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Designing & Cost Analysis of Solar Photovoltaic Power Plant in a Commercial Building

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***Abstract* - In this paper we will design a hybrid solar system in a commercial building. The Energy consumption cost of the example taken i.e. World Trade Park in Jaipur is very high. We will design a solar hybrid system to reduce the cost of energy consumption by providing Green energy in the form of Electricity. The solar module will be placed on the roof top so as to utilize the space available. We will calculate the ideal conditions of the site and the projected output for the available conditions with cost saving by the same. We would desire to obtain maximum cost efficiency form the available conditions. Ultimately we will conclude with amount of cost reduction along with system Performance ratio, Monthly output of the system, Specific yield, Payback time and future development.**

INTRODUCTION

After introducing of solar energy there is a continuously progress in the field of solar energy. Now days there is lot of investment and advancement in the big industry, corporate offices, homes, small scale industry and malls everywhere we can see the solar projects. The main reason behind this now solar energy is the big need of all over the world because there is lot of advancement take place in solar energy field and this gives us green energy which is the basic need and many other benefits. So in this paper basically we take a big building name world trade park for the reducing cost of energy by using solar energy. This building situated in Jaipur Rajasthan which is 26.92 latitude and 75.823 longitudes and this building get the proper and sufficient sun shine of 365 days of year. This building contains corporate offices, multiplex, restaurant, seminar haul, food court, shopping malls and many more things so there is big consumption of energy now days this building using 90 mw electricity and paying 9 lakhs Rs. Per month and after some time it will consume more energy and will pay more money so we want to reduce some cost by using solar energy because there is 6000 m^2 space to use of solar panels the roof top area. In this building we are using hybrid solar system which is works very efficiently.

Now initially we will convert the GMT into solar time t_s

Solar Radiation

Solar radiation is the most important factor in a solar system. This topic cover a lot of factors that all together determine the amount of radiation falling on a particular solar panel and thus resulting into the determining the output of the panel. There are certain terms and their values that are to be known prior that are listed below:

Latitude: 26.5(approx) [10]

Solar terrestrial radiation monthly data for the site[1]:

Month	Jan	Feb	Mar	Apr	May	June
Average solar radiation	9.75	9.42	9.92	10.53	10.12	9.60
Month	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Average solar radiation	7.95	7.72	8.67	9.77	9.45	8.90

Solar noon[1]:

Month	Jan	Feb	Mar	Apr	May	Jun
Average sun noon	707	711	706	657	654	657
Month	Jul	Aug	Sep	Oct	Nov	Dec
Average sun noon	703	702	653	643	642	650

Monthly average declination angle of the site[1]:

Month	Jan	Feb	Mar	Apr	May	Jun
Average	-20.7	-12.3	-1.8	9.7	18.8	23
Month	Jul	Aug	Sep	Oct	Nov	Dec
Average	21.2	13.7	3.08	-8.45	-18.1	-22.8

Where t_s=*GMT-solar noon+12*[3]

This Solar time is then converted to solar hour angle by the below formula: $\omega = (t_s - 12) \times 15°$[3]

Next we will calculate the Cos θ this is the declination factors due to all the above factor the formula for Cos θ is[3]: $\cos\theta = \sin\delta \times \sin\varphi \times \cos\beta - \sin\delta \times \cos\varphi \times \sin\beta \times \cos\gamma + \cos\delta \times \cos\varphi \times \cos\beta \times \cos\omega + \cos\delta \times \sin\varphi \times \sin\beta \times \cos\gamma \times \cos\omega + \cos\delta \times \sin\beta \times \sin\gamma \times \sin\omega$

θ = angle of incidence [°]
δ = solar declination [°]
γ = azimuth of the surface [°]
β = slope of the surface [°]
φ = latitude [°]
ω = hour angle [°]

Here as the solar panels are placed on the roof the slope will be 0. Though maximum output will be available at slope = 28° (approx to latitude) and Azimuth angle = 195° this is obtained using Solar Tilt Orientation plot (STO).[5]

Now we will calculate values of Cos θ with values of δ, and ω as stated above and β = 0° and φ = 26.5°.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0000 GMT	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
0100 GMT	n/a	n/a	n/a	0.17	0.25	0.27	0.15	0.10	0.13	0.07	n/a	n/a
0200 GMT	0.04	0.11	0.20	0.40	0.46	0.48	0.37	0.33	0.36	0.29	0.20	0.14
0300 GMT	0.25	0.32	0.42	0.60	0.65	0.66	0.57	0.54	0.56	0.49	0.39	0.33
0400 GMT	0.42	0.51	0.61	0.77	0.81	0.82	0.75	0.72	0.73	0.65	0.55	0.48
0500 GMT	0.56	0.65	0.75	0.88	0.92	0.93	0.88	0.86	0.85	0.76	0.65	0.59
0600 GMT	0.65	0.74	0.85	0.95	0.98	0.99	0.97	0.94	0.91	0.81	0.71	0.65
0700 GMT	0.68	0.78	0.88	0.95	0.98	0.99	1.00	0.98	0.91	0.81	0.70	0.65
0800 GMT	0.65	0.76	0.85	0.90	0.93	0.94	0.97	0.95	0.85	0.75	0.64	0.59
0900 GMT	0.57	0.67	0.77	0.78	0.82	0.84	0.89	0.86	0.74	0.63	0.53	0.48
1000 GMT	0.44	0.54	0.63	0.62	0.67	0.69	0.76	0.72	0.57	0.46	0.36	0.33
1100 GMT	0.27	0.36	0.45	0.43	0.48	0.50	0.58	0.54	0.37	0.26	0.17	0.14
1200 GMT	0.07	0.16	0.23	0.21	0.26	0.30	0.38	0.34	0.15	0.03	-0.05	n/a
1300 GMT	n/a	n/a	n/a	-0.02	0.04	0.08	0.17	0.11	n/a	n/a	n/a	n/a
1400 GMT	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1500 GMT	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
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2200 GMT	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2300 GMT	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Next we will calculate the zenith angle. An incidence angle of particular importance, the angle between a vertical line and the line to the sun. The zenith angle is zero when the sun is directly overhead and 90° when the sun is at the horizon. Because a horizontal surface has a slope of zero, we can find a equation for the zenith angle by setting β = 0° in the above equation, which is the same as we calculated above.[2]

Now by taking and average of all for each month we get average Cos θ or Cos θ_z (θ_z = zenith angle)[3]

Month	Jan	Feb	Mar	Apr	May	Jun
Average Cos θ or Cos θ_z	0.42	0.51	0.60	0.59	0.64	0.65
Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Average Cos θ or Cos θz	0.65	0.61	0.59	0.50	0.44	0.44

Now finally we will calculate solar insolation radiation by the below formula:

$I = S \times \cos\theta_z$[2]

θ_z = Zenith angle [°]

S = Solar radiation of a particular site which varies depending upon the atmospheric condition the solar radiation on the earth's surface is given below[1]:

Month	Jan	Feb	Mar	Apr	May	Jun
Average Solar radiation	9.52	9.26	9.05	10.40	10.04	9.56
Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Average Solar radiation	7.84	7.67	8.61	9.59	9.41	8.55

So the solar insolation radiation is:

Month	Jan	Feb	Mar	Apr	May	Jun
Average insolation radiation	4	4.71	5.46	6.11	6.38	6.24
Month	Jul	Aug	Sep	Oct	Nov	Dec
Average insolation radiation	5.09	4.71	5.12	4.79	4.16	3.74

This will be future used in the system design.

System Design

For system design the complete formula is [6]

Esys = P_stc x f_man x f_dirt x f_temp x H_tilt

Esys = Energy yield

P_stc = Rated output of a array at Standard Test Condition (STC) in watts

f_man = De-rating factor by manufacturer tolerance

f_dirt = De-rating factor due to dirt

f_temp = De-rating factor due to temperature

Minimum power generation will be considered to obtain E_sys

Here we will be using solar panel by Tata manufacturer i.e. TP-300 series

P_max = 300 W[8]

Tolerance of TP-300 is 5%,[8]

So Tolerated output power isP_max x 0.95(f_man) = 285 W

Now De-rating due to dirt is maximum of 5%,

So 285 x 0.95(f_dirt) = 270.25

Temperature Co-efficient for P_max = -0.44/°C[8]

Average temperature of Jaipur is as below[6] [1]:

Month	Jan	Feb	Mar	Apr	May	Jun
Maximum temperature(°C)	30.7	35.9	46.8	50.9	49.5	44.4
Deviation from standard temp. (25°C)	5.7	10.9	21.8	25.9	24.5	19.4
Loss due to temperature (1-f_temp)	0.03	0.05	0.10	0.11	0.11	0.09
Output after temperature De-rating	263.93	257.71	244.66	239.76	241.143	247.53
Output per plate using insolation radiation (DC)	1055.71	1213.79	1335.85	1464.90	1540.33	1544.61
Month	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	36.8	35.2	38.4	41.6	37.5	32
Deviation from standard temp. (25°C)	11.8	10.2	13.4	16.6	12.5	7
Loss due to temperature (1-f_temp)	0.05	0.05	0.06	0.07	0.06	
Output after temperature De-rating (DC)	256.63	258.54	254.71	250.88	255.79	262.37
Output per plate using insolation radiation	1306.24	1217.74	1304.14	1201.74	1064.09	981.28

Now we will calculate output for the entire system consider the below factor[4][6]:

Roof area = 6000 m^2 [10]

Let 500 m^2 be spared for other purpose

So available roof area =5500 m^2

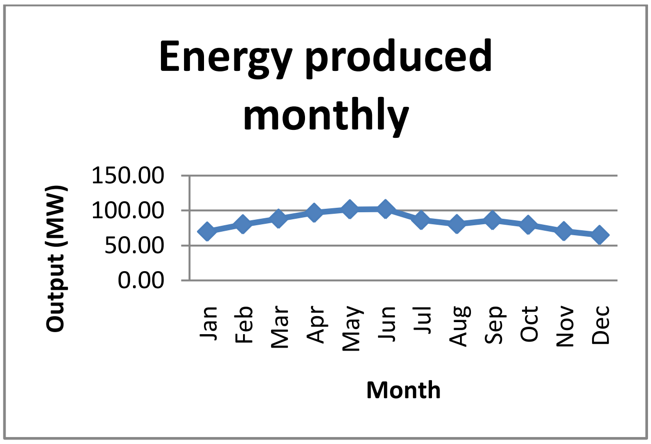
Area required by single plate of TP – 300 = 2 m^2 [8]

No. of plates = total available roof area / area per plate = 2750 plates

DC to AC conversion factor = **0.8**[4]

Now Output of the system is below[6]:

Month	Jan	Feb	Mar
DC output per day in watt	2903216	3337934	3673594
AC output per day in watt	2322572.8	2670348	2938875
AC output per month in KW	69677.18	80110.43	88166.26
Month	Apr	May	Jun
Dc output per day in watt	4028485	4235898	4247679
Ac output per day in watt	3222788	3388718	3398143
Ac output per month in watt	96683.63	101661.55	101944.29
Month	Jul	Aug	Sep
DC output per day in watt	3592161	3348785	3586373
AC output per day in watt	2873729	2679028	2869099
AC output per month in KW	86211.87	80370.83	86072.96
Month	Oct	Nov	Dec
Dc output per day in watt	3304776	2926250	2698506
Ac output per day in watt	2643821	2341000	2158805
Ac output per month in watt	79314.64	70229.99	64764.15



Total power generated by the system -Yearly output of the system in KW = 1005207.78 KW = 1005 MW

Now let us calculate the ideal output by[6]:

E_ideal = P_stc x H_tilt
And DC to AC conversion factor is ignored

Month	Jan	Feb	Mar
Ideal output per month in KW	99000	116572.5	135135
Month	Apr	May	Jun
Ideal output per month in KW	151222.5	157905	154440
Month	Jul	Aug	Sep
Ideal output per month in KW	125977.5	116572.5	126720
Month	Oct	Nov	Dec
Ideal output per month in KW	118552.5	102960	92565

Total yearly ideal output = 1497622.5 KW = 1498MW
Performance ratio = System output / Ideal output = 0.67[6]

Specific Energy Yield:

S = total system output per year / panel rating x no. Of panels= 1218.4337[6]

Now we will design the invertors' connections consider the inverter used SOLECTRIA PVI 28000TL 3-Phase Transformer less Solar Grid-Tie String Inverter with specification as below[9]:

Operating Voltage = 300 – 900 V [9]
Maximum power = 28KW [9]
Now let us consider all maximum and minimum condition for voltage per plate:

V_max = 36.6 V [8]
Tolerance = 5% [8]
Temperature co-efficient = 0.44/°C [8]
Maximum Tolerated output = 38.43 V
Minimum Tolerated output = 34.77 V

Minimum Temperature[1]	**8.15**	10.8	17	21.5	24.9	26.3	25.1	24.3	23	18.9	13.9	9.6
Deviation from standard temp. (25°C)	**16.85**	14.2	8	3.5	0.1	-1.3	-0.1	0.7	2	6.1	11.1	15.4
Increment factor for output due to temperature[7]	**0.07**	0.06	0.04	0.02	0	0	0	0	0.01	0.03	0.05	0.07
Incremented output due to low temperature	**41.29**	40.84	39.79	39.02	38.45	38.43	38.43	38.55	38.77	39.47	40.32	41.05

Maximum output voltage per plate = 42 V
Maximum no. Of panels in series = 900/42 = 21

Maximum temperature[1]	30.70	35.90	46.80	**50.90**	49.50	44.40	36.80	35.20	38.40	41.60	37.50	32.00
Deviation from standard temp. (25°C)	5.70	10.90	21.80	**25.90**	24.50	19.40	11.80	10.20	13.40	16.60	12.50	7.00
Decrementfactor for output due to temperature[7]	0.03	0.05	0.10	**0.11**	0.11	0.09	0.05	0.05	0.06	0.07	0.06	0.03
Decremented output due to low temperature	33.89	33.09	31.42	**30.79**	31.00	31.79	32.96	33.20	32.71	32.22	32.85	33.69

Minimum output voltage per plate = 30 V

Minimum no. of panels in series = 300/30 = 10

Now let's calculate the series and parallel connection plates[7][9]:

	No. Of strings					
No. Of panels per string	1	2	3	4	5	6
10	3000	6000	9000	12000	15000	18000
11	3300	6600	9900	13200	16500	19800
12	3600	7200	10800	14400	18000	21600
13	3900	7800	11700	15600	19500	23400
14	4200	8400	12600	16800	21000	25200
15	4500	9000	13500	18000	22500	27000
16	4800	9600	14400	19200	24000	28800
17	5100	10200	15300	20400	25500	30600
18	5400	10800	16200	21600	27000	32400
19	5700	11400	17100	22800	28500	34200
20	6000	12000	18000	24000	30000	36000
21	6300	12600	18900	25200	31500	37800

Here we can choose either of the configuration 18 x 5 or 15 x 6 = 90 panels per inverter

Total no. of inverter required = 31

Cost efficiency

Now here we will determine how much money is saved by generation of electrical power energy

Cost of per unit (kWh) = INR 10/unit [10]

Power generated per year in kW = 1005207 kW = 1005 mw

Cost saved energy generated = power generated x cost of unit = INR 1, 00, 52,070 /year

Now cost of the system

Cost of one solar panel = INR 7,500/-[8]

Cost of 2750 plates = INR 2, 02, 50,000/-

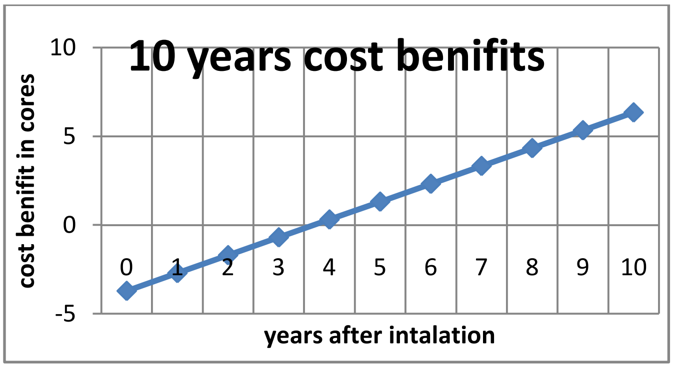
Cost of one inverter = INR 2, 22,200/-[9]

Cost of 31 invertors = INR 68, 88,200/-

Other Costs including (transportation, cables, installation, labour, other required peripherals etc.) =1, 00, 00,000/-

Total system cost = INR 3, 71, 38,200/-

Payback time = 3.6 years[10]



Other cost reducing factors

Cooling system (as bonus)

As people improve the cooling efficiency of building they rope the trees in a strategic manner around the building so that trees provide shade and improve the cooling efficiency. Solar panels also help keep buildings cool, reducing A/C needs when we mounted solar panel on roof, also provide valuable shade on the roof top of generating electricity. Researchers of the University of San Diego said that using thermal imaging during the day; a building ceiling was 5 degrees Fahrenheit cooler under solar panels than under an exposed roof.Muchof the heat is removed by wind blowing between the panels and the roof. The benefits are greater if there is an open gap where air can circulate between the building and the solar panel, so tilted panels provide more cooling**.** The amount saved on cooling the building amounted to getting a 5 percent discount on the solar panels' price, over the panels' lifetime**.** So if we used solar panel on roof building like world Trade Park then this will give 5 percent discount on solar panels' price.

Solar heating water system

We can use solar water heating system also on this building because in many large buildings heating water is a huge energy load and major expense.Installing a thermal solar water heating system will save significant money. A typical commercial solar water heating system west of the cascades can offset 90% of hot water demands in the summer, 75% in the fall and spring and 50% in the winter. Commercial systems are eligible for a 30% federal tax credit off of the total system cost, plus it will be eligible for 5 years accelerated MACRS in the renewable energy field. So this water heating system also has a big role to reduce costing of energy in the world trade park.

Solar cooker for cooking purpose

Now days LPG is main source of cooking food in the commercial building but LPG is costly and traditional sources which are 1 year cost for 30 to 40 people's cooking food is 21580 Rs. But solar concentrator complete installation cost 28000 Rs. But after this no extra charges required. So this is usable other 24 years to give free energy. Solar concentrators can give green and clean energy. Now we can say that solar cooker is the best option for cooking food by the solar concentrators and can save huge money also save the traditional sources for the emergency use. At world trade park restaurant, hotels should use the solar cooker with solar concentrators so that this building will be more efficient and will reduce the costing to make food.

Future development and other benefits

According to worldwide information, a share of renewable energy up to 50% is possible. For future development to reach such a share, advanced, intelligent and reliable policy measures have to be implemented at least in the majority of countries worldwide. Today solar investment is the best renewable source of energy. Because day by day natural resources of energy depleting continuously. As America said there is necessary 20% use of renewable energy. So there is many solar plant growing in Rajasthan and people used to solar panel for their home also. So they can independently generate the power of their own use and can save the money to except pay the monthly bills. Buildings like world Trade Park can generate the big amount of energy by using building integrated photo voltaic solar cells and save more money. There is lot of other benefits of use solar energy like tax benefits and pollution credits. Because government give many subsidies for the use of solar energy and gives tax relaxation. Solar energy is the green energy so that this building can be free by the pollution control department and save some money.

CONCLUSION

The hybrid system is a great success. World Trade Park the present energy usage is about 90MW per month which will be 270 MW on the complete operation this huge energy consumption will result into a substantial costing too. World Trade Park paying 9 lakhs Rs per month at present and it will pay 27 lakhs per month after some addition. After using our system it generates the 8 lakhs Rs solar energy per month. However our System will be producing an average of 83MW per month which is almost 1/3rd of the total consumption. The System being quite large will have a lower payback time that is of just 3.6 years. This will result into almost 3 time's profitable amount of the initial investment in 10 years time. So in future not only the building will enjoy free energy but may result into a great profitable unit killing its biggest expense that's of energy consumption. The performance ratio of the system is just 0.69 which is quite acceptable. After it we have add some other important factors which sincerely improve the building energy efficiency and reducing cost of energy by using solar energy. This will stand as a great example to all commercial and commerce as well as public building for usage of solar energy as there source for energy.

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