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The Required Land Area for Installing a Photovoltaic Power Plant

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ABSTRACT

Till now the conversion efficiency of the commercial photovoltaic (PV) solar modules is in the range of 14 to 20%. Therefore, PV power plants need very large area to achieve the desired output power. This paper presents some proper calculations to estimate land area occupied by the PV array. Calculations for the minimum and the maximum land area for a range of PV array with power capacity from 1 to 250 kW for different latitudes in the northern hemisphere were presented. Six different PV modules were selected for the calculation. A group of correlations are presented to roughly estimate both the land area and the number of PV modules per row as a function of the total power capacity required. In addition, correlations suggested to calculate the spacing between the rows in the PV array as a function of local latitude.

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INTRODUCTION

After 2002, the world primary energy demand increased 1.7% per year and it is expected to expend more than 50% at 2030 [1]. It is probable that the main global energy generation will remain continuously dominated by fossil fuel. Lately, as a result of the alertness of climate changes and global warming, governments are concerned of the carbon dioxide emissions rates and fossil fuel consumptions. Hence, clean renewable energy resources must play an important role and take part in the global energy in the forthcoming future [2]. However, investigations and predictions results showed that the share of energy from fossil fuel sources will be more than renewable energy sources over the course of the next two decades because of some reasons, one of them is the high cost of renewable energy power plants compared to conventional power plants [3].

Solar energy attracted the world's attention as it is a promising option of renewable energy. The sun radiates enormous amount of electromagnetic radiation as known as solar energy. Solar cells can convert the solar energy directly into electrical power via a phenomenon described as photovoltaic (PV) effect. The energy conversion process is static, silent, free of moving object, safe, does not need high supervision and most importantly does not have any damaging impact to the environment. Therefore, the annual growth of the world PV industry has reached an average of 30% during the past decade [4, 5]. PV power generators can be classified into stand-alone systems and grid-connected generators [6].

The output power characteristics of the PV cell, module or array is influenced by the amount of solar irradiance, cell temperature, tilt angle and the operating condition. However, the electricity generation is mainly affected by the amount of incident solar irradiance. The amount of incident radiation on the PV module determines the total generation of electron-hole pairs; hence the generated current in the PV module. Therefore, any obstruction that blocks the solar radiation from falling on the module (i.e. shading) should be avoided. Shading just one corner of a PV module can cut production in high percentage [7]. The shaded cells may get reverse biased, acting as loads, draining power from fully illuminated cells. Therefore, recently the impact of partial shadowing on the energy yield of PV systems has been widely discussed [8-18]. In PV arrays, where the PV modules are arranged in rows (strings), there is a high possibility for row-row shading, so avoiding the shade on the array is important. González [19] studied three

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different systems containing 4 to 9 PV modules with applying different modes of partial shade, even the shade from electrical cables in front of the modules. It was found that a 1kW string of 9 poly-crystalline silicon modules can have a power loss of 13% due to shading just 1% of its surface area. On the other hand, the spaces between of the rows should be kept as small as possible to keep the total land (ground area) in reasonable limits and not based on arbitrary decisions. The designer must have an idea about the sun path along the year to be away from row-to-row shading.

Selection of PV modules (especially the module efficiency) may play an important role in determining the area required for a PV power plant, the higher the efficiency the less the land area. Also, PV panels with tracking systems produce approximately 20% more energy on a yearly basis than the fixed ones. But, in terms of land occupation, fixed PV field requires about half of the area necessary for a tracker PV system. Therefore, it can be concluded that for a large utility scale PV plant, the fixed PV field arrangement should be preferable when land impact is considered [20].

In spite of that the main aim of this paper is to study and estimate the land area for a PV power plant, it still useful to take a look for the main characteristics that need to be considered in selecting the suitable site for installing a practical solar PV power generation project [21]:

- Solar resource – abundance in global horizontal irradiation.
- Local climate – extreme temperatures, high winds, flooding, snow.
- Available area – depending on the type and efficiency of the PV module, access requirements.
- Land use – this will impact land cost and environmental sensitivity.
- Topography – flat or slightly sloped to the south are preferable in the northern hemisphere.
- Geotechnical – including consideration of groundwater, resistivity, soil pH levels and seismic risk.
- Accessibility – proximity to existing roads, extent of new roads required.
- Grid connection – cost, timescales, capacity, proximity and availability.
- Module soiling – including local weather, environmental, human and wildlife factors.
- Water availability – a reliable supply is required for module cleaning.
- Financial incentives – tariffs and other incentives vary between countries and regions within countries.

It is preferred to install the PV modules over the ground with some height to avoid any dirt, snow or water accumulation on the lower edge of the modules, also to allow the air to flow below the modules. The air flow assists to give a cooling and ventilation effect which reduces the modules' temperature hence enhances the electrical performance.

PV power generation arrays mostly installed with two modes, the first mode is horizontal PV array (ground mounted) which is the most common for large power capacity. The second mode is the vertical PV which are installed usually on the buildings facades also considered from the building integrated PV systems (BIPV).

In literature review, Häberlin [22] suggested a rough estimation, that the field (land) required for a ground-based or rooftop PV generator equals the total area the PV modules multiplied by a factor named a land factor (between around 2 and 6 in Central Europe) for shading avoidance in cases where a series of solar generators are arranged behind each other in a large installation [22].

The land area required for a specific total power capacity depends on two main factors. The first is the efficiency of PV modules and the second is the row-row spacing to avoid shading which depends on the slope of the PV modules row, local latitude and the time in the year. The aim of this paper is to study the land area for a specific PV array/power plant in different latitudes in the northern hemisphere and for six different PV modules manufacturers. That will be done through a calculating the row-row spacing and the total number of the PV modules needed for installation.

MATERIAL AND METHODS

The conversion efficiency of a solar PV module is relatively low, in addition to that most locations for solar power applications expected to get around 5 to 7 net effective sunny hours per day; therefore, anything that reduce the received solar radiation must be avoided. To avoid the shading of the rows (sometimes called strings) as much as possible, the calculations has to be done for a low sun level, in this modeling at 9AM. Two different dates or seasons will be studied to compare their effect on the land area:

1. Maximum land area in winter solstice (21 December).

2. Minimum land area for both seasonal equinoxes, vernal equinox (21 March) and autumnal equinox summer (21 September).

This model is specified only for northern hemisphere and from 5º to 55º latitude with 5º (Fig. 1). For a PV array with a single line of PV modules per row, is shown in Fig. 2. There are other ways of setup structure with two or three lines per row.

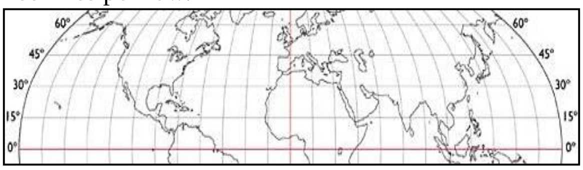

Figure. 1. World map illustrates the studied latitudes

Figure 2. Examples for single line and double lines of PV modules per row

A several assumptions will be considered in the hypothetical PV power plants and listed below:

- Fixed non-tracking PV module oriented due to south
- Fixed with the optimum annual tilt angle equal to the local latitude [23, 24]
- Sun window (sunny hours per day) from 9:00AM to 15:00PM
- Square shaped land area
- Single line of PV modules per row
- Designed for solar radiation 750W/m^2
-

First step in the modelling is to calculate the total number of PV modules required for a specific power capacity. The second step is to determine the shadow length or the spacing between rows to avoid shading. Finally, calculation the square land area and the number of PV module per row to achieve the square shape.

Number of PV modules

The Commercial PV modules are tested to give a certain rated power at standard test conditions with (1000W/m^2 solar radiation 25ºC cell temperature 1.5 Air Mass). As long as the solar radiation is not constant at 1000W/m^2 and considering the cloudy days, the solar radiation assumed to be less than 1000W/m^2 and in this study equals to 750W/m^2. To calculate the total number of PV modules N:

$$N = \frac{P_t}{P_m} = \frac{P_t}{\eta_m A_m\ G} = \frac{P_t}{750\ \eta_m A_m} \tag{1}$$

Where P_t is the total installation power capacity in Watts, η_m is the module efficiency at standard test conditions, A_m is the module area in m2 and G is the incident solar radiation in W/m2. The total number of PV modules equals the number of row n_r multiplied by number of PV modules per row n_m:

$$N = n_r \times n_m \tag{2}$$

Spacing between rows

The sun position in the sky with respect to a point on earth can be exactly specified by two angles, the sun altitude (α) and the solar azimuth (z) [25]. These two angles as given in Eqs. (3) and (4), respectively. It depends directly on the time of the day and the season (or the sequence of the day in the year, n):

$$\sin\alpha = \sin\varphi\ sin\,\delta + cos\varphi\ cos\delta\ \cosh \tag{3}$$

$$\sin z = \cos\delta\ \ sinh\ /\ cos\alpha \tag{4}$$

Where, δ is the declination angle which is the angle between the direction of the sun and the plane of orbit of the earth around the sun [25].

$$\delta = 23.45°\ sin\left[\frac{360}{365}(n + 284)\right] \tag{5}$$

For 21 December (winter solstice) δ equals to -23.45º and 0º for 21 March (winter solstice). Where the h is the hour angle, which is the angle through which the earth has rotated since solar noon.

$$h = (local\ time - 12) \times 15° \tag{6}$$

This calculation is done for 9:00AM, then the hour angle equals -45º. After finding the solar altitude and azimuth angles, the calculations to determine row spacing can begin. First we need to determine the horizontal projection X and vertical projection Y of the PV module as defined by Eq. (7), respectively:

$$X = L_m\ cos\beta \quad , \quad Y = L_m\ sin\beta \tag{7}$$

Where, L_m is the module length As assumed, the tilt angle of the modules with the ground equals the local latitude. Using the module vertical projection in Fig. 3, the shadow length (the distance between two rows in the direction of the sun) D_s which can be measured as the difference in height between the bottom/leading edge of one row and the maximum height of the next row south of it (Fig. 4) [26]:

$$D_s = \frac{Y}{\tan\alpha} \tag{8}$$

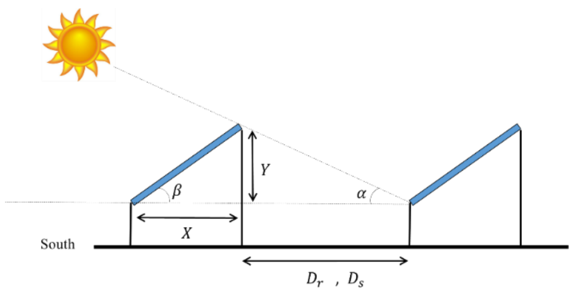

Figure 3. Side view of tilted PV row

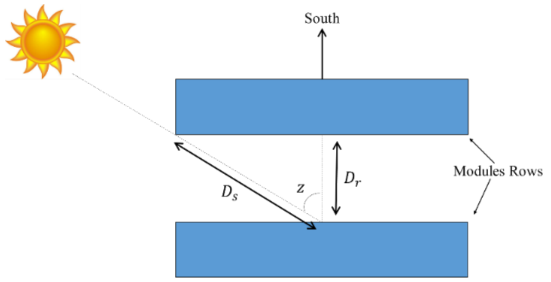

Figure 4. Top view of tilted PV row

While the spacing between the rows (the distance between two rows in the south direction)D_r as shown in Fig. 4 is given by the following expression:

$$D_r = D_s \cos z \ (9) \tag{9}$$

Total land area

The total installation land area A_L for a PV power plant is assumed to be square. Therefore, the total width W_t and the total length L_t of the land are equaled.

$$A_L = W_t \times L_t \tag{10}$$

The total width of the square is given by:

$$W_t = n_m W_m \tag{11}$$

Where, W_m is the width of the PV module From Fig .4 the total length is summation of the horizontal projection of the modules and the spacing between rows,

$$L_t = n_r X + (n_r - 1) D_r \tag{12}$$

To determine the number of PV modules per row, $L_t = W_t$:

$$n_m W_m = n_r X + (n_r - 1) D_r \tag{13}$$

By substituting Eq. (2) with Eq. (13) we get a quadratic equation should be solved to get its roots:

$$W_m n_m^2 + D_r n_m - N(X + D_r) = 0 \tag{14}$$

TABLE 1.

Manufacturer	SunPower	LG	Helios Solar Works	Panasonic	REC [1]	SHARP
Model	SPR-333NE-WHT-D	LG300N1C	6T-250	HIT Power 220A	REC 235 PE	ND-200U1
Module Efficiency, %	20.4	18.3	15.06	19.8	14.2	12.3
Dimensions, mm	1559 x 1046	1640x 1000	1680 x 990	1580 x 798	1665x991	1640 x 994
Maximum power, W	333	300	250	220	235	200
PV cell type	mc-Si [2]	mc-Si	mc-Si	HIT [3]	pc-Si [4]	pc-Si

[1]Renewable Energy Corporation.[2]mono-crystalline silicon. [3]Heterojunction with intrinsic Thin-layer.4poly-crystalline silicon

Six different commercial solar PV modules from different manufacturer were selected randomly to imply the modelling. Three of them are mono-crystalline silicon with efficiency range from 15-20%, two are poly-crystalline silicon and the sixth one is Hetero-junction with intrinsic Thin-layer PV module.

RESULTS AND DISCUSSION

For each PV module, the spacing between two rows was calculated from Eq. (9) for each local latitude, the results are tabulated in Table 2 for both studied cases. In winter, for latitudes above 50°, D_r reached greater than 8m because of the extremely low altitude of the sun (6.4°) at the chosen morning time. So another time must be selected let us say 10:30AM and recalculate or the PV power generation is not efficient and feasible at all for those cases.

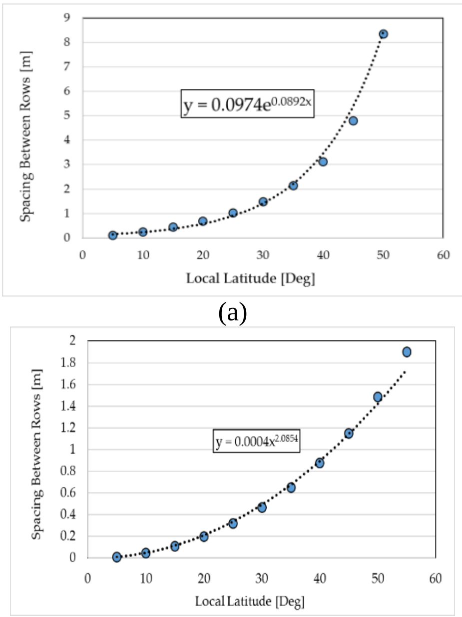

Figure 5. Average spacing between two rows for 5° to 55° local latitudes: (Left) winter solstice (Right) equinoxes

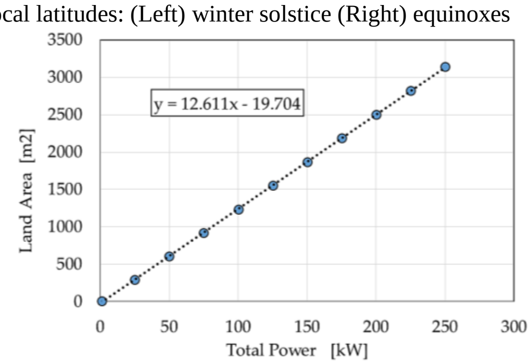

Figure 6. The maximum land area required as a function of the total power for Sun Power module and 33° latitude

Table 2. Spacing between rows for the selected module at different latitudes, winter solstice

	Sun Power	LG	Helios	Panasonic	REC	SHARP	Average
5	0.101	0.106	0.108	0.102	0.107	0.106	0.105
10	0.24	0.252	0.258	0.243	0.256	0.252	0.25
15	0.426	0.448	0.459	0.431	0.455	0.448	0.444
20	0.671	0.706	0.723	0.68	0.717	0.706	0.7
25	0.997	1.048	1.074	1.01	1.064	1.048	1.04
30	1.437	1.512	1.549	1.457	1.535	1.512	1.5
35	2.059	2.166	2.219	2.087	2.199	2.166	2.15
40	3	3.156	3.233	3.04	3.204	3.156	3.131
45	4.602	4.841	4.959	4.664	4.915	4.841	4.804
50	8.018	8.435	8.641	8.126	8.563	8.435	8.37
55	21.052	22.146	22.686	21.335	22.483	22.146	21.974

Table 3. Spacing between rows for the selected module at different latitudes, the equinoxes

	Sun Power	LG	Helios	Panasonic	REC	SHARP	average
5	0.0119	0.0125	0.0128	0.0120	0.0127	0.0125	0.0124
10	0.0477	0.0502	0.0514	0.0484	0.0510	0.0502	0.0498
15	0.1081	0.1137	0.1165	0.1096	0.1155	0.1137	0.1129
20	0.1941	0.2042	0.2091	0.1967	0.2073	0.2042	0.2026
25	0.3072	0.3232	0.3311	0.3114	0.3281	0.3232	0.3207
30	0.4500	0.4734	0.4850	0.4561	0.4806	0.4734	0.4698
35	0.6261	0.6587	0.6747	0.6346	0.6687	0.6587	0.6536
40	0.8409	0.8846	0.9061	0.8522	0.8980	0.8846	0.8777
45	1.1024	1.1597	1.1879	1.1172	1.1773	1.1597	1.1507
50	1.4233	1.4972	1.5337	1.4424	1.5200	1.4972	1.4857
55	1.8238	1.9186	1.9654	1.8484	1.9478	1.9186	1.9038

For most locations the solar radiation is abundant in the summer time where the sunny non-cloudy days and wide sun window. So the equinox was chosen for designing and sizing the minimum area for the installation land. For the same latitudes above 50º, at the equinoxes the solar altitude at 9:00AM is (27º) which is acceptable for designing a PV power array becauseof D_r is about 1.4 to 2m. It is important to notify that D_r values in Table 4 for latitudes 45º is practically not valid and 1 to 1.5m must be added to let a space for installation and maintenance team to move between the rows.

The average values of D_r are plotted against the local latitude and the following correlations are extracted from the best curve fitting equations:

$A_{L,maximum}$:

$$D_r = 0.0974\, exp(0.0892\, \varphi); \;\; for \;\; 5° < \varphi < 50° \quad (15.\text{a})$$

$A_{L,minimum}$:

$$D_r = 0.0004\varphi^{2.0854} \;\; ; \; for \;\; 5° < \varphi < 55° \quad (15.\text{b})$$

For each PV module, the land area was calculated from Eq. (10); for a power capacity range from 1 to 250kW, the results are tabulated in Tables 4 and 5 for both studied cases. Plotting the land area with respect to the total power capacity (see Fig. 6) revealed as expected that A_L has a linear relationship with the P_t. Tables 4 and 5 contain the values of the constants of the linear curve fitting equation (15. a and b) as follows:

$$A_L = a\, P_t - b \qquad (16)$$

Fig. 7 shows a comparison between A_L in winter solstice

Table 4. Maximum land area linear equation constants, Eq. (16) for the selected modules at different latitudes, in the winter solstice

	Sun Power		LG		Helios Solar Works		Panasonic		REC		SHARP	
	a	b	a	b	a	b	a	b	a	b	a	b
5	6.918	-0.285	7.710	-0.426	9.369	-0.376	7.128	0.102	9.942	0.340	11.480	0.558
10	7.406	1.028	8.254	1.019	10.032	1.264	7.631	1.474	10.646	2.061	12.296	2.395
15	8.032	2.894	8.951	3.073	10.883	3.597	8.276	3.420	11.551	4.504	13.343	5.003
20	8.847	5.535	9.860	5.979	11.990	6.902	9.116	6.169	12.728	7.957	14.708	8.694
25	9.931	9.323	11.069	10.151	13.465	11.650	10.233	10.109	14.296	12.913	16.525	13.995
30	11.423	14.940	12.732	16.341	15.495	18.701	11.771	15.944	16.454	20.266	19.028	21.866
33	12.611	19.704	14.056	21.591	17.111	24.689	12.995	20.889	18.173	26.505	21.022	28.551
35	13.576	23.747	15.131	26.048	18.424	29.774	13.989	25.083	19.570	31.801	22.643	34.230
40	16.913	38.829	18.851	42.679	22.969	48.773	17.428	40.713	24.404	51.572	28.257	55.449
45	22.718	68.687	25.322	75.623	30.880	86.475	23.409	71.616	32.825	90.764	38.042	97.581
50	35.207	146.040	39.244	161.050	47.929	184.490	36.278	151.550	9.942	0.340	59.178	207.280
55	81.442	545.910	90.794	603.330	111.300	695.050	83.923	564.010	10.646	2.061	138.200	782.110

Table 5. Minimum land area linear equation constants, Eq. (16) for the selected modules at different latitudes, in the equinoxes

	Sun Power		LG		Helios Solar Works		Panasonic		REC		SHARP	
	a	b	a	b	a	b	a	b	a	b	a	b
5	6.558	-1.074	7.309	-1.293	8.881	-1.360	6.758	-0.727	9.424	-0.699	10.880	-0.553
10	6.629	-0.749	7.388	-0.934	8.978	-0.955	6.831	-0.390	9.526	-0.279	10.999	-0.106
15	6.750	-0.196	7.523	-0.325	9.143	-0.265	6.956	0.183	9.702	0.436	11.203	0.655
20	6.927	0.604	7.720	0.557	9.383	0.734	7.138	1.012	9.957	1.472	11.499	1.757
25	7.166	1.679	7.987	1.743	9.709	2.079	7.385	2.127	10.304	2.867	11.901	3.242
30	7.480	3.076	8.337	3.282	10.136	3.826	7.708	3.575	10.758	4.680	12.428	5.175
33	7.710	4.095	8.593	4.405	10.449	5.102	7.945	4.630	11.090	6.004	12.815	6.587
35	7.884	4.860	8.786	5.249	10.685	6.061	8.123	5.424	11.342	6.999	13.106	7.650
40	8.400	7.133	9.362	7.754	11.388	8.909	8.656	7.780	12.090	9.959	13.974	10.811
45	9.064	10.050	10.102	10.970	12.291	12.569	9.339	10.804	13.050	13.763	15.089	14.878
50	9.925	13.859	11.062	15.169	13.464	17.354	10.227	14.752	14.298	18.737	16.537	20.204
55	11.066	18.972	12.334	20.807	15.017	23.785	11.403	20.052	15.951	25.426	18.455	27.371

and the equinoxes for the six studied module, at 33º latitude and 100kW total power. The land area at 21 December is approximately twice the required A_L in the equinoxes. The values in this figure is very useful for fast, rough estimation for installing any PV power plant for any countries lies on ~33º Latitude such as Iraq, Jordan, Iran, Syria, Tunisia, Libya, Morocco, south of USA, Afghanistan, Pakistan, Algeria, Japan, People's Republic of China and north of India.

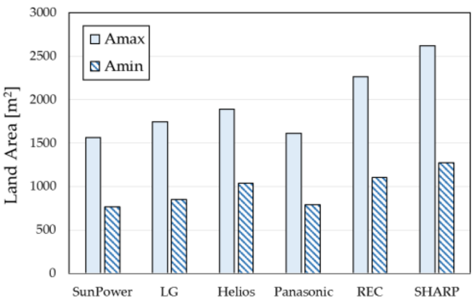

Figure 7. The required land area for the selected modules to generate 100kW power at 33º latitude: (Left) winter solstice (Right) equinoxes

Table 6. Quadratic equation constants of number of modules per row, Eq. (17) for the selected modules at different latitudes, in the winter solstice

	Sun Power			LG			Helios		
	c	d	e	c	d	e	c	d	e
5	5.1174	0.2417	0.0004	5.565	0.2683	0.0005	6.1968	0.2988	0.0005
10	5.2383	0.2504	0.0004	5.6958	0.278	0.0005	6.3477	0.3095	0.0006
15	5.3834	0.2612	0.0005	5.8526	0.2899	0.0005	6.5294	0.3228	0.0006
20	5.5605	0.2746	0.0005	6.0441	0.3048	0.0005	6.7514	0.3394	0.0006
25	5.7811	0.2915	0.0005	6.2828	0.3236	0.0006	7.0283	0.3603	0.0006
30	6.0629	0.3133	0.0006	6.5877	0.3478	0.0006	7.3821	0.3873	0.0007
33	6.2724	0.3296	0.0006	6.8146	0.3659	0.0007	7.6453	0.4075	0.0007
35	6.4342	0.3423	0.0006	6.9899	0.38	0.0007	7.8487	0.4232	0.0008
40	6.9458	0.3831	0.0007	7.5444	0.425	0.0008	8.4923	0.4737	0.0008
45	7.6994	0.4452	0.0008	8.3622	0.4941	0.0009	9.4429	0.5507	0.001
50	8.9483	0.5559	0.001	9.7197	0.6169	0.0011	11.028	0.6881	0.0012
55	11.651	0.8466	0.0015	12.668	0.9389	0.0016	14.522	1.0503	0.0018
	Panasonic			**REC**			**SHARP**		
	c	d	e	c	d	e	c	d	e
5	6.6865	0.3234	0.0006	6.303	0.3083	0.0006	6.7546	0.3302	0.0006
10	6.8432	0.335	0.0006	6.4585	0.3194	0.0006	6.9276	0.3421	0.0006
15	7.0311	0.3494	0.0006	6.6458	0.3332	0.0006	7.1365	0.3568	0.0006
20	7.2606	0.3673	0.0007	6.8749	0.3503	0.0006	7.3925	0.3752	0.0007
25	7.5465	0.3899	0.0007	7.1608	0.3719	0.0007	7.712	0.3983	0.0007
30	7.9118	0.4191	0.0007	7.5261	0.3997	0.0007	8.1205	0.4282	0.0008
33	8.1836	0.4409	0.0008	7.7981	0.4206	0.0008	8.4246	0.4506	0.0008
35	8.3936	0.4579	0.0008	8.0082	0.4369	0.0008	8.6597	0.4681	0.0008
40	9.0578	0.5124	0.0009	8.6736	0.489	0.0009	9.4043	0.524	0.0009
45	10.037	0.5954	0.0011	9.6576	0.5686	0.001	10.508	0.6096	0.0011
50	11.662	0.7433	0.0013	6.303	0.3083	0.0006	12.363	0.7626	0.0014
55	15.187	1.1312	0.002	6.4585	0.3194	0.0006	16.549	1.1683	0.0021

As aforementioned, the land area assumed to take a square shape. Therefore, it is useful to know the number of rows and the number of PV modules per row. The solution of Eq. (14) is plotted against the total power capacity as shown in Fig. 8 and the curve fitting is a second order polynomial with constants (c, d and e):

$$n_m = c + d\,P_t - e\,P_t^2 \quad (17)$$

Then, the number of rows is:

$$n_r = N - n_m \quad (18)$$

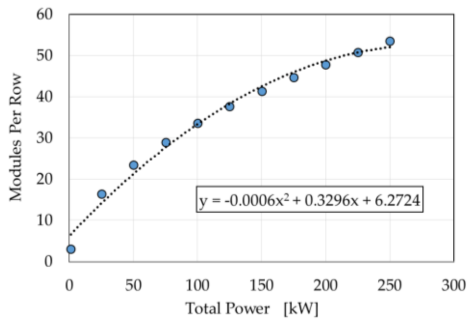

Figure 8. The number of modules per row as a function of the total power for SunPower module

Table 7. Quadratic equation constants of number of modules per row, Eq. (17) for the selected modules at different latitudes, in the equinoxes

	Sun Power			LG			Helios		
	c	d	e	c	d	e	c	d	e
5	5.019	0.2351	0.0004	5.4586	0.261	0.0005	6.0747	0.2906	0.0005
10	5.0309	0.2365	0.0004	5.4713	0.2626	0.0005	6.0903	0.2923	0.0005
15	5.0514	0.2388	0.0004	5.4933	0.2651	0.0005	6.1172	0.2951	0.0005
20	5.0818	0.2421	0.0004	5.5258	0.2688	0.0005	6.1	0.2992	0.0005
25	5.1237	0.2465	0.0004	5.5708	0.2737	0.0005	6.2112	0.3047	0.0005
30	5.1793	0.2521	0.0004	5.6306	0.2799	0.0005	6.2832	0.3116	0.0006
33	5.2206	0.2562	0.0005	5.675	0.2844	0.0005	6.3364	0.3166	0.0006
35	5.252	0.2592	0.0005	5.7088	0.2877	0.0005	6.3766	0.3204	0.0006
40	5.3457	0.2679	0.0005	5.8098	0.2974	0.0005	6.4966	0.3312	0.0006
45	5.4662	0.2787	0.0005	5.9399	0.3094	0.0006	6.6501	0.3446	0.0006
50	5.6211	0.2922	0.0005	6.1074	0.3243	0.0006	6.8467	0.3612	0.0006
55	5.8214	0.309	0.0005	6.3242	0.343	0.0006	7.1002	0.382	0.0007
	Panasonic			**REC**			**SHARP**		
	c	d	e	c	d	e	c	d	e
5	6.5588	0.3146	0.0006	6.1776	0.3	0.0005	6.6161	0.3212	0.0006
10	6.574	0.3164	0.0006	6.194	0.3017	0.0005	6.6353	0.3231	0.0006
15	6.6003	0.3195	0.0006	6.2222	0.3046	0.0005	6.6684	0.3262	0.0006
20	6.6391	0.3239	0.0006	6.2637	0.3088	0.0006	6.7169	0.3307	0.0006
25	6.6928	0.3298	0.0006	6.3206	0.3144	0.0006	6.7829	0.3368	0.0006
30	6.7643	0.3373	0.0006	6.3958	0.3216	0.0006	6.8697	0.3445	0.0006
33	6.8174	0.3427	0.0006	6.4512	0.3268	0.0006	6.9335	0.35	0.0006
35	6.8578	0.3467	0.0006	6.4931	0.3307	0.0006	6.9816	0.3541	0.0006
40	6.9786	0.3584	0.0006	6.618	0.3418	0.0006	7.1242	0.3661	0.0007
45	7.1343	0.3729	0.0007	6.7774	0.3556	0.0006	7.3054	0.3809	0.0007
50	7.3347	0.3908	0.0007	6.9814	0.3728	0.0007	7.5361	0.3994	0.0007
55	7.5943	0.4134	0.0007	7.244	0.3944	0.0007	7.8319	0.4225	0.0008

All The results and correlations presented is for the minimum number of PV modules. More PV modules installed, better the system will perform. If less number of PV modules are installed, the system may not be sufficient at all during cloudy periods.

CONCLUSION

In this paper, a theoretical study and mathematical modelling is presented for estimating the land required for the installation of a PV array/power plant to produce a specific power capacity. The area is highly dependent on the total power capacity (linear relationship) also depends on the spacing between rows which is determined based on the slope of the PV module, time in the day, time throughout the year (season) and finally the local latitude. The spacing between rows found to be increasing exponentially in winter solstice as we go north from the equator. But in the equinoxes, the spacing increases with a second order power function.

Several correlations ready to implement for fast, acceptable estimation for the followings:

1. The spacing between rows as a function of the local latitude.
2. Total land area required for a square ground mounted PV power plant as a function of power capacity.
3. Number of PV modules per row as a function of the total power capacity.

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Persian Abstract

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چکیده

تا کنون راندمان تبدیل یک صفحه خورشیدی تجاری فتوولتائیک در حدود ۱۴ تا ۲۰ درصد می¬باشد. بنابراین نیروگاه¬های فتوولتائیک برای توان خروجی مورد نظر به یک ناحیه بزرگ احتیاج دارند. در این مقاله محاسبات مناسب برای تخمین مساحت مورد نیاز برای آرایه صفحات خورشیدی ارائه شده است. محاسبات در حداقل و حداکثر مساحت زمین برای یک محدوده از آرایه فتوولتائیک با ظرفیت توان ۱ تا ۲۵۰ kw برای عرض جغرافیایی مختلف در نیمکره شمالی ارائه شد. شش صفحه فتوولتائیک مختلف برای محاسبه انتخاب شدند. یک سری از رابطه ها به منظور تخمین سردستی مساحت زمین و تعداد صفحات خورشیدی در هر ردیف به عنوان تابعی از ظرفیت توان کل مورد نیاز ارائه شده است. به علاوه رابطه¬ها به محاسبه فاصله بین ردیف¬ها در آرایه فتوولتائیک به عنوان تابعی از عرض جغرافیایی محلی اشاره می¬کند