PVT Module Modeling by Using the WOA

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Abstract- A solar photo voltaic array has three main components: solar cells, panels and array of the cells. The over energy produced by an array depends upon the configuration of these components collectively. The solar cell is design such that it can cool down at the peak sun light hours and can produce less thermal energy to get the maximum usable energy. In this work we used a latest heuristic optimization algorithm based on whales to tune the parameters of PV cell and comparison is done with previously used methods. The purpose of these methodologies is to obtain optimum values of the design parameters of SCPVT system, such that the overall economic profit is maximized throughout the PV system lifetime operational period which is not directly calculated in our work rather energy efficiency is calculated . Out of many design parameters available for this system, in the present work only few parameters are taken. The optimal design parameters chosen here are length of channel, depth of channel, velocity of fluid in the cell, and temperature of the cell. The objective function which calculates the energy every-time it gets a new set of four design variables, is used for whale optimization algorithm (WOA). Using the same objective function and input data, energy results of design optimization of SCPVT system by using gravitational search algorithm (GSA) and Genetic Algorithm (GA) are also obtained and compared. Simulation results shows that WOA has out pass the GSA and GA for more energy at every hour in an usual day, when all algorithms are computed for equal iterations and population size.

Keywords- PVT model, WOA, GA, GSA etc.

I. INTODUCTION

The hybrid photovoltaic thermal (PVT) module is a collection of collector with the provision of a channel or channels to convert solar energy into thermal and electrical energies simultaneously. The PVT collector can be used whenever both electrical and thermal energy are required, for domestic uses. It is well known fact that the efficiency of the photovoltaic cells decreases as operating temperature increases.

A PVT collector is a system in which the electrical and thermal energy produced simultaneously by the photovoltaic. In this way, heat and power are produced simultaneously; it is also called co-generation system. Since the demand for solar heat and solar electricity are often additional, it seems a logical idea to develop a device that can fulfill with both demands. The thermal energy available on the PV module can be tapped by flowing air/water in the duct or channel. This proposed system is known as PVT collector. The overall efficiency of a PVT collector is improved as compared to a PV system because it gives useful thermal energy in addition to the electricity. Further, a PVT collector is better than a PV system, as it gives a better electrical efficiency by withdrawing heat from the back surface of the PV module due to the presence of channel below the PV module. At standard test condition, (intensity 1000 W/m^2 and cell temperature 25^{0}C) (CEL, Sahibabad), a typical PV collector efficiency is around 15% to 20% and efficiency temperature coefficient range is around 0.3% to 0.6 % of efficiency loss per ^{0}C.

II. PHOTOVOLTAIC EFFECT

The basic idea of a photovoltaic cell is to convert light energy into electrical energy. The energy of light is transmitted with the help of photons, small packets or quantum's of solar light. Electrical energy is stored in electromagnetic fields, which in turn can make a current of electrons flow. In other words, we can state that a solar cell converts light (a flow of photons) to electric current (a flow of electrons). When a photovoltaic cell (p-n junction) is illuminated, electron-holes pairs are generated, and acted upon by the internal electric fields, resulting in a photo current (I_L). The generated photocurrent flows in a direction opposite to the forward dark current. Even in the absence of external applied voltage, this photocurrent continues to flow, and is measured as the short circuit current (I_{SC}). This current depends linearly on the light intensity, because absorption of more light results in additional electrons to flow in the internal electric field force.

PHOTOVOLTAIC CELLS

Photovoltaic (PV) cells are devices that converts sunlight into electricity without using any thermodynamic cycles and mechanical generators; the initials PV stands for a photo (light) and voltaic (electricity). The cell is commonly known as a solar cell. The photovoltaic cells were significantly developed at Bell Labs in 1950, primarily for space applications.

III. PV MODULE THERMALMODELING

To increase the efficiency of photo voltaic module, its design parameters are optimised in our work. In this thesis, the proposed PVT module is analyzed with a channel between tedlar and Insulation. The glass formation is considered above the solar cell. The schematic view of the proposed PVT module is shown in fig. 3.1which is usually called the single channel photovoltaic thermal tile (SCPVTC). In order to realize maximum overall thermal efficiency different parameters of the SCPVT module are optimized using gravitational search algorithm (GSA) which is based on the movements of planets in an orbit. When solar radiation is incident on the SCPVT module, the solar energy is converted into electrical and thermal energies. Out of these electrical energy is stored in a battery. Due to thermal energy the SCPVT cell gets heated giving reduced electrical efficiency because the module is constructed using semiconductor material. So, for optimizing electrical efficiency of the SCPVT module heat removal is essential. In order to convert this heat into useful thermal energy the SCPVT model is proposed in which the channel is formed below the tedlar and air flow occurs in the form of a flowing fluid through a DC fan. In SCPVT module solar radiation is absorbed by solar cell which conducts into to the base of the tedlar causing thermally heated air flowing into the channel below the tedlar as shown in figure .1

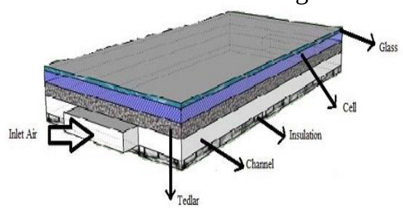

Fig.1: Proposed single channel photovoltaic thermal cell (SCPVT)[1]

In order to analyze energy balance of SCPVT module, the following assumptions are made:

1. there is no temperature gradient along the thickness of solar cell.
2. Heat capacity of solar cell is negligible
3. Specific heat of air remains constant in the course of observations.
4. The system is in the quasi-steady state.
5. Packing factor is unity.

WHALE OPTIMIZATION ALGORITHM (WOA)

Whale optimization algorithm (WOA) was published first in 2016 [2] and it formulated the foraging behaviour of humpback whales. The humpback whales feed themselves by consuming small fishes near the water upper surface. So they make a spiral or 9 like structure by bubbles around their prey. During foraging process they go down to 12 meter and make bubbles in circle to confuse the fishes and then swim up toward the surface as shown in figure 3.1. This foraging behaviour is called bubble net feeding method. The movement of whale is classified in two ways, one in which whale goes down, make bubbles and then goes up and second one includes different stages: coral loop, lobtail, and capture loop.

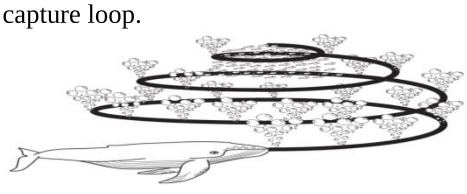

Fig. 2. Bubble-net feeding behaviour of humpback whales [2]

The encircling prey is to reach to optimal position which is position of fishes. To get this thing done whale must use some random seed (random search space) so that based on the optimal position can be obtained. since at this stage optimal position is not known so it is assumed that current position is the optimal one.

IV. PROPOSED WORK

Our WOA optimization is an iterative process and updates the position of whales in each step. The single channel PV cell tuning parameters are settled to gain maximum energy (usable energy). WOA method tunes these variables in SVPVT for the purpose. Both are isolated domains, still they work in a closed loop system. The objective function in WOA is called in each iteration and for each whale in the group. This objective function calculates the energy from electrical efficiency and thermal efficiency as in equation. The values of four design parameters which are

- temperature of fluid at inlet,
- length of channel in meters,
- velocity of fluid in the channel,
- depth of channel

is varied every time and a new value of energy is obtained. For an iteration we used 30 whales in a group and so we will get 30 different energy values for 30 distinct set of tuning variables of solar cell. The maximum value among these 30 values are calculated and stored in a different matrix. Every Whale try to converge at prey position, so considering the best position in previous iteration as best position so far, whale will move towards that position and reduce the gap. Following the position update equations from 3.14 to 3.18, every whale gets a new position or new set of SCPVT design variables. For these new input values, energy is calculated and best value among these new 30 values is compared with best value so far. The winning position will be considered as the optimal position of prey for the whale. This step keeps on repeating till maximum number of iterations. Total iterations to perform depends upon the application. In our case, we get the convergence up to 10 iterations so maximum of 20 iterations will be sufficient. The initial values of designing variables are chosen randomly with in the upper and lower bounds which introduce the random initial see behavior in the results. Due to it, after each simulation instance, results will be different than others.

Since WOA has a different terminology which is totally different from our work. There are some terms which can be correlated with our technical terms. Each agent's position in WOA is termed as the set of design parameters and energy efficiency by objective function designed in MATLAB is calculated for each agent. In each iteration and for each agent this function will be called in main script and a table in MATLAB will be used which save all values of maximum cost for each set of agents in every iteration.

Table 1 : Pseudo Code for SCPVT optimization process

1. initialise all PV module design parameters
2. load the solar irradiance and temperature for time being
3. for i=1:number of time stamps
4. randomly initialise the WOA parameters for four tuning variables of solar cell
5. for j=1:WOA iterations
6. set the bounds for all four tuning variables
7. pass these to objective function written to calculate the energy efficiency as per mathematical calculation
8. save this energy value for first iteration
9. update the tuning variables value by equation 3.1 to 3.5
10. repeat the steps from 7 to 9
11. all iterations finished
12. if yes
13. stop
14. else
15. repeat step from 7 to 11
16. pass the optimised value for each time stamp to main file
17. stop if all time stamps design variables are optimised

18. take the mean value of design parameters

compare with GA tuned parameters

V. RESULTS & DICUSSION

The proposed work of design parameters tuning for SCPVT is implemented in MATLAB. MATLAB provides a very user interface to design script. A lot of inbuilt functions in it makes the use easier and saves our time to build our code from scratch, so we can use that time in problem solution of research. We have developed our code in modules and are named as per their functions. These designed functions are called in main script, and user doesn't need to use them or call them separately. The structure of modules/functions designed and their significance is given in table 4.1. We also compared the results with previously used Gravitational search algorithm (GSA) and genetic algorithm (GA). The data for ambient temperature and solar ir-radiation has been taken from S. Singh et.al (2015) [1].

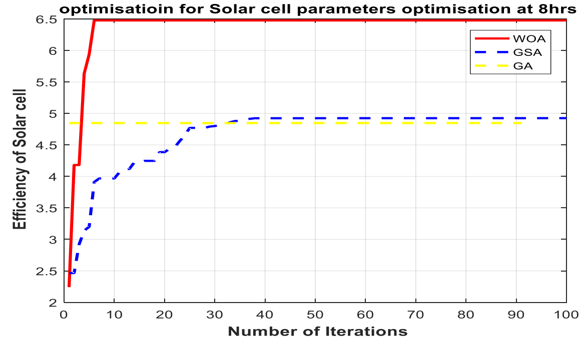

Fig.3: comparison of energy efficiency for WOA, GSA and GA with number of iterations

After optimization a plot of energy efficiency of solar cell vs iterations is plotted which verify the optimization efficiency. Our target is to maximise the efficiency, so the objective function output designed for WOA must be increasing with iterations and after some iteration it should settle at a maximum level beyond which no further improvement is possible. Higher the level good is the optimization.

It can be seen from the graph that WOA settles at higher energy level than GSA & GA which means the tuned design parameters by WOA are better than tuned by others. The WOA is also converging earlier than rest which proves the fast convergence property of WOA in this application.

To design the SCPVT module it is not possible to consider the different parameters for different time interval, so we have to take average of these parameters along with average of energy efficiency

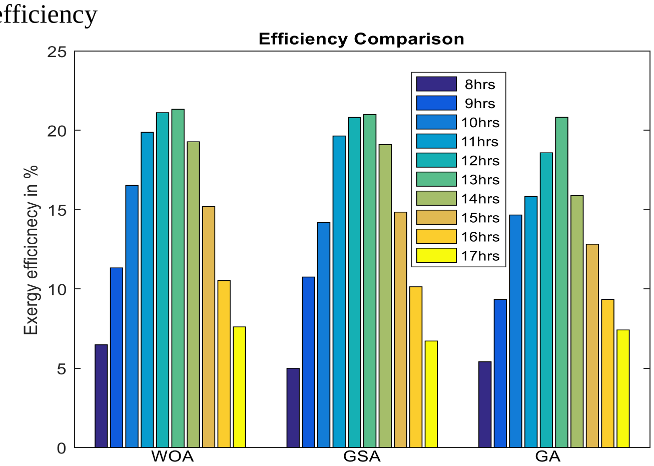

Fig.4: Energy efficiency for every time interval for GSA and GA

The proposed WOA optimization increase the overall energy by more than 3.44% compared to GSA tuned parameters and 27.11% compared to GA optimized energy.

VI. CONCLUSION

There has been constant work to gain maximum of usable energy from solar cell as a part of it is wasted in terms of thermal energy which also increase with the sun temperature. Our work is focused to improve the usable energy by selecting the suitable design parameters for single channel solar cell before fabrication. The motto is to keep the thermal energy minimal so that energy can be maximum. To cool down the cell the fluid flows in the channel under the upper layer. Dimension of that channel, velocity of fluid flowing into that also affects the energy efficiency. We optimally tuned these parameters before fabrication to fulfil our purpose.

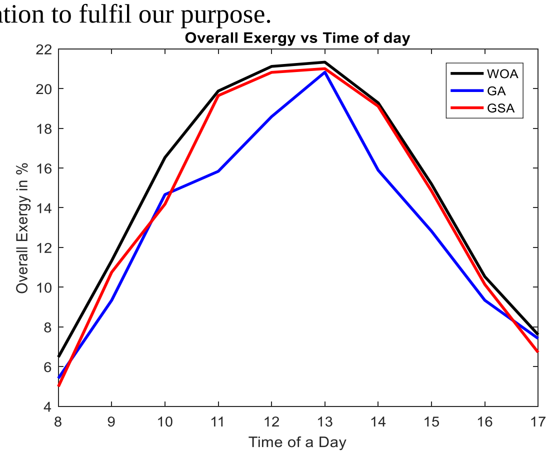

Fig.5: Energy efficiency comparison for GSA and GA vs time interval

We have used whale optimization algorithm (WOA) for that purpose. For the relevant literature survey a total of four parameters: temperature of fluid, length of channel, depth of channel and velocity of fluid, are considered the potential parameters to be optimised by WOA. Our target is to improve the energy efficiency of solar module by tuning of these four parameters. The work is compared with gravitational search algorithm (GSA) and genetic algorithm (GA) used previously. An improvement of 3.44% and 27.11% over GSA and GA calculated energy efficiency respectively. Results are shown for different irradiation intensity on solar panel and ambient temperature. For every interval our proposed algorithm performs better than both. The validation of our work and tuned parameters can be done in such a way that the graph in figure 4.3 follows the pattern of solar irradiation which is increasing form 8 AM to 1 PM and decreases thereafter as is clear form table 4.4. thus our work has provided a great improvement of 27.11 % over previous work.

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