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Enhancement of energy generation from two layer solar panels

Pragya Sharma[1*] and Tirumalachetty Harinarayana[1,2]

Abstract

The enhancement of energy using solar photovoltaic in a limited space is important in urban areas due to increased land cost in the recent years. Although there exist different procedures and methodologies to focus the sunlight on solar panels, we have suggested a new approach to enhance the energy generation from the photovoltaic panels, i.e., by keeping the two layers of photovoltaic panels as collectors of energy one above the other with the same size and orientation. Our results of two layer solar panels have shown about 75% increase in efficiency as compared to a single layer solar panel. This study can also be extended to n number of photovoltaic layers piled up one above the other, if the cost economics are justified with respect to the land cost.

Keywords: Simulation, PVSYST software program, Efficiency, Shade analysis, Land cost

Background

Among all possible alternative energy options, for example, wave energy, geothermal energy, solar energy, wind energy, and hydro energy, solar energy is becoming more popular in India. This is mainly due to (1) the availability of plenty of sunlight in all the seasons and also at all the locations of India and (2) the recent initiation of solar mission by the government of India with attractive incentives to the developers [1]. If we look at the world total renewable energy generation, which is around 5×10^{20} J per year, solar thermal contributes to 0.5%, wind 0.3%, geothermal 0.2%, biofuel 0.2%, and solar photovoltaic (PV) is only about 0.04% as per statistical review of world energy during 2007 [2]. In recent years, the technology upgradation has not only made solar photovoltaic technology price competitive but also as a viable technology. It is projected that by the year 2030, the solar PV electricity will also dominate compared to other sources of energy [3]. From the study growth of photovoltaic, an average about 45% annual increase is noticed during the years 2000 to 2009 [3,4]. From the study of cost economics of a solar photovoltaic power plant, PV modules cost about 45% and the other 55% is due to components, like transformers, cables, inverters, and civil works [5]. Additionally, cost of the power plant also depends on the land value. If the solar power plant is close to the substation near the populated area, the transmission of energy losses will be minimum, but the cost of the land will be high [6]. If the power plant is at a remote location, the cost of the land is low but the energy losses will be high. On the other hand, with less population and in a remote location, the use of energy is limited to the local community. Ideally, the solar power plant needs to be located at a place where the energy generation from the plant can be connected directly to the power grid at an optimum distance from the plant. Apart from the government of India's national solar mission program, the recent initiation by the government of Gujarat to establish the solar photovoltaic plants is commendable. While Gujarat alone crosses 600 MW power through solar, the rest of the country is far behind with only about 200 MW.

The Gandhinagar Photovoltaic Rooftop Programme for solar energy generation using PV modules has set an example by government of Gujarat to save the land cost (see http://www.gpclindia.com/gpcl_rsg/index.html). Another way to save the land cost is to adopt a new methodology to get maximum output from the solar power plant in a limited area. In India, the cost of the land has grown up five to ten times for the last 10 years. This is true in all the urban and semi urban regions of India. In view of the above problem, an attempt has been made to

* Correspondence: pragyasees@gmail.com
[1]GERMI RIIC (Research and Innovation Centre), Gandhinagar, Gujarat 382007, India
Full list of author information is available at the end of the article

study different configuration of solar panels to enhance the energy generation from a solar power plant. For this purpose, the PVSYST modeling software [7] has been used, and a design with a new concept for the solar PV module is suggested, and its advantages over conventional design are discussed.

The rationale behind the present work is to enhance the energy generation for the limited space availability. In recent years several methods have been suggested. For example, in concentrating solar power technology [8], the lens or mirror for concentration of sunlight is used by refracting the rays and focusing them in a small area. In another recent study, a 3D type of solar panels is also reported [9]. Here we present another way of enhanced solar energy with two layers of solar panels as discussed in more detail below. Accordingly, the present study aimed to investigate the advantages of two layer solar panels with the same dimension and orientation lying one above the other. Additionally, the cost benefit analysis is also described to highlight the advantages of considering the suggested solar panel configuration from the present study.

Methods

The new design suggested in the present study is the result of several different design attempts using PVSYST software program. Before presenting the methodology, brief details of the software is presented in the following.

The software program

Among the various software programs, PVSYST simulation software is the most popular to analyze the detailed performance of the plant in field conditions. It can be used for many ways, for example, to investigate different loads on the system, estimate the size of the system, determine the optimal size of the panel, and assess the energy production in the system Various other capabilities and options available in the PVSYST software simulation can be seen in [7]. PVSYST, a personal computer-based software package, can also be used to study the sizing and data analysis of complete PV system. It is used for different designs and sizes of the systems. It can evaluate monthly production and performance. It also performs economic evaluation of the PV system at the design stage itself. Its application performs a detailed simulation and also shading analysis according to several dozens of variables. PVSYST also considers the shading of a diffuse radiation [7,10-12]. The limitation of the software is that it can compute only a single layer of PV module. This

Table 1 Radiation measurement details

Name of site	Ahmedabad
Latitude (degrees)	23.067° N
Longitude (degrees)	72.633° E
Altitude (meter)	55 m
Radiation model	Default (hour)
Temperature model	Default (hour)
Radiation	1981-2000
Measured parameters (WMO nr: 426470)[a]	Gh, H_Dh, H_Gk, H_Dk, H_Bn, Ta
Azimuth	0°
Inclination	25°

[a]World Meteorological Organisation - station code for Ahmedabad, India.

Table 2 Monthly data from Meteonorm

Month	H_Gh	H_Dh	H_Gk	H_Dk	H_Bn	Ta
	(kWh/m^2)	(kWh/m^2)	(kWh/m^2)	(kWh/m^2)	(kWh/m^2)	(°C)
January	147	32	201	42	211	19.6
February	157	36	195	44	193	22.4
March	203	50	227	57	225	27.9
April	214	64	215	67	205	31.6
May	225	78	208	77	202	33.0
June	184	93	165	88	125	31.7
July	139	97	128	92	56	29.1
August	137	92	131	89	63	28.1
September	163	71	171	74	131	28.9
October	171	57	201	65	180	27.9
November	144	39	188	48	181	24.1
December	137	34	188	43	188	20.3
Total	2022	742	2218	786	1961	27.1[a]

[a]Annual average temperature; H_Gh, irradiation of global radiation, horizontal; H_Dh, irradiation of diffuse radiation, horizontal; H_Gk, irradiation of global radiation, tilted plane; H_Dk, irradiation of diffuse radiation, tilted plane; H_Bn, irradiation of beam; Ta, air temperature.

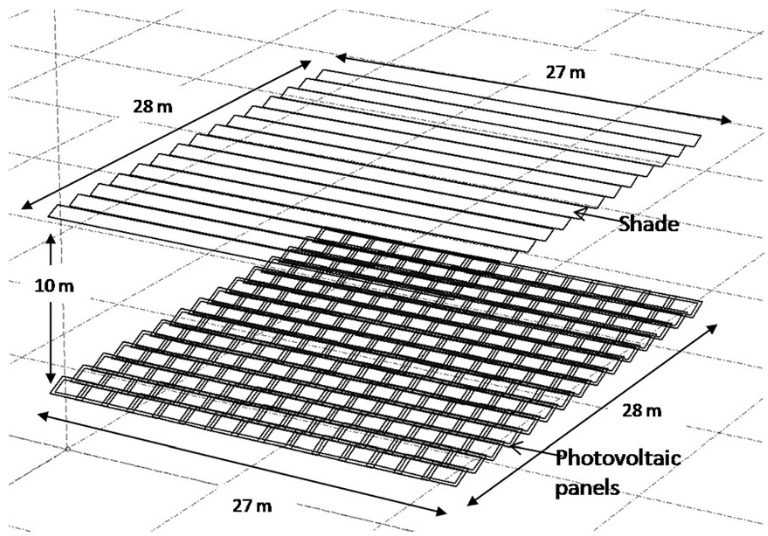

Figure 1 Schematic diagram showing the solar panel and above shade with 10 m height.

means that if there are two layers of PV modules, one above the other, the software has no provision or option to compute the solar energy. Apart from the PVSYST, there are about twelve other software tools currently in use for the simulation e.g., PV f-Chart, SOLCEL-II, PVSYSY, PVSIM, PVFORM, TRNSYS, ENERGY-10 PV, PVNet, PVSS, RETSCREEN, Renew, and SimPhoSys [10,13-24].

The data

For the grid-connected system, the basic input and model parameters required for modeling are the following - PV component database, grid inverter database, geographical site information, and monthly meteorological data for horizontal global irradiance and temperature [7]. In the present study, the meteorological data is acquired from Meteonorm version 6.1.0.23 (see Table 1), a comprehensive climatological database for solar energy applications [7,25-27].

In Table 1, the basic details of radiation measurement for Ahmedabad site are shown. The data have been measured and averaged over a period of 20 years. The radiation data is taken for 20 years period i.e., during 1981 to 2000. The meteorological data considered is given in Table 2. In this table, the information on the monthly average meteorological data of solar radiation, for Ahmedabad, is provided. The values provided are related to irradiation value of global radiation in horizontal direction (H_Gh), irradiation of diffuse radiation horizontal (H_Dh), global radiation in tilted plane (H_Gk), irradiation of diffuse radiation tilted plane (H_Dk), irradiation of the beam (H_Bn) and the air temperature (Ta). These values are used in our study to analyze the shading effects on the panels.

In Figure 1, the solar panel design configuration considered for our model study is shown. It is a schematic diagram with two sets of layers, one lying above the other in such a way that the bottom layer is a solar panel and the top layer is a blank shade with a height separation of 10 m. Since the PVSYST software cannot compute solar energy using the two solar panels with one lying above the other, the top panel is a shade without solar panel but has the same dimension and same orientation of the solar panels in our present study. Later, we will compute the solar energy without shade and add the same with the solar energy with shade to get the total solar energy generated from the two panels. In our model, the DelSolar PV modules (DelSolar Co., Ltd., Miaoli County, Taiwan) have been selected. As a sample,

Table 3 Details of the schematic model shown in Figure 1 and PV module specifications

Number of modules	225
Area of the field (land)	770 m^2 (approximately)
Active area of the modules (sensitive PV area)	372 m^2 (Each module length 1.67 m and width 99 m)
Name of the manufacturer	DelSolar
Technology	Si-polycrystalline
Year	2010
P_{MPP}	230.3 W
I_{MPP}	7.72 A
V_{MPP}	29.8 V
Module and shade tilt	23° N
Separation between rows of solar panel	2 m
Height between solar panel and shade	10 m
Orientation	0° (exactly south)

Table 4 Shading factor table for no shade over panels

Azimuth height	−180	−160	−140	−120	−100	−80	−60	−40	−20	0	20	40	60	80	100	120	140	160	180
90°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
80°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
70°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
60°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
50°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
40°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
30°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.961	0.856	0.824	0.856	0.961	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10°	Behind	Behind	1.000	1.000	1.000	1.000	0.82	0.613	0.51	0.479	0.51	0.613	0.821	1.000	1.000	1.000	1.000	Behind	Behind
0°	Behind	Behind	Behind	Behind	1.000	1.000	0.26	0.125	0.08	0.067	0.08	0.125	0.260	0.675	1.000	Behind	Behind	Behind	Behind

15 solar panel modules in X direction and a series of 15 rows of solar panels in another, say Y direction, are considered. Such a design is arbitrary and helps to compute parameters quickly. This configuration approximately provides about 50 kW of power output from the PV power plant. However, the same model can be extended to any length as required.

In Table 3, the information and details for the solar panels considered are shown. Details of the solar module and technology, power rating, and related module specifications are also provided. The technology considered is Si-polycrystalline DelSolar photovoltaic module which is available in PVSYST PV module library [7]. Each module can provide a maximum power output of 230.3 W. Accordingly, the 225 number of modules used in our study can provide a power output of about 50 kW. The modules are oriented in the south direction and accordingly, the azimuth angle is assumed as 0°. Both the modules and shade panels are tilted at the same angle of 23°. This tilt is chosen as the latitude (degrees) for the Ahmedabad site is 23.067°.

Shading factor analysis

The shading factor analysis provides the energy loss from photovoltaic panels due to near shading. Near shading means partial shading that affects a part of the panel(s) [7]. The shaded part changes during the day and also over a season. The shading factor is a ratio between the energy generated from the illuminated part and the total area of the field, or inversely, the energy loss [7].

In Table 4, the information of a single module mounting during no shade over the panels is provided. The shading loss is only a function of the sun's height and azimuth for a near shading scene. The values in the table represent the shading factor defined above, and are the ratios of the illuminated part to the total area of the field as a function of height and azimuth of the sun position. The value varies as per the season and time of the day. For example, value 1.000 represents 100% illumination or available radiation over the panels during any particular time of the day and .961 represent 96.1% illumination and so on. In 'no shade' layout, the illumination over the panel is 100% most of the times except during morning and evening hours, when

Table 5 Shading factor table for shade at a height 10 m above the solar panels

Azimuth Height	−180	−160	−140	−120	−100	−80	−60	−40	−20	0	20	40	60	80	100	120	140	160	180
90°	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194
80°	0.142	0.275	0.602	1.000	0.566	0.190	0.747	0.881	0.585	0.472	0.585	0.881	0.747	0.190	0.565	1.000	0.602	0.274	0.142
70°	0.365	0.623	1.000	0.194	0.919	0.548	0.492	0.637	0.793	0.597	0.792	0.636	0.491	0.547	0.919	0.194	1.000	0.623	0.365
60°	0.303	0.718	0.826	1.000	0.957	0.885	0.748	0.400	0.783	0.514	0.783	0.400	0.748	0.885	0.957	1.000	0.826	0.717	0.303
50°	0.896	0.352	0.899	0.665	0.642	0.847	0.390	0.476	0.538	0.352	0.537	0.475	0.390	0.847	0.641	0.665	0.899	0.352	0.896
40°	0.406	1.000	1.000	0.592	0.643	0.565	0.638	0.786	0.720	0.552	0.720	0.786	0.638	0.564	0.642	0.591	1.000	1.000	0.406
30°	1.000	1.000	1.000	1.000	1.000	0.929	0.797	0.808	0.648	0.678	0.648	0.808	0.796	0.929	1.000	1.000	1.000	1.000	1.000
20°	1.594	1.000	1.000	0.980	1.000	1.000	0.986	0.884	0.778	0.740	0.778	0.883	0.986	1.000	1.000	0.980	1.000	1.000	1.594
10°	Behind	Behind	1.000	0.960	1.000	1.000	0.821	0.613	0.512	0.479	0.512	0.613	0.821	1.000	1.000	0.959	1.000	Behind	Behind
2°	Behind	Behind	Behind	Behind	1.000	0.675	0.26	0.125	0.084	0.067	0.084	0.125	0.26	0.675	1.000	Behind	Behind	Behind	Behind

Table 6 Energy supplied to the grid by single layer with shade and two layer PV panel system

Height between the panels	No shade (a)	1 m (b)	3 m (c)	5 m (d)	10 m (e)
Total annual energy generated by solar panels and shade both of equal dimensions (372 m^2) (in kWh)	77,980	28,100	40,887	45,775	55,942
Total annual energy generated by two layer panels both of equal dimensions (372 m^2) (in kWh)	-	106,080 (a + b)	118,867 (a + c)	123,755 (a + d)	133,922 (a + e)

the height of the sun is 20° or below, with respect to site location, causes maximum shade.

Table 5 presents analysis for a shade at a height of 10 m above the photovoltaic panels. In our study, it is of the same dimension as of the bottom photovoltaic panel. Due to the presence of the shade, the shading factor in Table 5 showed lower value as compared to no shading scene in Table 4. Accordingly, the energy output reduces from the panels.

Annual energy yield

In Table 6, the energy that can be supplied to the grid, for annual generation is shown. The results of the shading analysis of photovoltaic panels for the whole year is shown with no shade and shade at different heights; and the cumulative energy form the average radiation data for the years 1980 to 2000, supplied to the grid for two layer panel system, is shown. The annual total yield of energy supplied to the grid, when there is no shade over the panels, is given in column 2, and the energy generated by the single layer solar photovoltaic system with different shade heights 1, 3, 5, and 10 m is provided in column 3, 4, 5, 6, respectively. Similarly, energy generated by the two layer solar photovoltaic systems with separation values of 1, 3, 5, and 10 m is provided in column 3, 4, 5, 6 respectively. As can be seen, the amount of energy supplied to the grid varies with respect to different height separations 1, 3, 5, and 10 m between the panels. It is observed from the present study, the energy supplied to the grid is at maximum for the case of 10 m height separation.

In Figure 2, a comparative study is shown for the energy supplied to the grid in different months of the year for the radiation data averaged for the years 1980 to 2000. The vertical axis shows the energy supplied to the grid for each month, for example, column 1 in the figure shows the total energy supplied to the grid for different months of the year.

In Figure 3, a comparative study is shown for the two layer photovoltaic panels. The details of the average energy generated per day (December 20), for the radiation

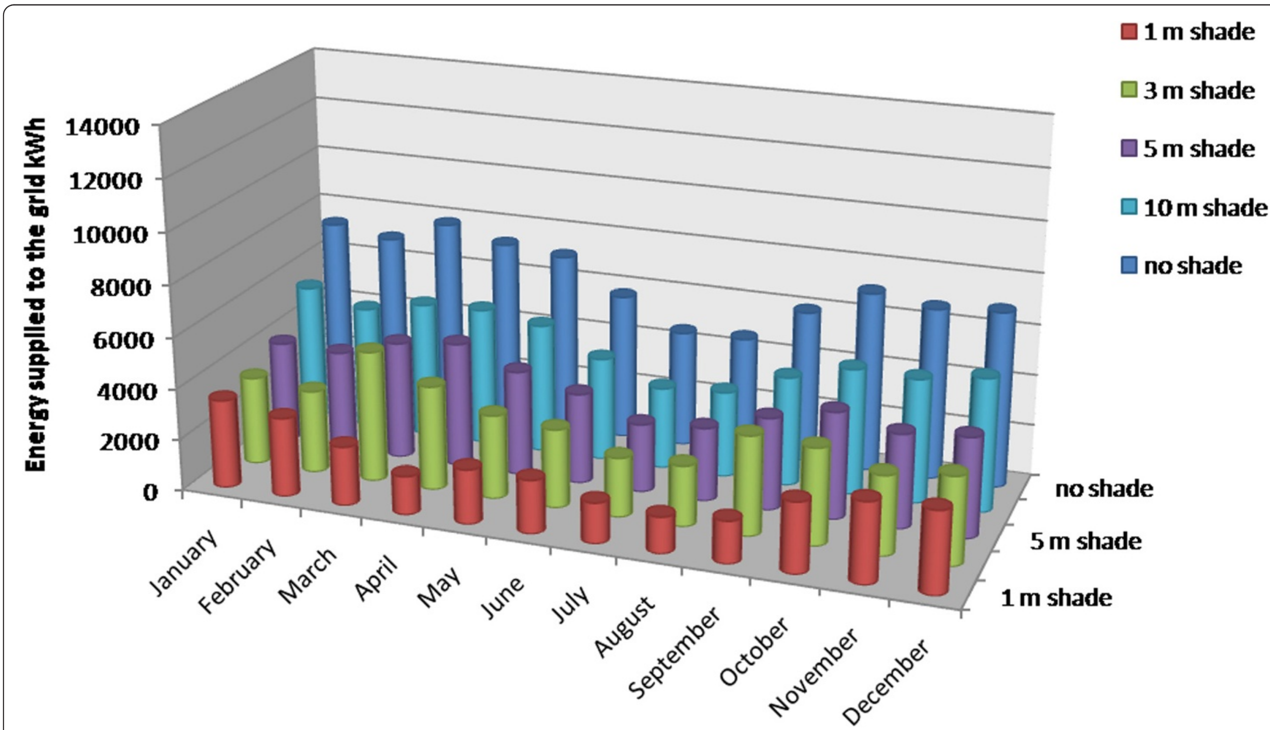

Figure 2 Monthly energy values supplied to the grid with or without the shade over the PV panels.

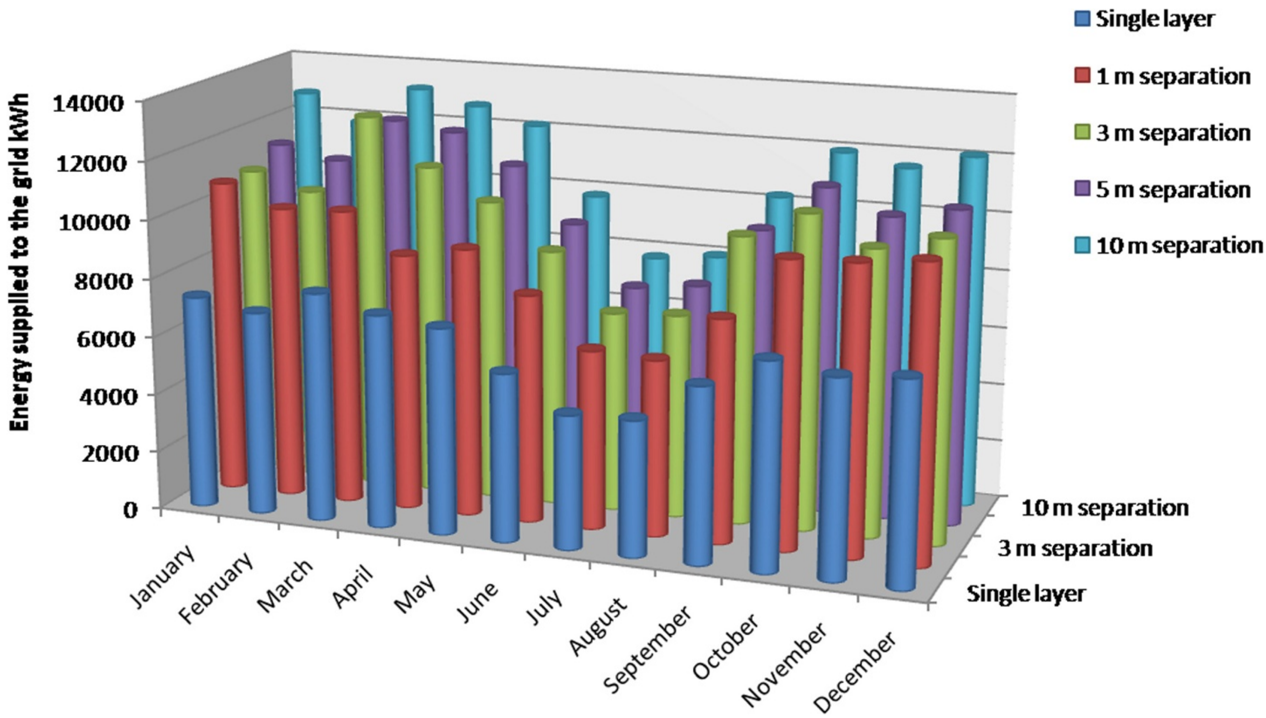

Figure 3 Monthly energy values supplied to the grid by two layer solar photovoltaic panels one above the other.

data averaged over a period of 20 years, are given in Table 7. It can be observed that the amount of energy enhanced with two layer photovoltaic panels increases with the increase in height between the panels. Obviously, the amount of energy supplied to the grid is higher for the two layer photovoltaic system as compared to single layer photovoltaic system. For example, in Figure 3 on *X*-axis, the histogram plot shows the amount of energy generated for the month of January to December. The cumulative energy yield for single and two layers system with different separations are presented as shown in the figure.

Results and discussion

In the following, the details of important results derived from our study are discussed and can be seen in Table 7 and also in Figures 4 and 5. The power output from a single layer solar photovoltaic system, with and without shade, and also for the two layer photovoltaic system separated by 1, 3, 5 and 10 m, are compiled and shown in Table 7. The results shown are for a single day i.e., December 20 and were averaged for the years 1980 to 2000. The increase in efficiency is observed for the two layer solar panels for a configuration presented in Figure 1. The result of two layer solar panels, one above the other, with different height separation between them, showed enhancement of the energy. The energy generation for no shade over the panels is about 250 kWh/day. For a single layer solar panel with shade at 10 m of height, (maximum in our study) the energy generation is about 190 kWh/day. By combining the power from the two panels, the net result increases its efficiency by

Table 7 Result of single solar panel with shade and two layer solar panels one above the other

Number	Height between the panels (meter)	Energy generated at the output of the array by single layer solar panels with shade (approximate kilowatt-hour per day)	Energy generated at the output of the array by two layer solar panels with different heights (approximate kilowatt-hour per day) (s. no.)	Increased in Efficiency for two layer solar panels with respect to single layer solar panel (approximate percentage)
1.	0[a]	252	-	-
2.	1	118	370(1 + 2)	46
3.	3	126	378(1 + 3)	50
4.	5	143	395(1 + 4)	56
5.	10	192	444(1 + 5)	76

[a]Single layer solar panel system.

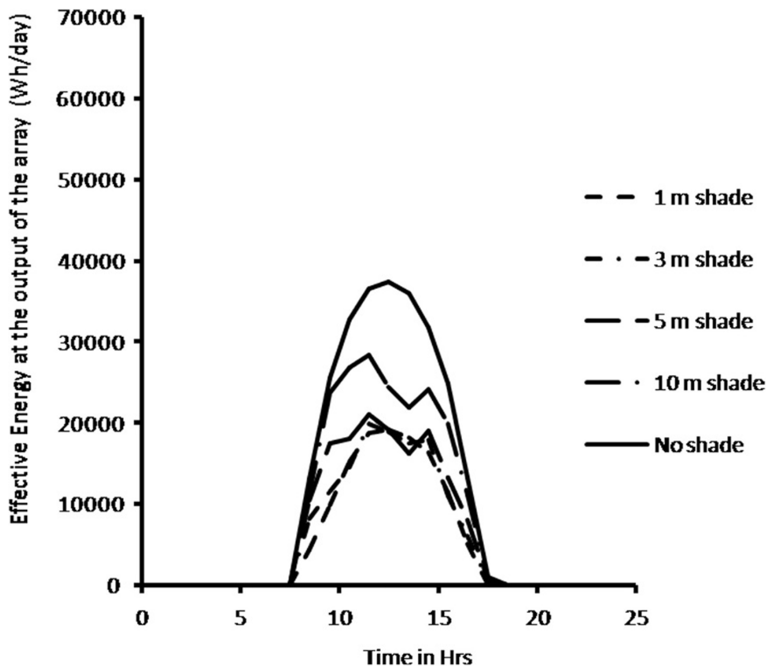

Figure 4 **Effective energy at the output of array for single layer solar panel with shade at different heights.**

approximately 76% as compared to the power generated by the single layer solar panel without shade. Similarly, one can see that the resultant increase in the efficiency is around 56% for 5 m height, around 50% for 3 m height, and 46% for the 1 m height between the solar panels. The reason for choosing this day (December 20) for modeling from Meteonorm radiation data [25] is due to its clear day in the month of December.

Figure 4 is a graphical plot of the effective energy at the output of array as a function of the local time of a day. In our case, we considered December 20 of Meteonorm radiation data averaged over a period of 20 years, 1981 to 2000. As can be observed from the figure, the obvious result that is closer the shade has less output. For example, for shade over the panel at a height of 1 m showed the lowest energy as compared to 3, 5, and 10 m. Figure 5 shows important result of enhancement in energy generation using two solar panels one above the other. As before, one can see that the enhancement increases with the height between the two layer solar panels. For 10 m height, considering a typical for a 50 + 50 kW photovoltaic system as an example, we observed as much as 65 kW peak around noon. In recent years, semi-transparent solar panels are also under way, and they pass on more solar energy to the bottom panels.

Although our study clearly demonstrates the enhancement of energy generation for the two layer solar panel system as compared to single layer, one should be careful about the cost economics involved for such a system. In Table 8, the economics of the two layer solar panel system have been compiled. The monetary benefit for two layer solar panel system over a single layer solar panel system is shown. For a 50 kW of system, we assumed the land cost (e.g., Ahmedabad, Gandhinagar, Rajkot in Gujarat) as 20 million Indian rupees (INR), module cost of 4 million INR, and 1 million INR for other accessories. Accordingly, single layer solar panel system provides about 10 kWh of energy per day per

Table 8 Monetary benefits

Number	Height between the panels (meter)	Land cost (in million INR)	Solar panel cost (in million INR)	Accessories (in million INR)	Energy generation per day (kWh approximate)	Output of energy per million investment (kWh/million INR/day)
1.	0[a]	20	4	1	252	10.1
2.	1	0	4	.5	370	12.5
3.	3	0	4	.6	378	12.7
4.	5	0	4	.8	395	13.2
5.	10	0	4	1	444	14.8

[a]Single layer solar panel system.

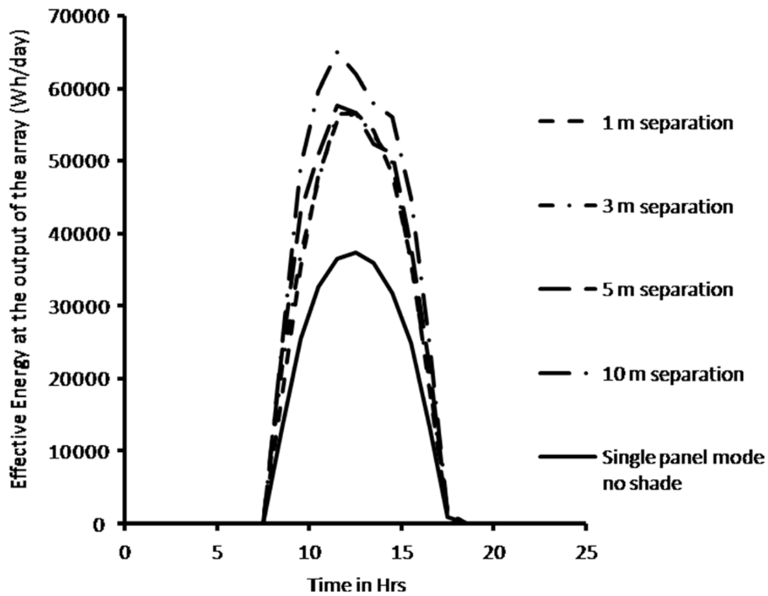

Figure 5 **Effective energy at the output of array for two layer solar panel.**

million INR of investment. For the two layer of solar photovoltaic system, as the area remains same the land cost are zero. But for the two layer, the added expenditure are the solar panels and other mounting accessories. Thus for 10 m separation one can have 14.8 kWh/million (INR)/day, which is nearly 50% extra benefit for the one million INR investment.

Conclusions

An attempt has been made in our study on near shade analysis of single and two layer solar panels through modeling for a limited dimension. The energy generation from a single layer solar panel system for a day (December 20 as a sample) is 252 kWh/day for 756 sq m area. It increases up to nearly 445 kWh/day with the two layer solar panels separated by 10 m in the same area. The output varies depending on the separation between the two layers of photovoltaic panels. Due to high land cost in urban areas, the present study is significant. We have shown an increase of over 70% in the output. The present modeling results are limited to the two layer PV system with opaque modules as solar energy collectors for small dimensions as shown in Figure 1. Our result is more applicable to roof tops of the houses or small scale plants. The study, however, can easily be extended to the n layer solar PV panel system of any dimension. However, the justification of the plant cost with respect to solar panels need to be considered. Thus, one needs to have an optimal cost in designing the number of solar panel layers. It should also be based on the foundations of the site location.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
PS carried out all the computation, system designing, modeling analysis, software simulation, and drafted the manuscript. TH conceived of the study and participated in its design and coordination. Both authors read and approved the final manuscript.

Authors' information
PS, a M. Sc., M. Tech, Research Associate, Solar Research Wing, is involved in research and development program of solar energy technology in GERMI Research Innovation and Incubation Centre (GRIIC), Gujarat, India with more than three and a half year of experience in the field of solar photovoltaic. She is an M. Tech. from School of Energy, Devi Ahilya Vishwavidyalaya (DAVV), Indore, India. She has also done M. Sc. in Physics. She has worked with a dedicated unit from the Ministry of New and Renewable Energy Government of India, Solar Energy Center on 'Design and Development of 20 kWp roof top PV power plant at SEC', in Gurgaon, India. She has presented her research work in various national and International conferences.
TH, a Ph.D, Director of GRIIC, Gujarat and earlier as Head of Magnetotellurics, National Geophysical Research Institute, has done outstanding contributions in the field of deep electromagnetics both on land and also in marine environment. TH is one of the top scientist among the geomagnetism and electromagnetic scientists in the world. His pioneering works are related to oil exploration, geothermal energy assessment, deep crustal studies, tsunami studies, earthquake studies, etc. He is instrumental in introducing a new geophysical technique - marine magnetotellurics - in Gulf of Kutch for hydrocarbon exploration that has delineated 4 km thick buried sediments below the volcanic cover. This work was initiated as a part of international cooperation with Scripps Institution of Oceanography, USA. This has opened up a new scenario of search for oil in the Gulf. He has received a National Mineral Award from Ministry of Mines, Government of India at an early age of 40. He was chosen as the best scientist by Government of Andhra Pradesh. He was elected to the prestigious Russian Academy of Natural Sciences, in Moscow, Russia. He is an elected fellow of the Indian Geophysical Union and Fellow of Andhra Pradesh Academy of Sciences. He has taken up controlled source electromagnetic modeling studies for gas hydrates as a part of his research at University of Texas at Austin, USA as a visiting scientist and also carried out tsunami studies at University of Tokyo, Japan as a visiting professor.

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Author details
[1]GERMI RIIC (Research and Innovation Centre), Gandhinagar, Gujarat 382007, India. [2]CSIR-NGRI (National Geophysical Research Institute), Hyderabad 500007, India.

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