Economic feasibility of Off Grid Solar PV System

Xma R.Pote[1], V.S.Rajguru[2], S.P.Adhau[3], Mrunmayee Gujar[4]

[1]*Department of Electrical Engineering, Yeshwantrao Chavan College of Engineering, Nagpur, India* potexma@gmail.com

[2]*Department of Electrical Engineering College of Engineering, Pune, India,* Vsr.elec@coep.ac.in

[3]*Department of Electrical Engineering, Yeshwantrao Chavan College of Engineering, Nagpur, India,* adhau_sp@yahoo.co.in

[4]*Director,Grid Integration Engineering, Nexamp,Boston Massachusetts,US,* mrunmayeegujar1604@gmail.com

Abstract :

The recent figures on power generation shows that about 50.7 % of the power is being generated from conventional coal fired power stations. The fuels like coal and oil lead to heavy degradation of clean surrounding air. In order to cope with the declination of petroleum reserves and also to reduce pollution Electric automobiles are being designed and implemented on a large scale. This will also necessitate the increased power generation. this paper highlights analytical study of household Solar Rooftop system. The payback period for two different cases is calculated as 7 years and 6 years and the reduction in Carbon dioxide emission is 931 and 136 tons per MWh respectively. The paper gives the explanation based on current market rates and conditions.

Keywords : *Financial, Payback period, Carbon emission, Solar Panels*

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I. INTRODUCTION

As per the statistics available the total installed capacity of in India in June 2022 is 403.760 GW. Out of this the generation with fossil fuel is 236.075 GW and generation with renewable energy is 167.694 GW [1]. This includes generation with hydro as 46 GW and with nuclear it is 6.78 GW. The fossil fuel share is 58.5% and renewable energy share is 39.7 %. A system involving generation of power in a clean way is the need of century. India has huge potential for generation of power by utilizing solar energy During the month of January Southern Peninsula receives 4.5 kWh/m^2/day, Western Ghats receive 5.5 kWh/m^2/day. In the duration of April to May, more than 90 % of wind energy it is 61525 MW and power generation from small hydro is 9256 MW. The data is accessed from the site of Government of India[13].

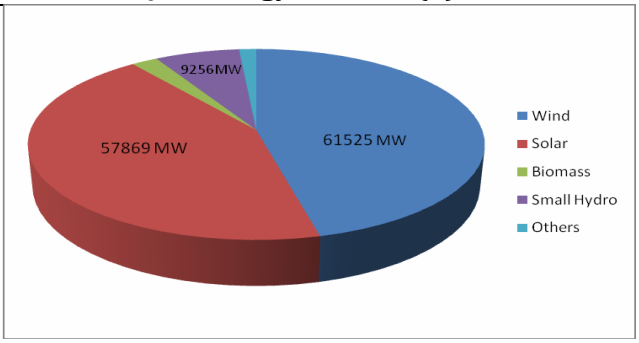

Fig 1:Generation of renewable energy[13]

A basic photovoltaic system is shown in figure 2 .It consists of solar panel arrangement which has solar arrays connected to charge controller. The function of a charge controller is to regulate the voltage and current of the solar panel so that the battery is protected from overcharging. The solar panel arrangement generates direct current (DC) which is stored by the battery. If the load to be supplied is DC then it can be directly utilized from battery, but if the load connected is AC type the we have to use an inverter.

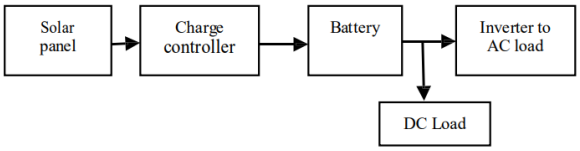

Fig.2: Block diagram Solar PV System

II. OPERATION OF SOLAR PV SYSTEM

The power generation by renewable energy sources has achieved great heights in the recent years. This is due awareness among the masses and great support from the government in terms of economy. Figure 1 shows the generation of power by different renewable energy sources. The recent figures show that the power generation from solar energy is nearly 57869 MW, from the country receive about 5 kWh/m^2/day with highest recorded 7.5 kWh/m^2/day in the western plain. This will help in heavy reduction of carbon emission and result in conservation of fuel to a great extent. The current figure of carbon dioxide emission is 2.88 Gigaton per year [3]. The solar photovoltaic panels can be installed on ground level as well as buildings. utilization of place. This gives optimum

The arrangement of PV system is not complicated, it consists a photovoltaic module and DC load if the load to be supplied is DC in nature. However, when for example a whole house should be powered, the system must be operational day and night. It also may have to feed both AC and DC loads, have reserve power and may even include a back-up generator. Depending on the system configuration, three main types of PV systems can be identified: stand-alone, grid-connected, and hybrid. The elementary working principle and components connected remains similar. Systems are adapted to meet requirements by varying the type and quantity of the basic elements. A modular system design allows easy expansion and flexibility when power demands change.

Stand-alone systems rely on solar power only. These systems consist of the PV modules, a load and necessarily include batteries for energy storage. When batteries are utilized, charge regulators are also included, which disconnect the PV modules when batteries are fully charged, and it also turn off the load to prevent the batteries from being discharged below a specific limit. The batteries must have enough capacity to store the energy produced during the sunshine hours, to be used in the dark and during periods of bad weather. Grid-connected PV systems became increasingly popular for building integrated applications. They're linked to the grid through inverters, which change the DC power into AC electricity. In small systems as they're installed in residential homes, the inverter is connected to the distribution board, from where the PV-generated power is transferred into the electricity grid or to AC appliances within the house.In case of domestic applications the inverter is linked with the distribution panel. This distribution panel acts as a way to move the electricity generated from photovoltaic arrangement to the main grid or appliances at home which needs AC for operation. These systems do not require batteries, since they are connected to the grid. PV generated electricity is transported while the grid also supplies the house in times of insufficient PV power generation.

The advantages of off-grid rooftop solar PV system can be summed up as follows. (i) the consumer gets continual power supply (ii) the return on investment is out matched to other alternative sources (iii) Lessen dependency on the utility grid, (iv) it helps to keep away from polluting diesel generator set, (v) rock bottom need to maintenance, and needless to purchase fuel regularly, compared to diesel generator set (vi) only first investment is needed and power generated over the life time, and (vii) protection from inflation in conventional power tariffs.

The main aim of this paper is to elaborate a method for technical, economical and environmental analysis of a standalone Solar PV system. This paper explains the benefit a consumer will get if he is switching from conventional grid system to installed solar PV system. The benefits are in the form of all the three parameters mentioned above [14]. The analysis done in this paper highlights the number of panel requirement, batteries

required depending on days of autonomy and depth of discharge. After getting the number of components required the cost of these components have been found and hence cost of whole system is estimated. A basic photovoltaic system is shown in figure 1.It consists of solar panel arrangement which has solar arrays connected to charge controller. The function of a charge controller is to regulate the voltage and current of the solar panel so that the battery is protected from overcharging. The solar panel arrangement generates direct current (DC) which is stored by the battery. If the load to be supplied is DC then it can be directly utilized from battery, but if the load connected is AC type then we must use an inverter.

III. CALCULATIONS FOR OFF GRID DOMESTIC ROOFTOP SOLAR POWER PLANT

A. Technological parameters

1. Energy consumed

The important parameters of the design are proper electrical and physical dimensions of Photovoltaic system and also appropriate rating and number of batteries.

In this portion a model is developed in which equations for total solar panels required, power generation capacity of solar panels,number of batteries depending on load fulfillment is represented.The technical and financial concept is covered in the model.

2. Number of solar panels required

The number of solar panels will depend on the amount of energy to be produced. This necessitates the need to know what the types and numbers of loads are connected. Also, we need to know the number of hours of operation of each type of load. A typical requirement of commercial and household set up is considered for the purpose of analysis and comparison. To start with energy utilized per day will be calculated.

*Energy consumed per day=Ed=N*H*P/1000 kWh (1)*

where N refers to total number of a particular load for example LED Lights or fans.H refers to hours of operation and P refers to power rating of each load.This can be applied to each type of load and summation of power consumption of all loads gives the total power consumption.

3. Power generation capacity of Solar panels

In order to supply the above requirements completely with generation of solar power, the terms like efficiency and derating factors are to be considered [2]. Hence, the complete PV generation capability required can be calculated as

*Pgen =Ed /(Hs*d) kW (2)*

where Hs refers to the number of sunshine hours at a particular location and d refers to derating factor.Derating factor refers to the difference in actual output and the output which will be practically obtained from the solar PV considering different factors like degradation of PV Panel,ambient temperature etc.

4. Number of Solar Panels

After knowing the values of energy consumed by the load and power generation capacity of panels now we can calculate the number of solar panels required.It will be the ratio of power generated to power output of each panel.

Ns = Pgen / Pout (3)

5. Number of batteries

The availability of solar energy is variable in nature. Though while designing a system we have a study of solar energy availability still in case of storage requirement we need to use a battery. This improves reliability of the system. We always have a mindset for savings which can be used in case of emergencies hence using a battery backup can definitely improve efficiency of energy fulfillment. Hence people are concentrating on using

battery solution to make maximum possible use of energy in an efficient way [4].

*BN = (Ed * Ad) /(Bv *Iah*D)* (4)

where BN is the number of batteries required for satisfying the load requirement. Ad is the term used for referring days of autonomy (days for which load will be satisfactorily supplied without bright sunshine).BV is the voltage of battery, Iah is the ampere hour rating and D is the depth of discharge.

6. Capacity of inverter

An inverter is an important component if the lad to be utilized is of AC type.This also has a major share in the cost of overall system.Initially size of inverter is decided and hence the cost.The size of inverter depends on factors like power rating of devices and diversity factor.The value of diversity factor is normally taken more than 1 as it the ratio of summation of individual maximum demands to maximum demand on the whole system.

*Capacity of inverter = (Rating of device*Number of devices)/DF*

(5)

B. Financial parameters

1. Overall cost of solar PV arrangement

The main components of solar arrangement are PV panels, charge controller, batteries and inverter. The overall cost will include the cost of these components along with some miscellaneous cost for physical installation.

Ct =Cp + Cc + Cb + Ci

(6)

In order to encourage the use of solar energy on a higher level, government offers subsidies on purchase of panels. Central financial assistance (CFA) of 40% of the benchmark cost of the system is provide by the government.

Assuming the subsidy component as Ps, the total cost of solar

arrangement will be represented as

*Ct = (1-Ps) * Ct* (7)

Now we need to find the cost of power which is obtained from the grid(Cg). The cost of power from the grid depends on factors like load to be satisfied per day Ed , cost of per unit of energy Cp and duration to be considered Y years. Assuming lifetime of panel arrangement to be 26 years (it is approximately in the range of 25-30 years) the cost of grid power can be calculated as follows

*Cg = Ed * Cp * Y *365* (8)

Hence for a particular duration of time the profit by using solar

installation can be calculated as

Overall profit = Cg -Cpv (9)

2. Payback period

After investing money into a solar PV system, it is desirable to find the time period to recover the invested money or save the invested money. This comparison is required with respect to other source which is used without having solar PV like grid

electricity. The simple payback period is the amount of time that is obtained by dividing the initial investment in a PV system by the cost of annual energy savings due to a PV system in which money is invested [7].

Simple payback period = I / S (10)

where I refer to initial investment and S refers to savings in terms of money.

C. Environmental concern regarding carbon dioxide emission

As per the data available from Ministry of Power, Government of India, CEA, the weighted average emission rate for coal fired power plants is 0.79 tons of carbon dioxide per Megawatt hour of energy generated. By utilizing this component we can also compute the decline in carbon release so as to make our environment less polluted [9]. The term Ccarbon refers to carbon emission.

*Ccarbon = Ed * 365* 0.79*26 /1000 tons/MWh*

(11)

IV. CALCULATIONS AND ANALYSIS

1. Calculations for a commercial building

Consider a commercial building set up having loads with their power rating and hours of operation.

Table 1: Load requirements with ratings for commercial set up

Load	Hours of	Power	Power
150 LED	10	22 W	33 kWh
50 FANS	12	75 W	45 kWh
2 FRIDGE	12	600 W	14.4 kWh
2	6	60 W	0.72 kWh
50	9	75 W	33.75 kWh
TOTAL		292 W	126.87

In order to start with the analysis, we need to consider certain parameters which are refereed from data source mentioned in the references. This part of the paper gives the analysis of two examples, one referring to commercial setup and another referring to household example. The study of technoeconomic parameters and parameter causing disturbance to the environment is presented in this portion. Some data is considered which is available for Indian market and provided by government database. The cost of 12 V,250 Ah battery is taken to be Rs.13500[6].The cost 250 watts solar photovoltaic panel is taken as Rs.11,250[11].The cost of inverter is taken to be 6.75 Rs per watt[10].The cost of charge controller is taken to be Rs.3000[12]. The diversity factor (DF) is assumed to be 1.6 and derating factor is 0.8.

A. For commercial Purpose

Pgen = Ed / (Hs x d) kW = 126.87/(8 x0.8)= 19.823

taking H_S = 8 hours, d=0.8

Number of Solar panels required with power rating 250 W each

Pgen / Pout = 19.823 x 1000) /250 = 79.292 ≈ 80

Cost of each Solar panel = Rs 11,250 Total cost of solar panel = Rs 11,250 x 80

= Rs 9, 00, 000/-

(a)

Number of Batteries (of rating 12 V, 250 Ah) BN = (Ed x Ad) / (BV x Iah x D)

BN = (126.87 x 3 x 1000) / (12 x 250x 0.85) = 149.258 W

≈ 150

Total Cost of Batteries =150 x 13,500 = Rs 20,25,000 (b) Cost of Charge controller = Rs 3,000 (c)

Size of inverter = Power rating of Device * number of devices / Diversity Factor

Size of inverter = 12120 /1.6 = 7575 VA

Assuming cost of inverter = Rs 6.75 / VA

Cost of Inverter =7575 x 6.75 = Rs 51,131.25 (d) Total cost of whole equipment = a+b+c+d = Rs 29,79,131.25

Considering subsidy to be 40% = 0.4 x 29,79,131.25

= Rs 11,91,652.5

Total price of whole equipment after subsidy

= 29, 79,131.25- 11, 91,652.5 = Rs 17, 84,478.75/-

For the units consumption above 100 kWh the rate of grid electricity is taken as Rs.7.34 hence total electricity bill for 26 years using grid system without using solar energy considering rate per unit is

= 126.87 x 7.34 x 26 x 365

= Rs.88,36,636.276

Difference in amount using solar power

= 88,36,636.276-17,87,478.75

=Rs. 70,49,157.526 (in 26 years)

Total carbon-dioxide limitation in 26 years

= Ed x 0.79 x 365 x 26/1000 tons / MWh

= (126.87 x 0.79 x 365 x 26) / 1000=951.157

Simple Payback period = 17,84,478.75/271121.4433

=6.581

≈ 7 years

2. For household purpose

Table 2: Load requirements with ratings for household set up

Load	Hours of operation	Power Rating (Watts)	Power Consumption (watt-hour)
10 LED bulbs	5	12	600
3 fans	8	75	1800
1 Refrigerator	24	600	14400
1Mixer	0.25	500	125
1 Washing Machine	1	1000	1000
1TV	3	60	180
Miscellaneous	2	50	100
		2297	18205

Pgen = Ed/(Hs x d)Kw = 18.205/(8 x0.8)= 2.844

taking Hs = 8 hours, d=0.8

Number of Solar panels required with power rating 250 W each Pgen /Pout =(2.844 x 1000) /250 = 11.376 W ≈ 12 W

Cost of each Solar panel = Rs 11,250 /-

Total cost of solar panel = Rs 11,250 x 12

= Rs.1,35,000/-

(a)

Number of Batteries (of rating 12 V, 250 Ah) BN = (Ed x Ad) / (BV x Iah x D)

BN = (2.844 x 2 x 1000) / (12 x 250x 0.85) = 2.23

≈ 3

Total Cost of Batteries = 3 x 13,500 = Rs 27,000

(b) Cost of Charge controller = Rs 3,000

(c) Size of inverter = 2555 /1.6 = 1596.875 Watts ≈1597 Watts Assuming cost of inverter = Rs 6.75 per Watt

Cost of Inverter =1597 x 6.75 = Rs 10779.75

(d)

Total cost of whole equipment = a+b+c+d = Rs 175779.75 Considering subsidy to be 40% = 0.4 x 175779.75

= Rs 70311.9

Total price of whole equipment after subsidy

= 175779.75- 70311.9=Rs.1,05,467.85

Total electricity bill for 26 years using grid system without using solar energy, considering rate per unit.

= 18.205 x 3.36 x 26 x 365

= Rs.580491.912

Difference in amount using solar power (in 26 years)

= 580491.912-1,05,467.85=Rs.4,75,024.062

Total carbon-dioxide limitation in 26 years

= Ed x 0.79 x 365 x 26/1000 tons / MWh

= (18.205 x 0.79 x 365 x 26) / 1000=136.4847 tons/MWh

Simple Payback period = I/S

=105467.85/ 18270.15623

=5.7726 ≈ 6 years

v. CONCLUSION

1. The payback period in both the cases are justified as after this the total cost of fuel required will be nil.

2. The carbon emission is limited to a great extent which gives the value of 136.4847 tons/MWh in one case and

951.157 tons/MWh in the other case.

3. Moreover, due to dynamic market conditions the rate of inverters and choice of batteries is possible, so the economy of the complete system can be optimized.

4. It is observed that as we reduce the days of autonomy

the number of batteries and hence cost of the

system gets reduced. For household application the days of autonomy could be minimum to reduce the cost.

5. The share of battery cost in terms of percentage is 68 % and share of inverter cost is 17 % and share of panel cost is approximately 30 %. So, it is observed that battery cost holds the prominent share in overall cost of system.

6. The subsidy offered by the government in different states of India is variable depending on its application. For example, subsidy for commercial solar streetlamps is different as compared to subsidy offered for solar lamps for students.

7. The future scope of this paper will be calculations of grid power can be taken by considering the inflation in rates of per unit of power.

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