL model for water cooled combined photovoltaic-thermal solar panel [6]. However, due to transient nature of several environmental and system parameters, an enhanced model which incorporate these variations has been studied in this paper. The performance of a hybrid photovoltaic-thermal model is evaluated by utilizing COMSOL 4.4 Multiphysics software and the results are validated against experimental data by Joshi et al [7].

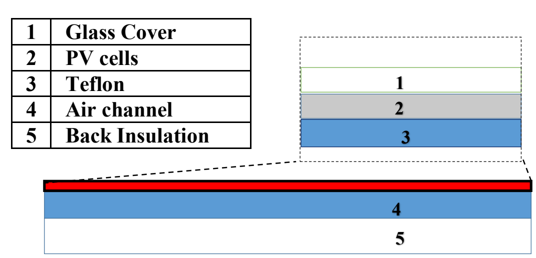


Figure 1. Schematics diagram of PVT system

2. Governing equations

The heat absorbed by the PV panels is given by:

$$\dot{Q}_{net} = \dot{Q}_{abs} - \dot{Q}_{rad,r} - \dot{Q}_{conv} \qquad 1$$

where Q_{abs} is the product of incident insolation on the PV surface (G), efficiency of PV (η_{pv}) and area of the PV (A_P).It is represented in the computational model as a heat source in PV domain.

$$\dot{Q}_{abs} = (1-\eta_{PV})GA_P \qquad 2$$

$\dot{Q}_{rad,r}$ is the heat reflected back to the surrounding air and is described as:

$$\dot{Q}_{rad,r} = \varepsilon\sigma(T_{PV}^4 - T_{amb}^4)A_p \qquad 3$$

where ε is the emissivity of the PV surface, σ is the Stefan-boltzmann constant and T_{Pv} and T_{amb} are the temperature of PV panel and the surrounding air respectively. It is represented as surface boundary condition 1 (BC1 in Fig 2).

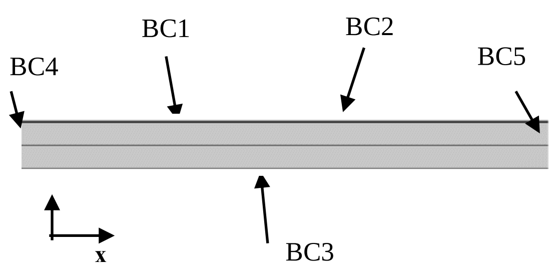


Figure 2. Computational model with boundary conditions

$\dot{Q}_{conv}$ represents the convection heat loss to the surrounding atmosphere and is depicted as surface boundary condition 2 and 3 which are BC2 in the PV surface and BC3 on the surfaces of fins.

$$\dot{Q}_{conv,f} = h(T_{PV} - T_{amb})A_P \qquad 4$$

$$\dot{Q}_{conv,bc} = h(T_{BC} - T_{amb})A_P \qquad 5$$

where h is the convection heat transfer coefficient and T_{BC} is the insulation back surface temperature. At the back surface of Tedlar, the net Q is absorbed by cooling air in the channels.

$$\dot{Q}_{net} = \dot{m}_a C_{p,a}(T_{a,out} - T_{a.in}) \qquad 6$$

where $T_{a,out}$ and $T_{a,in}$ are the outlet and inlet temperature of the air in the channel, m_a and $C_{p,a}$ are the mass flow rate and specific heat of air respectively. The inlet boundary condition (BC4) represent the temperature and velocity of air while outlet boundary condition (BC5) is a pressure outlet.

Table 1. Thermal properties

Name	Value
k_glass	1.8[W/(m*K)]
C_p_glass	480[J/(kg*K)]
k_PV	134[W/(m*K)]
C_p_PV	700[J/(kg*K)]
k_tedlar	0.25[W/(m*K)]
C_p_tedlar	1250[J/(kg*K)]
k_air	k[T[1/k]) [W/(m*K)]
C_p_air	C_p[T[1/k]) [J/(kg*K)]
k_back insulation	139[W/(m*K)]
C_p_back insulation.	154.4[J/(kg*K)]

Table 2. Geometrical Properties

Name	Value
height glass cover	3[mm]
width glass cover	1.2[m]
height PV	0.3[mm]
width PV	1.2[m]
height tedlar	0.5[mm]
width tedlar	1.2[m]
height air channel	50[mm]
Width air channel	1.2[m]
height back insulation	50[mm]
width back insulation	1.2[m]

3. Use of COMSOL Multiphysics

The current 2D model attempts to capture major system and environmental variables which are usually time dependent. The solar irradiance and ambient temperature are varied throughout the day based on the environmental data. In the experiments [3], the inlet water temperature and velocity was recorded and they fluctuate with time. Thus, the input boundary condition are varied to simulate a more realistic boundary conditions instead of constant boundary conditions which are mostly used to simplify the numerical modeling. For the external convection heat transfer coefficient, the values are also written as an equation which varies with the wind velocity at each step time. In addition, the efficiency of the PV panels are also affected by temperature, thus the conversion efficiency of PV panels is also varied dynamically at each time step using the temperature information from the running steps. The general heat transfer and fluid flow is modeled using conjugate heat transfer module in COMSOL in conjunction with functions and equation modeling capabilities of COMSOL Multiphysics.

Mesh grid independence study were carried out and fine mesh with 48000 elements were used. Time dependent solvers were used for solving Temperature field (T), Velocity field (U), and pressure. Transient simulations were carried out for 540 s with convergence criteria of 10^{-6}.

4. Results

The model has simulated the variation of solar cell temperature, back cell temperature and outlet temperature very well as compared to experimental data. Thus it is a useful tool that can be applied in parametric and performance analysis of PVT designs

In Fig. 3, the temperature of the PV cells is compared to experimental data [7] between 8 AM to 5 PM. The average percentile error between simulation result and experimental data is around 4%. Taking into consideration an inherent error in experimental observation, it could be inferred that the simulation has a very good agreement with experimental data. Similarly, the back surface temperature of PVT module is simulated and values are compared against experimental data.

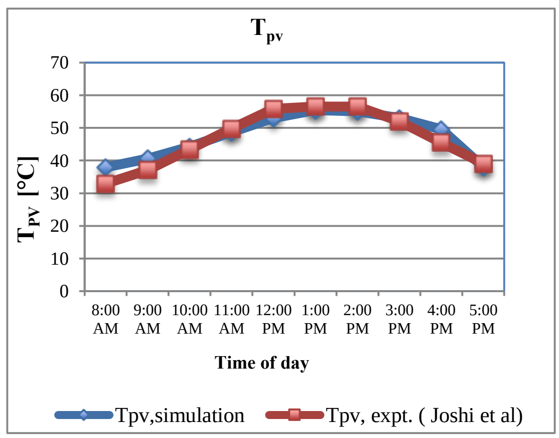


Figure 3. Simulated PV cell temperature (T_{pv}) compared with experimental data

The average error is estimated to be around 6.3%. The simulated temperature is the average temperature of the back side of the PVT module. For the air temperature at the air channel outlet, the simulated error differed from experimental results by 8 %. The difference is more pronounced at the 11 AM and 12 AM result.

Nevertheless, it could be seen that there is generally a good agreement between the simulation and experimental data and the overall trend in temperature fluctuation during the day was well simulated.

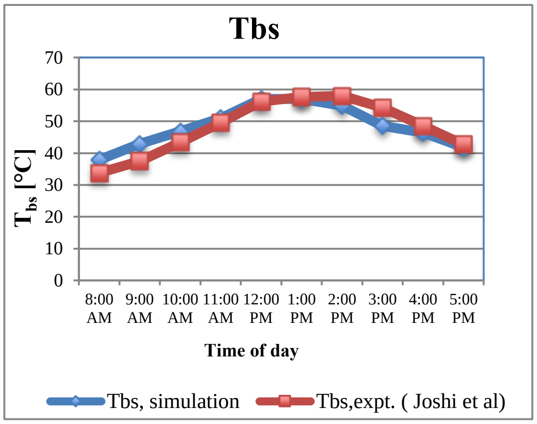


Figure 4. Simulated Back surface temperature (T_{bs}) compared with experimental data

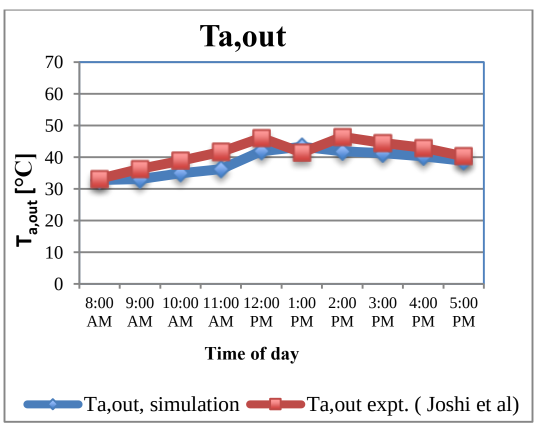
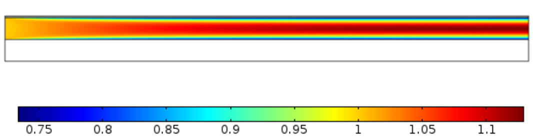


Figure 5. Simulated air outlet temperature ($T_{a,out}$) compared with experimental data

In addition, simulation results for velocity distribution was obtained as shown in Fig 6.



Velocity [m/s]

Figure 6. Velocity of air inside the air duct

5. Conclusion

In this study, an enhanced transient Photovoltaic thermal (PVT) model is developed which takes into consideration the variation of environmental and system parameters with time. The simulated model is compared against experimental data and good agreement was obtained. Thus, the model could be useful to perform parametric analysis of PVT design as well as testing the performance of PVT design in different environmental and system conditions.

8. References

[1]Ibrahim,A.,Jin,G.L.,Daghigh,R.,Salleh,M.H. M.,Othman,M.Y.,Ruslan,M.H.,Mat,S.and Sopian,K.,. Hybrid Photovoltaic Thermal (PV/T) Air and Water Based Solar Collectors Suitable for Building Integrated Applications, *American Journal of Environmental Sciences*, **5**(5), 618-624(2009).

[2]Sarhaddi,F.,Farahat,S.,Ajam,H.,Behazadmehr, A.,Adeli,M.M.,. An improved thermal and electrical model for a solar photovoltaic thermal (PV/T) air collector, *Applied Energy*, **87, 2328**-2339(2010).

[3] Bergene, T., and Lovvik, O.M., , Model calculations on a flat plate solar heat collector with integrated solar cells, *Solar Energy*, **55**, pp. 453-462(1995).

[4] Zondag, H. A., Vries, D. W., Van Hendel, W. G. J., Van Zolingen, R. J. C., Van Steenhoven, A. A., , The thermal and electrical yield of a PV-thermal collector, *Solar Energy*, **72**, No. (2), pp. 113-128(2002).

[5] S.A. Kalogirou, L. Aresti, P. Christodoulides, G. Florides, The Effect of Air Flow on a Building
Integrated PV-panel, IUTAM Symp. Nonlinear Interfacial Wave Phenom. Micro- Macro-Scale. 11, 89–97(2014).

[6] Fontenault, B., Gutierrez-Miravete, E. Modeling a Combined Photovoltaic-Thermal Solar Panel, in: Proc. 2012 COMSOL Conf. Boston.

[7] Joshi, A.S., Tiwari, A., Tiwari, G.N., Dincer, I., Reddy, B.V., Performance evaluation of a hybrid photovoltaic thermal (PV/T) (glass-to-

glass) system, *Int. J. Therm. Sci*. **48** 154–164(2009)