Study and Design of 10 kW_P Roof Top Solar PV System Special Reference to Suncity Jodhpur (Rajasthan)

Ashish Mathur, Vivek Prakash
Department of Electrical Engineering Banasthali Vidyapith, Tonk, India
Email: ashishmathur810ster@gmail.com

***Abstract*— Renewable energy sources (RES) are the best alternative to meet the requirement of increasing energy demand. In India, RES is abundant and generation share from these sources has shown tremendous growth in the recent year. Now a days, about 33% of India's primary energy consumptions is full fill by RES. In the last two and half decades, there has been a vigorous pursuit of activities relating to research, development, demonstration, production and application of a variety of RES technologies for use in different sectors. The objective of this work is to estimate the potential of grid quality solar photovoltaic power in Jodhpur district of Rajasthan and finally develops a system based on the potential estimations made for a chosen area of 100m² (1076.4sq.ft.). Equipment specifications are provided based on the availability of the components in India. Moreover, the cost estimation of grid-connected SPV power plant is discussed to show economic viability.**

Keywords—Photovoltaic system, renewable energy sources, solar generation, Indian solar generation scenario.

I. INTRODUCTION

India has an abundance of solar radiation, with 300 sunny days in a year. Due to low cost of Solar Photovoltaic (SPV) is progressively becoming more attractive, than other renewable sources of power. The various factors leading to decline in cost includes setting up of large scale plants, integration across the value chain, declining cost of raw material, reducing material consumption and higher efficiency of modules. Solar power as a solution to the Indian power scenario India receives abundant sunlight throughout the year Due to its proximity to the equator, Solar PV solution has the potential to transform the lives of 450 million people, primarily to light up their homes. Renewable energy source is a practical solution to address the persistent demand supply gap in the power industry [1], [2].

A grid connected SPV is reliable as compare to other photovoltaic power plant; it is the system that is connected to the utility grid [3]. This system consists of solar panels, number of inverters, a power conditioning unit and grid connection equipments. In grid connected SPV system there is no use of battery so capital cost is also less as other systems. Whenever condition is right, the grid connected PV system supplies the excess power to the utility, beyond consumption by connected load. The grid connected system is used for small residential and commercial rooftop system to large utility scale solar power station.

The objective of this work is to estimate the potential of grid quality solar photovoltaic power in Jodhpur district of Rajasthan and finally develops a system based on the potential estimations made for a chosen area of 100m² (1076.4sq.ft.). Equipment specifications are provided based on the availability of the components in India. In the last cost estimation of grid connected SPV power plant to show whether it is economically viable or not. So if we prefer Roof -Top Grid connected SPV system for our site, we have to analyses so many factors. Important things need to be considered before plan for a Roof-Top PV plant these are as follows [4]:-

i) Shadow Test: During the day to collect maximum sunlight, the solar panel is installed as much as in south direction as possible. When SPV is installed at roof it must be checked for the shadow of trees and adjoining building and commercial places particularly for south direction. For ideal case of solar photo voltaic install on roof it must be consider as a clear roof without any shadow. In case of shadow on roof , a detailed analysis is done with respect to time and direction for receiving maximum sunlight, this can be done by an expert engineer

ii) Type of Roof Top: The structure weight of solar panel is around 15 Kg per square meter. This weight is varies according to technology use and type of structure. So it is necessary to check the load carrying capacity of roof

iii) Solar System Sizing: It is mandatory to calculate the area of roof for installing the solar panel; this can be calculated as the available area of roof divided by area of each panel and multiplying it by panel's rated output as a thumb rule 70% of roof top area can be used for panel's installation. Some solar panel available in market can use as high as 90% of roof top area they have much higher cost. As a thumb rule 10 sq meter area is required for 1 KW capacity of solar system.

Solar System Size = 70% * (Rated output of Panel) * (Area of Roof top / Area of each panel)

iv) Output of System (Units generated annually): The system output depends on output of per panel, efficiency of panel and solar radiation at the site. These factors define as CUF (Capacity Utility Factor) for solar system for as particular location. In India for estimation CUF is taken as 19% . The unit generated annually by solar system can be calculated by

Annually Units Generated (in KWH) = Size of System in KW * CUF * 365 * 24.

One KW capacity solar system generates 1600 – 1700 KWh of electric energy per year it is a thumb rule. The CUF varies according to geographical location of the installation site cities in India.

The organization of paper is as follows: section-II introduces the designing of PV system, section-III covers the system sizing and cost analysis while conclusion is drawn in section-IV.

II. DESIGN OF PV SYSTEM

There are various ways of designing PV system for example with battery, without battery, with or without transformer etc. Because of short life time, large replacement cost and minimum installation cost we adopt without battery grid interconnected system. for boosting the AC voltage and fed to to the grid transformer is used. We have design 10 KWp solar photovoltaic power plant & can be developed on 100 m² chosen area. Corresponding system sizing and specifications are provided along with the system design.

For the10 KWp plant required no. of PV modules = ($10000W_p/200W_p$) =50. Now to form a solar photovoltaic power plant 50 modules are connected in series-parallel Combination.10 modules are connected in series and there are 5 parallel paths of 10 modules each. It also supports the fact that these 50 PV modules can be accommodated within 100 m^2 available area as shown in Fig. 1.

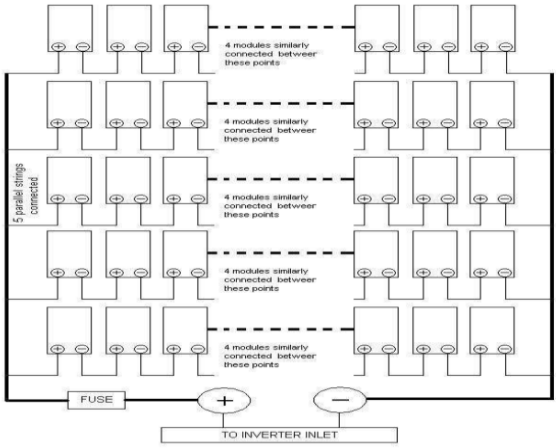

Fig.1. Combination of Series Parallel Module of 10kW SPV [5].

The irradiance of the Jodhpur city can be calculated from Table 1.

TABLE I Monthly Solar Insolation in Jodhpur City

Month	Solar Insolation kWh/m²
January- 2018	4.38
Feburary-2018	5.20
March-2018	6.16
April-2018	7.06
May-2018	7.52
June-2018	7.06
July-2018	6.23
August-2018	5.62
September-2018	6.01

SPV system without battery backup system gives 67.5% of the maximum power output when clear sunny day remaining 32.5% loss is due to , dust, module mismatch, internal heating DC-AC conversion losses and wiring an affecting the overall system performance. if a battery is added to the system the net output power is further reduces 6% to 10%. at the year 2050 solar energy will meet about 21% of global electricity needs. As per the current estimates, more than 3 million people, globally, benefit from small SPV system. Also, the per peak watt price of solar modules in India is less than INR 80 and is further on decline. India currently has few major grid interactive SPV plants and a lot more are being commissioned through private participation in the best sun –soaked regions of Karnataka, West Bengal, Maharashtra Punjab, and Rajasthan among others. The grid interactive SPV capacity in the country has grown nearly 10 times from pre-JNNSM to 481.8 MW as of today.

Considering the above factors, a module of Tata BP Solar Panel :Tata BP solar module and the Model is SSI-M6-200 is selected. Its maximum output power is 200 watt. If irradiance is 1000 watts per meter square then the module's nominal power output is 160 watt if irradiance is 800 watts per meter square. The irradiance of Jodhpur City is 647.95 watts per meter square. So it will give power less than 160 watts, (approximately 135 watts). 25 years power output warranty is 80%. The panel efficiency is 15.62%. Short circuit current of the panel is 8.28A at standard test condition and 4.56 Amp at nominal condition.

A. PV array designing

Some parameter are checked to design the array there are one of the most important thing to choose proper inverter and combiner box. So that, it can withstand the PV modules voltage and current.

SMA Sunny Tripower 10000 TL/Delta 10kW inverter's MPP voltage range = 360 - 800 V

Tata BP solar module and the Model is SSI-M6-200Module's open circuit voltage = 37.6 V

10 module in series = 37.1* 10 = 371 Volt

This is within the inverter's MPP voltage range. We didn't put more modules due to Safety.

Module's maximum power voltage = 29.6 Volt

Inverter MPP voltage range: 360 - 800V.

(360 - 800V)/10 = (36 – 80) (Module maximum power voltage = 29.6 Volt) so, power maximum power voltage is in the inverter's voltage range 10kW inverter's current rating:

Inverter's rated voltage = 360 V

Maximum current: (10000/360) = 27.77 Amp

At 647.95 Watt/m2 maximum short circuit current = 4.56 Amp. (Isc=134 Watt/29.6 Volt)

If we put 5 parallel string (1 string consist of 10 series module) = 5*4.56 = 22.8 Amp

Now, each module produces 29.6 Volts. So total 10 series connected module will produce = 29.6 *10 = 296Volts.

We cannot put more string, because if there rise a weather condition with low temperature and high isolation excessive current can flow For safety considering 20% excessive current = 27.36 Amp.

(22.8 * 20/100 = 4.56; (4.56+22.8 = 27.8))

This is also in inverter's capacity

Combiner box Maximum input fuse rating = 600 V DC, 30A.This is also can withstand 5 parallel string each consist of

10 series modules. Therefore, chosen PV array design is 5 parallel strings each consist of 10 series Modules for 1 combiner box and 1 inverter.

Number of inverter calculation

No of Inverter = (No. of total Module)/ (In a string no of series module * In a string no of parallel module)

= 50 / (10*5) = 01

No. of combiner box is equal to the number of inverter. So, we will need 01 Combiner boxes.

Rated short circuit current is 8.28 Amp from the PV module. If there is a effect of higher Insolation and lower temperature access current can flow. To prevent these to happen the Safety factor is considered. Average insolation at Jodhpur city is 647.95 Watt/m^2 Therefore maximum short circuit current will be = 4.56 Amp

For 5 parallel string = 5*4.56 = 22.8 Amp.Considering 20% safety factor Maximum current rating is 27.36 Amp.

So, we have chosen 30Amp rating wiring

B. Energy supplied by the proposed PV solar system:

The solar irradiance in Jodhpur is 647.95 Watt/m^2 .The energy supplied by the SPV system in a year can be found by the following formula.

Total energy supply = Maximum Power at defined irradiance of a solar panel * Average bright sunshine hour * 365 days * total no. of solar panels

= 135* 8.55 * 365 * 50

= 21,065,062.5 Watt h/ year

= **21.065** MWh/year

Considering 80% of panel's output efficiency the total energy supply = **16.852** MWh/year

(21.065 * 80/100 = 16.852MWh/year)

The daily output energy is **46.1698** kWh/day

(16.852 * 1000/365=46.1698 KWh/day)

III. CASE STUDY

The proposed work is demonstrated for the SPV plant in Jodhpur district of Rajasthan, India. Its Co-ordinates are:- Latitude : 26.2389469, Longitude: 73.0243094.

A. Grid Specification

TABLE II Monthly Solar Insolation in Jodhpur City

No. of Phases	3-φ
Voltage rating	400 Volts AC
Frequency	50 Hz

TABLE III SPV Plant Specification

Plant Capacity	10 KW
Voltage Output	371 Volts DC
Current Output	27.77 Amp. DC
No. of Modules	50 nos.
Area	100m²

PWM inverter are used for suppressing the harmonics produced after DC to AC Conversion PWM inverters are used here and for finding the output voltage of inverter the calculation is shown below:

Phase voltage= Vph = 0.4714 * Vdc= 0.4714 * 296 = 139.62 Volts.

Line voltage = VL = 0.779 * Vdc = 0.779 * 296 = 230.584 Volts.

TABLE IV Inverter Specification

KVA rating	11.5 - 12 KVA or 10 KW
Input DC voltage	296 Volts DC
Input dc current	27.36 Amp
Output AC voltage	139.62 V ac (phase voltage) 230.58 V ac (line voltage)
No. of Phases	3-φ
Type	PWM (for suppressing 3rd harmonics)
Efficiency	Almost 98.1%
Total harmonic distortion	< 3%

TABLE V Transformer Specification

KVA rating	12 KVA
No of phases	3-φ
Frequency rating	50 Hz
Primary voltage rating	230.584 V
Secondary voltage rating	400 V
Primary current rating	52.04 Amp + (10-15% extra)
Secondary current rating	30 Amp + (10-15% extra)
Connections	Primary – delta (for suppressing Secondary – star 3rd harmonics) 10 to 25 taps in secondary
Efficiency	Almost 95 %
Extra features	Air cooled

TABLE VI Solar Panel Specification

Watt	200 Watt
Voltage	29.6 Volts
Current	7.6 Amp
Type	monocrystalline
Efficiency	15.6%
Temperature	25 deg c
Dimensions (mm)	1660X990X42 (mm) Area of single panel = 16,43,400 (mm^2) Area of single panel = 1.643 $meter^2$
Tilt angle(slope) of PV Module	26°.23"
Mounting	Fixed Type

B. Cost Analysis for 10 kW Grid Connected SPV plant

The most powerful module Manufactured by Tata BP Solar Panel Model No. SSI-M6-200 , cost of solar panel is Rs.40 per watt. So cost of 200 Watt panel is (200 × 42) =Rs. 8, 400.

Cost estimate for total 50 numbers of panels used are (50 × 8400)= Rs.4, 20,000.

One piece of 11.5 - 12 KVA or 10 KW of an inverter/Power Conditioning Unit is used; multiply the size of the inverter by Rs. 25 per rated watt.

Cost estimate for Inverter (25 × 10000)= Rs. 2, 50,000.

One piece of 12 KVA or 10 KW of a step up Transformer is used; multiply the size of the Transformer by Rs. 20 per rated watt.

Cost estimate for Inverter (20 × 10000) Rs. 2, 00,000.

Subtotal: Rs.8, 70,000

Multiply the subtotal above by 0.15 (10%) to cover balance of system costs (wire, fuses, switches, installation testing & commission etc.).

Cost Estimate for Balance of System: (8, 70,000 × 0.15) Rs.1, 30, 500

Total Estimated PV System Cost is Rs.10, 00,500/-

is no significant reduction of curtailment on PHES incorporation, due to system security constraints.

C. Proposed SPV Viability

To check our plant is viable or not:

a. Consider the plant life is for 25 Years
b. Cost of 10KW plant is Rs 10, 00,000/-
c. Subsidy @ 30% given by MNRE (10, 00,000 *30/100 = 7, 00,000/-)
d. Take Salvage value 30% of plant (70, 00,000 * 30/100 = 2, 10,000/-)
e. Take Degradation 0.25% Year of Year for 25 Year
f. Civil Work (include Bricks, Rocks making Foundation etc) by 70,000/- So,Net Cost of our plant is (7, 00,000 +70,000 = 7, 70,000/-)
g. Take Operation & Maintenance Cost of plant include Insurance of plant per Annum is Rs 30,000/- with annual increment of Rs 1500/-
h. Bank loan for the period of 10 years for first five @ 8.5% & remaining five year @ 12% as per Government Rule
i. Payment to the bank yearly interest plus installment of Rs. 77,000/- for the Period of 10 years.
j. Sale our generated electricity @ Rs 9.83/- as Govt. Norms for those Solar plant commission in the year of 2013-2014.
k. Consider ideal condition that we export or sale out all the generated Electricity to the utility.
l. Generate 16,852 KWh/ year of electricity & sale @ Rs. 9.83/-

The detailed analysis of profit is discuused in Appendix-I.

IV. CONCLUSION

This paper proposes the design of SPV system on the basis of the potential measured. Sizing of system and specifications are provided based on the design made and analysis of cost is carried out for the proposed design. Estimated total cost of PV System is Rs. 10,00,000/- generations of annual energy is also calculated generated annual energy feed into the grid is estimated approximately as 16.852 MWh/year.

V. REFERENCE

[1]. Mukund R.Patel, "Wind and Solar power System". CRC Press Boca Raton London New York Washington, D.C.
[2]. Handbook for Solar photovoltaic (PV) system [Online]. Available: www.bca.gov.sg.
[3]. Photovoltaics in Buildings, A Design Handbook for Architects and Engineers. Editors Friedrich Sick and Thomas Erge, Fraunhofer Institute for Solar Energy Systems ISE Freiburg, Germany.
[4]. [Online]. Available: http://www.sma-america.com/en/products/solar-inverters/sunny-central/combiner-boxes.html.
[5]. Grid- connected photovoltaic power system. [Online] Available: www. Wikipedia.com.

APPENDIX-I

Year	Principle Amount	Bank Interest	Net Amount Pay to Bank (B.I.+77000)	O & M Cost of Plant per annum	Degradation YoY 0.25%	Generated KWh/year	Earn from utility	Net Saving
1	7,70,000	65,450	1,42,450	30,000	_ _ _	16,852	1,65,655	(-) 6,795/-
2	6,93,000	58,905	1,35,905	31,500	42.13	16,810	1,65,242	(-) 2,163/-
3	6,16,000	52,360	1,29,36	33,000	42.02	16,768	1,64,829	2,469/-
4	5,39,000	45,815	1,22,815	34,500	41.92	16,726	1,64,417	7,102
5	4,16,185	35,376	1,12,376	36,000	41.815	16,684	1,64,005	15,628
6	3,39,185	40,702	1,17,702	37,500	41.71	16,642	1,63,594	8,392
7	2,62,185	31,462	1,08,462	39,000	41.60	16,600	1,63,182	15,720
8	1,85,185	22,222	99,222	40,500	41.5	16,559	1,62,770	23,048
9	1,08,185	12,982	89,982	42,000	41.40	16,518	1,62,368	30,386
10	31,185	3,742	80,742	43,500	41.30	16,478	1,61,979	37,737
11	-----	-----	-----	45,000	41.20	16,437	1,61,574	1,16,574
12	-----	-----	-----	46,500	41.09	16,396	1,61,173	1,14,673
13	-----	-----	-----	48,000	41	16,355	1,60,70	1,12,770
14	-----	-----	-----	49,500	40.89	16,314	1,60,368	1,10,868
15	-----	-----	-----	51,000	40.79	16,273	1,59,966	1,08,966
16	-----	-----	-----	52,500	40.68	16,232	1,59,564	1,07,064
17	-----	-----	-----	54,000	40.58	16,192	1,59,162	1,05,162
18	-----	-----	-----	55,500	40.48	16,152	1,58,770	1,03,270
19	-----	-----	-----	57,000	40.38	16,112	1,58,381	1,01,381
20	-----	-----	-----	58,500	40.28	16,072	1,57,985	99,485
21	-----	-----	-----	60,000	40.18	16,032	1,57,593	97,593
22	-----	-----	-----	61,500	40.08	15,992	1,57,201	95,701
23	-----	-----	-----	63,000	39.98	15,952	1,56,808	93,808
24	-----	-----	-----	64,500	39.88	15,912	1,56,416	91,916
25	-----	-----	-----	66,000	39.78	15,872	1,56,022	90,022
Net Saving								**16,80,777/-**
Consider Salvage Value								**2,10,000/-**
Total Profit								**18,90,777/-**