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A case study: Design and assessment of 1.5kW/day rooftop solar PV system

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ABSTRACT

In this paper designing, performance of rooftop solar PV system is presented. To acquire power from solar PV panels in case of rooftop PV system involves a proper selection, design, and determination with specification of various components that are used in the system. This paper presents an update on a case study undertaken on a rooftop PV system situated in rural area near a major city Meerut, India. This case study also includes Life cycle assessment of the rooftop PV system considering the inflation rate and discount rate.

Keywords: *Solar, PV system, Insolation, Inverter, LCC*

1. INTRODUCTION

Photovoltaic (PV) systems are one of the fastest-growing types of renewable energy sources being integrated worldwide into transmission and distribution systems. Small-scale residential and commercial projects account for the majority of on-grid PV installed capacity. Typically, these projects range from a few kW to 500 Kw. Lack of electricity is one of the major challenges facing the contemporary world, with more than 1.8 billion being unable to access electricity. Most of these people live in rural areas as they are not able to afford life in urban areas where the national grid is mainly available. This study involves feasibility of Roof-top solar PV including Life Cycle Cost (LCC) analysis of the system.

2. OVERALL PV SYSTEM DESIGN

This system comprises 1.5 kW solar PV panel mounted on the roof of the house. The PV panels are tilted at an angle of 30^o from horizontal, During the time of system design, system losses are also taken into consideration, 10% of various system loss and 96.5% of inverter efficiency. It consists of a single phase (1kW-3kW) off-grid inverter more specified in Table I and 80-Ah battery connected 2 in series and these two batteries connected in parallel with 180-Ah battery, which supplies for 2-3 hours provided all the loads to be used simultaneously. The system is connected to the fan, light, TV, washing machine, iron, refrigerator and other typical household appliances. Solar PV panels with specification given in Table II. It consists of 6 solar panels connected all in parallel.

Table 1: Inverter specification used in off-grid PV system (UTL Solar)

Parameters	Specifications
Type	Energy storage type off-grid inverter
Capacity	3 kW
Maximum DC voltage	500 V
MPPT Voltage range	100-490 V
Number of MPPT trackers	1
Maximum input current per MPPT tracker	11 A
THD	<3%
Topology	Transformer-less
Inverter Efficiency	96.5 %
MPPT Efficiency	99.90 %

Table 2: Solar panel specification

Parameters	Specifications
Power output	250 W
Maximum voltage (VMPP)	30.8 V
Maximum current (IMPP)	8.12 A
Open circuit voltage (VOC)	37.2 V
Short circuit current (ISC)	8.96 A
Module efficiency	15.4 %

3. SOLAR PV SYSTEM SIZING AND DESIGN

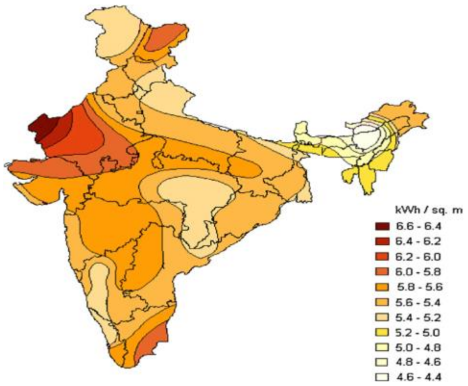
Solar PV systems design involves determination of the size of each component of standalone PV system with the aim of meeting the load requirement.

Table 3: Solar radiation data for Meerut

Month	Average(kWh/m2)
January	3.6
February	4.53
March	5.73
April	6.7
May	7.28
June	6.68

July	5.54
August	4.9
September	5.17
October	5.01
November	4.15
December	3.47

Annual Average = 5.23 (kWh/m^2 /day)



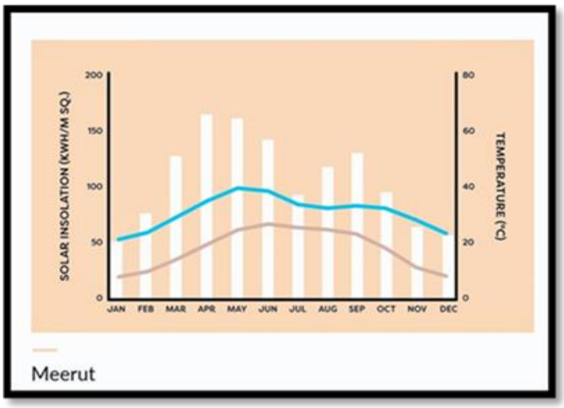


Chart-1 Insolation and Temperature of the City

- Maximum temperature (monthly average)
- Minimum temperature (monthly average)

Table 4: Average daily load demand of household

Loads	**Units**	**Power (W)**	**Total Power (W)**	**Operating Hour (h/day)**	**Total Energy (W-h)**
LED Bulbs	16	7	112	8	896
Fans	6	60	360	6	2160
Refrigerator	1	150	150	4	600
TV	1	60	60	5	300
Washing Machine	1	500	500	1	500
Straightening Iron	1	150	150	0.5	75
Home Sound System	1	95	100	0.5	50
Total			1432		4581

Designing of the 1.5 kW PV System:

3.1 Battery Designing

Battery specifications:
Nominal Voltage = 24 V
Depth of Discharge = 50%
Battery Capacity = 180 Ah
Battery Efficiency = 85%
Life of a Battery = 5 years

Battery Cap. req (Ah)

$$= \frac{(\text{Total watt hours required}) * (\text{Days of Autonomy})}{Nominal\ battery\ voltage * (1 - D) * Battery\ efficiency}$$

= (4581*1)/(24*0.5*0.85)
= 449 Ah

Number of batteries required

$$= \frac{\text{Battery capacity required (Ah)}}{Battery\ capacity}$$

= 449/180
= 3 Batteries

3.2 Inverter rating, panel sizing,

$$\text{Inverter size} = \frac{\text{watt peak} * 1.3}{1}$$

= 1432*1.3
= 1861.6 W

$$\text{No. of Inverter required} = \frac{\text{Inverter Size}}{Rated\ power\ of\ the\ Inverter}$$

= 1861.6/3000 = 0.62
= 1 Inverter

A (2-3) kW 24V DC to 240 V AC sine wave inverter is desirable for this PV System.

$$\text{Modules required} = \frac{\text{Total watt peak rating}}{PV\ module\ peak\ rated\ output}$$

= 1432/250 = 5.7
= 6 Modules
(considering the avg. kWh/m2 of the city)

$$\text{Panel sizing} = \frac{\text{Maximum OC voltage of inverter}}{open\ circuit\ voltage\ of\ each\ module}$$

= 40/37.2
= 1.075

1 module in series in each Panel others are in parallel.

$$Maximum\ voltage\ input\ to\ the\ inverter = (Maximum\ voltage\ from\ a\ module) * (No. of\ modules\ in\ series)$$

= (30.8 * 1)
= 30.8 V

Max. open circuit voltage to the inverter = 40 V

$$\text{Total No. of Panels required} = \frac{\text{No. of modules}}{No. of\ series\ modules\ in\ the\ panel}$$

= 6/ 1.075 = 5.58
= 6 Panels

$$Sizing\ of\ the\ charge\ controller = (Parallel\ connected\ modules) * (Isc\ of\ the\ module)$$

= 6*8.96
= 53.76 A

A 60 Amp charge controller would therefore be ideal for this system.

3.3 Sizing the cables

Sizing the cables involves determination of cable length by physical measurement of the distance between the components of the solar system and the site. 2.5 mm2 wires will be ideal due to their relatively low energy loss and are less costly.

4. LIFE CYCLE ASSESSMENT OF THE PV SYSTEM

The Life Cycle Cost Analysis is carried out according to the longest life component of all the PV system parts. The optimum life cycle for a PV system is 20 years. Storage batteries on the other hand have a life cycle of 5 years. The assessment of the rooftop PV system includes the amount of energy consumed by the system components for their materials. In the LCC analysis of future estimations, two important parameters are considered; the inflation rate (i) and discount rate (d). Inflation rate is the escalation trend throughout the systems life. Discount rate is the projected decrease in the components cost with future mass production. Considering inflation (i) and discount (d) rates of 3% and 5% respectively.

The operation and Maintenance cost for the system's life cycle can be calculated as

$$\text{O|Mcost} = 2\% * \text{PVcost} * \frac{(1+i)}{(1+d)} * \frac{1-[\frac{(1+i)}{(1+d)}]^{\wedge}20}{1-[\frac{(1+i)}{(1+d)}]}$$

Since the storage Battery's life is just 5years, it must be replaced thrice in the system's lifetime. The battery replacement costs are determined for the first time after 5 years, after 10 years and after 15 years.

$$\text{B1} = \text{Bcost} * [\frac{(1+i)}{(1+d)}]^{\wedge}5$$

$$\text{B2} = \text{Bcost} * [\frac{(1+i)}{(1+d)}]^{\wedge}10$$

$$\text{B3} = \text{Bcost} * [\frac{(1+i)}{(1+d)}]^{\wedge}15$$

LCC can be calculated by adding the costs of PV (PVcost), Battery cost (Bcost) and replacements of battries (B1 + B2 + B3), Inverter (INVcost), Charge controller (CCcost), Installation (Inst.cost), and Operation and Maintenance costs (O|Mcost).

[LCC = PVcost + Bcost+ B1 + B2 + B3 + INVcost + CCcost + Inst.cost + (O|MCost)]

5. ANNUALIZED LIFE CYCLE COST (ALCC)

The annualized LCC (ALCC) of the system in terms of present-day cost can be calculated as

$$\text{ALCC} = \text{LCC} * \frac{1-[\frac{(1+i)}{(1+d)}]}{1-[\frac{(1+i)}{(1+d)}]^{\wedge}20}$$

The ALCC is important in knowing the annual cost of the system and it helps determine the daily unit cost of PV electricity.

6. PV SYSTEM ANALYSIS

In this case study, optimization of a 1.5 kW/day for a single household of about 8 people was carried out. Six PV modules 250 W would be ideal according to the PV system sizing with a total power of 1432 W. It consists of 6 solar panels connected all in parallel to generate an operating DC bus voltage of 24 V and charging current of 53.76 A. It also consists of three storage batteries B1=24 V, 180Ah, B2=B3=12 V, 80Ah, B2, B3 connected in series, a 60 A charge controller and a DC-AC inverter rated 2000 W.

The system is stand-alone meaning that there will be no grid connection. During the day, it supplies power directly to the load and charges the batteries.

7. CONCLUSION

Stand-alone solar PV is easy to install and has minimal interruptions given that the area has a relatively uniform irradiation throughout the year. From the study, load analysis of an average household in the region consuming 4.581 kWh/day was carried out. From the sizing of the PV system, the household require 1432 W, which translates to about 6 modules of 250 W each, 3 batteries 24 V, 180 AH each, a 60 A PWM charge controller, and a 2000 W sine wave inverter. In this case study, certain key steps to install a Stand-alone Rooftop PV systems from conceptualization to real time operation is presented.

8. REFRENCES

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