INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 5, Issue 3)
Available online at: www.ijariit.com

System seizing and performance analysis of 30 kW grid connected solar PV plant in five different regions in India

Ashutosh Tripathi
ashutosh.tripathi2709@gmail.com
Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, Madhya Pradesh

Romi Jain
romijain210@gmail.com
Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, Madhya Pradesh

ABSTRACT

This report will help us to understand how the 30-kW solar PV cell-based power plant will perform if all the system components are same and simulated in 5 different regions of India when the sun is over the equator (at equinox). Generally, performance analysis is based on PSH of different locations, module tilt angle, row spacing, array matching and several other losses (Soiling loss, temperature loss, mismatch, voltage drop, irradiance, shadow loss, etc.). This system is useful for new entrepreneurs to understand the system performance analysis in different regions in India if the system having the same components.

Keywords— *Solar photovoltaic cell, Altitude, Modules, Array matching, Row spacing, Specific energy yield*

1. INTRODUCTION

The plant having capacity 1 kW to 10 kW comes under in the category of Micro-Grid while SPV plant having a capacity between 11 kW to 50 kW comes under in Mini Grid category. In this report, we will discuss 30 kW Solar PV Plant performance, if all the components of the system are the same viz. (inverter, modules, cables, combiner boxes, etc.), then how the system will behave if the system introduces into different regions and in different weather conditions. This system will helpful for those who are new in the solar industry or designers if they are using the same components and design in the system then how the system will perform.

For the system performance analysis, we took 5 locations in India viz. Leh, Bhopal, Singh Pura, Lamba, Kanhappapuram situated at Northern region, Central Region, North East Region, Western Region and in Southern Region respectively. Here are the exact locations of all these sites in below Table 1. (Coordinates sources: Google Earth).

Table 1: Selected locations for simulation in Helioscope

S no.	Location	Region	Coordinates
1	Leh, J & K	Northern Region	34.12670799N,77.58205664 E
2	Bhopal, Madhya Pradesh	Central Region	23.325237630N,77.36413279 E
3	Singh Pura, Assam	North East Region	26.36670003 N, 94.105370 E
4	Lamba, Gujarat	Western Region	22.1498326 N, 69.2400734 E
5	Kanhappapuram, TN	Southern Region	8.1486932 N, 77.5840328 E

2. CURRENT ISSUE

In the Solar Industry, there are various issues regarding module tilt angle and their performance. Entrepreneurs are matching array with different modules and inverter according to geographical location sometimes this method is economically for the customer whereas sometimes it becomes expensive as well. The performance of a Photovoltaic (PV) solar module is affected by its tilt angle and orientation with respect to the horizontal plane. PV systems are among the most important renewable energy sources that can satisfy the world’s energy requirements [1].

3. METHODOLOGY

(a) Fetch solar radiation data and temperature data (at 10 m above) of selected locations from NASA Power Calculator in PSH at a various tilt angle.
(b) Calculate Cell temperature (maximum and minimum) of all selected locations.
(c) Array Matching
(d) Single Line Diagram, Layout Diagram and 3-D diagram.

(e) Cable Seizing
(f) Loss considerations
(g) Specific energy yield.

3.1 Yearly Solar Radiation

NASA provides over 200 satellite-derived meteorology and solar energy parameters. These are monthly averages from 22 years of data [2].

Table 2: Yearly Solar Radiation data (in PSH) of all sites when the sun is over the equator

Months	Leh (at 34^0)	Bhopal (at 23^0)	Singh Pura(at 26^0)	Lamba(at 22^0)	Kanhappapuram (at 8^0)
Jan	4.29	6.51	6.42	6.32	6.25
Feb	4.31	6.77	7.04	6.89	6.69
Mar	5.10	7.23	7.14	7.12	6.89
Apr	5.45	7.14	5.59	7.19	6.00
May	5.66	6.40	5.76	6.72	6.06
June	6.00	5.50	4.89	6.41	5.16
July	5.92	4.84	4.88	5.29	5.39
Aug	5.90	4.12	4.88	5.60	5.96
Sep	6.21	5.57	5.18	6.04	6.14
Oct	6.38	5.65	5.75	6.60	5.61
Nov	5.48	5.02	6.41	6.41	4.98
Dec	4.46	4.42	6.24	6.04	5.44
ANN(PSH)	5.43	5.64	5.85	6.39	5.88

(*Source: NASA power Calculator)*

3.2 Yearly Temperature Data

Yearly Temperature data (maximum and minimum) of all selected sites at above 10 m to calculate cell temperature is given in Table 3 [3].

Table 3: Temperature data of all selected locations

Months	Leh (at 34^0)		Bhopal (at 23^0)		Singhpura (at 26^0)		Lamba(at 22^0)		Kanhappapuram (at 8^0)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Jan	-21.80	-11.51	9.98	27.55	8.62	21.10	17.73	25.81	23.13	28.76
Feb	-20.90	-10.14	12.42	30.89	10.41	23.93	18.93	27.00	23.89	30.47
Mar	-16.04	-5.11	17.36	36.05	13.96	28.22	21.75	29.73	25.48	32.06
Apr	-9.42	0.54	22.66	27.03	17.89	30.94	24.47	31.53	26.67	31.75
May	-5.72	5.57	27.03	42.48	20.43	31.86	26.93	32.20	26.64	30.53
June	-2.48	11.10	26.48	37.93	22.33	31.72	28.45	31.87	25.56	28.57
July	0.89	15.57	23.92	31.36	22.58	30.65	27.74	30.24	24.79	28.01
Aug	0.82	15.19	23.07	29.32	22.64	30.59	26.68	29.38	24.72	28.26
Sep	-3.31	10.16	21.63	29.85	21.44	29.44	26.20	29.90	24.93	28.74
Oct	-8.57	1.69	18.04	30.27	18.56	27.30	25.16	31.55	24.92	28.43
Nov	-14.33	-3.87	14.03	29.46	13.95	24.42	22.49	30.30	24.55	27.92
Dec	-18.6	-8.49	10.85	27.95	10.24	21.82	19.37	27.44	23.53	27.87
ANN	-9.66	1.72	18.96	32.79	16.92	27.67	23.83	29.74	24.90	29.28

(*Source: NASA power Calculator)*

Calculate Cell temperature with the following formula

$$T_{cell=}T_{air} + \frac{NOCT-20}{800} \times S$$

Average Solar irradiance = 800 W/m^2

3.3 Array matching and tools using

Given Parameters of module and inverter for system seizing which are shown below which is given by the manufacturer which is tabulated at Table 4.

Table 4: PV module and Inverter specifications

Solar PV Module	ELDORA VSP.72.325.05	Solar Inverter	TRIO-27_6-TL-OUTD-400
Power	325.0 W	Max Power	30.0 kW
Vmp	37.8V	Min Power	140.0 W
Voc	46.2V	Max Voltage	1,000V
Isc	9.13A	Min MPPT Voltage	500V
Imp	8.6A	Min Voltage	500V
Technology	Si-Poly (72 cells)	AC Output	400Y/230V
Dimensions	1956 x 992 x 40		
Temp Coefficient Pmax	-0.41%/°C		
Temp Coefficient Voc	-0.31%/°C		
Temp Coefficient Isc	0.052%/°C		

3.3.1 Module Tilt Angle

Solar Module should place so that the amount of radiation is large as possible. To achieve this when facing either true north or south. It depends whether the system is located on a northern hemisphere or Southern Hemisphere. To get the highest annual energy yield, modules should face south and tilted at an angle that is equal to the latitude of the site especially in India because India is located at the northern hemisphere. The orientation of modules in our designed plant is in true South [4].

a) Calculating the altitude of the sun when it is over the equator (Y_e) for a specific latitude is:

$$Atitude\ of\ the\ Sun(Y_e) = 90^0 - Ltitude(in\ degrees)$$

b) To calculate the ideal tilt, we use the altitude of the sun and the following formula

$$Module\ Tilt(\beta) = 180^0 - 90^0 - Atitude\ of\ the\ Sun(Y_e)$$

c) To calculate the minimum number of modules in a string (Maximum Cell Temperature)

$$V_{MP\ CELL\ EFF} = V_{MP\ STC} + [\gamma_V\ x\ (T_{CELL} - T_{STC})]$$

d) To calculate the maximum number of modules in a string (Minimum Cell Temperature)

$$V_{OC\ CELL\ EFF} = V_{OC\ STC} - [\gamma_V\ x\ (T_{CELL} - T_{STC})]$$

γv = Voc temperature coefficient ,V/^{0}C
Cell temperature (maximum and minimum) of selected locations

3.3.2 Cell temperature

Table 5: Cell temperature of all five locations (Source: NASA Power Calculator)

Months	Leh (at 34^0)		Bhopal (at 23^0)		Singhpura(at 26^0)		Lamba(at 22^0)		Kanhappapuram (at 8^0)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Cell Temp(in degree)	8.01	33.17	42.97	59.87	8.62	31.86	17.73	32.20	51.72	55.02

3.3.3 Array matching

Here we are doing array matching for one location as we are trying to keep all components and design same but still for safety point of view, we are doing matching array for all locations. While calculations we should consider the negative sign of temperature coefficient. Here we are showing calculation only for one site and rest suggested configurations will be based on given calculations.

3.3.4 Minimum No. of modules in a string

Table 6: Calculation for Minimum no. of modules in a string

Maximum Cell Temperature	33.17° C
STC Cell Temperature	25° C
Temperature Coefficient of power	-0.41%/°C
Temperature Coefficient of Vmp	0.154
Multiply this by the temperature difference between (Cell temperature and STC)	8.17 x 0.154 = 1.258 V
Vmp of module	37.8 V
Voltage gain due to temperature (because normal temperature is less than 25° C)	37.8 V + 1.258 V= 39.05 V
Corrected Vmp (Loss due to temperature)	39.05 V
Voltage Drop DC Side	2%
Corrected Vmp (loss due to voltage drop)	39.05 x 0.98 = 38.27 V
Inverter minimum MPP Voltage	500 V
Safety Margin for minimum MPPT voltage	10%
Corrected Inverter Voltage	500 x (1+10%) = 550 V
Minimum No. of modules in a string	550/38.27 = 14.36
	Rounded up ≈ 14 Minimum 14 Modules can be connected in a series in a string

3.3.5 Maximum No. of modules in a string

Table 7: Calculation for maximum number of modules

Minimum Cell Temperature	8.01° C
STC Cell Temperature	25° C
Effective Cell Temperature (Maximum temp + NOCT Temp-20)	8.01-25 = -16.99° C
Temperature Coefficient of power	-0.31%/°C
Temperature Coefficient of Voc	0.143

Multiply this by the Voc temperature coefficient in(V0/C)	0.143*16.99 = 2.43 V
Voc of module	46.2 V
Voltage gain due to temperature (because normal temperature is less than 25° C)	46.2 V - 2.42 V = 43.76 V
Corrected Vmp (Loss due to temperature)	43.76 V
Inverter Maximum Mpp Voltage	800 V
Safety Margin	5%
Corrected Inverter Voltage	800 x (1-5%) = 760 V
Maximum No. of modules in a string	760/43.76 = 17.36
	Rounded Down ≈ 17 17 numbers of maximum modules can be connected in series in a string.

As we have seen, we can connect 14 modules in a string and 17 modules in a string in the Leh region. If we calculate for rest of locations, we get 13 modules in a string in those locations who have high cell temperature. Here we will connect 3 string in one MPPT and rest 4 MPPT will connect with another.

3.3.6 Maximum No. of strings: To find the maximum number of strings connected with the MPPT calculation is given in

Table 8: Maximum Number of Strings

Temperature Difference	8.17° C
Temperature Coefficient (Isc)	0.052 % / ° C
Isc of Module	7.38 A
Current Gain due to temperature	{(0.052 % × 7.38) × 8.17} = 0.031 A
Corrected Isc (gain due to temp.)	(7.38 + 0.031) = 7.41 A
Inverter Max. DC input current	32 A
Maximum Number of Strings (per MPPT)	32/7.41 = 4.24
Maximum 4 Strings can be connected in Parallel per MPPT	

1.1.1 **3.3.7 Power Matching and Suggested Configurations:** Power matching and suggested configuration for Solar PV plant is given below at

Table

Table 9: Power Matching and suggested configuration

PV module Rated Capacity	325 Wp
Max AC power of the Inverter (apparent power)	30.6 kWp
Number of modules that can be connected to the inverter	30.6/0.325 = 94.15 ≈ 94
Minimum No of Modules per string	13/14
Maximum No. of Modules per string	17
Maximum No. Of strings per MPP	4
Total no of Strings	7
Maximum No. of Modules by Capacity	94

3.3.8 Tools: For the simulation of this plant in five different regions in India, we use Helioscope. Helioscope is one of the best PV simulators available in the solar industry to simulate design with meteorological data provided by NASA. The 3-D simulator provides the data of energy generation through this plant on a monthly basis.

Helioscope is a simulation which is generally very useful to simulate On-grid Solar System. This is an online application-based simulation software [5].

3.4 Single Line, Layout and 3-D diagram
3.4.1 Single Line Diagram

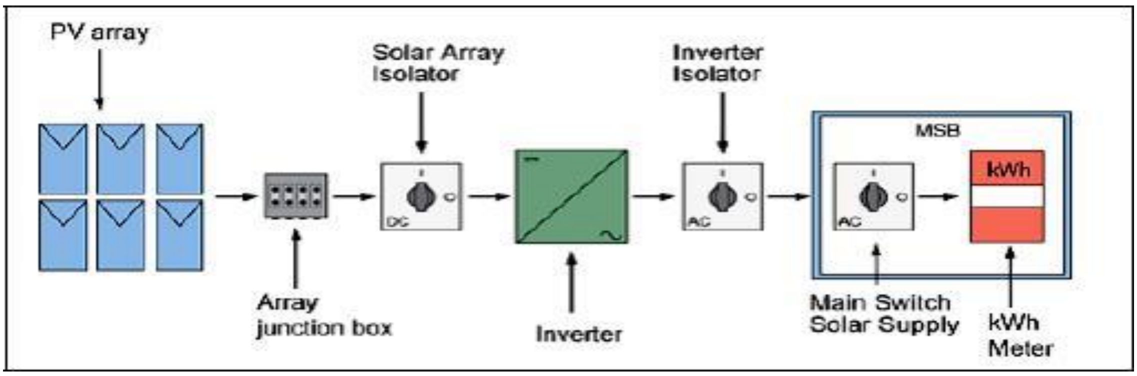
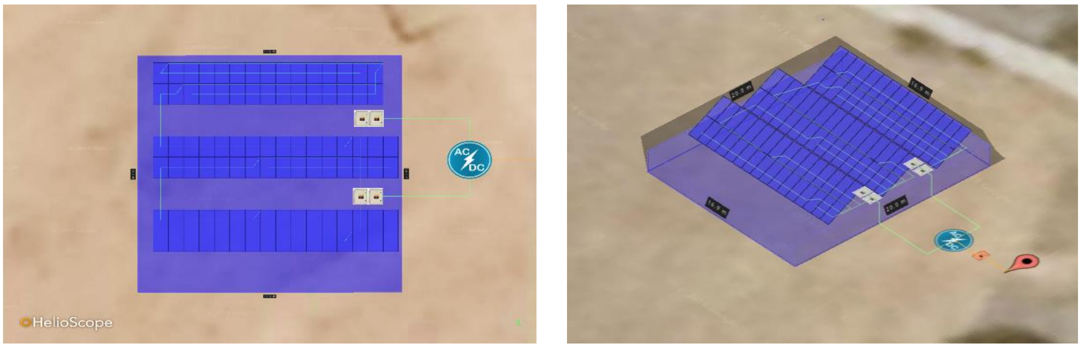


Fig. 1: Single Line Diagram of on-grid PV system

3.4.2 Layout and 3D diagram



(a) Layout Diagram **(b) 3-D Diagram**

Fig. 2: (a) Layout and (b) 3D diagram of the designed system

3.5 Cable Seizing

- The system must be electrically safe, and it should be safe from environmental degradation
- The wiring must not impede the performance of the system as a whole

Here we need to do proper cable seizing and keeping in mind that length should be more than enough, and wire should not be less than 4 mm^2 in three phase system. As we have system 30 kW then the 4 mm^2 is enough for cable seizing.

- There is no excessive voltage drop (which equates to an equivalent power loss) in the cables.
- The current in the cables will not exceed the safe current handling capability of the selected cables [6].

Most commercially available cables could be used in the DC wiring, but it is recommended that multi-stranded DC cables are used. Here we used 4 mm^2 DC cable and AC cable in designed plant. The voltage drop should not more than 2%.

3.5.1 Shadow Analysis

To reduce the shadow loss, we need to maintain row spacing between arrays.

$$\text{Row Spacing(Y)} = \text{X} \times \frac{\text{Cos (Azimuth angle)}}{\text{Tan(Altitude angle)}}$$

Where X is the height of the structure which is calculated by

$$\sin\theta = \frac{\text{X}}{\text{Module Length (in mm)}}$$

After calculation, we got 2.4 m long row spacing so we maintained row spacing at 2.5 m to make shadow-free area.

3.6 Losses

It is not possible for a solar system to operate at 100% efficiency. Therefore, all the factors that will reduce the overall efficiency of the PV system must be calculated for the given conditions.

The losses will include things such as soiling, shading, manufacturer's tolerance, temperature, voltage drop, inverter efficiency, orientation and tilt angle of the module. Total Loss consideration in all selected locations (in percentage) when simulated at Helioscope shown in Table 10.

Table 10: Total losses consideration in sites

Losses (categories)	Losses at Leh (34^0)	Losses at Bhopal (23^0)	Losses at Singh Pura (26^0)	Losses at Lamba (22^0)	Losses at Kanhappapuram (8^0)
Shading	5.2	2.3	0.3	2.1	0.3
Reflection	3.1	3.0	3.4	2.7	3.4
Soiling	2.0	2.0	2.0	2.0	2.0
Irradiance	0.6	0.4	0.4	0.3	0.4
Temperature	0.2	8.2	8.7	8.9	8.7
Mismatch	4.9	3.2	2.7	3.1	2.7
Wiring	0.6	0.7	0.3	1.3	0.3
Clipping	0.2	0.0	0.0	0.0	0.0
Inverter loss	2.7	2.9	2.9	2.9	2.9
AC System	1.2	1.3	1.5	0.9	1.5
Total (in %)	20.7	24	22.2	24.2	22.2

4. SPECIFIC ENERGY YIELD

The below-mentioned formula is to calculate the energy yield by PV plant due to this we will be able to calculate the system performance throughput the year on a monthly basis. In this we must know the irradiation level either by NASA's website which is having the accuracy level at 10m or there is a section in HelioScope where the meteonorm data is available for the location. The simulated data of energy generation is provided by helioscope is tabulated below.

$$\text{Energy Yield} = \text{Irradiation(PSH)} \times \text{Module Rated Power} \times \text{Losses (as efficiencies)}$$

Table 81: Specific Energy Yield (Source: Simulation result in Helioscope)

Months	**The energy at Leh (34^0)**	**The energy at Bhopal (23^0)**	**The energy at Singh Pura (26^0)**	**The energy at Lamba (22^0)**	**The energy at Kanhappapuram (8^0)**
Jan	3,186.70	5,087.40	4,271.00	6,441.70	5,275.80
Feb	3,762.30	5,161.30	3,926.30	5,352.60	5,120.60
Mar	4,889.50	6,216.60	4,516.70	6,531.00	5,836.20
Apr	4,670.50	5,700.80	4,014.70	5,431.30	5,093.50
May	5,119.50	5,543.60	3,847.30	4,869.40	4,709.20
June	4,953.50	4,343.20	3,501.70	4,074.60	3,804.40
July	5,452.10	3,497.90	3,860.40	3,253.00	4,202.40
Aug	5,288.80	3,445.70	3,526.50	3,391.40	4,764.00
Sep	5,160.00	4,220.70	4,129.00	4,667.00	5,002.70
Oct	4,813.80	5,388.80	4,243.90	6,095.50	4,851.20
Nov	4,056.30	4,950.00	4,634.60	6,038.90	4,283.80
Dec	3,204.40	4,899.00	4,685.20	5,859.50	4,821.80
Total (kWh)	51,353.00	53,556.00	44,472.10	56,146.40	52,943.80

5. RESULTS

As we have seen while designing system every value is having their special role in the designing process. Value of Peak Sun Hour at the solar time plays a vital role while designing the system. Temperature data is also vulnerable to calculation. As we seen in losses section (f), Losses are more than 20% this is happening because we designed the system when the sun is over the Equator (at equinox) for selected locations. As we are not using sun tracker module, keeping in mind the geographical locations and weather conditions of India we simulate the system at equinox then the module tilt angle will be the same as latitude(in degrees).

As we know the temperature, shadow and mismatching are the major losses in the system these losses affect the system performance. As we saw the temperature loss is minimum in Leh, because of geographical location but due to high tilt angle the shadow loss increase. Gujarat, Bhopal and Singh Pura are located near the tropic of cancer these locations having a high temperature during summer solstice that’s why the system is having high-temperature loss above 6%. As we decrease the tilt angle the shadow loss will also decrease. Here shadow loss is nearly about 2% - 2.5% which is acceptable.

6. CONCLUSION

In this design, there are total of 7 strings having total of 94 modules which relate to the two MPPT of the inverter. Our demand is to designed system of about 30 kW PV plant and we took 325Wp module to designed this system which needs 94 modules and it is impossible to connect them in even number of strings, according to our calculation then, then we connect 52 modules with one MPPT having 13 modules in each string which means 4 strings are connected with the one MPPT of the inverter and rest 42 modules are connected withanother MPPT having 14 modules in each string means 3 strings are connected with the MPPT. We know that if the temperature increases the voltage will decrease while the current will increase and if the temperature decreases then the voltage will increase and current will decrease which effects the system performance.

This module is having certification of various IEC standards which are as follows IEC- 61215, IEC-61730, IEC-62716, and IEC-62804 [7]. The string inverter design is described as a full bridge, neutral point clamped (NPC) topology which is combined with patent-pending modulation scheme to provide an inverter that is extremely efficient with minimal leakage current and high maximum allowed DC voltage [8] Here we see the system performance when the system seizing and all components (Modules, Inverter, Wire rating, length, row spacing, fuses, structure etc.), and kept at different five locations when the sun is over the equator (at equinox) [9].

Hence, we can say that a low tilt angle does not cause an effective shadow. Acceptable shadow loss where modules are tilted between 22 and 26. This is an average tilt angle for modules. We can also say that if the module tilt angle will less than the production may increase, and the plant will not under perform through the year.

7. REFERENCES

[1] L. A. K. Salih Mohammed Salih, Effect of Tilt Angle, Iraq: ISESCO JOURNAL of Science and Technology, 2014.

[2] NASA Earth Science’s, “POWER Project Data Sets,” NASA, 15 May 2019. [Online]. Available: https://power.larc.nasa.gov/. [Accessed 10-16 May 2019].

[3] NASA, “Power Calculator,” 2015. [Online]. Available: https://power.larc.nasa.gov/downloads/POWER_SinglePoint_Climatology_034d13N_077d58E_8.

[4] Mr Dwipen Boruah and Geoff Stapleton, Grid-Connected Advance PV system, New Delhi, Australia: Global Sustainable Energy Solutions, 2017.

[5] Folsom Labs, “Helisocope,” 531 Howard St Floor 1 94105, 2018.

[6] “Best Practice guidelines for the hybrid system,” Kenya, 2015.

[7] Vikram Solar, "Eldora Grand Series Pv Modules," Vikram Solar Limited, [Online]. Available: https://www.vikramsolar.com/products/eldora-grand/.
[8] Jukka Nurmi, "Efficiency with Usability," ABB Solar Inverter, Helsinki, Finland.
[9] ABB (Asea Brown boveri ltd), "Detailed information for: 3M22990F201A," ABB (Asea Brown boveri ltd). [Online].

BIOGRAPHY

Ashutosh Tripathi
Student
Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, Madhya Pradesh, India

Romi Jain
Assistant Professor
Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, Madhya Pradesh, India