International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2014): 5.611

Khatkar Kalan SPV Electricity Generating System: A Case Study

A. F. Sherwani

Department of Mechanical Engineering, Faculty of Engineering and Technology, Jamia Millia Islamia, New Delhi, 110025

Abstract: ***Solar photovoltaic systems are prohibitively expensive in terms of installation costs. Power from them is intermittent and available if solar radiations are available. On the other hand, PV electricity systems are free from ever-rising costs of conventional fuel. They also incur very less operation and maintenance costs. Using solar-PV power, it looks uneconomical in the short term, but may be profitable in the long term. It is therefore, interesting to identify the factors that can make investment in solar PV power generation is to be acceptable. In this paper life cycle analysis for 200 kWp solar photovoltaic electricity generation system has been carried out. It identifies the factors that can make the investment in a solar PV plant more favourable than investment in other conventional electricity generation sources. The energy payback time and the normalized greenhouse gas (GHG) emissions has been evaluated and found to be 4.73 years and 143.86g-CO_{2eq}/kWh_e respectively.***

Keywords: Energy payback time, GHG emissions, India, Life Cycle assessment, SPV.

1. Introduction

Life cycle assessment study is also called as cradle to grave study of the system/ product. It is used to calculate the energy consumption in manufacturing, installation and transportation of SPV systems. LCA studies also aims in comparing and analysis of the environmental impacts of products and services [1, 2]. The EPBT (energy pay-back time) period is used as an indicator to show the amount of energy consumed. EPBT is the time required for the system to generate the equivalent amount of energy which is consumed in the construction, operation, maintenance and decommissioning of the energy generating system. It indicates number of years required to recover the energy consumed in the installation of the plant through energy (electricity) generation by the plant. The total energy requirement of the electricity generating projects and the annual power generated are concerned with the primary energy. To convert the annual power generation (kWh_e) to primary energy, the average efficiency of the electricity generation projects in the studied country is needed. For the present study best average efficiency of electricity generation for India is considered as 0.40. Estimation of EPBT is given as:

$$EPBT\ (years) = \frac{Total\ primary\ energy\ requirement\ of\ system\ throughout\ its\ life\ cycle\ (GJ)}{Annual\ primary\ energy\ generation\ by\ the\ system\ (GJ/year)}$$

The total life-cycle GHG emissions (Mg-CO_{2eq}) were generally estimated according to the full operational life cycle of each system from the commissioning of the plant to its full operation (cradle to grave). These emissions are found to vary widely within each technology. For the estimation of GHG emissions for the present study, life time of the projects is considered to be 20 years. Estimation of GHG emissions is given as:

$$GHG\,emissions = \frac{Total\ CO_2\ emissions\ throughout\ its\ life\ cycle\ (g - CO_{2eq})}{Annual\ power\ generation\ (kWh_e / year) \times lifetime\ (year)}$$

Numerous LCA studies have been carried out for SPV systems and a wide range of results in EPBT have been found. Various studies on GHG emission estimation for SPV systems have also been carried out and also a wide range of results have been found [2-6].

SPV system design is very dependent on the geographical location of the system, since the amount of electricity generated varies with the irradiance and temperature.

Under the demonstration of grid interactive solar photovoltaic program, a 200 kWp capacity, grid interactive power plant has been installed at village Khatkar Kalan district Nawanshahr (Punjab) with the help of MNES (Ministry of Non-conventional Energy Sources), IREDA (Indian Renewable Energy Development Agency Limited) and state government of Punjab under world bank credit of line. The village Khatkar Kalan is a small village comprising around 300 households. Due to its historical importance, it has been provided electricity along with four other villages. However, due to the increasing load demand, grid voltage drops along the line during peak demand which causes the transformer to overheat. The village load consists of mainly lighting and water pumping which has a daily average value of about 140 kVA. As good grid availability is there from the nearby lines, it would be ideal to establish a SPV grid interaction power plant in parallel with the grids so that the conditions of providing supports to the grids as well as 1-2 hours backup for emergencies are met during blackout periods. During periods of non utilization, the power generation can be exported to the grids. For the present study

2. Description of System

The system is designed to provide maximum export of solar power of the grid and to provide 2 hours autonomy in case of grid outage. The nominal capacity of the project is 201.6 kWp based on 70Wp PV module. SPV module shall be stand voltage up to 2KV DC between the earthen frame and shorted line terminals. The overall dimensions of PV module is 1208(±3) × 528(±2) × 38(±1) mm^3. Module is single glass laminated type 36 cells (9×4) in series and having 8.0 kg weight. The SPV module consists of mono crystalline silicon cell which is having an efficiency of 13%. The total area required for installation of array is approximately 3000 m^2 which was available at selected site. 20 module of 70 Wp each connected in series will form a series string and 144 such string will be connected in parallel. Each array output of MTB is terminated onto PJB (panel junction box). As the entire generation data was not available for the complete year. Based upon average monthly data, electricity generation for a year has been estimated. The average approximate yearly electricity generated by the system is 312350 kWh_e. A list of components and materials used and the site details of the present SPV system has been given in Table 1 & Table 2 respectively.

3. Material Inventory

Numerous studies have been carried out to estimate the energy consumption in the manufacturing of mono-crystalline solar PV modules [7, 1]. Hence for energy consumption for mono-crystalline SPV modules has been taken from the above mention study. The energy consumption for module is considered 16 MWh_t/kW_p. The mono-crystalline PV cell having an efficiency of 17% is considered. In the present study, 10% of the module weight is considered to be the weight of the frame. Frame has been made up of aluminum. There are few available data about energy requirements for change regulators and inverter manufacturing, especially for small and medium size facilities. Sherwani et al. [11] estimated a 0.5 MWH for energy requirements. No significant material inflow is involved during operation and decommissioning phases.

4. Life Cycle Input Energy

The weight and embodied of different components of SPV system are shown in Table 3. To convert primary energy into its equivalent electrical energy, a best average efficiency is considered to be 40%. For the estimation of concrete structures, the studies of Reddy & Jagadish [8] and Shukla et al. [9] are used which has been carried out for India. The energy adopted for inverter and aluminium is based on its energy consumption presented by GEMIS [10]. The distance by road between Khatkar kalan and Bharat Heavy Electrical Limited (Hyderabad) is approximately 2000 km. The primary energy value is considered as 0.41 MJ/Ton-km for transportation purpose.

5. Life Cycle GHG Emissions

GHG emissions are normally occurs during manufacturing, installation and transportation phases of solar PV modules. Among all the electricity generation sources, the coal has highest value of GHG emissions while nuclear based electricity generation has the maximum value. The GHG emissions of different components of SPV system are shown in Table 4. In this study, GHG emission is evaluated throughout 20 years lifetime of SPV system. Among the renewable energy based electricity generation, wind has the highest potential and then there is a potential for small hydropower. An average value of GHG emission factor for the entire electricity generation sector has been taken from Sherwani et al. [11]. As wind and small hydro have the lesser value than the 35 and in the electricity generation.

Table 1: Technical specification of the PV plant

S. No.	Component	Specification	Material	Numbers
1	PV Module	1208(±3)×528(±2)×38(±1)	Anodised aluminium	2880
2	PV Cell	l:100, b:55	Mono-crystalline silicon	103680
3	Array junction box	l:4000, h:300, t:100	Copper	96
4	Main junction box	l:4000, h:300, t:100	Copper	6
5	Sub main junction box	l:4000, h:300, t:100	Copper	28
6	Control room and battery	l:6040, b:4530, h:4433	Steel, Bricks, Cement	1
7	Battery	l:500, b:212, h:256	Plastic, Rubber, Lead	120
8	Power wire	d:6, l:3800	Copper	95
9	Structural column	d:76.5, h: 1900, t: 30	Steel	324
10	Wire	l:6435	Copper	150
11	Inverter	l:1500, b:1290, h:1410	Mix material	3

l=length, b=breadth, t=thickness, h=height and d=diameter; All dimensions are in mm.

Table 2: Location and Site details of Solar PV system

Location	Punjab
Land ownership	Owned by local Panchayat (A local governing body)
Ambient Temperature	4 - 45°C
Latitude	31.42° N
Longitude	75.58° E
Elevation	238 m above mean sea level
Tilt angle	30° (fixed)

Table 3: Component Wise Distribution of Embodied Energy for PV system

S. No.	*Component*	*Material*	*Weight (kg)*	*Embodied Energy (kWh_e)*
1	PV module	Mono-crystalline	-	1290240.00
2	Frame	Aluminum	907.2	99447.95
3	Support structure	Steel	1611.95	9465.48
4	Power wire	Copper	12.04	361.92
5	Array junction box	Copper	66	2018.84
6	Main junction box	Copper	5	183.06
7	Sub main junction box	Copper	22	550.59
8	Wire	Copper	125	3054.71
9	Building	Mix material (Steel, Brick, Cement, Sand, Other)	81145.96	32250.44
10	Pavement	Brick	157	9344.88
11	Grounding	Plastic, Rubber, Other	124.8	3229.80
12	Inverter	Mix Material	-	7000
13	Transportation	-	-	20986.12
Total				1478133.79

Table 4: Component wise GHG emission of SPV system

S. No.	*Component*	*GHG Emissions (kg-CO_2)*	*Percentage GHG Emissions*
1	PV module	784465.92	87.29%
2	Frame	60464.3536	6.73%
3	Support structure	5755.01184	0.64%
4	Power wire	220.04736	0.02%
5	Array junction box	1227.45472	0.14%
6	Main junction box	111.30048	0.01%
7	Sub main junction box	334.75872	0.04%
8	Wire	1857.26368	0.21%
9	Building	19608.26752	2.18%
10	Pavement	5681.68704	0.63%
11	Grounding	1963.7184	0.22%
12	Inverter	4256	0.47%
13	Transportation	12759.56096	1.42%
Total		**898705.3443**	**100%**

6. Results

The total primary energy requirement for the Khatkar Kalan solar PV electricity generation system is 1478133.79 kWh_e. The EPBT is calculated and it comes to be 4.73 years which is very less if we compare this value with the other studies related to PV based electricity generation system. As the mono-crystalline solar cells are very less energy intensive elements as compared to others but their conversion efficiency is also very less as compared to others solar cells. The total GHG emissions for Khatkar Kalan SPV system is 898705.3443 kg- CO_2. The life time of this system is considered to be 20 years. The GHG emission for 1 kWh_{el} is calculated as 143.86 kg-CO_2/kWh_{el}.

7. Conclusions of Case Study

LCA study has been performed for Khatkar Kalan SPV electricity generation system. The generation of electricity by using SPV is environmentally friendly as compared to fossil fuel based energy generation sources. It has been observed that highest energy consumption & GHG emissions are in manufacturing/fabrication of PV modules. The initial cost of installing this type of system is high and having less efficiency. A good amount of work has already been going on in this area which will lead to more improvement and cost reducing in these systems which further reduce the cost of electricity generation.

References

[1] Kannan, R. Leong, K.C, Osman, R. Ho. H.K. Tso, C.P. (2005). “Life Cycle assessment study of solar PV systems: An example of a 2.7 kW_p distributed solar PV system Singapore”, Solar energy. (68)

[2] Niewlaar, E. Alsema, E. Van, Engelenburg B. Usinf. (1996). “Life cycle assessments for the environmental evaluation of greenhouse gas mitigation options”. Energy Conversion and Management;37:831-6. (69)

[3] Alsema, E. A. (2000). “Energy pay back time and CO_2 emissions of PV system”, Progress in Photovoltaic Research and Application;8:17-25. (70)

[4] Pacca, S, Sivaraman, D. Keoleain, G. A. (2007). “Parameters affecting the life cycle performance of PV technologies and systems”, Energy Policy;35:3316-26. (71)

[5] Ito, M. Kato, K. Komoto, K. Kichimi, T. Kurokava, K. (2008). “A comparative study on cost and life cycle analysis for 100 MW very large-scale (VLS-PV) systems in deserts using m-si, a-si CdTe and CIS modules”, Progress in Photovoltaic Research and Applications;16:17-30.(72)

[6] Srinivas, K. S. (1992). “Energy Investments and Production Costs of Amorphous Silicon PV Modules”, Report for the Swiss Federal Department of Energy, Universite de Neuchatel.(73)

[7] Schaefer, H. Hagedorn, G.. (1992). “Hidden energy and correlated environmental characteristics of P.V. power generation”. Renewable energy;2(2):159-66. (37)

[8] Reddy, B.V. Jagadish, K.S. (2003). “Embodied energy of common and alternative building materials and technologies”, Energy and Buildings; 35(2):129-137. (75)

[9] Shukla, A. Tiwari, G.N. Sodha, M.S. (2009). “Embodied energy analysis of adobe house”, Renewable Energy; 34(3):755-761.(76)

[10] GEMIS, (2002), Global emission model for integrated systems, GEMIS 4.1 Database (September 2002), Oko-Institute Darmstadt, Germany.(77)

[11] Sherwani, A.F. Usmani, J.A. Varun, Siddhartha. (2011). “Life cycle assessment of 50 kW_p grid connected solar photovoltaic system in India”, International Journal of Energy and Environment; 2(1):49-56(78)