HARVESTING THE MAXIMUM ENERGY FROM SOLAR PV SYSTEM BY PROPER SELECTION OF ARRAY & STRING

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Abstract: PV system is best renewable sources available with us to harvest the electrical energy from sunlight with zero emission to atmosphere. PV system can be installed in residential sector, commercial building, educational institution either in ground or roof top of the building. Ground based solar installation is used to harvest the energy in high volume especially to meet the energy demand in larger extent and it is integrated with the grid sources also. Size of the ground based PV plant would be ranging from MW to GW, if the available ground place is more than the size of the PV plant would be high and vice-versa. Roof top solar PV plant would be smaller in capacity that would be used to meet the partial energy demand of the particular residential building or educational institution or commercial building. Roof top PV plant size is limited to available roof space in the particular building. Selection of string i.e number of panel in the series and number of array i.e no of parallel string would determine performance of the PV plant. If the number of strings and number of array was not selected properly it would directly impact the efficiency of PV plant and we couldn't get expected energy output from the PV plant. In this paper we investigated four different string and array selection and corresponding the energy output from each combination is analyzed and presented. It is found that improper selection of array and string is having more impact on the output on the PV plant. Worst selection of array and string result in energy output of only 264 units from 132KW PV plant and whereas same capacity of PV plant yielded maximum energy output of 1,80,422 units for optimum selection of array and string. The complete PV system was modelled and analyzed using Solar Pro tool.

Keywords – Solar Pro, Strings, array, energy output.

1. Introduction

In India usage of renewable sources for generatingthe power especially from the solar sources is more popular and getting more penetration in to our grid system. Share of power generation from PV sources is high as compared to other renewable sources as on 31st December 2024 total installed capacity of PV system in India is 97.86GW. In these ground based solar system contributes 75.19GW, Roof top ON Grid system contributes 15.67 GW, Stand-alone PV system contributes 4.23 GW and Hybrid solar system contributes 2.77 GW [1]. Fig.1 depicts the power generation from PV system which includes PV panel, Inverter and energy storage system. Main component in generating the power from PV system is PV panels , on year on year efficiency of PV panel is improving gradually initially efficiency of the panel was lying below 15% but now efficiency of PV panel available in the commercial market is 21%. This improvement in the PV panel's efficiency is leading to a gradual increase in its energy generation [2]. As on Nov 2024, India ranks globally 3rd position in generating the power from the PV system. On year on year India was adding the PV plant in different parts of the country through private firms supported by Govt. subsidy in installing the PV plant [3]. Author described about power generation from the PV system and it is classified based on the technology deployed. There are two types of technology used to harvest the energy from Sun,one way is through PV panel using photovoltaic effect and it is direct method in converting the visible light energy in to electrical energy.

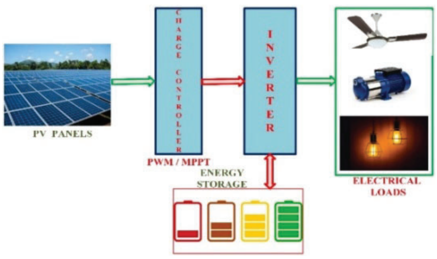

Fig.1 Components of PV system

The second method is an indirect approach that uses a concentrated solar panel (CSP) to convert light energy into heat energy, which is then transformed into electrical energy through thermal effects.

In India power generation through direct method is deployed more than 90% and output from the PV system is depend on the temperature and solar radiation [4]. Author describes about the technology advancement deployed in the power generation from PV system. Power generation through satellite system and transmitting to the earth surface through microwave beams was described in the paper. Author stressed about the importance of the energy storage system in PV system due to intermittent output from the PV panel and to ensure the continuous power supply to the load without any interruption caused due to unavailability of solar sources. Author describes about need of solar hybrid power system in combination with other sources such as wind sources, Hydel sources, Diesel generator system and Biomass sources [5].Floating PV power plants is becoming popular in harvesting the energy apart from ground based PV plants. Only concern in deploying the floating PV plants is capital investment and investment cost is high as compared to ground based PV plants. For small capacity floating PV plant is almost 25% is high as compared to other PV plants so author demonstrated the cost of floating PV plant is highly feasible for higher capacity in term of capital investment for installing the PV plants. Efficiency of floating PV plant can be improved by having bifacial PV modules and temperature of PV module is maintained without having additional cooling arrangement since water beneath PV panel reduces the operating temperature of PV panel which results in increase in energy generation from floating PV plants [6]. Author described about the land requirement of installing the PV plants and climate impact due to deployment of large PV plant in European countries, India, Japan and South Korea was detailed in his research. Author developed model called Integrated Assessment Model (IAM) which is used to relate the climate change, potential generation of power from PV plant from the available land and economic aspects related to installing the PV plant [7]. Scheduling the power generation from other resources based on the output received from forecasting the irradiance. Author proposed concept to harvest the maximum energy from the PV plant based on forecasted irradiance level and scheduling the other power generating at least cost so that overall energy demand of the consumer can be met with least energy cost. Ultimate aim of harvesting the energy from the PV system is have least carbon emission and provide clean energy to consumer with zero emission to the atmosphere [8]. Author proposed novel concept of generating the power from solar tree which occupies less space as compared to conventional ground based PV plants. Solar tree occupies only 23% of space as occupied by the conventional PV plants due to this less land requirement pushes the generation of power from PV plant in urban areas also instead of concentrating in rural areas. With space as occupied by ground based PV plant, proposed solar tree can generate more energy with less space [9].Three different configuration of PV modules arrangement was described by the author . Author demonstrated that power generation from modular mounting structure having configuration of 3 Panel in vertical and 8 panel with tilt angle of 14^o in Row will yield more energy output and cost of energy is least in this configuration as compared to other configuration which includes 2 Panel in vertical and 12 panel in Row with tilt angle of 14^o& 30^orespectively [10].

The optimum energy from PV plants is possible under partial shading condition is demonstrated by author. By effective reconfiguration of PV array is carried out under partial shading condition, maximum energy from PV system can be harvested with minimum loss from the system [11]. Author proposed Hybrid configuration of PV array so as to harvest the maximum energy from PV system. Author demonstrated that proposed Hybrid configuration yields more energy as compared to conventional PV array configuration and it overcomes the local maximum power points which results in high conversion efficiency from PV arrays [12]. The shadow from one PV array on another PV array is due to less inter row spacing and this spacing is increased then output from PV module can be increased but only concern is it requires more space in the land. Author demonstrated that with sufficient inter row spacing would result in more energy from PV array as compared to less inter row spacing [13].

Optimum placement of Bifacial PV modules in order to generate the maximum energy from PV plant was explained in detail and author developed AI (Artificial Intelligence) model to find optimum placement of panel in terms of inclination angle, irradiance reflecting factor and spacing between the array [14].In order to mitigate problem caused due to the emission of carbon particles in to atmosphere due to excessive use of fossil fuel for power generation best solution to use the renewable sources. Power generation through renewable sources especially through PV sources will provide zero emission. Author described about use of PV sources to get sustainable power generation without any emission [15].

Many researcher discussed about Inverter topologies used in grid tie inverter, technology advancement used in solar cell to get optimum generation of power from the PV Plant but they were not discussed about optimum selection of array matching with operating voltage window of the inverter. This research paper is focus on selection of proper array sizing with respect to the inverter voltage range. If the inverter voltage is range is not matching with PV array then inverter can't generate the optimum energy and performance of PV plant would be greatly affected. Objective of this research is

a. To model the building under study in Solar Pro to study the performance of PV plant
b. To Model the PV plant in the roof top of building in solar pro tool
c. To select the appropriate the optimum array configuration from the outcome of I-V Characteristic study
d. To carry out the power study to forecast the energy output from the PV plant.
e. To evaluate the Specific AC energy per kwp of PV plant installed in the building.

2. Methodology

In this research paper, we adopted the methodology which is depicted in the Fig.2. It is seen from the Fig.1 that Solar Pro tool [16] optimizes the PV plant output based on the selection of number of array and strings. Apart from these, Solar Pro tool uses auto array installation option which places the PV panel in the available roof place of the building under study and also it sizes the PV plant capacity with respect to available roof place. Solar Pro tool output the I-V curve of PV plant which gives complete information about the maximum voltage correspond to peak point and open circuit voltage based on these two values , Inverter Voltage MPP (Maximum Power Point) can be selected so that we can harvest maximum energy output from the PV Plant.

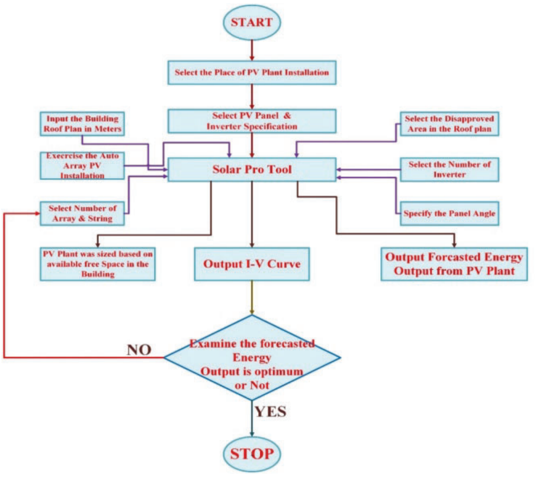

Fig.2 Methodology

3. System Components

Main system components considered for the study involves building and PV system. Building roof top is considered for installing the PV module for generation of electrical energy to meet the energy demand of the building. PV system is used to generate the electrical power through PV panel by Photovoltaic effect.

3.1 Building

Building under study is located in the Chennai, Tamilnadu, India which correspond to altitude and longitude 13.0843° N, 80.2705° E. Building is having the roof place in length and breadth in meters is 33m X 83m which corresponds to total area of 2739m^2. Building under study receives the total irradiation of 1952.21kWh/m2 and average air temperature is 28.33^{o}c.building to harvest the electrical energy from the roof place of the building and it doesn't

3.2 Solar Plant

Solar Energy is the best renewable source to generate the electrical energy from available visible light received from the sun. PV plant is best suitable for residential building, educational institute and commercial building to harvest the electrical energy from the roof place of the building and it doesn't requires any costly infrastructure to install the solar panel and other supporting electrical accessories.

4. Modelling

Building and Solar plant is modelled in solar Pro tool [17].

4.1 Modelling of Building

Dimension of building especially roof dimension of building should be measured and same was given as input to the solar pro tool. In solar pro tool, there is option available to input the roof dimension of the building. The roof dimension of the building is drawn in the tool and if any disapproved area is there then same should be specified in the solar pro tool. After specifying the roof dimension, disapproved area and height of the building, solar pro tool creates the 3D dimension of the building which includes roof place also. Modelling of building is important since size of PV plant is freezed based on available roof place so this tool gives accurate sizing of the PV plant. Fig.3 depicts the 3D of the building which is modelled in the solar pro tool.

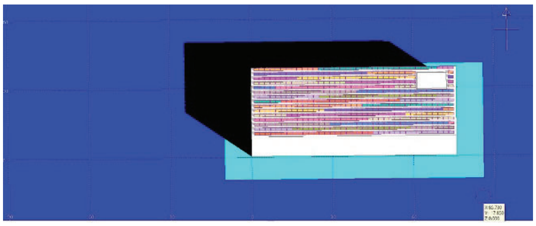

Fig.3. 3 DBuilding Modelling in Solar Pro Tool

4.2 Modelling of PV Plant

Modelling of PV Module in Solar Pro is done based on I-V characteristic of solar module

4.2.1 PV Module Equivalent Circuit

I –V Characteristics of PV module is modelled [17] as per equation 1 & 2

$$I = I_{ph} - I_0 \left| e^{C(V+IR_s)} - 1 \right| - \left(\frac{(V+IR_s)}{R_P} \right) \quad (1)$$

$$C = \frac{q}{D_p k T_m} \quad (2)$$

I_{ph}-Photovoltaic Current, Io-Diode Saturation Current, Rs-Inner Series Resistance R,Rp- Inner Parallel Resistance, q q- Elementary Charge, k: Boltzmann Constant, Tm-Module Temperature, Dp- Diode Factor (Number of Cell In-Series Diode Efficiency Index)

4.2.2 Output Characteristic Equation:

The effects of solaris radiance and module temperature [17] are calculated as per relation (3),(4) & (5):
In this case, we considered the 15 parallel strings and 18 series strings and total number of PV panel per inverter is 270. Total number of PV panel combining two inverter is 540 panels. Complete result of study was presented in the table 2.

Table 2 Performance of PV plant -15 Parallel and 18 Series String

Name	Total Irr.	PV Energy	AC Energy	PV Voltage	PV Current	Specific PV Energy	Specific AC Energy
Unit	kWh/m2	kWh	kWh	V	A	kWh/kWp	kWh/kWp
Jan	191.2	17675.99	16888.52	527.93	96.8	133.15	127.22
Feb	188.84	16428.48	15696.59	527.9	96.74	123.76	118.24
Mar	209.66	17431.23	16654.67	527.49	90.15	131.31	125.46
Apr	180.45	15234.7	14556	527.07	80.31	114.76	109.65
May	166.84	13951.57	13330.02	527.24	69.23	105.1	100.41
Jun	134.14	11999.02	11464.47	527.35	61.53	90.39	86.36
Jul	134.2	12499.32	11942.47	527.34	62.02	94.16	89.96
Aug	144.36	13405.08	12807.88	527.2	67.45	100.98	96.48
Sep	156.06	14236.47	13602.24	527.2	76.11	107.24	102.47
Oct	153.48	14571.94	13922.76	527.01	76.49	109.77	104.88
Nov	137.17	13533.84	12930.91	527.64	75.5	101.95	97.41
Dec	155.8	15221.93	14543.79	527.87	83.36	114.67	109.56
Max Value	209.66	17675.99	16888.52	527.93	96.8	133.15	127.22
Mean Value				527.44	77.97		
Sum Value	1952.21	176189.57	168340.32			1327.23	1268.1

The DC input power is 67.5 KW per inverter and total DC input power is 135KW. Total irradiation forecasted in the site under study in KWH /m2 is 1952.21. Average Air temperature pertaining to cite under study is 28.33oC. Average PV voltage available at the input of the inverter is 527.44 and corresponding average DC input current is 77.97Amps

Table 3 Performance of PV plant -08 Parallel and 33 Series String

Name	Total Irr.	PV Energy	AC Energy	PV Voltage	PV Current	Specific PV Energy	Specific AC Energy
Unit	kWh/m2	kWh	kWh	V	A	kWh/kWp	kWh/kWp
Jan	191.2	18590.7	19.58	913.74	58.26	140.84	0.15
Feb	188.84	17969	4077.6	897.58	62.05	136.13	30.89
Mar	209.66	19663.4	7532	888.63	61.4	148.96	57.06
Apr	180.45	16992.9	5602.2	882.98	53.25	128.73	42.44
May	166.84	15667.5	5236.4	869.41	45.85	118.69	39.67
Jun	134.14	12911.1	113.73	878.11	37.75	97.81	0.86
Jul	134.2	13150.1	88.1	893.71	37.09	99.62	0.67
Aug	144.36	14121.3	80.77	898.06	40.92	106.98	0.61
Sep	156.06	15137.3	43.39	898.61	46.86	114.68	0.33
Oct	153.48	15171.8	30.62	911.83	45.98	114.94	0.23
Nov	137.17	13860.2	31.23	929.18	43.68	105	0.24
Dec	155.8	15609.9	22.19	926.95	47.65	118.26	0.17
Max Value	209.66	19663.4	7532	929.18	62.05	148.96	57.06
Mean Value				899.07	48.39		
Sum Value	1952.21	188845	22878			1430.64	173.32

Total PV energy forecasted per year is 176189.57 KWH. The combined AC energy output from the both inverter is 168340.32 KWH. Conversion efficiency which is calculated based on AC energy output with respect to PV energy input is 95.54%.

Specific PV energy output in KWH /KWp is 1327.23 and corresponding AC energy output in KWH /KWp is 1268.1

6.3. Case 3:

In this case, we considered the 08 parallel strings and 33 series strings and total number of PV panel per inverter is 264. Total number of PV panel combining two inverters are 528 panels. Complete result of study was presented in the table 3. The DC input power is 66 KW per inverter and total DC input power is 132 KW. Total irradiation forecasted in the cite under study in KWH /m2 is 1952.21. Average Air temperature pertaining to cite under study is 28.33oC. Average PV voltage available at the input of the inverter is 899.07 and corresponding average DC input current is 48.37 Amps. Total PV energy forecasted per year is 188844.99 KWH. The combined AC energy output from the both inverter is 22877.69 KWH. Conversion efficiency which is calculated based on AC energy output with respect to PV energy input is 12.11%. Specific PV energy output in KWH /KWp is 1430.64 and corresponding AC energy output in KWH /KWp is 173.32

Table 4 Performance of PV plant -10 Parallel and 27 Series String

Name	Total Irr.	PV Energy	AC Energy	PV Voltage	PV Current	Specific PV Energy	Specific AC Energy
Unit	kWh/m2	kWh	kWh	V	A	kWh/kWp	kWh/kWp
Jan	191.2	18671.42	4.05	742.95	71.66	140.65	0.03
Feb	188.84	18048.4	9.08	730.89	76.31	135.96	0.07
Mar	209.66	19750.55	14.72	724.05	75.5	148.78	0.11
Apr	180.45	17069.07	23.62	719.94	65.45	128.58	0.18
May	166.84	15738.36	33.35	709.87	56.34	118.56	0.25
Jun	134.14	12969.55	52.17	717.36	46.4	97.7	0.39
Jul	134.2	13209.56	34.2	729.66	45.59	99.51	0.26
Aug	144.36	14184.67	43.15	732.67	50.32	106.85	0.33
Sep	156.06	15204.9	21.04	732.22	57.65	114.54	0.16
Oct	153.48	15238.98	8.39	742.98	56.53	114.79	0.06
Nov	137.17	13921.12	13.16	756.51	53.73	104.87	0.1
Dec	155.8	15677.69	7.07	753.91	58.62	118.1	0.05
Max Value	209.66	19750.55	52.17	756.51	76.31	148.78	0.39
Mean Value				732.75	59.51		
Sum Value	1952.21	189684.3	264			1428.88	1.99

6.4. Case4:

In this case, we considered the 10 parallel strings and 27 series strings and total number of PV panel per inverter is 270. Total number of PV panel combining two inverters are 540 panels. Complete result of study was presented in the table 4. The DC input power is 66 KW per inverter and total DC input power is 135 KW. Total irradiation forecasted in this cite under study in KWH /m2 is 1952.21. Average Air temperature pertaining to cite under study is 28.33oC. Average PV voltage available at the input of the inverter is 732.75 and corresponding average DC input current is 59.51Amps. Total PV energy forecasted per year is 189684.27 KWH.

The combined AC energy output from the both inverter is 264 KWH. Conversion efficiency which is calculated based on AC energy output with respect to PV energy input is 0.139%. Specific PV energy output in KWH /KWp is 1428.88 and corresponding AC energy output in KWH /KWp is 1.99.

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6.5 Performance Analysis

Different configuration of array and string of PV plant with respect to inverter was analyzed and same was presented in the table 5. From the results it is seen that conversion efficiency was high and it is about 95% in case 1 &2, whereas case 4 conversion efficiency was only 0.14%. Reason for less conversion efficiency in the case 4 was array and string selection was not matching the inverter voltage range due to this conversion efficiency was very less and it is only 0.14%. In the case 1 and case 3 number of PV panel per inverter is same but conversion is not same and there is huge difference in the conversion efficiency. This is due to improper selection of array and string with respect to the MPP (Maximum Power Point) range of the inverter. AC energy from the PV plant is dropped from 180422 Units in case 1 to 264 Units in case 4 due to mismatch in the selection of array and string

Table 5: Comparison of Different Configuration

Condition	No. Of Parallel Array	No of Strings in Series	No of PV Panel per Inverter	Total DC Capacity in kW per Inverter	PV Energy	AC Energy in kWh	Conversion efficiency
Case 1	12	22	264	66	188835	180422	95.55
Case 2	15	18	270	67.5	176190	168340	95.55
Case 3	8	33	264	66	188845	22878	12.11
Case 4	10	27	270	67.5	189684	264	0.14

Conclusion

Detailed performance analysis of 132 PV plant was carried out for four different configuration of array and string. Real time input pertaining to the solar panel of 250kWp and inverter of 60kW was taken for the study and same was considered for simulation in the Solar Pro tool also. In these research extensive study was carried out for building located in the Chennai, India and roof top solar was modelled for the building using solar pro tool. To understand the importance of selection of array and string with respect to the output of PV plant four different configuration was considered. Each configuration of array and string selection was simulated and result of each selection is detailed discussed and it is found that if the selection of array and string was not carried out properly with respect to voltage window of the inverter, we could not get expected energy output from the PV plant so this paper concludes that proper selection of array and string is needed and should be selected based on physical configuration of inverter not based on any thumb rule.

If selection of array and string is perfect we can harvest optimum energy from the PV plant. In these research, we demonstrated optimum AC output of 180422 Units is harvested for proper selection of Array and string which correspond to conversion efficiency of 95%.

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