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GSA Tuned High Exergy in PV Array

Meenu
M. Tech. Student
Indus College Jind, India

Shelly Garg
Assistant Professor
Indus College Jind, India

Abstract

A solar PV array system is comprised of the following components - solar cells, panel modules, and an array system. Thus, overall optimal design of a solar PV system involves the optimal design of the components at three levels - solar cell, panel module, and array. In the present work, a comparison between different optimization methods is applied to design optimization of single channel Photovoltaic (SCPVT) system. 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 of the proposed optimization algorithm which is Gravitational Search Algorithm (GSA) implemented for design optimization of the system is the energy efficiency, which has to be maximized.

Keywords: SCPVT, Exergy, GSA

I. INTRODUCTION

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. Therefore, the use of these cells as a hybrid photovoltaic thermal collector is better and a more efficient for cooling the cells as well as getting thermal energy. Another method for cooling the PV cells is to use a heat exchange system, which cools the cells by means of a heat absorbing medium, such as water, flowing in pipes. Another advantage of the PVT collector is its higher overall efficiency per unit area and lower packaging costs due to its compact design. The electricity conversion-efficiency of a solar cell for commercial application is about 6–15%. More than 85% of the incoming solar energy is either reflected or absorbed as heat energy. 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. In applications of PVT system, the main work of the PVT module is to produce electricity, and therefore, it is necessary to operate the PV modules at low temperature in order to keep the PV cell electrical efficiency at a sufficient level. The heat from the back surface of PV modules is withdrawn with the help of natural or forced air circulation. It is simple and low cost methods to remove heat from PV modules. It is simple and low cost methods to remove heat from PV modules, but they are less effective. when ambient air temperature is over 25°C. To overcome this problem, the heat can be extracted by circulating water through a heat exchanger that is mounted on the back surface of the PV module.

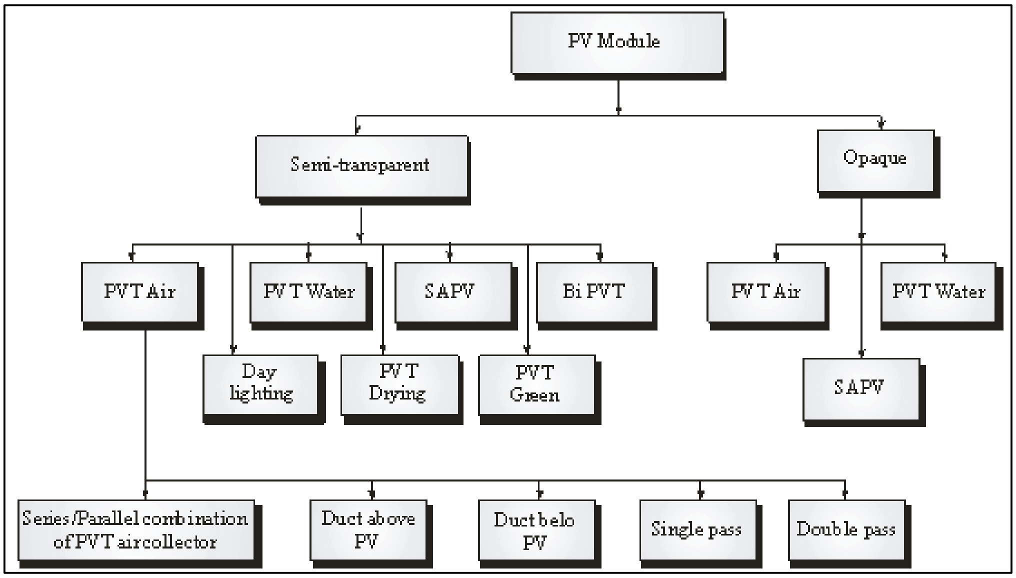

Fig. 1: Classification of photovoltaic systems on the basis of their use

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.

II. PRESENT WORK

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.2 which 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.

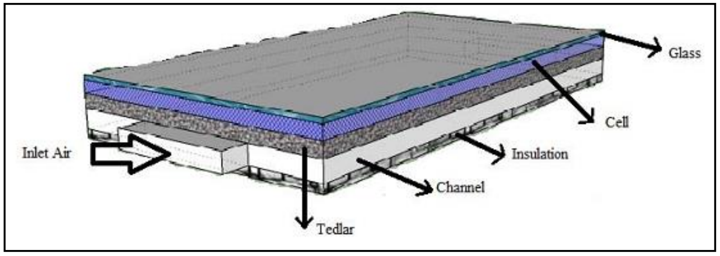

Fig. 2: Proposed single channel photovoltaic thermal cell (SCPVT)

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.

The mathematical formulation of energy efficiency and energy efficiency of SCPVT shown in figure 1.2 is as under. The nomenclature table is presented in table 1.

Table - 1
Nomenclature for mathematical formulation of SCPVT efficiency

Symbol	*Meaning*	*Symbol*	*Meaning*
A_{SC}	*Area of solar cell, m²*	b	*Width of the channel, m*
D	*Depth of the channel,m*	$Cair$	*Specific heat of air, J/KgK*
Dx	*Small length, m*	Dt	*Small time, s*
H	*Heat transfer coefficients, W/m2K*	h_{TA}	*Heat transfer coefficient from back of tedlar to ambient, W/m2K*
In	*Incident solar Intensity, W/m2*	h_{GA}	*Heat transfer coefficient from top glass cover to ambient, W/m2K*
K_T	*Thermal conductivity, W/Mk*	h_{TF}	*Heat transfer coefficient from back of tedlar to flowing fluid, W/m2K*
L	*Length of the channel, m*	h_{IA}	*Heat transfer coefficient from back of insulation to ambient, W/m2K*
m_F	*Mass flow rate of fluid, kg/s*	N_C	*Number of channel in SCPVT*
Q_U	*Useful heat, W*	U	*Overall heat transfer coefficient, W/m2K*
T_A	*Ambient Temperature, K*	U_{SCAG}	*Overall heat transfer coefficient from cell to ambient through glass, W/m2K*
T_{Avg}	*Average Temperature, K*	U_{SCFT}	*Overall heat transfer coefficient from cell to fluid through tedlar, W/m2K*
V_F	*Velocity of fluid in channel, m/s*	U_{FA}	*Overall back loss heat transfer coefficient from fluid to ambient, W/m2K*
V_{air}	*Velocity of air, m/s*	η_C	*power, Power conversion factor*

$$\begin{gathered}[\text{rate of solar energy availabel on glazed solar cell}] \\ = \begin{bmatrix}\text{rate of heat loss from top surface of solar} \\ \text{cell to ambient through glass cover}\end{bmatrix} + \begin{bmatrix}\text{rate of heat transfer form solar cell to} \\ \text{flowing fluid i. e. air through tedler}\end{bmatrix} \\ + [\text{rate of electrical energy prodiced}] \qquad (1)\end{gathered}$$

$$[\alpha_c \tau_g In * bdx] = [U_{SCAG}(T_{SC} - T_A)bdx] + [U_{SCFT}(T_{SC} - T_A)bdx] + [\tau_g \eta_{TC} In * bdx] \qquad (2)$$

After solving equation 3, we get

$$T_{SC} = \frac{\alpha_{eff} In + U_{SCAG} T_A + U_{SCFT} T_F}{U_{SCAG} + U_{SCFT}} \qquad (3)$$

Where

$$\alpha_{eff} = \tau_g(\alpha_{sc} - \eta_{TC})$$

Energy balance for air flowing in the channel of Single channel PVT for elemental area bdx is given by –

$$\begin{bmatrix}\text{rate of heat transfer form solar cell to flowing} \\ \text{fluid i. e. air through tedler}\end{bmatrix}$$

$$= \begin{bmatrix}\text{thermal heat gain by flowing fluid i.e. air in} \\ \text{the channel}\end{bmatrix} + \begin{bmatrix}\text{rate of heat transfer from flowing fluid to} \\ \text{ambient}\end{bmatrix} \quad (4)$$

$$U_{SCFT}(T_{SC} - T_F)bdx = m_F C_{air}\frac{dT_F}{dx}dx + U_{FA}(T_F - T_A)bdx \quad (5)$$

Where

$$m_F = \rho L d V_F$$

The thermal gain is as follows:

$$\eta_{Th} = \frac{m_F C_{air}}{U_L N A_{SC}}\left[1 - \exp\left(\frac{-NbU_L L}{m_F C_{air}}\right)\right]\left[h_p \alpha_{eff} - U_L\frac{(T_{FI} - T_A)}{In}\right] \quad (6)$$

The rate of useful thermal energy obtained for nR row of SCPVT module

$$Q_{U,N} = n_R m_F C_{air}\left[\frac{h_p \alpha_{eff}}{U_L}In - (T_{FI} - T_A)\right] * \left[1 - \exp\left(\frac{-NbU_L L}{m_F C_{air}}\right)\right] \quad (7)$$

A. Instantaneous Electrical Efficiency

An expression for electrical efficiency of hybrid SCPVT which is temperature dependent is as follows:

$$\eta = \eta_{TC}\left[1 - \beta_0\left\{\frac{\alpha_{eff} In}{U_{SCAG} + U_{SCFT}}(T_{Fo} - T_A)\frac{U_{SCFT} h_p \alpha_{eff}}{U_L(U_{SCAG} + U_{SCFT})}\left\{1 - \frac{\exp\left(\frac{-NbU_L L}{m_F C_{air}}\right)}{\frac{NbU_L L}{m_F C_{air}}}\right\} + \frac{U_{SCFT}}{U_{SCAG} + U_{SCFT}}\left\{1 - \frac{\exp\left(\frac{-NbU_L L}{m_F C_{air}}\right)}{\frac{NbU_L L}{m_F C_{air}}}\right\}\right\}\right] \quad (8)$$

B. Energy Analysis

The energy analysis is based on the first law of thermodynamics, where the total thermal gain can be represented as follows:

$$\sum Q_{UT} = \sum Q_{U,th} + \frac{\sum Q_{U,EL}}{\eta_{c,power}} \quad (9)$$

Where

$$\sum Q_{U,th} = \frac{Q_{UN}}{1000} \quad (10)$$

C. Energy Analysis

The general energy balance for a Single channel PVT module is expressed as:

$$\sum Ex_{out} = \sum Ex_{th} + \sum Ex_{EL} \quad (11)$$

Where

$$\sum Ex_{th} = Q_{U,N}\left[1 - \frac{T_A + 273}{T_{FO} + 273}\right] \text{and} \sum Ex_{EL} = [\frac{\eta A_m In}{1000}]$$

The expression for input energy is given as:

$$\sum Ex_{IN} = A_{SC} N_c * In[1 - \frac{4}{3}\left(\frac{T_A}{T_{sun}}\right) + 1/3\left(\frac{T_A}{T_{sun}}\right)^4] \quad (12)$$

The energy efficiency is given by

$$\eta_{Ex} = \left(\frac{Ex_{out}}{Ex_{IN}}\right) * 100_{IN} \quad (13)$$

D. GSA Optimization

GSA was introduced by Rashedi et al. in 2009 and is intended to solve optimization problems. The population-based heuristic algorithm is based on the law of gravity and mass interactions. The algorithm is comprised of collection of searcher agents that interact with each other through the gravity force. The masses are actually obeying the law of gravity as shown in Equation (3.4) and the law of motion in Equation (5).

F = G (M1M2 / R2)
a = F/M

Based on Equation (4), F represents the magnitude of the gravitational force, G is gravitational constant, M1 and M2 are the mass of the first and second objects and R is the distance between the two objects. Equation (3.4) shows that in the Newton law of gravity, the gravitational force between two objects is directly proportional to the product of their masses and inversely proportional to the square of the distance between the objects. While for Equation (5), Newton's second law shows that when a force, F, is applied to an object, its acceleration, a, depends on the force and its mass, M. The steps of GSA are as follows:

1) Step 1: Agents Initialization

The positions of the N number of agents are initialized randomly.

$$X_i = x_i^1, x_i^d, \ldots\ldots x_i^n \text{ for } i = 1,2 \ldots\ldots, N \quad (14)$$

x_i^d Represents the positions of the ith agent in the dth dimension, while n is the space dimension.

2) Step 2: Fitness evolution and best fitness computation:

For minimization or maximization problems, the fitness evolution is performed by evaluating the best and worst fitness for all agents at each iteration.

– Minimization Problems

$$\mathrm{best}(t) = \min_{j\epsilon\{1,..N\}} \mathrm{fit}\, j(t) \qquad (15)$$

$$\mathrm{worst}(t) = \max_{j\epsilon\{1,..N\}} \mathrm{fit}\, j(t) \qquad (16)$$

– Maximization Problems

$$\mathrm{best}(t) = \max_{j\epsilon\{1,..N\}} \mathrm{fit}\, j(t) \qquad (17)$$

$$\mathrm{worst}(t) = \min_{j\epsilon\{1,..N\}} \mathrm{fit}\, j(t) \qquad (18)$$

fit j(t) represents the fitness value of the j^{th} agent at iteration t, best(t) and worst(t)represents the best and worst fitness at iteration t.

3) Step 3: Gravitational constant (G) computation:

Gravitational constant *G* is computed at iteration *t*

$$G(t) = G_0 e^{-\alpha t/T} \qquad (19).$$

G0 and α are initialized at the beginning and will be reduced with time to control the search accuracy. T is the total number of iterations.

4) Step 4: Masses of the agents' calculation:

Gravitational and inertia masses for each agent are calculated at iteration *t*. Mai = Mpi = Mii = Mi, i = l, 2, ... ,N. (20)

$$\mathrm{m_i(t)} = \frac{\mathrm{fit(t) - worst(t)}}{\mathrm{best(t) - worst(t)}}$$

$$\mathrm{M_i(t)} = \frac{\mathrm{m_i(t)}}{\sum_{j=1}^{N} \mathrm{m_j(t)}}$$

Mai and Mpi are the active and passive gravitational masses respectively, while Mii is the inertia mass of the ith agent.

5) Step 5: Accelerations of agents' calculation:

Acceleration of the ith agents at iteration t is computed.

$$a_i^d(t) = F_i^d(t)/M_{ii}(t) \qquad (20)$$

$\mathrm{F_i^d(t)}$is the total force acting on ith agent calculated as:

$$F_i^d(t) = \sum_{j\in kbest} rand_j F_{ij}^d(t) \qquad (21)$$

Kbest is the set of first K agents with the best fitness value and biggest mass. Kbest will decrease linearly with time and at the end there will be only one agent applying force to the others.

$F_{ij}^d(t)$ can be computed as:

$$F_{ij}^d(t) = G(t).\left(M_{pi}(t) \times \frac{M_{ai}(t)}{R_{ij}(t)} + \varepsilon\right).\left(x_j^d(t) - x_i^d(t)\right) \qquad (22)$$

$F_{ij}^d(t)$ is the force acting on agent *i* from agent *j* at *dth* dimension and *tth* iteration. *Rij(t)* is the Euclidian distance between two agents *i* and *j* at iteration *t. G(t)* is the computed gravitational constant at the same iteration while ε is a small constant.

6) Step 6: Velocity and positions of agents:

Velocity and the position of the agents at next iteration (t+1) are computed based on the following equations:

$$v_i^d(t+1) = rand_i x v_i^d(t) + a_i^d(t) \qquad 2.23$$

$$x_i^d(t+1) = v_i^d(t+1) + x_i^d(t) \qquad 2.24$$

7) Step 7: Repeat steps 2 to 6

Steps 2 to 6 are repeated until the iterations reach their maximum limit. The best fitness value at the final iteration is computed as the global fitness while the position of the corresponding agent at specified dimensions is computed as the global solution of that particular problem.

III. RESULTS & DISCUSSION

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. The basic description of MATLAB is given in appendix. 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.

Our work is based on GSA optimization and results are compared with genetic algorithm which is used previously on same set of equations. Results have been tested over different irradiations intensity of solar panel with different ambient temperature.

A. Intensity of Solar Light (In)

In = [132.99, 355.56, 554.69, 680.73, 726.74, 733.85, 656.08, 500.00, 311.46, 106.42] kwh

B. *Ambient Temperature (TA)*

TA = [7.90, 7.90, 7.90, 6.60, 6.40, 7.70, 10.60, 13.00, 15.00, 16.50] 0C

C. *Day Time*

Time = [08.00AM 09.00AM 10.00AM 11.00AM 12.00 Noon 01.00 PM 02.00PM 03.00PM 04.00PM 05.00PM]

After optimisation 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 GSA/GA must be increasing with iterations and after some iteration it should be settle at a maximum level beyond which no further improvement is possible. Higher the level good is the optimisation. GSA is run for different time interval with corresponding irradiation intensity and temperature. Keeping the conditions same, GA result is also plotted in figure 3 along with GSA.

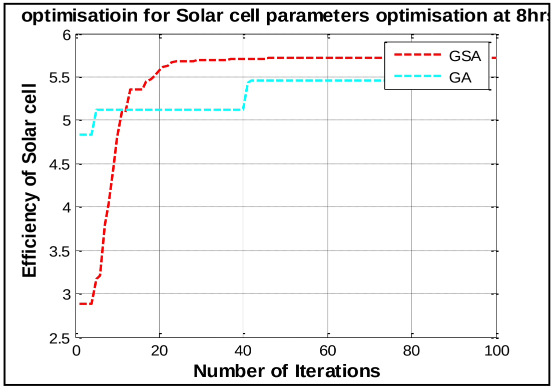

Fig. 3: comparison of energy efficiency for GSA and GA with number of iterations

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. Table 2 inherits these values.

Table - 2

Average value of tuning parameters

Depth of channel		*Length of channel (m)*		*Velocity of fluid (m/s)*		*Temperature at inlet (^{o}C)*		*Energy Efficiency*	
GSA	*GA*	*GSA*	*GA*	*GSA*	*GA*	*GSA*	*GA*	*GSA*	*GA*
0.0010	*0.00092242386*	*0.299993057*	*0.27948140*	*1.4919964*	*1.370707*	*4.741486*	*3.6205045*	*14.480959*	*11.7323058*

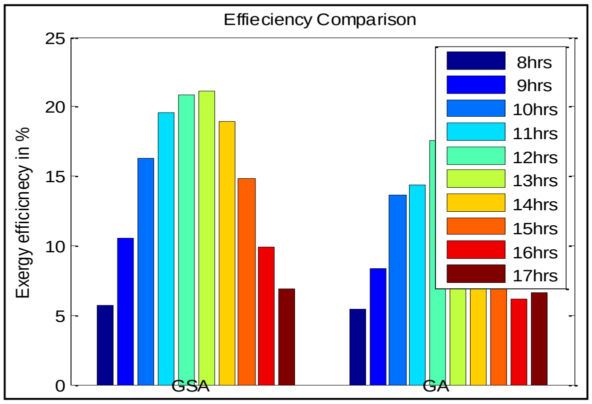

Fig. 4: Energy efficiency for every time interval for GSA and GA

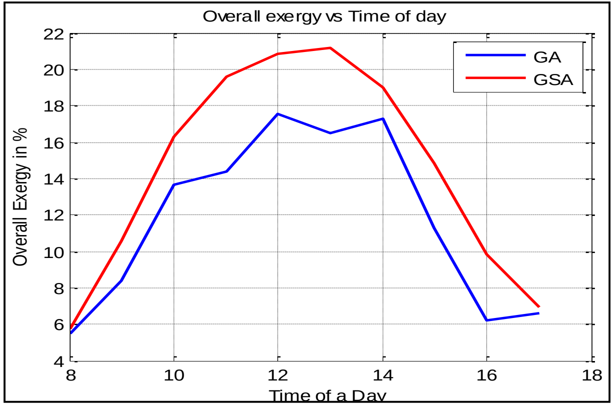

Fig. 5: Energy efficiency comparison for GSA and GA vs time interval

IV. CONCLUSION

Our work is targeting the tuning of design parameters of single channel photo voltaic module. We have used gravitational search algorithm (GSA) 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 GSA. Our target is to improve the energy efficiency of solar module by tuning of these four parameters. GSA serves our purpose. The work is compared with genetic algorithm (GA) used previously. An improvement of 23.43% in energy efficiency is visible by using GSA over GA. Results are shown for different irradiation intensity on solar panel and ambient temperature. For every interval our proposed algorithm performs better than GA. The validation of our work and tuned parameters can be done in such a way that the graph in figure 5 follows the pattern of solar irradiation which is increasing form 8 AM to 1 PM and decreases. Thus our work has provided a great improvement of 23.43 % over previous work.

APPENDIX

Table - 3
Optimized output parameters with their energy efficiency

Time	*Depth of channel*		*Length of channel (m)*		*Velocity of fluid (m/s)*		*Temperature at inlet (°C)*		*Exergy Efficiency*	
	GSA	*GA*	*GSA*	*GA*	*GSA*	*GA*	*GSA*	*GA*	*GSA*	*GA*
8 AM	*0.00100*	*0.00085*	*0.30000*	*0.28298*	*1.50000*	*1.50000*	*3.02827*	*0.10000*	*5.72206*	*5.45986*
9 AM	*0.00100*	*0.00082*	*0.2999*	*0.2849*	*1.4349*	*1.5000*	*3.4173*	*5.6302*	*10.577*	*8.3898*
10 AM	*0.00100*	*0.00095*	*0.3000*	*0.3000*	*1.5000*	*1.2798*	*4.1322*	*0.6500*	*16.282*	*13.655*
11 AM	*0.00100*	*0.00094*	*0.3000*	*0.2576*	*1.5000*	*1.3717*	*5.4289*	*8.3469*	*19.604*	*14.410*
12	*0.00100*	*0.00100*	*0.3000*	*0.2714*	*1.5000*	*1.3721*	*5.7036*	*1.3466*	*20.846*	*17.570*
1 PM	*0.00100*	*0.00089*	*0.3000*	*0.2638*	*1.5000*	*1.5000*	*4.0291*	*3.7283*	*21.149*	*16.474*
2 PM	*0.0010000*	*0.00100000*	*0.3000000*	*0.29034149*	*1.50000*	*1.40440*	*6.5175*	*7.18129*	*18.975*	*17.273*
3 PM	*0.00100*	*0.00097*	*0.3000*	*0.3000*	*1.5000*	*1.1410*	*5.6068*	*7.1097*	*14.871*	*11.305*
4 PM	*0.00100*	*0.00077*	*0.3000*	*0.2555*	*1.4849*	*1.2762*	*6.6633*	*0.1000*	*9.8632*	*6.1799*
5 PM	*0.00100*	*0.00100*	*0.3000*	*0.2880*	*1.5000*	*1.3616*	*2.8873*	*2.0117*	*6.9167*	*6.6024*

Above table hold the values for each time interval, it is generally observed that solar light is at it's peak between 12-2 PM, so the energy efficiency is also highest during that interval for both GSA and GA tuned parameters. Though energy is highest for GSA than GA.

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