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A Review on Exergy Analysis of Solar Photovoltaic Systems

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Abstract: Solar photovoltaic systems energy is currently growing fast around the world. The increasing of installed area of solar energy production around the world gives us an unlimited potential energy source available from sun. In our daily life thermal energy and solar light can provide sufficient electricity. Adding to this one photovoltaics, concentrationphotovoltaic, concentrationphotovoltaic, photovoltaic / thermal and solar electric have been developing for energy conversion. The main aim of the present study is to make review on exergy analysis and their assessment related to performance of a wide range of solar photovoltaic systems. Exergy is used to asses and improve energy systems. After that the studied systems are exergetically analysed and evaluated solar energy production includes solar photo voltaics (PV's) and hybrid (PV/T_{water} or PV/T_{air}) solar collectors. The concentrated solar power systems with Nano fluid and PCM studies are exhibited. The advantage and disadvantages of these all the systems are presented.

Index Terms - : Exergy Analysis, Solar photovoltaic systems, concentrated solar power systems, Hybrid solar collectors.

I. Introduction

Now a days, the use of renewable sources more important with dependence on finite renewable sources. The ultimate source of most of our renewable energy supplies by the sun. Among all the resources solar energy is most useful one, cheap and environmental friendly renewable source. In recent years, the power production from the solar energy becomes very popular due to reducing of their investment cost. The main systems to produce solar energy to electricity are photovoltaics (PV's) and concentrated solar power systems. Also, the combination of PV with other types of systems such as water or air heating plays a major role in energy producing.

From the thermodynamics aspect exergy is evaluation of the maximum useful work which can be done by the system interacting with environment. Exergy is an important tool to evaluate the efficient usage of the solar electricity producing systems by using second law of thermodynamics. Dincer and Rosen et.al., have investigated thermodynamic aspects of renewables for sustainable development. They explained relations between exergy and sustainable development. The energy conversion factor of a solar PV system sometimes is described as the efficiency, but this usage sometimes leads to difficulties[1-2]. PratishRawat and PardeepKumar .et.al.,Solar radiation consists of both direct beam radiation and diffuse radiation. Solar photovoltaic systems uses onlybeam radiation and very small component of diffuse radiation. But even on clear and sunny day, the diffuse radiation contributes about 20 percent of the total solar radiation [3]. The maximum useful work which can be obtained from input energy is called exergy. Many engineersrecognized exergy analysis to be a useful tool for the evaluation of the thermodynamic performance of system in general . Exergy analysis of the solar photovoltaic system provides an alternative method of evaluating and comparing performance of the system [4]. The present scope of this work is to make a presentation on exergy analysis of solar energy production from different non-conventional energy sources.

2. Studies conducted on exergy analysis of solar energy

The section 2.1 discusses the review of exergy analysis of solar photovoltaics. The solar photovoltaic systems are the direct convertor of sun light to electrical energy. It has clean and renewable; the solar PV cells are used in different sectors of residential, industrial and commercial purposes. Energy and exergy analyses of flat plate collectors have beencarried out by Jafarkazemi and Ahmadifard[5] and Gewang at al [6]. The exergetic efficiency of finned double-pass solar collectors has been evaluated by Fudholi et al. [7].

Nomenclature

A area of collector (m^2)
Ex Exergy (W)
h_{ca} heat transfer coefficient ($W/m^2 K$)
h_{conv} convective heat transfer coefficient ($W/m^2 K$)
h_{rad} radiative heat transfer coefficient ($W/m^2 K$)
T temperature (K)
V_m voltage at the maximum power point
v wind velocity (m/s)
Q heat emitted to the surrounding (W)

Subscripts

a ambient
elec electrical
in input
m module
out output
therm thermal
PV photovoltaic
PV/T photovoltaic/thermal

Greek letters

η Exergy efficiency (dimensionless)
σ Stefan Boltzmann Constant (W/m^2K)

II. Exergy analysis of solar photovoltaic systems

Coventry and lovegrove suggested development of the ratio between the electrical and thermal output of domestic PV/T systems.it has a dimensionless factor. This dimensionless factor was founded as 1.0 based on the first law analysis, and it changed to 17 by applying the exergy analysis and second law of thermodynamics. In order to analyse the energy and exergy of optimum inclination, they had determined the conditions[8]. And also solar Photovoltaic System Illustrated in Fig 1.

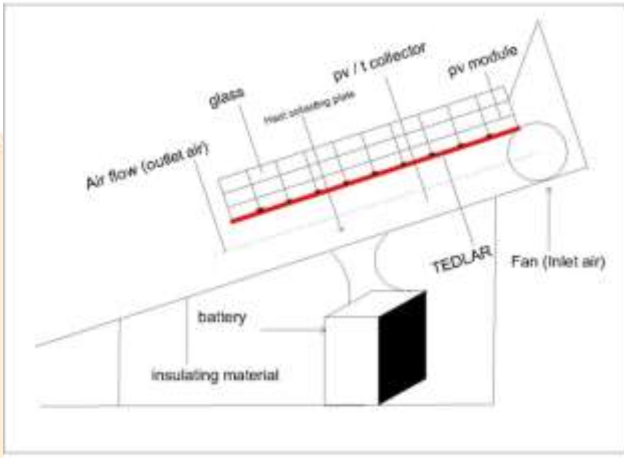

Fig 1: Solar Photovoltaic system

The exergy analysis contains a consideration of energy quality and also solar PV capability. The overall exergy balance of photovoltaic system can be expressed as follows[9]. And also illustrated figures for classification of energy production systems from Solar (Fig 2),Classification of solar Photovoltaic / Thermal collectors (Fig 3).

$\sum Ex_{in} = \sum Ex_{out}$ (1)

$\sum Ex_{in} = \sum Ex_{out} + \sum Ex_{loss} + \sum Ex_{irreversibility}$ (2)

This corruption in the quality of energy is called exergy loss. The exergy efficiency of the PV system is presented. It is the proportion of total output energy to total input energy.

$\eta_{PV} = Ex_{out} / Ex_{in}$ (3)

Input energy of solar PV system includes only solar radiation intensity exergy as below.

$Ex_{in} = IA[1 - \frac{4}{3}(\frac{T_a}{T_s}) + \frac{1}{3}(\frac{T_a}{T_s})^4]$ (4)

Or the input exergy is calculated as follows

$Ex_{in} = IA [1 - (\frac{T_a}{T_s})]$ (5)

Where T_s is the sun temperature which is taken as 5777 K.

The exergy output of the photovoltaic system can be presented below:

$Ex_{out} = Ex_{elec} + Ex_{therm} + Ex_d = Ex_{out} + I`$ (6)

Where,

$I` = \sum Ex_d = Ex_{d,therm} + Ex_{d,elec}$ (7)

$Ex_{elec} = V_m I_m$ (8)

The heat loss from the photovoltaic surface to the environment is called as thermal energy. it is presented below.

$Ex_{therm} = [1 - (\frac{T_a}{T_{cell}})]Q$

Where,

$Q = h_{ca}A (T_{cell} - T_a)$

$h_{ca} = 5.7 + 3.8v$

where h_{ca} is heat transfer coefficient and v is the wind velocity.

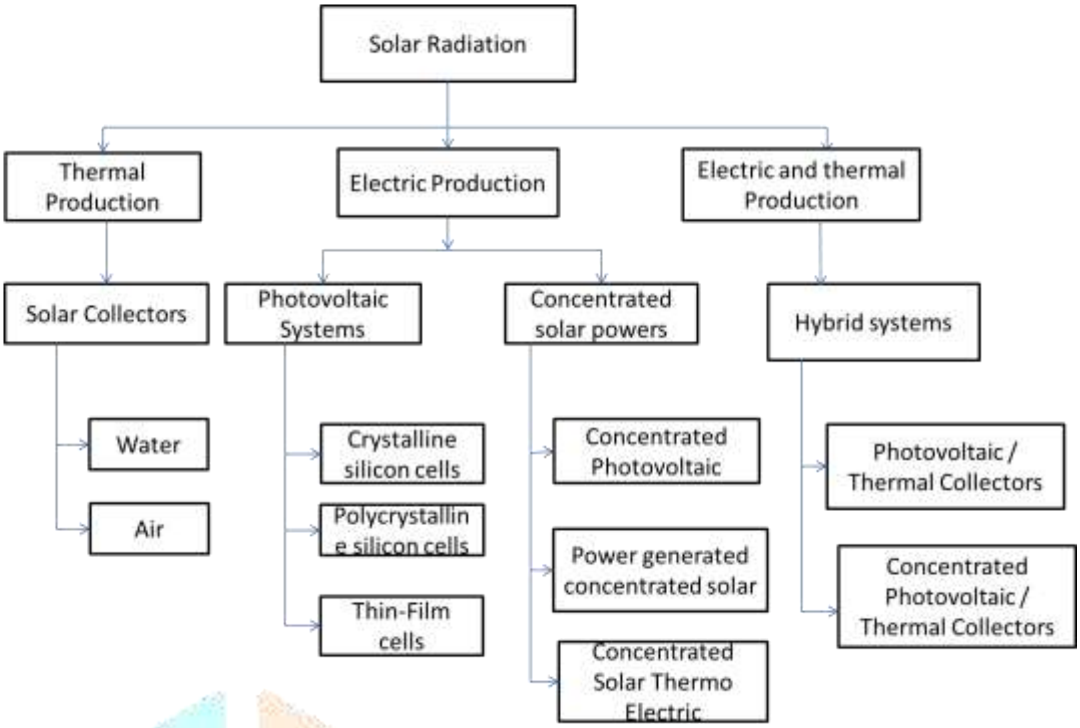

Fig 2: Classification of energy production systems from Solar

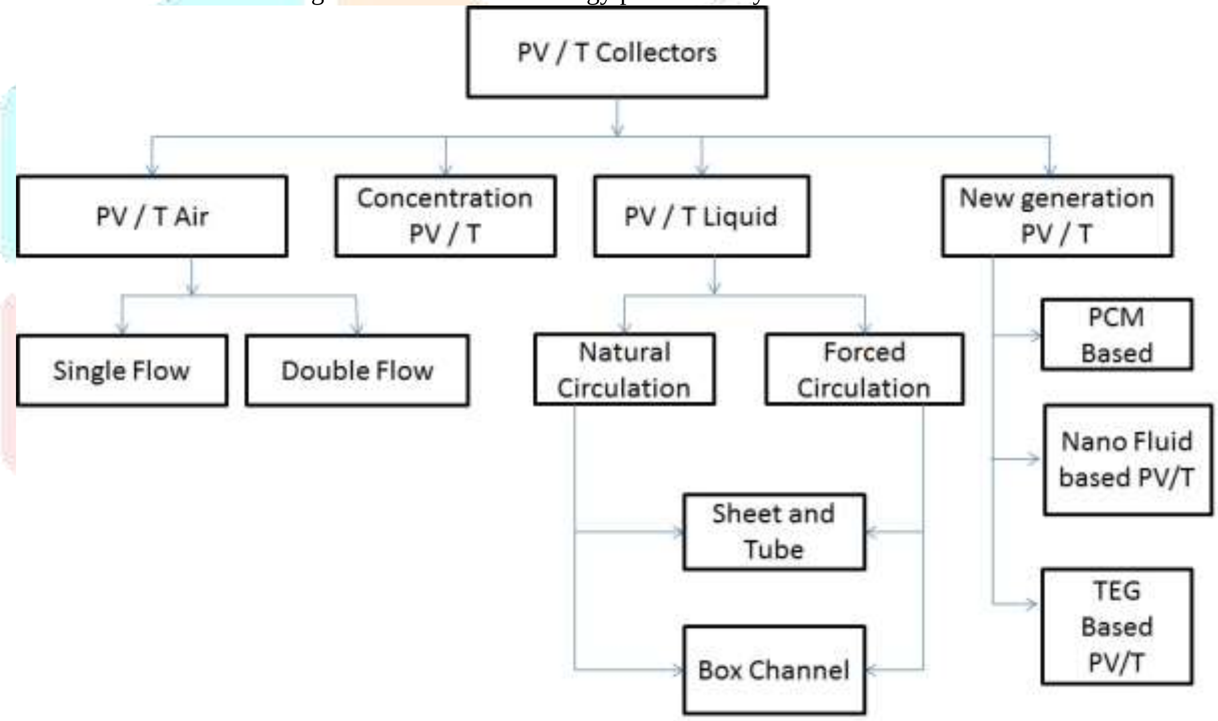

Fig 3: Classification of solar Photovoltaic / Thermal collectors.

3. Historical development of PV and PV/T systems

In the year of 1839, the French scientist Alexander Edmond Becquerel discovered the photo-electric effect while carrying out electro-chemical experiments. In 1873, the british engineer w.smith founded semiconductor selenium show photoconductivity. After about three years later, Williama dams and Richard day found the photovoltaic effect in solidified selenium and published a paper on the selenium cell.

Renewable energy resources have a great potential and they can meet the electricity and thermal energies for mankind. These sources can enhance the diversity in energy supply markets, secure long term sustainable energy supply and reduce local and global atmospheric emissions. One of the most possible renewable energy technologies can be given as photovoltaic (PV) technology. These systems are popularly configured as stand-alone, grid connected and hybrid systems [9].

S.No	Solar collector system	Exergy efficiency
1	The glazed PV/T water collector	13.30 %
2	The coverless PV/T water collector	11-13%
3	The unglazed PV/T air collector	10.75 %
4	The (glass-to-glass) PV/T air collector	10.45 %
5	The PV array	3-9%

6	The unglazed PV/T air collector integrated greenhouse with earth air heat exchanger	5.50%
7	The unglazed PV/T air collector integrated greenhouse	4%
8	The double glazed flat plate water collector	3.90%

Table 1: Exergy efficiency of solar collectors [10].

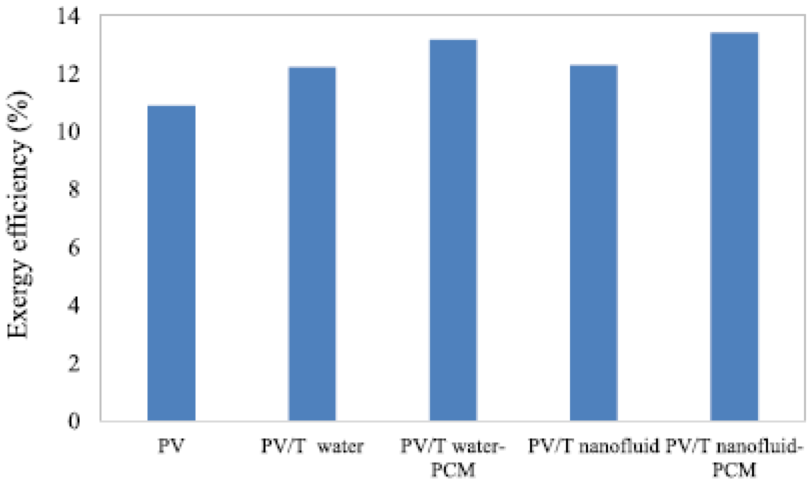

Fig 4: Exergy Efficiency Vs Various PV Systems [11].

I. Photovoltaic systems

Exergy concepts are applied for different types of solar electricity systems. Most of these systems has been done in the field of flat plate solar collectors. Another popular area of research refers to combined photovoltaic and thermal collectors in the literature. Parthak et al. worked on the optimization limit of solar roof access by exergy analysis for three systems as solar thermal, photovoltaic and hybrid photovoltaic thermal systems. They simulated the problem for three different locations at different solar flux. They showed that PV/T systems are approximately 69% for all the locations[12].

II. PV/T air collectors

Joshi et al. investigated the performance characteristic of a photovoltaic (PV) and photovoltaic-thermal (PV/T) systems based on energy and exergy efficiencies, respectively. They applied exergy analysis of a PV system and its components to evaluate the exergy efficiency [13].

These type collectors are hybrid collectors , produce both hot air and electricity simultaneously. Thus, it brings many benefits from the investment and location point of view. These type collectors can be classified based on air flow types. These are classified with respect to air flow above the absorber, below the absorber,unglazed and on both sides of the absorber in single and double pass[14]. The application of PV/T air collectors are classified in the Fig. 5 from (a)-(e).

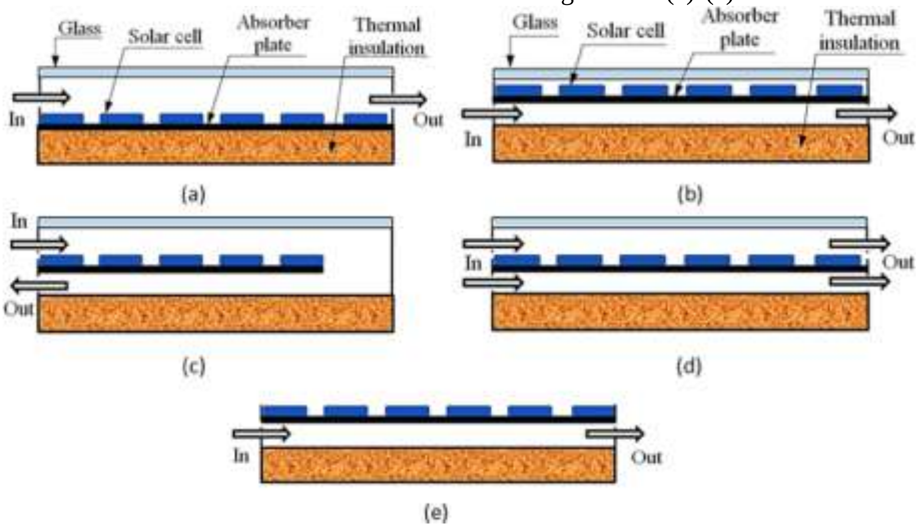

Fig. 5. Cross-sections of PV/T air collectors (a) air flow above the solar cell, (b) air flow below the solar cell, (c) double pass, (d) both above and below of solar cell, (e) unglazed single pass.

III. New generation PV/T

These photovoltaic thermal collectors are a new hybrid technology that produces heat and electricity simultaneously. these are based on type of working fluid used. However if consider low thermal conductivity of the working fluids have always been the primary limitation in the development of energy efficient heat transfer fluids, and more PV/T collector performances are examined [15,16].
In this section, the effects of using phase change materials (PCM) and nano fluids on the performance of new generation PV/T are discussed. Bobadilla et al. [17] analyzed the effects of nano fluid in PV/T collectors. This author chosen as pure water, Ag-water nano fluid and alumina-water than that of Ag-water. They also compared results with numerical works and they found an agreement between them about the nano fluid studies in solar energy systems, there is still problems on nana fluids such as agglomeration and sedimentation thus, it is difficult to get a commercial product on solar electricity production systems. Fig 6 showing Energy and Exergy flows for various solar energy systems

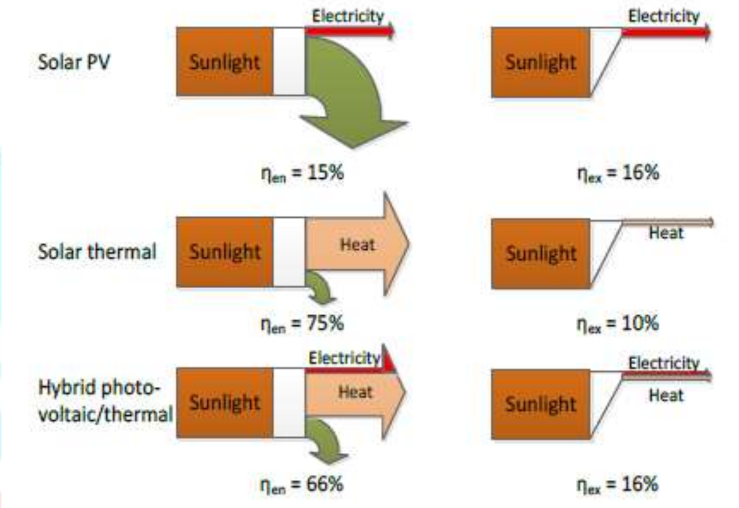

Fig 6: Energy and Exergy flows through typical some solar energy systems[18].

4. Conclusions

In this paper a review of exergy analysis of solar thermal systems is presented based on last few years. The review includes analysis of various types of solar collectors and solar thermal systems processes.

The main points can be drawn from this review work as

- production of electrical energy from solar technology is becoming more popular in recent years due to its advantages such as clean energy and increasing of efficiency with decreasing investment cost.
- Exergy analysis is also an effective tool to analyze the effectiveness of PV/T systems.
- In recent years, PV/T collector's usage increases to produce both electricity and heat water or air.
- Still the efficiencies of PV systems are low. Thus, CSP systems can be more suitable from the electricity production point of view even though it's high cost.
- Exergy efficiency of PV/T system [19,20] is two times higher than that of PV system. As an expected results exergy efficiency of PV/T(air) collectors is lower than that of water and it obtains around10%.

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