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Experimental Investigations and Exergetic Assessment of 1 kW Solar PV Plant

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ABSTRACT

The huge potential of solar energy and increasing demand of energy, made researchers to work on solar photovoltaic systems. In this paper, experimental investigations and exergy based thermodynamic assessment of 1 kW solar photovoltaic (SPV) plant have been carried out. The system is installed at Amity University Gurgaon, India. With the aim to assess the performance/efficiency of the plant, two exergy techniques have been applied based on concepts of thermodynamics and chemical/photonic energy of input solar insolation. The input energy and exergy at different wavelengths ranging from 0.4 µm-0.7 µm have been formulated and illustrated. The electrical and operating parameters of SPV plant includes short-circuit current, open-circuit voltage, temperature of photovoltaic (PV) modules, and fill factor are found, carrying an experiment on a sunny day of 5th October 2017. The variations of electrical exergy input at different fill factors have been computed which signifies its role in characteristic behavior of PV system. The energy/exergy efficiencies are found to be between 7.76% to 9.98% and 9.86% to 11.63% whereas the photonic energy/exergy efficiencies are found to be between 4.85% to 11.24% and 6.08% to 12.89%. It is also found that the temperature of SPV plays a vital role on exergy efficiency and it can be improved with a mechanism which removes the generated heat from the system. With the experimental results, it can be noticed that the exergy loss increases as the temperature of SPV module goes up.

Keywords: Chemical/Photonic energy, energy analysis, exergy analysis, electrical energy, solar insolation rate, solar photovoltaic system, thermal energy

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INTRODUCTION

Energy demand is increasing day by day and lot of research is going on to explore the sustainable and clean sources of energy. SPV systems are direct energy conversion devices which converts input solar radiations into useful electrical output. The intensity of solar radiations depends on many factors like season, local weather conditions, location of the place and to fully utilize solar energy orientation of the device also plays a very vital role. For Indian perspective, solar energy has got the huge potential as future energy resource, since we have almost 260-300 clear sun days. India (between 6^o to 32^o N latitude) lies in most sunny regions of the world with annual average solar radiations intensity varying between 500 to 800 W/m^2. This is sufficient to fulfil numerous energy demand through solar PV or solar thermal energy conversion routes. In current years, the solar energy technologies are widely acceptable due to steep fall in their investment cost, eco-friendly output and longer life with low maintenance requirements. Solar PV systems are better than the solar thermal as the former needs small installation areas, easy operation/maintenance tools, variable capital cost of investment and adaptability with other systems like thermoelectric, and solar thermal. Solar PV cells convert input solar radiations (direct/diffused) into useful electrical output through a semiconductor solid state device. The input solar radiations comprise of direct and diffused components. The diffused radiations are due to scattering, reflection/transmission process of solar radiations in atmosphere by dust, fumes, pollutants or other minute particles. SPV systems work on both direct and diffused radiation components and the maximum output can be obtained when the input rays fall perpendicular to the surface. Therefore, before installation of solar PV power system, side survey needs to be carried out. It gives us the information of input solar intensity, tilt for PV system, wind speed and other meteorological data. A fixed SPV system with proper tilt and appropriate estimation of monthly/yearly average solar radiation intensity can yield maximum output (Duffie & Beckman, 1991). A solar cell is made up of p-n semiconductor as a diode. When solar radiation having photons of high energy falls on solar cell, electrons of n-type combine with holes in p-type. This is due to the recombination process which generates electrical output in the circuit known as electrical exergy. A typical single diode configuration of solar cell is illustrated in Figure 1. It consists of a diode, series/shunt/load resistances namely R_s, R_{sh} and R respectively and a constant current source generating current. The first law efficiency of SPV system is measured as the ratios of power output to the product of solar insolation and the area of the module. The power generated is a product of V_{mp}/I_{mp} (Voltage/Current at peak power points). Energy/Exergy analyses are carried out on the basis of first/second laws of thermodynamics.

Energy analysis cannot give the complete efficiency investigations as it is based only on the quantitative aspects of energy used and the process efficiency. It does not consider the areas where there is reduction in the true energy potentials of the system taking

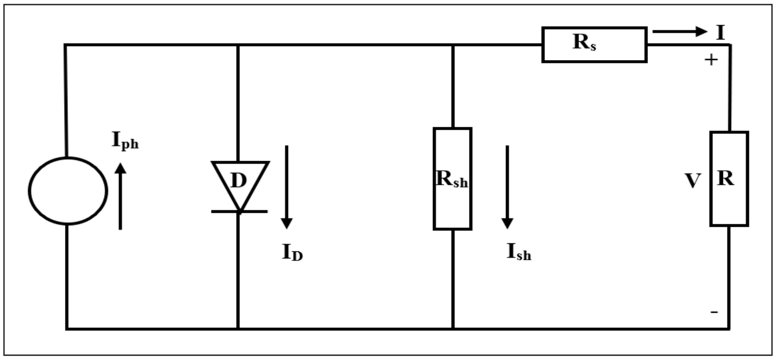

Figure 1. Representation of solar cell in single diode configuration

place. It accounts the amount of available energy to do work. Conversely, the maximum possible useful output attained from energy is known as exergy (Hepabsli, 2008). Exergy analysis presents the true thermodynamic potential and accounts for the usable/unusable (irreversibility) energy fractions. The thermodynamic analysis and economic investigations have been done with the help of exergetic analysis which is proven to be a versatile and prevailing technique (Rosen et al., 2008, 1996, 1988; Rosen, 1999). Likewise, the thermodynamic investigations on SPV systems can be accomplished using exergy analysis as it quantifies the usable and unusable energy known as exergy and irreversibilities respectively. It can also evaluate the efficiency of energy utilization for any conversion process/system and can find the irreversibilities present in the system. With a proper measure, these irreversibilities can be minimized to yield maximum possible output. Therefore, it is gaining wide popularity as it is very helpful in improving the system performance. Several researchers have significantly contributed in the performance characterization of SPV plant. Joshi and Tiwari (2007) enunciated energy/exergy investigations on PV/T parallel plate air collectors under four climatic conditions and formed the range of efficiency variations for the system. Sahin et al. (2007) investigated the thermodynamic assessment of solar modules in context with the exergy analysis for possible system improvement. The comparative analyses of SPV/PV-T systems based on of energy/exergy efficiency have been carried out by Joshi et al. (2009). Akyuz et al. (2012) carried out analytical comparison on simulated and experimental results for a PV system installed in Turkey. Rajoria et al. (2012) investigated the thermal energy/exergy for cascaded SPV array. Afterwards, Saloux et al. (2013) enunciated the electrical/thermal models for the analysis of SPV/PV/T systems to identify the exergy destructions. Sudhakar and Srivastava (2014) performed the energy/ exergy investigations for 36 W solar PV modules on a particular day. The experimental investigations on exergetic efficiency of SPV-T water collector system were performed by Yazdanpanahi (2015). Khan and Arsalan (2016) studied concentrated solar power technique and solar photovoltaics to enhance the efficiency/performance of sustainable electrical output generation technologies. An integrated photovoltaic and unglazed transpired collector has been investigated by Gholampour and Ameri (2016) on the basis of first/second laws of thermodynamics. They emphasized on the significance of energy investigations and electrical/thermal conversion of energy in the whole heat transfer process. Shukla et al. (2016) reviewed PV modules integrated with buildings on the basis of parametric and chemical potential methods. They studied the exergy efficiency for different wavelengths in visible range of spectrum. The comprehensive review on the performance assessment and exergetic analysis of various solar electricity production routes were presented by Bayrak et al. (2017). Afterwards, Ozalp and Bayat (2017) demonstrated various exergy efficiency techniques for thermodynamic investigations of solar PV system. In context with literature review, the major objectives achieved in the present work are as follows:

1. Parametric and photonic energy/exergy of 1 kW installed SPV plant analysed.
2. An accurate model for the prediction of SPV plant performances developed.
3. The thermodynamic considerations for heat transfer study and identification of exergy losses in SPV plant presented.
4. The time domain variations of energy and exergy inputs, efficiencies for the range of wavelengths in the visible region of spectrum investigated.

METHODS

In the present work, the energy/exergy analyses have been carried out for 1kW solar power plant installed at Amity University Gurgaon, as shown in Figure 2. It consists of four 250 W Microsun: MS24250M solar panels connected in electrically parallel configurations. In the given experimental setup, the current from each module is 7.6A and the total current from the system is 30.4A with 44.91V specifications. The system is installed with DC-DC voltage converter and an inverter to suffice the heating and cooling requirement of the building. The required voltage is easily obtained by an installed DC-DC converter and the high current requirement at the application end is obtained by connecting the modules in parallel configurations. The specifications of the 250W module has been mentioned in the Table 1. The longitude and latitude of the place are 76.717^o East and 28.15^o North. The fluctuations in the ambient temperature are noticed in the span of 4 to 48^{o}C in the whole year at above place. The experimental testing of SPV system has been done and the measurement of the variables viz. I_{sc}, V_{oc}, solar insolation, wind speed and the surrounding temperature etc. has been accomplished between 9 AM to 5 PM with an average gap of 1 hour. Figure 3(a) shows the input solar insolation rate measuring device, called pyranometer (Eppley Laboratory Model, PSP36851F3) whereas the lux meter, as shown in Figure 3(b), has been utilized to measure the ambient temperature and moreover, the solar insolation has also been measured/verified with it due to its easy portability and robustness. Figures 3(c) shows the anemometer that is used for the measurement of wind speed. The input parameters of the chosen module have been mentioned in the Table 2.

Table 1
Input parameters

Input parameter (s)	Value
Nominal operating cell temperature (NOCT)	47^{o}C
Stefan's Boltzman Constant	5.67×10^{-8} Wm^{-2}K^{-1}
Emissivity of the panel	0.89
Sun Temperature	5780 K

Figure 2. Experimental test of the thermoelectric module

Table 2
Specifications of 250 W Photovoltaic module

Model	Micro Sun: MS24250M
Maximum Power	250 W
Open Circuit Voltage	44.91 V
Short Circuit Current	7.6 A
V_{mp}	37.030 V
I_{mp}	6.910 V
No. of cells	72
Dimensions	1666 mm × 978 mm × 42 mm
Weight	18.65 kg
Fill Factor	0.75

(a) (b) (c)

Figure 3. (a) Pyranometer; (b) Lux meter; and (c) Anemometer

Thermodynamic Assessment

Energy Analysis. According to the law of conservation of energy, the equations on energy balance for a system can be expressed as

$$\sum_{in} en_{in} m_{in} - \sum_{out} en_{out} m_{out} + \sum_{k} Q_k - W = 0 \quad (1)$$

Where en_{in}/en_{out} represents the inlet and outlet energies, m_{in}/m_{out} are the mass flow rates through inlet/outlet, Q_k is heat flow rate whereas W is the work done across the system.

Further, according to law of conservation of mass,

$$m_{in} = m_{out} \quad (2)$$

The steady state assumption for the system gives $m_{in}=m_{out}=0$. Therefore, Eqn (1) can be rewritten as

$$\sum_{k} Q_k - W = 0 \quad (3)$$

The conversion of input solar insolation into useful electrical output in SPV system can be calculated by the current generated in the system given as

$$I = I_1 - I_0 \times \exp^{q\times(V-IR_s)/A\times K\times T} \quad (4)$$

The output electrical power can be represented as

$$P_{el} = I \times V \quad (5)$$

The maximum magnitude of output electrical power for the system is represented as

$$P_{\max} = V_{oc} \times I_{sc} \times FF = V_{mp} \times I_{mp} \quad (6)$$

The efficiency of solar cell is a measurement of its capability to translate input solar radiations into useful electrical output where the output electrical power comprises of the current/voltage from the system. This efficiency of conversion varies with the intensity of solar radiations. Besides, at the maximum power point, one can obtain the maximum conversion efficiency from the system with the help of maximum voltage V_{mp} and current I_{mp} as shown in Figure 4.

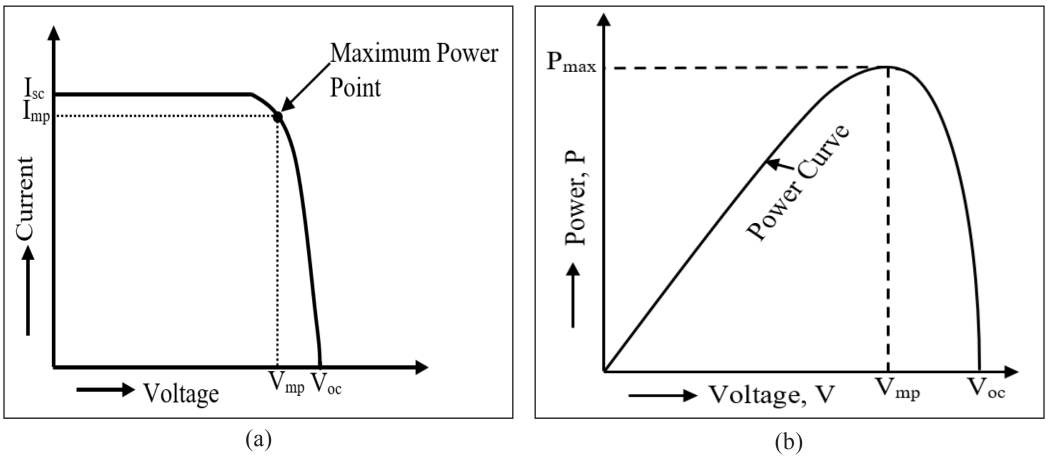

Figure 4 . (a) I-V Characteristics and (b) P-V characteristics of solar photovoltaic system

The output criterion followed in the system is $V_{mp}<V_{oc}$ and I_{mp} is also smaller than the magnitude of short circuit current I_{sc}. The fill factor restricts the maximum power obtained from the system and represents it by maximum power point.

$$FF = \frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{sc}} \quad (7)$$

The conversion energy efficiency of SPV plant is computed with the help of the following formula

$$\eta_{en} = \frac{V_{mp} \times I_{mp}}{A \times E} \quad (8)$$

Here, A is the area of the module in m^2 and E is solar insolation in Wm^{-2}.

The input solar radiations being absorbed the solar cell get converted into useful electrical output and thermal energy, which further get dissipated by the phenomenon of conduction, convection and radiation. However, the design and geometry of SPV module effects the heat transfer process rate. In order to obtain the SPV system efficiency, T_c, ahe oerating temperature, should be computed and assumed to be homogenous on the exposed surface. This temperature varies with the surrounding temperature. As the surface temperature increases, it can cause significant dip in the system efficiency and some cooling phenomenon should be employed at the back side to improve the efficiency. The cooling can be air or water depending upon the application.

Conventional Method. The conversion of input solar radiations into useful electrical output by solar PV plant is known as electrical exergy which can be entirely exploited for the suitable purpose. On the other hand, the thermal output cannot contribute towards the productive yield and appears as high heat loss in the system.

Under steady state assumption of an open system, the equations on exergy balance is given as

$$\sum_{in} ex_{in} m_{in} - \sum_{out} ex_{out} m_{out} + \sum_{k} Ex^{Q} - Ex^{W} - I^{'} = 0 \quad (9)$$

Where, ex_{in}/ex_{out} denotes the input and output exergies for the system, m_{in}/m_{out} are the mass flow rates through the system at inlet/outlet, E_x^Q is exergetic heat flow rate whereas E_x^W is the net exergetic work done across the system. The term I', denotes the electrical and thermal exergy losses in the system.

Further, the steady state assumption for the system gives $m_{in}=m_{out}=0$. Therefore, Eqn (9) can be rewritten as

$$\sum_{k} Ex^{Q} - Ex^{W} - I^{'} = 0 \quad (10)$$

Where,

$$I^{'} = T_{amb} S_{gen} \quad (11)$$

The input exergy for SPV system including the effects of solar input radiations intensity, area of the panel and ambient temperature can be computed as

$$Ex_{in} = A \times E \left\{ 1 - \frac{4}{3}\left(\frac{T_{amb}}{T_{sun}}\right) + \frac{1}{3}\left(\frac{T_{amb}}{T_{sun}}\right)^{4} \right\} \quad (12)$$

The electrical and thermal exergy output for the system can be formulated as

$$Ex_{el} = V_{oc} \times I_{sc} \times FF \quad (13)$$

$$Ex_{th} = Q\left\{ 1 - \left(\frac{T_{amb}}{T_{ml}}\right) \right\} \quad (14)$$

For the net exergy output calculations, the module temperature can be evaluated with respect to normal operating cell temperature (NOCT) as

$$T_{ml} = T_{amb} + (NOCT - 20) \times (E/800) \quad (15)$$

The system experiences the heat loss which includes the convective and the radiative factors and can be represented as

$$Q = A \times (h_c + h_r) \times (T_{ml} - T_{amb}) \tag{16}$$

Where, h_c and h_r are convective and radiative heat loss coefficients respectively and are represented as

$$h_c = 2.8 + 3v \tag{17}$$

$$h_r = \varepsilon\sigma(T_{sky} + T_{ml})(T_{sky}^2 + T_{ml}^2) \tag{18}$$

For further calculations, the effective sky temperature is

$$T_{sky} = T_{amb} - 6 \tag{19}$$

Based on the above formulation, the net exergetic efficiency for the system is

$$\eta_{ex} = \frac{Ex_{out}}{Ex_{in}} \tag{20}$$

Photonic Method. The input solar radiations consist of tiny energy packets called photons. On the basis of their energy level, the energy of solar radiations can be calculated, known as energy of photons. This can be computed as

$$E_{ph}(\lambda) = \frac{hc}{\lambda} \tag{21}$$

It can be calculated by the estimation of rate of number of photons falling on a particular surface. According to Markvart (2003), there are $4.4X10^{17}$ number of photons which are falling every second on $1cm^2$ area on the earth surface on a hazy day. With the assumption of the magnitude of solar constant as 1367 W/m^2, this figure can further be formulated with the multiplication of solar radiation intensity with the factor $4.4X10^{21}/1367$. As a result, the photonic energy for SPV system is the multiplication of figure of photons which falls every second on a $1m^2$ area, photonic energy and the area absorbing solar energy. Henceforth, this is the estimation of available chemical potential or photonic energy of any photovoltaic system and can be formulated by the given formulae (Marti & Luque, 2004):

$$E_{cp} = E_{ph}(\lambda)\left\{1 - \frac{T_{ml}}{T_{sun}}\right\} \tag{22}$$

$$= AN_{ph}\left(\frac{hc}{\lambda}\right)\left\{1 - \frac{T_{ml}}{T_{sun}}\right\} \tag{23}$$

This can further lead to the photonic exergy of the system if multiplied with the energy conversion efficiency of solar cell and is computed as

$$Ex_{cp} = \eta_{en} \times A \times N_{ph} \left(\frac{hc}{\lambda} \right) \left\{ 1 - \frac{T_{ml}}{T_{sun}} \right\} \quad (24)$$

RESULTS AND DISCUSSION

The real-time analysis has been carried out for a typical day of October 2017 at Amity University Gurgaon, Haryana, India and the data is utilized to evaluate the influence of environmental conditions on the throughput of 1 kW SPV system. On the basis of the thermodynamic second laws and the available energy of solar radiation photon, the energy/ exergy inputs have been evaluated and presented. The analytical comparisons among photonic energy/exergy efficiencies have been computed and presented with respect to various input parameters. It is noticed that exergetic efficiency represents better perspective of the system performance as it takes into the account all losses and irreversibilities in the system. Therefore, it is highly effectual and powerful tool for evaluation and investigations of systems in real world. Additionally, the root means square percent deviation' factor, p and correlation linear coefficients, q can be formulated with the help of given expressions as

$$p = \sqrt{\frac{\sum (p_i)^2}{n}} \quad (25)$$

Where, $p_i = \left(\frac{Y_{1(i)} - Y_{2(i)}}{Y_{1(i)}} \right) \times 100$ (26)

$$q = \frac{N\left(\sum Y_2 Y_1\right) - \left(\sum Y_2\right)\left(\sum Y_1\right)}{\sqrt{N(\sum Y_2^2) - (\sum Y_2)^2} \times \sqrt{N(\sum Y_1^2) - (\sum Y_1)^2}} \quad (27)$$

This needs to be done for the comparison of various computed efficiencies with the predicted ones. The magnitude of q varies between -1 and 1 and is a measure of direction/ intensity of linear relation amongst two chosen variables. If the value of q approaches 1, then the two variables are assumed to have strong positive relationship on linear curve and *vice-versa*.

Figure 5 illustrates the variations of input solar insolation and ambient temperature with time between 9AM and 5PM. The variation in wind speed is observed between 0.98-1.2 m/s which influences the convective coefficient of heat transfer between surface of SPV array and the surroundings. The ambient temperature is observed to be varying between 307 K to 310.2 K on the chosen day. The input solar insolation intensity observes the variation between the range 710 W/m^2 and 1150 W/m^2.

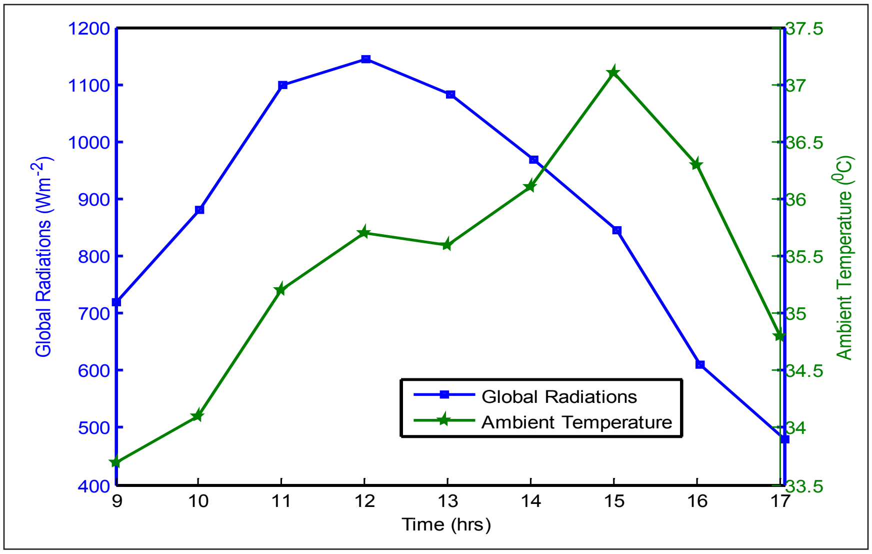

Figure 5. Variation of input solar insolation and surrounding temperature with time

The energy inputs at different values of wavelengths in visible region (0.4 µm-0.7 µm) are plotted with respect to time in Figure 6. Both solar radiations and energy inputs follow the same pattern with time. It is observed that input energy and photonic energy for the PV plate possess a synchronism with respect to root mean square percentage deviation (p) with 13.76% and correlation linear coefficient (q) as 0.978 for a typical chosen wavelength of 0.55 µm. However, p/q approaches their lowest magnitudes (p=5.36% and q=0.988) at a wavelength of 0.60 µm.

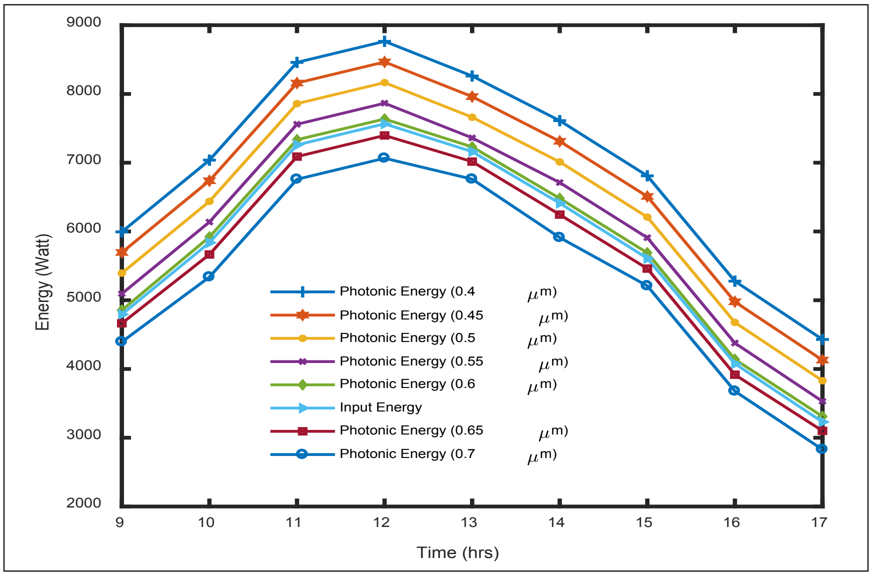

Figure 6. Variations of exergy input and exergy efficiency with time

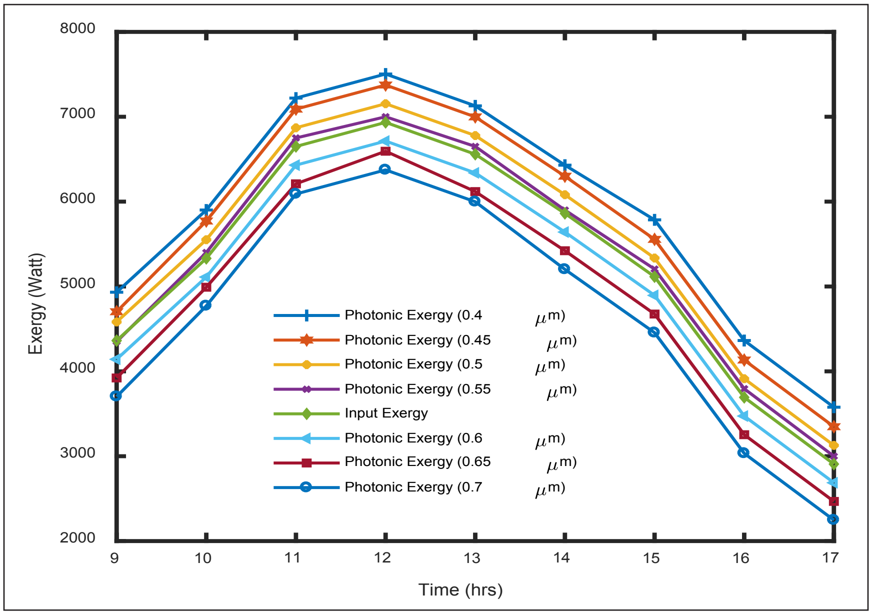

Figure 7. Exergy Inputs at different wavelengths in visible region on 5th October, 2017

On the other hand, the exergy inputs at different values of wavelengths in visible region (0.4µm-0.7µm) are plotted with respect to time in Figure 7. It is noticed that input exergy and photonic exergy (0.55 µm wavelength) are in agreement with p=4.98% and q=0.994. However, at maximum solar intensity, the exergy inputs approach their peak values due to larger value of sun temperature.

The variations in electrical exergy for different fill factors with respect to time has been illustrated in Figure 8. It signifies that the output electrical exergy can be considerably enhanced by improving the fill factor in SPV system. It can be achieved by minimizing the optical and thermal losses in the system and thus improving the throughput across it.

On the basis of experimental observations, it has been found that the loss of exergy in the whole day is exceeding more than 85% and has been shown in Figure 9. Large amount of useful exergy is lost due to inefficiency of silicon modules to convert input solar radiations input useful output. The complete analysis yields an average exergy/energy efficiency of 10.25% and 8.4% respectively. The system possesses low exergetic efficiency due to inferior quality of energy output and suffers huge losses in useful exergy during the conversion process. The magnitude of exergy destruction factor is more than 88% in the system and needs lot more of improvement in material aspect.

Figure 10 illustrates the variations in the magnitude of energy/exergy efficiencies along with the photonic/chemical potential on a typical day of October 2017. It clearly shows that the two efficiencies changes with the temperature and to attain their maximum value,

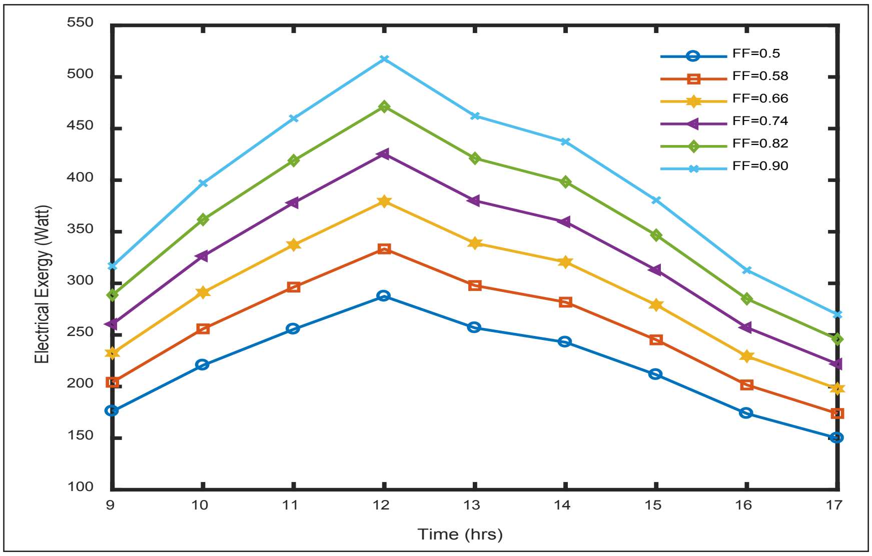

Figure 8. Variations of electrical exergy and input solar exergy with time

the temperature of SPV module should work closer to the operating temperature of the cell. The system observes low energy/exergy efficiency for the whole day with reference to ideal 100% reversible phenomenon. This is because of irreversible nature of solar PV energy conversion process. Only a certain part of input solar radiations gets converted into useful electrical output. Rest get wasted into heat and other optical losses. The conventional available silicon cell modules suffer huge exergy loss due to low conversion efficiency. However, it increases with the rise in input solar insolation.

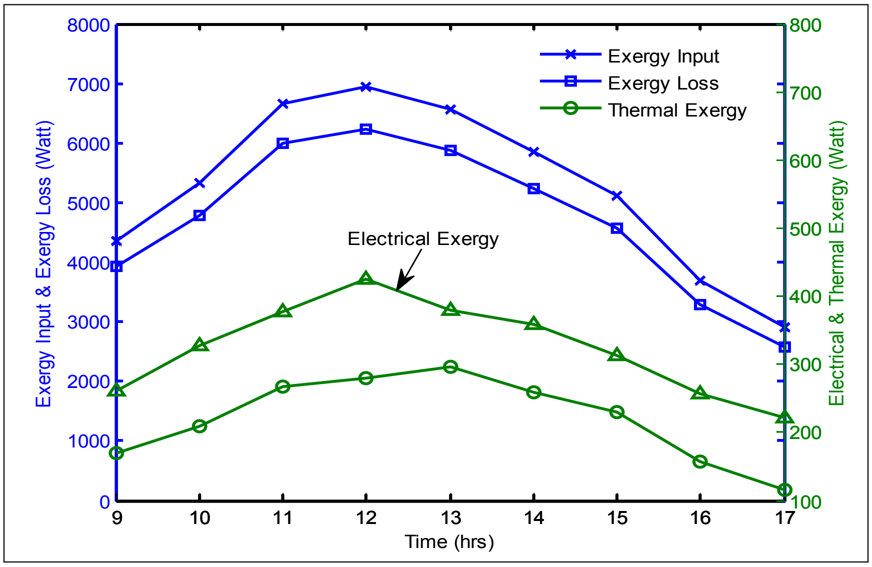

Figure 9. Variations of thermal, electrical and exergy loss with time

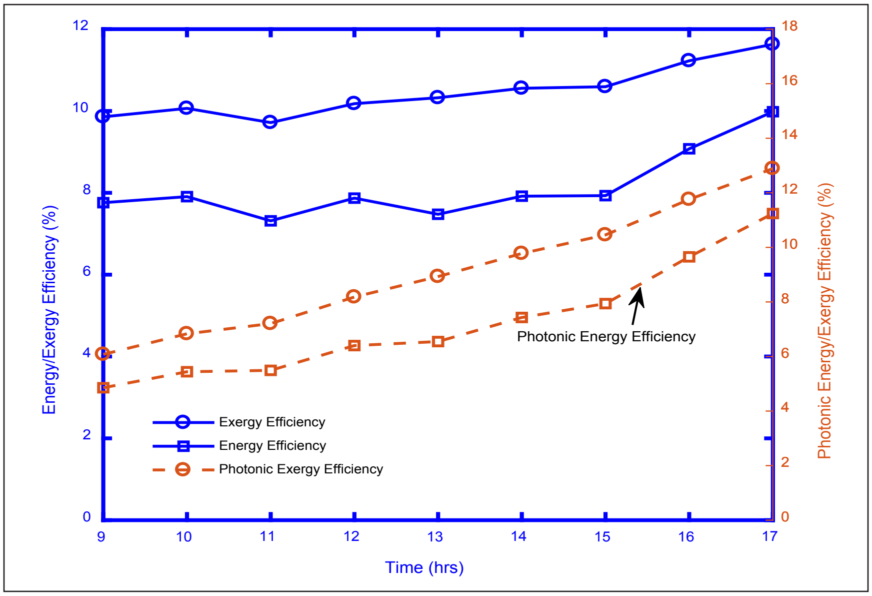

Figure 10. Energy/exergy efficiency versus time

CONCLUSION

The parametric and photonic energy/exergy investigations have been carried out for performance estimation of 1 kW solar photovoltaic system installed at Amity University, Gurgaon, India. Two different methods for the assessment of energy/exergy analysis are demonstrated for real time monitoring of the SPV system on a typical day of October 2017. The obtained experimental figures are utilized to investigate an optimal temperature in order to get maximum exergy efficiency. Various exergetic losses are also quantified for energy conversion process. The major outcomes of the research work are summarized as below:

1. With the study, it is found that exergetic analysis based on both thermodynamic principles and photonic/chemical potential yield realistic and time bound results. Thus, either of the method can be employed for the performance assessment of thermodynamic modeling, installation and planning of SPV plants.
2. It is also observed that fill factor is the key feature for the estimation of exergetic efficiency of SPV plant and projects a clearer perspective for possible improvement in the system. High value of fill factor leads to better exergetic efficiency.
3. The exergetic efficiency of the system rises with input solar radiation and attains its maximum value. Thereafter, it shows a slight dip and get stabilized. The system possesses maximum energy/exergy efficiencies of 11.24% and 12.89% respectively. However, the low exergetic efficiency signifies that the modules are unable to process high energy content of available solar radiations to useful electrical output.

4. The exergetic efficiency possesses an inverse relationship with the ambient temperatures. The reason is the rise in module temperature and various irreversibilities occurring in the system, whereas useful electrical output increases with increase in intensity of input solar radiations.
5. The visible spectrum wavelength is a key factor in estimating photonic/chemical potential energy/exergy. It has been observed that at lower wavelengths, the energy/exergy possess higher values.
6. The current study suggests the development of better and low-cost materials for solar PV energy conversion process. This can significantly improve system efficiency.

It is observed that SPV systems are direct energy conversion devices and can yield huge amount of power at minimum operating/maintenance cost. Moreover, these eco-friendly and environmentally sustainable sources of energy can solve all the power problems in coming era. Additionally, new optimization technique for exploring design and performance parameters of solar panels can lead to better results for the system. Moreover, focused investigations on modelling and designing are required in context with better efficiency and output performance of the SPV modules. The work can be extended to get the optimal efficiency by suitable formulations and computations of the system parameters. The experiment can further be conducted for more number of days in a year and research findings can be precisely verified.

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APPENDIX

Nomenclature

A	Area (m^2)
c	Speed of light ($3X10^8$ ms^{-1})
E	Solar insolation (Wm^{-2})
Ex	Exergy rate (W)
En	Energy rate (W)
F	Fill Factor
h	Plank Constant ($6.625X10^{-34}$Js)
h_c	Convective heat transfer coefficient ($Wm^{-2}K^{-1}$)
h_r	radiative heat transfer coefficient ($Wm^{-2}K^{-1}$)
I	Current (A)
I'	Exergy consumption (W)
N_{ph}	Number of photons/s.cm^{-2}
NOCT	Nominal operating cell temperature (^oC)
P	Power (W)
R_s	Series resistance
R_{sh}	Shunt resistance
T	Temperature (K)
U	Overall heat transfer coefficient ($Wm^{-2}K^{-1}$)
v	Wind velocity (ms^{-1})

Greek symbols

η	Efficiency
σ	Stefan's Boltzman Constant ($Wm^{-2}K^{-4}$)
ε	Emissivity
λ	Wavelength (m)

Subscripts

amb	ambient
el	electrical
th	thermal
in	inlet
ex	exergy
en	energy
out	outlet
ph	photonic
max	maximum
ml	module
oc	Open circuit
mp	Maximum power
sc	Short circuit
cp	Chemical potential

Superscripts

Q	Heat
W	Work

Abbreviations

PV	Photovoltaic
SPV	Solar Photovoltaic
NOCE	Normal operating cell temperature