Performance assessment of hybrid PVT air collector using GSA-CS algorithm

Sourav Diwania¹, Anmol Gupta²,³, Anwar S Siddiqui¹, Sanjay Agrawal⁴, Yash Pal²
¹Jamia Millia Islamia, New Delhi, India
²National Institute of Technology, Kurukshetra, Haryana, India
³KIET Group of Institutions, Ghaziabad, Uttar Pradesh, India
⁴SOET, IGNOU, New Delhi, India
* Corresponding author email: anmol.engg@gmail.com

Abstract. In the last few decades, enormous attention is drawn towards PV/T systems due to their advantages as compared to solar PV or solar thermal systems individually. In this proposed paper, hybrid Gravitational Search Algorithm (GSA)-Cuckoo Search (CS) has been implemented to optimize the parameters of glazed hybrid PVT air collector. Although there are various parameters which affects the thermal and electrical performance of PVT system but in this paper only four parameters namely Channel length below the PV panel, channel depth, velocity of fluid flowing through the channel and temperature of fluid at the inlet of the channel have been considered for optimization using the hybrid approach. The outcomes shows that GSA-CS algorithm is proved to be very efficient techniques to be used to optimized the parameters of hybrid PVT module. The result of the analysis shows that the average value of exergy efficiency is 14.8228% when the parameters are optimized using hybrid GSA-CS algorithm.

Key Words: Gravitational Search Algorithm; Cuckoo Search; PVT module

1. Introduction
The industrial reformation in the 18th century has tremendously hiked the energy demand globally. Around 14% of total energy consumption globally is provided by sustainable power sources [1]. Amongst all the available renewable energy sources, the solar PV has the highest capital cost, but due to its lower operational cost and maintenance [2], this technology is acknowledged around the world. Other advantages of solar PV are increased efficiency and pollution free energy [3]. The installed capacity of solar PV is increasing day by day worldwide due to its above-mentioned point of interests.
Banker & Pearce [4] discussed the development in PV technology over the last two decades. The PV technology gained popularity due to decline in the price of a photovoltaic module. This reduction in cost is mainly due to competition among the manufacturers. Different governments in various parts of the world also show interest in emerging PV technology. Incentives had also been provided to the consumers in many parts of the world. Liou [5] discussed different silicon and non-silicon based technologies utilized for photovoltaic applications as depicted in Figure 2.

The crystalline silicon technology is widely accepted as compared to other solar cell technologies because it exhibits higher efficiency as compared to other silicon based PV modules. In the most recent research, efficiency of multi-crystalline silicon technology up to 23% is reported in the literature [6]. But there are various hindrances such as easy availability of the sun energy, lesser efficiency and high payback time. Most of the incident sunlight is converted into heat and only a small portion (15%-19%) of it is converted into electrical energy. This heat energy not only reduces the lifetime of PV module but also decreases its electrical efficiency [7]. In order to utilize the wasted heat, the concept of PVT is introduced. The PVT system combines the solar PV technology and solar thermal technology. In PVT system, a duct/channel/tube is used below or above the module and circulating fluid is used in the channel to pull out the heat energy absorbed by the panel [8].

An experimental study is conducted by Ahn et al. [9] to examine the performance of PVT-air collector. The heated air exhausted from the channel was again passed through heat recovery ventilation (HRV) to preheat the heated air to improve the thermal efficiency (ηth) of the system. It has been observed from the experimental investigation that the thermal and electrical performance of
the system has improved significantly. Slimani et al. [10] compared a single pass design of PVT-air collector with a glazed double pass PVT-air collector. The outcomes of the experiments show that the introduction of glazing (additional glass cover) caused an increase in temperature of all layers due to the greenhouse effect. The outlet temperature of double pass design reached up to 47 °C while in single pass design, the maximum temperature at the outlet was around 32 °C. The increase in temperature of upper PV module surface causes the decrease in electrical efficiency (ɳele). Thus, the double pass design has a lesser electrical efficiency compared to single pass design. Sarhaddi et al. [11] worked upon a mathematical expression of overall energy of flat plate PVT air collector. From the experimental evaluation, the electrical, thermal and overall efficiencies of the flat plate PVT system are found to be 10.01%, 17.18%, and 45%, respectively. From the experimental analysis, following inferences are drawn: 1. The ɳth and ɳoverall of PVT-air collector reduced with an increase in input temperature at the channel, 2. The ɳth and ɳoverall increases with increase in inlet air velocity, 3. The ɳth and ɳoverall initially increases with an increase in solar radiation intensity (up to 100 W/m²) but later the overall energy efficiency and electrical efficiency tend to reduce slightly.

Hegazy [12] experimentally investigated the effectiveness of the four different types of PVT-air collector depicted in Table 1. These PVT configurations are classified as model A, B, C and D based on the position of channel.

| Model | Air flow pattern |
|-------|-----------------|
| A     | Above the PV panel |
| B     | Below the PV panel |
| C     | Single pass type with channel both sides of PV |
| D     | Double pass type with channel both sides of PV |

The effect of air velocity through the channel and selectivity of absorber plate has also been examined. From the experimental investigation, following inferences are drawn: 1. The electrical energy output and thermal output of model B and model D are almost similar and higher than that of model A, 2. The model C demands least fan power, hence its electrical efficiency is better than other three configurations discussed and 3. The thermal gain of any particular model increases with increase in fluid mass flow rate through the channel but at the same time, this requires more fan power hence has a slightly lower electrical efficiency. Qureshi et al. [13] discussed the impact of various environmental parameters viz. Air velocity, humidity, atmospheric temperature and temperature of solar cell on the performance of hybrid PVT-air collector.

PVT-system with upper glazing traps the heat from the sunlight and helps in improving the thermal efficiency when compared with unglazed system. Additional glass cover (glazing) is used above the PV surface to trap more heat energy which increases the thermal energy output almost double that of unglazed PVT but decreases the electrical energy output [14]. Other effects of glazing are edge shedding and increased temperature which may lead to reduction in electrical output [15] and increase the sensitivity of photovoltaic module towards reflection losses and lead to the formation of hot spots. The ɳele of the PVT-air collector is inversely proportional to number of glass cover (glaze). As the number of glass cover over the PV module increased, the ɳth of the system increases while the ɳele reduces [16].

Jin et al. [17] worked upon modified PV/T air collector by adding rectangular tunnel heat exchanger in the channel and compared its performance with conventional PV/T air collector. From the experimental investigation, it has been concluded that the thermal and electrical efficiencies for the modified system were 54.70% and 10.02% respectively which is significantly higher as compared to conventional PV/T air collector. Hussain et al. [18] uses honeycomb heat exchanger of hexagonal shape in the air channel. It has been concluded from the experimental investigation that the thermal efficiency of the system was improved significantly with the modification in the air channel. At a solar
irradiance level of 828 W/m² and mass flow rate of 0.11 kg/s, the ηth of the system was found to be 87%.

2. System description
In the proposed work, a single channel gazed PVT module is considered having 36 cells arranged in 9 rows as shown in Figure 3. The solar cells are arranged in series and in parallel to increase the voltage and current ratings respectively of the module. The objective of the proposed work is to analyze the exergetic performance of the PVT system using hybrid GSA-CS algorithm. In the proposed model, the extra glass cover is used above the PV module to trap the sunlight. Below the PV module, a channel is used in which air is circulated to absorb the heat energy of the panel. The layer of insulation is used below the channel so that the trapped heat in the channel may not dissipate through the bottom part of the system. Only four variable parameters i.e. Channel length, channel depth, velocity of air flowing through the channel and temperature of fluid at the input of channel have been considered for the analysis.

![Proposed single channel photovoltaic thermal module](image)

Figure 3. Proposed single channel photovoltaic thermal module [20]

3. Optimization of the system
In this paper, the hybrid GSA-CS algorithm is used to find out the optimum value of objective function (exergy efficiency) by considering the values of variable parameters within the specified limit (upper and lower bound). The hybrid GSA-CS algorithm combines the best properties of gravitational search algorithm and cuckoo search algorithm. In GSA, each search agent is categorized according to its position, gravitational mass, velocity and inertial mass. In cuckoo-search (CS) algorithm, the swarms were divided into various groups according to their identity (roosters, chickens and hens). The groups were decided on the basis of fitness function. The swarms with highest fitness value will be categorized as roosters while the swarms having lowest fitness value will be identified as chickens and rest will be categorized as hens. Hens can choose a group for its survival haphazardly and the relation between the hens and chickens is resolved arbitrarily. In Cuckoo Search algorithm, the initialization of population is arbitrary. That’s why it can’t ensure success in every solution. The irregular arrangements of population cause the solution to be far away from the optimized solution. In each selected group, every chicken can be viewed as an answer, though a moved chicken is another arrangement. The optimal arrangement is held at last, which is the extreme objective of this calculation. The hybrid GSA-CS optimization technique is applied to the PVT module and the fitness value of each search agent is calculated according to gravitational search algorithm. The best fitness value so far is the optimal location of the search agent. The position of the search agent is updated in
the next iteration according to the cuckoo search algorithm [19]. The best updated solution is find out using the hybrid approach for \( t = t+1 \) iterations. The pseudo code for the hybrid GSA-CS algorithm is shown in figure 4.

![Pseudo-code for hybrid GSA-CS algorithm](image)

Figure 4. Pseudo-code for hybrid GSA-CS algorithm

4. Optimization results and analysis
The exergetic performance of glazed PVT module has been evaluated by optimizing its four different variable parameters (length of the channel, depth of the channel, velocity of air flowing through the air duct and temperature at the input of the air channel) using hybrid GSA-CS algorithm. In glazed PVT module, a single channel is used below the PV module in which air is used as a cooling fluid to absorb the heat energy from the PV surface. By using channel/duct below the PV module, its electrical efficiency is enhanced significantly. Therefore, the removal of heat from the PV module is necessary. The hourly data for solar radiations and ambient air temperature used for the optimization has been taken from IMD, Pune for a day in the month of January for the climatic conditions of New Delhi, India as shown in Figure 5 [20]. There are various parameters which have an impact over the effectiveness of PVT module but in this proposed work, only four parameters have been considered. For the proposed module, the variation in temperature at the output of channel, exergy efficiency,
electrical energy and thermal energy have been calculated according to thermal modeling presented by Agrwal and Tiwari [20].

The convergence curve for the hybrid GSA-CS algorithm for the different time of a day shows that the iteration converges at a very fast rate and it takes less time in the recognition of optimized value of parameters. The curve showing the convergence rate is depicted in Figure 6 when the intensity of sunlight is maximum i.e. 1:00 PM. From the plot, it has been observed that the exergy efficiency ($\eta_{Ex}$) is highest when the intensity of sunlight is maximum.

The variation in $\eta_{Ex}$ of the PVT module with time of a particular day is depicted in Figure 7. The Trend for exergy efficiency is increasing when the intensity of sunlight is increasing i.e. from morning 08:00 AM to 13:00 PM and it shows decreasing trend when the intensity of sunlight is decreasing i.e. from 13:00 PM to 17:00 PM. By using hybrid GSA-CS optimization algorithm, the solution converges with less than 10 iterations and also the convergence time is very less. The average value of $\eta_{Ex}$ of the PVT system is 14.85228% at the optimized values of the parameters as shown in table 2.
Table 2. Optimized values of variable parameters

| Exergy efficiency | Length of channel | Depth of channel | Temperature of fluid at the input | Velocity of fluid at the input |
|-------------------|-------------------|-----------------|-------------------------------|-------------------------------|
| 14.85228          | 0.414538 m        | 0.3 m           | 2.3                           | 1.5 m/s                       |

Figure 7. Variation in overall exergy efficiency of system with of a day

5. Conclusion
The following conclusions are drawn on the basis of above study:
• The convergence rate of hybrid GSA-CS algorithm is fast. The solution converges in less than 20 iterations.
• The average value of exergy efficiency ($\eta_{Ex}$) of the glazed PVT module is 14.85228% at the optimized value of parameters.
• The hybrid GSA-CS algorithm is proved to be an efficient technique for optimizing the parameters of PVT systems.

References
[1] N.L. Panwar, S.C. Kaushik, S. Kothari. Role of renewable energy sources in environmental protection: a review. Renewable Sustainable Energy Rev. 15, 2011. 1513-24.
[2] A. Sharma. A comprehensive study of solar power in India and world. Renewable Sustainable Energy Rev. 15, 2011. 1767-76.
[3] P. Bhubaneswari, I.S. Goicranco. A review of solar photovoltaic technologies. Renewable Sustainable Energy Rev. 15, 2011. 1623-36.
[4] K. Branker, J.M. Pearce. Financial return for government support of large scale thin-film solar photovoltaic manufacturing in Canada. Energy Policy 38, 2010. 4291-303.
[5] H.M. Liou. Overview of the photovoltaic technology status and perspective in Taiwan. Renewable Sustainable Energy Rev. 14, 2010. 1202-15.
[6] F. Schindler, J. Schön, B. Michl, S. Riepe, P. Krenckel, J. Benick, F. Feldmann, M. Hermle, S.W. Glunz, S. Warta, M.C. Schubert. How to achieve efficiencies exceeding 22% with multi-crystalline n-type silicon solar cells. Energy Procedia 124, 2017. 777-80.
[7] E. Skopiká, J.A. Palyvos. On the temperature dependence of photovoltaic module electrical performance: a review of efficiency/power correlations. Sol. Energy 83, 2009.614–624.
[8] A. Braunstein, A. Kornfeld. On the development of the solar photovoltaic and thermal (PVT) collector. IEEE Trans. Energy Convers. EC-1. 1986, pp. 31–33.

[9] J.G. Ahn, J.H. Kim, J.T. Kim. A study on experimental performance of air-type PV/T collector with HRV. Energy Procedia 78, 2015, 3007–12.

[10] M.El. Slimani, M. Amirat, S. Bahria. Analysis of thermal and electrical performance of a solar PV/T air collector. 3rd International Conference on Control, Engineering and Information Technology (CEIT), Tlemcen, 2015.

[11] F. Sarhaddi, S. Farhat, H. Ajam, A. Behzadmehr, M.M. Adeli. An improved thermal and electrical model for a solar photovoltaic thermal (PV/T) air collector. Applied Energy 87, 2010, 2328-39.

[12] A. Hezagy. Comparative study of the performance of four photovoltaic/thermal solar air collectors. Energy Conservation and Management 41, 2000, 861-81.

[13] U. Qureshi, P. Bareda, A. Kumar. Effect of weather conditions on the hybrid solar PV/T collector in variation of voltage and current. Int J Res (IJR) 1(6), 2014, 872–9.

[14] H.A. Zondag. Flat plate PV-thermal collectors and systems: a review. RSER 12(4), 2008, 891-959.

[15] A. Pascal, E. Wolfgang, F. Hubert, R. Matthias, S. Anton, S. Henrik. Roadmap: A European guide for the development and market introduction of PV thermal technology, contract no-502775(SES6).

[16] T.T. Chow, G. Pei, K.F. Fong, Z. Lin, A.L.S, J. Ji. Energy and exergy analysis of photovoltaic-thermal collector with and without glass cover. Appl Energy 86, 2009, 310–6.

[17] G.L. Jin, A. Ibrahim, Y.K. Chean, R. Daghigh, H. Ruslan, S. Mat, M.Y. Othman, K. Ibrahim, A. Zaharim, K. Sopian. Evaluation of single-pass photovoltaic-thermal Air collector with rectangle tunnel absorber. American Journal of Applied Sciences, 7, 2010, 277–82.

[18] F. Hussain, M.Y. Othman, B. Yatim, H. Ruslan, K. Sopian, Z. Anuar, S. Khairuddin. Comparison study of air base photovoltaic/thermal (PV/T) collector with different design of heat exchanger. In: World renewable energy forum, WREF 1, 2012, 189–94.

[19] S. Liang, T. Feng, G. Sun. “Sidelobe-level suppression for linear and circular antenna arrays via the cuckoo search– chicken swarm optimisation algorithm”. IET Microwaves, Antennas & Propagation 2016. DOI: 10.1049/iet-map.2016.0083.

[20] Diwania et al. Performance enhancement of single-channel glazed photovoltaic thermal module using Whale Optimisation Algorithm and its comparative study. International Journal of Ambient Energy 2018. DOI:10.1080/01430750.2018.1537937.