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Life Cycle Conversion Efficiency Analysis of Roof-Top Solar Photovoltaic System

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Abstract: India has a great potential to generate electricity from solar energy and the Country is on course to emerge as a solar energy hub. It is very important to have good conversion efficiency of solar system that's why we need to do analysis on it. This paper present Life Cycle Conversion Efficiency analysis of 100 KW GRPV system. This GRPV system is designed and constructed on institute building. The step-by-step based approach for the energy & efficiency analysis is covered in the presented study. Also the embodied energy calculation, annual generation of the electricity is covered in the study.

Keywords: GRPV system, Embodied Energy, Energy analysis, Life Cycle Conversion Efficiency [LCCE].

I. INTRODUCTION

Renewable energy often referred to as clean energy, comes from natural sources or processes that are constantly replenished. Renewable energy reduce greenhouse effect and protects ozone layer of atmosphere to depletion. Many non-conventional energy resources today are well developed, reliable, and cost competitive with the conventional fuel generators. There are many renewable energy resources such as biomass, solar, wind, mini-hydro, and tidal power. In these sources the solar energy one of the most popular among all renewable energy resources. Solar energy can be made available almost anywhere there is sunlight. Solar panels cost is currently on a fast reducing track and is expected to continue reducing for the next years. Residential solar panels are easy to install on rooftops or on the ground without any interference to residential lifestyle.

In 2013, Embodied energy, energy payback time, electricity production factor and life cycle conversion efficiency for various silicon and non-silicon based semitransparent hybrid PV thermal double pass facade (HPVT-DPF) estimated by (Deepali and G N Tiwari, 2013#). Which were equal to 14061.15 kWh, 1.67, 6.74 years, 17.97, 4.45 and 32.85, 6.68 respectively [1]. (DB Singh, Tiwari, Al-Helal and Yadav, 2016#) had evaluated life cycle conversion efficiency for single slop and double slop passive solar still based on annual energy and annual exergy. Which were equal to 1159.43, 1037 kWh and 108.48, 89.24 kWh respectively [2]. In 2017, Energy payback time , Energy production factor, Annual thermal energy gain of a U-shaped evacuated tabular collector Integrated with compound parabolic concentrator was estimated by (R K Mishra, Vihang and Tiwari, 2017#) [3]. (Promod, Yogesh, Tiwari, Sastry and Dubey 2018#) had evaluate the life cycle assessment of the 3.2kw CdTe PV system has been done on the basis of energy Metrics. The energy payback time for a 3.2 kW CdTe PV system which was equal to 3.60 years [4]. (Ramanan P and Karthick A, 2019#) had evaluated energy Metrics of grid connected PV system are based on polycrystalline (P-si) and (CIS) technology of capacity 1 kWp and 1.36 kWp respectively [5]. In 2019, (Chandrasekhar and Nitin Pal) had evaluated embodied energy of the installed photo voltaic system in Delhi and energy payback time for a rooftop PV system which was equal to 8493.16 kwh and 8.61 years respectively [6]. (Nawaz & Tiwari, 2005, #) had evaluated embodied energy without battery replacement and energy payback time (EPBT) for a rooftop system which were equal to 1380 kWh/m² and 13 years respectively. But the system for which they had evaluated embodied energy and EPBT was an off grid system [7]. (Barnwal & Tiwari, 2008, #) in 2008 had estimated embodied energy, Energy payback time, energy production factor and life cycle conversion efficiency for a rooftop system which were equal to 249.04 kWh, 3.53 years, 2.84 and 0.1064 respectively [8]. In 2009, embodied energy, energy payback time, energy production factor and life cycle conversion efficiency of a stand-alone photovoltaic system was estimated by (Prabhakant & Tiwari, 2009, #) which were equal to 198166.89 kWh, 17.21 years, 1.99 and 0.22 respectively [9]. In 2014, an experimental study was conducted by (Sudan & Tiwari, 2014, #) for evaluation of energy matrices of the building by incorporating daylight concept for composite climate. In that experimental study energy payback time, energy production factor and life cycle conversion efficiency were estimated equal to 5.5 year, 9.09 and 0.17 respectively [10]. A case study was conducted by (Gupta & Tiwari, 2017, #) to study and analyze the integration of residential buildings with Photovoltaic systems. For an intensity of 450 W/m² and AT = 8°C. Energy payback time, Energy production factor and Life cycle conversion efficiency were estimated equal to 15.32 years, 19.58 and 0.47 respectively [11]. (Yadav & Bajpai, 2019, #) in 2019 had calculated Performance ratio, Energy payback time and Energy return on energy invested for four photovoltaic systems [12].

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The paper is organized as follows-
Section 2 is the description of the solar PV system located on institute building.
Section 3 is the detailed energy based analysis of solar PV system.
Section 4 includes the methodology for Life Cycle Conversion Efficiency analysis of the system.
The result and conclusion part is covered in the Section 5 of the paper.

II. PHOTOVOLTAIC SYSTEM DESCRIPTION

100kW Roof Top PV System has been considered for study. An effective area of each module is 1.919 m^2 and produces 320W peak power. The total effective area of the associated 308 number of modules in series/ parallel string combination is 591.052 m^2. PV module is made of semiconductor material. When the sun radiation falls on the PV cells, it produces electricity by the photovoltaic effect. In this rooftop PV array, the power output of the PV is converted from direct current supply to alternating current supply by inverter. The three-phase commercial two inverters (50 kW) is used in the system. The inverter output terminals are connected to the common coupling point, and the common coupling point is connected to the load. There is two load connected first hostel load is connected to 315 kVA transformer and second college load is connected to 500 kVA transformer. Due to fault or cloudy weather conditions, if the roof top PV system is not able to supply the load, a change is made to the grid by a switch located at the common coupling point. Supplies are not available in the grid, so generators are used to supply the load (single phase AC operated). This complete system is shown in figure 1.

The GRPV system consist of 308 number of PV modules. The rating of each
Module is as follows-
Peak Power : 320 W
Open circuit voltage : 46.56 Volt
Rated voltage : 37.85 Volt
Short circuit current : 9.05 Amp
Rated current : 8.46 Amp
Module efficiency : 16.49%

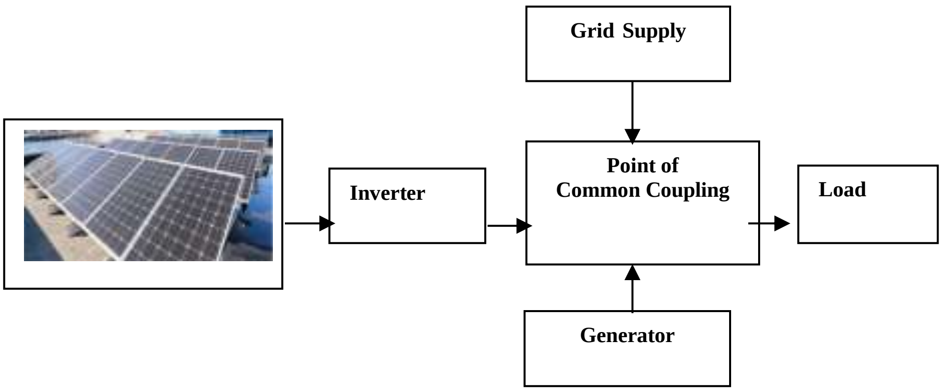

Fig. 1. Block diagram of rooftop PV system

III.ENERGY ANALYSIS OF ROOF TOP SOLAR PHOTOVOLTAIC SYSTEM

The energy analysis of rooftop solar PV system done in two parts- first is the measurement of annual energy (kWh) generation by the plant and second is the calculation of Embodied energy of the plant. After that the Life Cycle Conversion Efficiency is calculated and analysed.

(a) Annual Energy (kWh) generation of plant.
For the energy analysis of the plant, we took the data by software installed along with the system. Table 1 shows energy generated by GRPV in kWh for previous one year.
Table 1. Solar electrical energy generated (By Dates)

Date	Generation (kWh)
27.11.2019 – 14.01.2020	9574.320
14.01.2020 – 31.08.2020	92122.5

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31.08.2020 – 30.09.2020	12313.500
30.09.2020 – 31.10.2020	9380.4
31.10.2020 – 27.11.2020	6768.6
	130159.32 (Total)

The total generation of electrical energy by the solar PV system is calculated by summing the all energy generation for previous one year.
$E_{\text{per year}}$ =130159.32 kWh.

The Results for Annual solar electrical energy generation include the highest ratio of actual production in the solar plant for a year under ideal conditions.

(b) Embodied Energy of Solar PV System.
The embodied energy is defined as the amount of power needed for all tasks related to the manufacture process, transportation to site and construction throuout the whole life. A solar system embodied energy should be less as well as possible. If embodied energy is greater than output energy then system is not efficient. Energy used in making equipment and other supporting function (i. e. direct energy and indirect energy).
The embodied energy of various materials used in the manufacture of solar panels is given below in Table 2.

Table 2. Material production Energy (E_{mpe})

Material	Embodied Energy (kWh/m^2)	Total Area (m^2)	Total Embodied Energy (kWh)
Silicon Purification and Processing: Metallurgical grade silicon production, Electronic grade silicon production, Silicon crystal growth	670.00	591.052	396004.84
Solar Cell Production	120.00	591.052	70926.24
PV Module Lamination and Assembly: Steel infrastructure, Ethyl vinyl acetate, Tedlar production, Glass Sheet production, Aluminium frame production, Other materials	190.00	591.052	112299.88

Total material production energy (Empe) = 579230.96 kWh.

The embodied energies and weights of materials used in the supporting structure are shown below in Table 3

Table 3. PV system installation energy ($E_{inst.}$)

Item	Embodied Energy	Total Weight	Total Embodied Energy (kWh)
Support Structure: Iron stand Screw	7.70 (kWh/kg) 8.63 (kWh/kg)	1500 kg 40 kg	11550 (kWh) 345.2 (kWh)
Inverter	210.00 (kWh/kW)	100 kW	21000 (kWh)
Wires	3.00 (kWh/m^2)	591.052 m^2	1773.156 (kWh)

Total material production energy (Einst) = 34668.356 kWh.

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Table 4. Energy used in maintenance (E_{main})

Item	Embodied Energy (kWh/m^2)	Total Area (m^2)	Total Embodied Energy (kWh)
Human labour	9.84	591.052	5815.96

Table 5. Energy used in administration (E_{admin})

Item	Embodied Energy (kWh/m^2)	Total Area (m^2)	Total Embodied Energy (kWh)
Transportation	53.50	591.052	31621.282

Total manufacturing energy (Emfg) = Empe + Emain
= 579230.96 + 5815.96
= 585046.92 kWh.

Total Material Production Energy (Einst) = 34668.356 kWh.

Total energy used in administration (Eadmin) = 31621.282 kWh.

Embodied energy (Ein) = 585046.92 + 34668.356 + 31621.282
Ein = 651336.558 kWh.

This contain the assessment of the overall energy consume to extract the raw material, manufacture a product or components, installation and maintain the component element whichever is being assessed.

IV. LCCE ANALYSIS OF SOLAR PV SYSTEM

This is the net energy productivity of the system with respect to the solar energy (radiation) over the life time of the system. The following methodology has been adopted for life cycle conversion efficiency Analysis of solar system.
For the complete analysis of solar system, the embodied energy, annual generation of energy and the LCCE analysis of the system is also done. The LCCE of the system mainly depends on embodied energy, total energy generation by system, solar input (radiation) and total life time of the system that is 25 years.
For calculation of LCCE first calculate the solar input energy (Esol) by solar module efficiency. Solar module efficiency is defined as the ratio of energy output from the solar PV cell to input energy from the sun.

$$\text{Module Effeciency} = \frac{Eaout}{Esol}$$

$$16.49\ \% = \frac{130159.32}{Esol}$$

$$Esol = 789322.74\ kWh$$

The solar PV system input (radiation) energy is 789322.74 kWh that is converted into solar PV system output energy by PV module with 16.49 % efficiency. The solar PV system annual output energy is 130159.32 kWh.
The Life Cycle Conversion Efficiency (LCCE) of the solar PV system

$$LCCE = \frac{Eaout \times n - Ein}{Esol \times n} \quad [2]$$

Eaout = Annual output energy of the PV system
Esol = Solar input energy (radiation) of the system
n = Life time of the system in years
Ein = embodied energy

$$LCCE = \frac{130159.32 \times 25 - 651336.558}{789322.74 \times 25}$$

$$LCCE = 0.1318$$

LCCE is always less than one. For an energy efficient system, LCCE should approach to one. The performance of the solar PV systems on typical days of winter and summer are analysed. The year-round performance of the PV systems under actual outdoor environmental conditions are compared and validated with the simulated values obtained from the PV system optimization tool. Finally, to assess the overall energy performance of the PV systems embodied energy and energy metrics mainly life cycle conversion efficiency (LCCE) have been estimated.

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V. CONCLUSION

Based on the technical performance of the PV systems under study, it can be concluded that the system itself take a huge amount of energy for its construction, manufacturing & installations. That's why it becomes very important to analyze the energy efficiency of the system. The term "energy efficiency' means- whether the system is capable of recovering its embodied energy during its life time or not? If the system is capable of recovering its embodied energy, then only the system is considered as energy efficient system.

In our study, the LCCE of the solar PV system is 0.1318 and the annual electricity generation is 130159.32 Kwh. Also we found the embodied energy and solar input energy of the system is 651336.558 kWh and 789322.74 kWh respectively. Considering this, the Energy Payback Time and Electricity Production Factor of the PV system is 5.0 years and 0.2 year respectively.

For make solar panels is more efficient in real world condition the efficiency quoted for each model of solar panel is calculated at Standard Test Conditions. However, in the real world solar panels seldomly operate in such conditions. In real-world conditions solar panel efficiency is impacted by things including like temperature, dust, dirt, snow, and other debris. Based on the PV system under study, we concluded that for energy efficient system the Energy Payback Time of the system should be less as well as possible, and LCCE should approach to one.

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