Impact Factor (SJIF): 3.632

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

Volume 3, Issue 4, April-2016

Design of 5 kwp Off Grid Solar Power System for Industrial Lighting Application

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***Abstract* —Off-grid (stand-alone) photovoltaic (PV) systems have become widely adopted as reliable option of electrical energy generation. In this paper, the electrical energy demand (load) of the industry based on watt-hour energy demands. The estimated load is 18 kWh/ day. An off grid PV system was designed based on the estimated load. Based on the equipment selected for the design, 20 PV modules, 10 batteries, a voltage regulators and an inverter will be required to supply the electrical energy demand of the industry. The cost estimate of the system is relatively high when compared to that of fossil fuel generator used by the industry. The payback period of the system is estimated to be 8.3 years, which is obviously much shorter than the lifespan of the selected PV modules which is 30 years.**

Keywords- PV panel, inverter, batteries, etc…

I. INTRODUCTION

Photovoltaic is the process of converting sunlight directly into electricity using solar cells. Today it is a rapidly growing and increasingly important renewable alternative to conventional fossil fuel electricity generation. This paper is *discussed about off grid solar power system.*

A. OFF_GRID POWER SYSTEMS

When the utility power is unavailable or too expensive to bring in to your home or cabin, solar panels allow you to be your own utility company! You can live in peace, with no noisy gas generator to disturb the quiet. There are several variations of off-grid solar power, depending on your needs and budget.

All variations of off-grid solar power depend on solar electric panels and store electricity in a bank of *batteries.* DC off-grid solar power systems are most often used to power DC appliances in boats, and cabins, as well as farm/ranch appliances like cattle gates and rural telecommunications systems when utility power is not accessible DC solar power is less expensive than AC solar power because an inverter is not required to convert the electricity produced by solar panels and stored in batteries from DC to AC. Now inverter is used to again use this power to supply the load from batteries if ac supply is required .

B. LOAD ESTIMATION

The daily load profiles were determined by calculating the power demand (kWh/day) for all load types in the off grid system. The estimated daily energy demand is given in Table 1 below. All the appliances used in the off grid which is to be supply.

Load	Rated Power (W)	Quantity	Hours used per day	kW	kWh/day
Lighting Bulb	40	35	12	1.5	18
TOTAL				1.5	18

***Table 1. Estimated Daily Energy Demand For off grid system*.**

(Note: Here load is about 1.4KW take approx 1.5KW)

II. PV SIZING OF ONGRID AND OFF GRID SYSTEM

A. Selection of PV Module

In selecting a PV module for PV system, the main criteria are the performance warranty in case of any problems, module replacement ease; compliance with natural electrical and building codes and manual should be available to see the quality and characteristics of the module.

B. Determination of PV Array size

The PV array output power ($P_{PVARRAY}$) can be obtain by equation 1

$$P_{PVARRAY} = (E_L \times PSI) \div (\eta_{BO} \times H_{TILT} \times K_{LOSS}) \quad (1)$$

E_L =Estimated average daily load energy consumption in kWh/day
H_{TILT} =Average solar radiation in peak sun hour's incident for specified tilt angle.
PSI =Peak solar intensity at the earth surface (1kW/m2)
η_{BO} =Efficiency of balance of system assumed(0.85)
K_{LOSS}= A factor determined by different losses such as module temperature, losses, dust, etc

$$K_{LOSS} = F_{MAN} \times F_{TEMP} \times F_{DIRT} = \text{Assumed } (0.833)$$

Where,
F_{MAN}= manufacturer's tolerance
F_{TEMP}=Temperature de-rating factor
F_{DIRT}=De-rating due to dirt if in doubt, an acceptable de-rating would be 5% [1]

$$P_{PVARRAY} = (18\times 1) \div (0.85 \times 16 \times 0.833) = 1.5 \text{ KW}$$

(NOTE: Here, our requirement is of 1.5kw but installation capacity is of 5 KW. so consider $P_{PVARRAY}$ = 5KW)

C. Number of modules in series

The number of modules in series N_{MS} as given in equation 2 is determined 1by dividing the designed system voltage V_{SYSTEM} (usually determined by the battery bank or the inverter) by the nominal module voltage V_{MODULE} at Standard Test Condition [1]

$$N_{MS} = (V_{SYSTEM}) \div (V_{MODULE}) = (48) \div (30) = 2 \text{ modules} \quad (2)$$

D. Number of modules in parallel

The number of modules in parallel N_{MP} as given in equation 3 is determined by dividing the designed array output $P_{PVARRAY}$ by the selected module output power P_{MODULE} and the number of modules in series N_{MS} [1]

$$N_{MP} = (P_{PVARRAY}) \div (N_{MS} \times P_{MODULE}) = (5000) \div (2\times250) = 10 \text{ modules} \quad (3)$$

Total number of modules is given by equation 4

$$N_{MT} = N_{MS} \times N_{MP} = 2 \times 10 = 20 \text{ modules} \quad (4)$$

III. DETERMINATION OF BATTERY BANK CAPACITY

A. Battery Capacity Calculation :

The storage battery capacity can be calculated using equation 5 [3]

$$C_x = (N_C \times E_L) \div (DOD_{MAX} \times V_{SYSTEM} \times \eta_{OUT}) \quad (5)$$

Where,
C_X = Required battery capacity
N_C = Number of days of autonomy
E_L = Estimated load energy in Wh
DOD_{MAX} = Maximum depth of discharge
η out = Battery loss

Batteries used in all solar systems are sized in ampere hours under standard test condition of 25˚C. Battery manufacturers usually specify the maximum allowable depth of discharge for their batteries. The depth of the discharge is a measure of how much of the total battery capacity has been consumed. The minimum number of days of autonomy that should be considered for even the sunniest locations on earth is 5 days . In this design the day of use in month max is taking as 30 days and the maximum allowable depth of discharge is taken as 75% The battery bank capacity required (C_x) is given by; [1]

$$C_x = (N_C \times E_L) \div (DOD_{MAX} \times V_{SYSTEM} \times \eta_{OUT})$$
$$= (30 \times 1500) \div (0.75 \times 48 \times 0.85)$$
$$= 1470 \text{ Ah}$$

Where,
η_{OUT}=0.85(assumed)

B. Specification of Battery type to be used

The battery selected is EXIDE 6EL 150+ 150AH TALL TUBULAR BATTERY. The battery has a capacity of 150AH and a nominal voltage of 12V. From equation 6, number of batteries required (N_{Breq}) is; [1]

$$N_{Breq} = C_x \div C_{selected} \quad (6)$$
$$= 1470 \div 150$$
$$= 10$$

Number of batteries in series is given by equation 7

$$N_{BS} = V_{SYSTEM} \div V_{BATTERY} \quad (7)$$
$$= 48 \div 24$$
$$= 2$$

Number of batteries in parallel is given by equation 8

$$N_{BP} = N_{Breq} \div NBS \quad (8)$$
$$= 10 \div 2$$
$$= \mathbf{5}$$

IV. DETERMINATION OF INVERTER SIZE

In sizing the inverter, the actual power drawn from the appliances that will run at the same time must be determined as first step. Secondly, we must consider the starting current of large motors by multiplying their power by a factor of 3. Also to allow the system to expand, we multiply the sum of the two previous values by 1.25 as a safety factor [2].

$$P_{total} = (P_{load} + P_{lsc})\times 1.25$$

Where;
P_{total} = Inverter power ratting(KVA).
P_{load} = Power required by load. (1.5KW)
P_{lsc} =Power of large surge current appliances. (0)

The input rating of the inverter should never be lower than the total watt of appliances.

$$P_{total} = (P_{load} + P_{lsc})\times 1.25$$
$$= (1.5+0) \times 1.25$$
$$= \text{approx } 2 \text{ KVA}$$

The inverter to be used for this system should have capacity not less than 2 KVA but we have take 5KVA and a nominal voltage of 48VDC.

V. Determination of Voltage Regulator Size

The voltage regulator is typically rated against amperage and voltage capacities. The voltage regulator is selected to match the voltage of PV array and batteries. A good voltage regulator must have enough capacity to handle the current from PV array. The rated current of the regulator is given by equation number 9,

$$I_{RATED} = N_{MP}\times I_{SC}\times F_{SAFETY} \quad (9)$$

In this design, F_{SAFETY}=1.25[3]

$$I_{RATED} = 10 \times 8.84 \times 1.25$$
$$= 110.4 \text{ A}$$

The voltage regulator selected is Xantex C60 controller 60A, 12/24V. It has nominal voltage of 12/24VDC and charging load/current of 60 amperes. Number of voltage regulator required is given by equation 10.

$$N_{VREG} = (I_{RATED}) \div (I_{SELECTED}) \quad (10)$$
$$= 110.4 \div 60$$
$$= 2 \text{ voltage regulator.}$$

VI. RESULTS OBTAINED FROM THE SIZING OF THE PROPOSED OFF-GRID PV SYSTEM

Component	Description of component	Result
Load estimation	Total Estimated Load	1.5 KW
PV array	Capacity of PV array	5000W
	Number of module in series	2
	Number of module in parallels	10
	Total number of modules	20
Battery bank	Battery bank capacity	1470Ah
	Number of batteries in series	2
	Number of batteries in parallels	5
	Total number of batteries	10
Voltage regulator	Capacity of voltage regulator	110.4 A
	Number of voltage regulator	2
Inverter	Capacity of the inverter	5 KVA

Table 2. Shows results obtained from the sizing of the proposed off-grid PV system

VII. COST ESTIMATE OF THE SYSTEM

Component	Model	Quantity	Unit price in Rs	Cost per component in Rs
Modules	NCS-6BP250	20	11000	2,20,000
Batteries	EXIDE 6EL 150+ 150AH TALL TUBULAR BATTERY	10	20000	2,00,000
Voltage regulator	Xantrex C60	2	10000	20,000
Inverter	SPCTUE50208	1	15000	15,000
SUB TOTAL				4,55,000
Other BOS costs (wires,fuses etc..)				91,000
TOTAL COST				5,46,000

Table 3 Cost Estimate of the System's Components

Cost per Component = Quantity× Unit price
Other Balance of System Component (BOS) Cost = 20% of subtotal.

The operating costs for solar PV installations are negligible, but the annual maintenance cost may amount to 0.5% to 1% of the capital cost of the system.

Maintenance cost of the PV system = 0.5% of TOTAL COST
= 2, 730 Rs
Overall cost of the system = 5, 46,000 + 2730
=5, 48,730 Rs

VIII. ESTIMATED COST OF ELECTRICITY BIL PAYED TO G.E.B

- Assume that cost of One unit for industries = Rs 10/-
- Total number of unit per day = 18 kWh/day
- Total number of unit used per year = 18 × 365
  =6570 kWh/year
- Total bill cost per year = 6570 × 10
  =65700 Rs
- Total installation cost of solar = 5,48,730 Rs

IX. PAYBACK PERIODE

- Payback period can be given by equation 11.

Payback period = (Overall cost of the PV panel) ÷ (Total bill cost per year) (11)
= 5,48,730 ÷ 65,700
= 8.3 years

(Note: In this whole paper all the values are assumed nearer to actual value.)

X. CONCLUSION

In this paper, the electrical energy demand (load) of some private industry was estimated .The estimated load is 18 kWh/ day. System sizing and specifications were provided based on the estimated load. The results show that a 5 kW PV array capacity of 20 modules, 10 (12V, 150Ah) batteries, a 5kVA, 48V inverter and a 60A, 24V voltage regulator are needed to supply the electrical load of the industry. The cost estimate of the of the system is relatively high when compared to that of electricity bill paid by industry to GEB but the payback period of the system is estimated to be 8.3 years, which is obviously much shorter than the lifespan of the selected PV modules which is 30 years. The recommendation would be that the system can be made utility- interactive to enable the purchase of surplus solar energy from users.

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