The Optimum Solar Chimney Structure to Improve Photovoltaic System Efficiency

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Abstract:- The electrical efficiency of a photovoltaic system drops as its operating temperature rises and PV cooling is necessary. Solar chimney is passive elements and one of the most promising method to improve photovoltaic system efficiency. In this paper, optimum Solar Chimney (SC) structure to improve photovoltaic (PV) system efficiency by using Particle swarm optimization (PSO) was proposed. First, a brief description of theoretical solar cooling chimney module and discusses the effect it’s parameter on the PV system efficiency. The PSO algorithm used to optimize SC structure representing height Hc, Width Wc, and thickness tc. The range of Sc simulation model were, Hc range 0.5m–3m and, Wc range 0.1m-1m, tc range 0.1m-0.25m, and Pressure difference between inlet and outlet increase from 0.5 to 5.3 KPa. Theoretical analysis shows the PV system efficiency has positive effected by increase Hc, compared to negative effect to increase Wc and tc.

Key-Words: - Solar Chimney, PV panel, efficiency, PSO.

1 Introduction

Photovoltaic panels have negative temperature coefficient due to which its open circuit voltage decreases by certain V/°C of rise in the panel temperature. Cooling of solar panel to maintain its efficiency has been studied since long time by many researchers [1-5]. Solar chimney utilizes solar radiation to increase the air flow temperature which works as passive cooling PV panel through air flow in the channel. The heat lost to the air gap heats up the air which cools the PV panel and the preheated air is channeled through proper SC systems design. Some other important possibilities for enhancing the cooling effect of both buoyancy-driven and forced air flow have been suggested and focus generally on the channel geometry, creation of more turbulence in the flow channel and increasing of the convective heat transfer surface area in the channel [6-7].

Many research during past few decades studies had been performed on the SC concept as a passive cooling system, that have deepened our knowledge on the parameters that affect the performance and the applicability of the system for natural ventilation. The heat transfer mechanisms (by conduction, convection and radiation) in the SC channel were studied in detail, using the numerical method of finite-difference control volumes[8]. Various methods of cooling a solar cell have been previously suggested in the literature [1-5,9]. Most of the methods that are used for cooling of PV panel involve an active medium which requires auxiliary power. Having an active cooling system for photovoltaic cell will make it costly and complicated have the ongoing maintenance cost. This is the motivation to explore the passive cooling methods for PV panels. In certain studies numerical modeling was employed to perform parametric analysis on the SC system. The effects of solar heat gain and glazing type [10], cavity width [11] (Gan, 2006), inclination and low emissivity coating [12](Mathur, et al., 2006) were some of the issues investigated using CFD modeling. Recently [13] Gan (2010) found that the size of the computational domain (for CFD simulations) has an impact on the airflow and heat transfer coefficient predictions in solar heated cavities, and made corresponding suggestions. An extensive parametric analysis for a SC integrated in a prototype residential building was
performed by Ho Lee [14], using numerical modeling in the program Energy Plus. In this paper focus on improving PV panel by optimization SC structure using PSO algorithm was proposed. A mathematical model was brief described for solar chimney integrated with photovoltaic (PV) modules with difference geometrical and physical parameters such as the height and the solar radiation.

2 Related Works

2.1 Solar Chimney model

In [15] from Stuttgart University first introduced the concept of SC for power generation application. These solar radiations is incident on the transparent bottom surface and absorbed by the air that is under the solar chimney which eventually gets warmed up and its density decreases. The warm air will try to rise up due to the buoyancy force and escape through the chimney and this helps to increase the air temperature and in turn the air velocity by a pressure difference between the bottom and the top. This velocity of air is utilized to drive the turbine inside the chimney that will generate the electricity.

Air flow due to buoyancy and heat transfer in a vertical channel heated with simulated heat source has been investigated numerically and experimentally and has shown that 30% of heat flux is transfer to the unheated wall of the duct from the PV panel by radiation.

![Figure 1. Solar cooling chimney dimension](image)

Figure 1, the performance analysis of collector and in the chimney power plant is based on a mathematical model of momentum and energy balance equations such as.

**PV panel section (point i to point 1)**

Energy received by PV panel:

$$E_{in-pv} = I \times A_{pv} \times \left(1 - \eta_{pv}\right) \times \tau_{pv}$$  \hspace{1cm} (1)

Heat is transferred from outer and inner surface of the PV panel via natural convection and radiation.

$$E_{loss-pv} = h_{nat} A_{pv} (T_{spv} - T_a) + h_{for} A_{pv} (T_{spv} - T_a) + \varepsilon \sigma A_{pv} (T_{spv}^4 - T_a^4)$$  \hspace{1cm} (2)

The temperature of the air at outlet of the PV section $T_1$ can be determined using the log mean temperature difference between the ambient temperature and the PV surface temperature.

$$T_1 = T_{spv} - T_a \ln \left(\frac{T_{spv}}{T_a}\right)$$  \hspace{1cm} (3)

The density of moist inlet air is calculated by

$$\rho_i = \rho_{dry,i} + \rho_{v,i}$$  \hspace{1cm} (4)

where density of dry air and water vapor are both estimated by ideal gas law.

The natural draft pressure caused by the difference in outside and inside air density is given by

$$\Delta P_s = (\rho_i - \rho_1) \times g \times H_c$$  \hspace{1cm} (5)

where $H_c$ is the height of chimney duct and $g$ is the gravitational acceleration (9.81 m/s²).

The total pressure loss in a duct can be calculated by

$$\Delta P_{lossPV} = \frac{fL}{D_h} \left[\frac{\rho_{avg} V_1^2}{2}\right] + \left[\frac{kP_{avg} V_1^2}{2}\right]$$  \hspace{1cm} (6)

By equating Eq(5) and Eq(6), we can determined the velocity, $V_1$ of the air.

$$V_1 = \frac{(\rho_i - \rho_1) \times g \times H_c}{\frac{\rho_{avg} fL}{2D_h} + k}$$  \hspace{1cm} (7)

**Absorber section (point 1 to point 2)**

Energy absorbed by absorber surface:

$$E_{in-abs} = I \times A_{abs} \times \tau_{trans} \times \tau_{abs}$$  \hspace{1cm} (8)

Energy loss of the absorber:
Similar to the PV panel section, Tsa can be found by equating Eq(8) and Eq(9).

The log mean temperature of the absorber section is

\[
T_2 = \frac{T_{sa} - T_1}{\ln \left( \frac{T_{sa}}{T_1} \right)}
\]  

(10)

Similar procedure is used to calculate the velocity of air, V2 at this section.

\[
V_2 = \frac{(\rho_1 - \rho_2) \times g \times H_c}{\frac{\rho_{avg}}{2} \left( \frac{fL}{D_h} + k \right)}
\]  

(11)

The Reynolds number, Re is a function of the inlet velocity, V2 which is unknown.

Nusselt number equation for natural convection over inclined plate [16]:

\[
Nu = 0.825 + \frac{0.387 R_d^{1/6}}{1 + (0.492 / Pr)^{9/16}}
\]  

(12)

Nusselt number equation for forced convection [16]:

\[
Nu = \frac{0.3387 Pr^{1/3} Re^{1/2}}{\left(1 + (0.0468 / Pr)^{2/3}\right)^{1/4}}
\]  

(13)

The process for implementing PSO for optimizes SC model parameter is as follows:

Step 1: Initialize related parameters, including the size of swarm m, the inertia weight w, the acceleration constants c1 and c2, the maximum velocity Vmax, the stop criterion and the initial position and velocity of each particle.

Step 2: Evaluate the desired fitness eq. (13) function values for each current particle.

Step 3: Compare the evaluated fitness value of each particle with its Pbest. If current value is better than Pbest, then set the current location as the Pbest location. Furthermore, if current value is better than g best , then reset g best to the current index in the particle array.

Step 4: Change the velocity and location of the particle according to the Eqs. (14) and (15), respectively [17-18].

\[
v_{id}^{n+1} = w v_{id}^{n} + c_1 r_{1}^{n} (p_{id}^{n} - x_{id}^{n}) + c_2 r_{2}^{n} (g_{id}^{n} - x_{id}^{n})
\]  

(14)

\[
x_{id}^{n+1} = x_{id}^{n} + v_{id}^{n+1}
\]  

(15)

where w is the inertia weigh; c1, c2 are two positive constants, called cognitive and social parameter respectively; d=1,3,...,D; i=1,3,...,m and m is the size of the swarm; r1, r2 are two random numbers, uniformly distributed in [0,1]; and n=1,3,...,N denotes the iteration number, N is the maximum allowable iteration number.

3 Proposed Method

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Step 4: Change the velocity and location of the
particle according to Eqns. 14 and 15, respectively.

Step 5: Loop to step 2 until the stop criterion is met. The criterion usually is a sufficiently good fitness value.

4 Result And Discussion

The proposed method implemented with Matlab software and although the PSO method seems to be sensitive to the tuning of some weights or parameters, according to the experiences of many experiments, the following PSO and GA parameters can be used.

1) PSO Method
   population size = 100;
   generations = 40;
   inertia weight factor \( w \), where \( w_{\text{max}} = 0.7 \) and \( w_1 = 0.4 \);
   the limit of change in velocity of each member in an individual was
   \[
   V_{p_d}^{\text{max}} = 0.5 P_{d}^{\text{max}}, V_{p_d}^{\text{min}} = 0.5 P_{d}^{\text{min}}; \\
   \]
   acceleration constant \( c_1 = 2 \) and \( c_2 = 2 \).

2) GA Method
   population size = 100;
   generations = 40;
   crossover rate \( P_c = 0.6 \);
   mute rate \( P_m = 0.05 \);
   crossover parameter \( a = 0.5 \).

The objective function used to identify the optimum SC parameter can be calculated by Eq.13 Where, the optimization process is to get the optimal parameters \( H_c, W_c \) and \( t_c \) which makes \( \text{Nu}_{\text{max}} \). In addition, the searching area of the coefficients is set according to the experience, \( H_c=0.5\sim3m, W_c=0.5\sim1m, \) and \( t_c=0.1\sim0.25m \).

Table 1 show the output result from the PSO algorithm and GA algorithm applied to the SC model at normal operating conditions by wall temperature in the range of 30°C to 60°C.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PSO Algorithm</th>
<th>GA Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H_c )</td>
<td>0.0392</td>
<td>0.0395</td>
</tr>
<tr>
<td>( W_c )</td>
<td>0.0243</td>
<td>0.0241</td>
</tr>
<tr>
<td>( t_c )</td>
<td>0.5347</td>
<td>0.5346</td>
</tr>
</tbody>
</table>

In addition, sensitivity analysis is done by using CFD for the parameters in table 1 to determine the effect of each parameter against system’s performance as shown in figure 2 to 6.
From above Figures prove that parameter selected by PSO algorithm have position impact of SC system itself and Solar panel.

5 Conclusion

In this paper, two optimization PSO and GA algorithms have been used for the parameter identification of SC System to improve solar panel efficiency. A mathematical model was developed for SC integrated with PV panel system was also explained briefly. In addition, the performance analysis is evident that air velocity depends on surface area of solar chimney. The simulation results show that better performance was obtained with parameter selected by PSO algorithm or reduction of the effort and time required determining the air velocity in SC as compared GA Algorithm.

References:


