International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 11 (2019), pp. 1978-1985

Optimum Photovoltaic Solar Cells Area Estimation for Feeding Micro-Grid Loads

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Abstract

Optimum solar cells area depends on the tilt angle of the panel concerning the horizontal plane. The tilt angle determines the amount of solar insolation on the panel surface, and the intern determines the quantity of energy collected. Conventionally the best tilt angle is equivalent to latitude of the location at which the installed panel. The value of optimal tilt angle at a defined area depends on the local atmospheric conditions, the altitude of the region, movement of the sun, etc. The solar cell panel output power is profoundly affected by the sunlight incident angle, and its efficiency can be improved if the solar-cell panel correctly installs with the optimum angle. The relationship between the sunlight incident angle and the sunlight radiation intensity on the optimum solar-cell area presents in this paper. Climatic data are utilized to calculate the optimum number of the solar-cell panel for different locations.

Keywords: Orientation, Solar power generation, Solar radiation, optimum solar cell area, Optimal Tilt Angle

I. INTRODUCTION

The solar energy emerges from the fusion reaction of four hydrogen nuclei into one helium nucleus. The intensity of the ar radiation absorbed at the earth's surface mainly depends on (a) insolation at the earth's surface and (b) properties of the earth's surface. Various factors that affect the output of a complete solar PV system depend upon the factors affecting the production of a single solar cell and a solar panel as well. Different parameters, such as cell temperature, energy conversion efficiency, and the maximum power point tracking, affect the output of a single solar cell. The factors which mainly concern the production of a solar panel are orientation and tilt angle of the solar panel [1]. For the minimum cost, it will be necessary to determine the correct size. It is noting that the design should be done on meteorological data, solar irradiance, and the exact load profile of consumers over long periods [2].

The solar energy reaching a solar PV array on the earth surface consists of the main beam which is direct radiation, the diffused glow which is direct radiation affected by atmospheric absorption and the ground reflected beam which is as a result of the reflection of the direct beam from the earth surface as shown in the Figure 1.

Figure 1 shows that not all the radiation released by the sun will reach the solar PV array surface placed on the earth. It makes the orientation of the solar PV array significant for energy absorption. The direction of the Solar PV array has two vital parameters: the slope and the azimuth. The hill is the angle of tilt concerning the horizontal ground surface, and the azimuth is the direction towards which the array surface face. When a solar PV array installs south of the equator, azimuth is due north, and when established north of the equator, azimuth is due south. The azimuth can be owing south or due north, depending on the latitude of the site or location on the earth's surface. At noon every day, the sun rays are perpendicular to the earth's surface on the equator and give maximum radiation. Any other time of the day, the position of the sun is affected by the latitude, longitude, time of the day and day of the year. The angle formed between the plane of the equator and a line drawn from the center of the earth is called the solar declination angle denoted by δ.

Global radiation comprises three components; the first is the direct solar radiation, which refers to the sun radiation received directly from the sun. The second is the diffuse radiation scattered by the atmosphere and clouds. Finally the third is reflected radiation that reflected from the ground.

The orientation of the PV array is one of the more essential aspects of the site assessment [1]. Solar radiation measures in the form of global and diffuse radiation on a horizontal surface [3]. Solar panels are positioned at an angle to the flat to increase the amount of radiation falling on the group, so the optimum tilt angle should be calculated, which then determines the solar conversion efficiency. The bi-axial tracking system is used to obtain optimum tilt. The tracking systems classify into two: Manual and Automatic [3]. Manual methods are usually employed to fix the tilt angle of the panel at a particular angle defined by the latitude of the location. However, model-based determination of optimum tilt angle has emerged as a popular method of operating the solar system in the recent years. These angles implement in both manual and automatic tracking systems. The following two methods can be used to achieve optimum tilt: a) Monthly optimization. b) Seasonal optimization.

Automatic tracking systems are expensive and need energy (a part of solar energy) for their operation. Further, they cannot be applied and maintained easily [4]. The techniques proposed by researchers for calculating optimum tilt angle bases on:
a) Geographic factor (Rb),

b) Clearness index (KT) and
c) Declination angle (δ).
Through experimental analysis, it is proven that the geographic factor method of estimating the optimum tilt angle is the best method for finding the optimum tilt angle of solar panels at a location [5].

Problem statement: Estimate the optimum number of solar panels depending on the type of PV panels, site latitude, climate conditions, and other factors

II. RELATED WORK

The suggested model is used for the determination of monthly average and seasonal average of optimal tilt angle. It examines the factors affecting tilt angle for the solar panel and aims to select an appropriate theoretical model for determining the optimal tilt angle for solar PV panels [1]. The solar panels collected energy can be increased by varying the tilt angle. In [3], the collector surface is assumed to be facing toward equator. Calculations are based upon the data of monthly mean daily global solar radiation and monthly average clearness index on a horizontal surface. It is shown that nearly optimal energy can be collected if the angle of tilt is varied seasonally, four times a year. The annual optimum tilt angle is found to be approximately equal to latitude of the location. In [16] there is a mathematical model was used for estimating the solar radiation on a tilted surface, and for determining the optimum tilt angle and orientation (surface azimuth angle) for the solar collector in the main Syrian zones, daily, as well as for a specific period. The optimum angle was computed by searching for the values for which the radiation on the collector surface is a maximum for a particular day or a specific period. The results reveal that changing the tilt angle 12 times in a year (i.e. using the monthly optimum tilt angle) maintains approximately the total amount of solar radiation near the maximum value that is found by changing the tilt angle daily to its optimum value.

III. METHODOLOGY

This study utilizes the geographic factor method for estimating the daily beam radiation on tilted surfaces. The parameters used in determining the global solar radiation are as follows:

Declination Angle (δ): is the angle between the sun-earth center line and the projection of this line on the equatorial plane. Declinations north of the equator are positive, and those south are negative. For any given day n (the day number (1-365) of the year) the declination angle estimate as follow:

$$\delta = 23.45 \times \sin\left(\frac{360\times(284+n)}{365}\right) \tag{1}$$

Solar Altitude (α): Angle between the horizontal plane and the line joining the centers of the earth and the sun (solar elevation)

Solar Azimuth Angle (Z): The angle between the projection of the straight line joining the centers of the earth and the sun on the horizontal plane and the north-south line at a given location

Zenith Angle (θ_z): The angle between the suns ray's and the vertical

Local Latitude (Φ): the angle between a line from the centre of the earth to the site of interest and the equatorial plane.

Incidence Angle (θ): the angle between the sun's rays and the normal on a surface,

Reflectance (ρ) is the ratio of radiation reflected from a surface to that incident on the surface. Reflectivity is the property of reflecting radiation, possessed by all materials to varying extents, called the albedo in atmospheric references. Depending on the type of the surface (ρ) can be determinates from the following table 1.

Tilt angle (β): is the angle between the horizontal and solar panel

Hour Angle (ω_s): The angle between the sun projection on the equatorial plane at a given time and the sun projection on the same flight at solar noon.

Table 1. Reflectance values for different surface types

Surface	ρ
Grass	0.25
Macadam	0.18
Asphalt	0.15
Snow	0.45-0.9
Dark soil	0.08-0.13
Savanna	0.16-0.21
Dry sand	0.35
Concrete	0.25-0.35
Red tiles	0.33
Aluminum	0.85

The earth rotates one revolution per day corresponding to 360° longitude = 24 hours. This implies that the day length is $2\times(\omega_s/15)$

$$\omega_s = \cos^{-1}(-\tan\phi \tan\boldsymbol{\delta}) \tag{2}$$

Where ϕ is the latitude of the location, hence the sunrise and sunset angles for a tilted surface (ω'_s), facing the equator is given by;

$$\omega'_s = \cos^{-1}(-\tan(\phi-\beta)\tan\delta) \tag{3}$$

Irradiance is The rate at which radiant energy is incident on a surface, per unit area of surface (W/m^2).

Irradiation is the energy collected per square meter during a specific time interval. If the considered time interval is a day or a year, the terms 'daily irradiation' or 'aa annual irradiation' may be used (Wh/m^2).

Beam Irradiation for the Horizontal Surface (H_o) is the monthly mean horizontal daily total extraterrestrial solar radiation energy given by:

$$H_o = \frac{24}{\pi} S \left\{1 + 0.033 * cos\left(\frac{2\pi n}{365}\right)\right\} * (\cos\phi\cos\delta\sin\omega_s + \omega_s \sin\phi\, sin\delta) \quad [6, 7] \quad (4)$$

Where S is the solar constant equal to 1367 W/m^2

$$\omega_o = \min(\omega_s, \omega'_s) \quad (5)$$

Clearness Index (K_T)

This is the ratio of the monthly mean horizontal daily radiation to the monthly mean horizontal daily total extraterrestrial solar radiation.

$$K_T = \frac{H}{H_o} \quad (6)$$

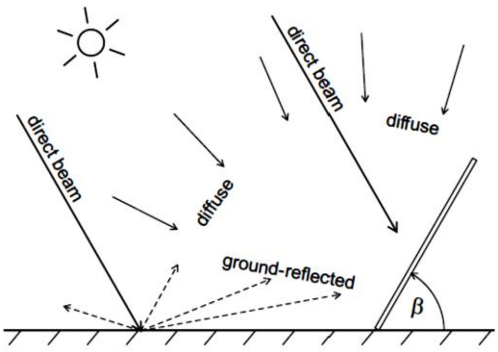

Fig. 1. Tilt angle (β)

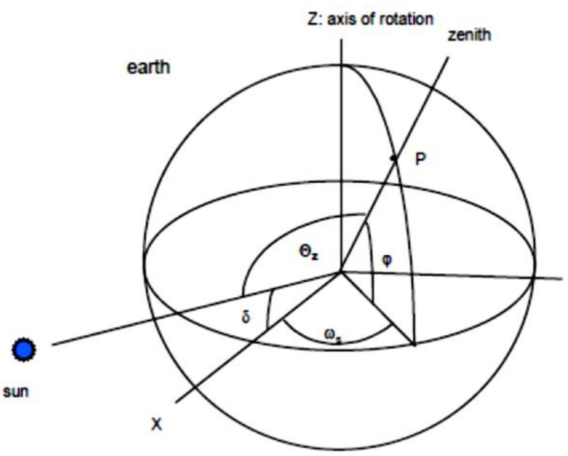

Fig. 2. Definition of latitude, hour angle, zenith angle and solar declination.

H is the monthly mean horizontal daily terrestrial solar radiation

Diffused Irradiation (H_d)

The monthly average daily value for the scattered irradiation incident on a horizontal surface.

$$H_d = H * (1-1.13K_T) \quad (7)$$

III.I Estimation of total solar radiation on the inclined surface

Monthly-average of total daily radiation on a tilted surface (H_T) can be calculated by calculating the direct beam radiation (H_B), diffuse radiation (H_S), and reflected components (H_R) of the radiation. Thus the total incident radiation on tilted surface is given by the equation [3]:

$$H_T = H_B + H_S + H_R \quad (8)$$

III.I.I Estimation of Daily Beam Radiation (H_B)

The beam radiation received by a tilted solar collector is:

$$H_B = (H - H_d)\, R_b \quad (9)$$

Where H is monthly-average daily global radiation for the horizontal surface; H_d is the diffuse radiation component for the horizontal surface; R_b is the ratio of average daily beam radiation on a tilted surface to that on a horizontal surface [3].

It has suggested that R_b can be estimated by assuming that there is no atmosphere. In the northern hemisphere, the surfaces which are sloped towards the equator, R_b is given as [6]:

$$R_b = \frac{\cos(\phi-\beta)\cos\delta\sin\omega_o + \omega_o\sin(\phi-\beta)\, sin\delta}{\cos\phi\cos\delta\sin\omega_s + \omega_s\sin\phi\, sin\delta} \quad (10)$$

In the southern hemisphere the surfaces which are sloped towards the equator, R_b is given as below:

$$R_b = \frac{\cos(\phi-\beta)\cos\delta\sin\omega_o + \omega_o\sin(\phi+\beta)\, sin\delta}{\cos\phi\cos\delta\sin\omega_s + \omega_s\sin\phi\, sin\delta} \quad (11)$$

$\omega_o = \min(\omega_s, \omega'_s) = \min\{\cos^{-1}(-\tan\phi\tan\delta), \cos^{-1}(-\tan(\phi+\beta)\tan\delta)\}$

III.I.II Estimation of Ground Reflection Radiation (H_R)

The ground reflected radiation can be given after assuming the reflection as isotropic. Hence the daily ground reflected radiation can be expressed as**:**

$$H_R = H\,\rho\,(1-\cos\beta)/2 \quad (12)$$

III.I.III Estimation of Sky Diffused Radiation (H_S)

Diffuse irradiance is defined as the solar radiation which is coming from the skydome except from the direct radiation from the sun and the circumpolar region (three degrees of the sun). Sky diffused emissions are challenging to measure because for measuring diffuse sky radiation the pyranometer should be shaded so that it could not receive direct radiation and radiation from the circumsolar region [8].

Isotropic and anisotropic models are used to determine the ratio of diffuse solar radiation on a tilted surface to that of a horizontal surface. The isotropic models assume that the diffuse sky radiations are uniformly distributed over the skydome. Hence, the diffuse radiation is dependent on the portion of the skydome, which can be seen by the collector. The anisotropic models assume that diffuse sky radiations are a collection of anisotropically distributed diffused radiation components in the circumpolar region (sky near the solar disc) plus and isotropically distributed diffuse component from the rest of the skydome [3, 9].
The sky-diffuse radiation can be expressed as:

$$H_S = R_d H_d \tag{13}$$

Here R_d is the ratio of the average daily diffuse radiation on a tilted surface to that on a horizontal surface. The scattered radiation models chosen for the study are as follows:

The isotropic models assume that the diffuse sky radiations are uniformly distributed over the skydome. Hence, the scattered radiation is dependent on the portion of the skydome which can be seen by the collector.

(a) Liu and Jordan model (1962) [6]

$$R_d = \frac{1}{2}(1 + cos\beta) \tag{14}$$

(b) Koronakis model (1986) [10]

$$R_d = \frac{1}{3}(2 + cos\beta) \tag{15}$$

(c) Tianet al. model (2001) [11]

$$R_d = 1 - \frac{\beta}{180} \tag{16}$$

(d) Badescu model (2002) [12]

$$R_d = (3 + cos(2\beta))/4 \tag{17}$$

After substituting the values of H_S, H_B, and H_R in equation (1) the total solar radiation on a tilted surface can be expressed as [13 - 17]:

$$H_T = (H – H_d) R_d + H \rho (1- \cos \beta)/2 + H_d R_d \tag{18}$$

$$\bar{R} = \left(1 - \frac{H_d}{H}\right) R_d + \frac{1 - \cos\beta}{2} + (1 - 1.13K_T)R_d \tag{19}$$

This equation will be used for determining the optimum tilt angle while substituting the value of R_d for the various models described in eq.(10) to eq.(18), respectively.

III.II Optimum Solar cells Area (OSCA) estimation for PVPS

In autonomous PV systems, the PV panels are the only source of generation. Therefore, the PV panel needs to be large enough to generate a minimum of the annual load requirement, taking the system losses into account. As the power produced from the PV array varies throughout the year a trade-off between increasing the number of PV panels and increasing the storage system, which supplies the load during periods of low or no solar radiation, exists. For an optimization horizon of one year. The minimum SCA required to meet the annual load requirement is calculated according to the following equation:

$$SCA_{min} = \frac{\sum_{t=1}^{t=8760} P_{Load}(t)}{\sum_{t=1}^{t=8760} P_{PVmax}(t)} \tag{20}$$

Where P_{Load} is the Load power taking account of system losses; P_{PVmax} is the Maximum power output from one PV panel fixed at the optimum tilt angle

The maximum quantity of PV panels is set to the minimum number of PV panels required to supply the maximum daily load for the worst day of the year, the day when the PV panel receives the lowest solar radiation. The maximum quantity of

PV panels are determined by equation (21)

$$SCA_{max} = \frac{\max[\sum_{t=1}^{t=24} P_{day\ Load}(t)]}{min[\sum_{t=1}^{t=24} P_{PVmax}(t)]} \tag{21}$$

Where day varies from 1 to 365, to step through each day of the year. The minimum and maximum values of PV panels are two opposite extremes which are not optimal and would require an extensive storage system for the minimum quantity of PV panels and a small storage system if the maximum quantity of PV panels is utilized. While varying the amount of PV panels the PV power and the load requirement are compared to obtain the charge/discharge profile of the storage system for each stepping point over the optimization horizon.

The average SCA (SCA_{ave}) is the average value between SCA_{max} and SCA_{min}; it can be calculated as:

$$SCA_{ave} = \frac{SCA_{max} + SCA_{min}}{2} \tag{22}$$

PVPS has enormous capital cost, so optimization is used for estimating:

1- The optimum values of (SCA) or several solar cell panels used.
2- Capacity rates of power conditioning devices.
3- The amount of stored energy required in the backup energy system.
4- The power rates of fuses, circuit breaker, wires and so…

The annual Energy balance is used to estimate the OSCA and capacity stored energy in backup energy system so the following methodology is used [18]:

1- Hourly PVPS output power, KWh

$$PVO(t) = SCA \times H_x(t) \times \eta_{cell} \times \eta_{pc} \times \eta_w \times \frac{VF}{FS} \tag{23}$$

$$\eta_{cell} = \eta_{cr} \times [1 - 0.0062 \times (T_{cell}(t) - T_{cr})] \tag{24}$$

$$T_{cell}(t) = T_{am}(t) + \left(\frac{NOCT-20}{800}\right) \times H_x(t) \tag{25}$$

Where: SCA is initial Solar Cell Area, m^2. H_x is hourly solar radiation on the tilted surface with angle x, kW/m^2. T_{am}: Ambient temperature, °C. VF: variation factor which influences on solar radiation from year to year. It about 0.95. FS is factor of safety includes data accuracy and weather conditions and dust (It is about 1.1). T_{cell}: hourly cell

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 11 (2019), pp. 1978-1985

temperature, °C . NOCT: Nominal Operating Cell Temperature, °C. η_{cell}, η_{pc} and η_w are respectively solar cell efficiency, power condition efficiency, and wiring, and transmission line efficiency.

After calculating PVO for total yearly hours (8760 hours). Make a comparison between hourly PVO and hourly load power required. As follow

$$\sum_{t=1}^{t=8760}\left(PVO(t) - P_{Load}(t)\right) = dE \quad (26)$$

Where dE is the difference between generated energy and energy required. There are three cases for dE value. Upon the value of dE SCA is adjusted to be optimum value for economic sizing and high reliability. These three cases are:

1- If dE greater than zero, then there is surplus energy, so SCA must be decreased by an incremental area and return calculations.
2- If dE less than zero, then there is deficit energy, so SCA must be increased by an incremental area and return calculations.
3- If dE equal zero or a minimal positive number close to zero then there is no deficit or surplus energy, so SCA is the optimum area (SCA = OSCA)

For optimum sizing, previous procedures must be applied to obtain OSCA. If the storage energy device is used. The efficacy of this device must be taken into account.

IV. APPLICATION AND RESULTS

Communications stations must be cover all sites in any country. Any places can have one or more renewable energy sources. In Egypt almost all locations have solar energy ar renewable energy. Other sites have wind energy besides solar energy as sites in Red Sea coastal and the Mediterranean Sea coastal. So three sites in Egypt are selected to be the application of this study, the first site is Marsa-Alam that located on southern red sea coast of eastern desert, El-Minia is the second site that found in Nile Valley, and the third site is Shark El *Oweinat* that found West desert of Egypt. The latitudes and longitude of the selected locations are in table 2.

Table 2. Represent the latitudes and longitudes of the previously selected sites

Site	Marsa-Alam	El-Minia	Shark El Oweinat
Latitude	25.0676° N	28.2502° N	22.5857° N
longitude	34.8790° E	29.9741° E	28.7166° E

IV.I Estimation of radiation on tilted surfaces

The proposed computer program has been designed dependent upon the methodology to estimate the parameter R and hourly radiation on sloped surfaces. The input data of this program can be summarized as follow:

Radiation and climate data

Extraterrestrial radiation and radiation on the horizontal surface are the radiation data required. Also the average monthly ambient temperature is required. The fallout on flat surface and ambient temperatures have been obtained from Egyptian Meteorological Authority for three selected sites. The values of (H_o) can be used in calculation or equation 4.

By applying equations from (1) to (19) the following results for the three selected three sites can be shown in tables 3,4, and 5. In these tables (R and H_T) for monthly best tilt angle and (**R_Φ** and **$H_{T\Phi}$**) for fixed-tilt angle equal to the latitude of each site.

Three selected PV modules are used in this paper, and the characteristics of these PV modules are shown in table .6

The average hourly loads per month for the selected communication station can be shown in fig. 3

By applying the results of solar radiation calculation, parameters the chosen sites, load demand in fig. 3, selected PV modules and energy balance technique. The results of OSCA can be gotten, and it can be shown in table .7 and fig. 4.

It can be noted that from the tables 7 and fig. 4 that with higher efficiency PV modules, the different in OSCAs is larger than OSCAs with low-efficiency PV modules.

Fig. 6 shows the percentage difference in OSCAs between monthly best tilt angle and latitude angle.

Table 3. Design parameters For Marsa-Alam Site

Date	H (KWh/m^2	Tilt angle (β°)	R	H_T	R_Φ	$H_{T\Phi}$
17 Jan.	4.1414	45.9	1.471	6.09	1.34	5.55
16 Feb.	5.4127	37.9	1.294	7.01	1.242	6.72
16 Mar.	6.5059	27.4	1.113	7.24	1.111	7.23
15 Apr.	7.1743	15.5	1.008	7.23	0.986	7.08
15 May	7.3759	6.2	1	7.38	0.905	6.67
11 Jun.	6.5334	1.9	1	6.53	0.879	5.74
17 Jul.	7.6776	3.8	1	7.68	0.886	6.81
16 Aug.	7.2423	11.6	1	7.24	0.951	6.88
15 Sep.	6.4165	22.9	1.058	6.79	1.057	6.78
15 Oct.	5.0007	34.7	1.201	6.01	1.177	5.89
14 Nov.	4.7956	44	1.456	6.98	1.336	6.41
10 Dec.	4.1698	48	1.573	6.56	1.397	5.82

Table 4. Design parameters for Shark El Oweinat Site

Date	H (KWh/m^2)	Tilt angle (β°)	R	H_T	R_Φ	$H_{T\Phi}$
17 Jan.	3.768	43.8	1.37	5.1516	1.261	4.750
16 Feb.	5.661	35.81	1.26	7.139	1.21	6.847
16 Mar.	7.256	25.26	1.1	8.0137	1.102	7.996
15 Apr.	7.812	13.43	1.01	7.848	0.983	7.675
15 May	8.002	4.067	1	8.002	0.903	7.227
11 Jun.	8.638	-0.199	1	8.638	0.864	7.46
17 Jul.	8.548	1.75	1	8.548	0.880	7.525
16 Aug.	7.221	9.513	1	7.221	0.95	6.856
15 Sep.	7.191	20.771	1.05	7.5679	1.052	7.562
15 Oct.	5.811	32.584	1.2	6.9601	1.17	6.796
14 Nov.	4.821	41.87	1.39	6.7091	1.281	6.176
10 Dec.	4.309	45.968	1.50	6.4703	1.336	5.755

Table 5. Design parameters for Elminya Site.

Date	H (KWh/m^2)	Tilt angle (β°)	R	H_T	R_Φ	$H_{T\Phi}$
17 Jan.	2.43	48.975	1.340	3.26	1.272	3.09
16 Feb.	4.96	40.99	1.339	6.65	1.287	6.39
16 Mar.	6.71	30.44	1.151	7.73	1.149	7.71
15 Apr.	7.72	18.607	1.019	7.87	0.997	7.7
15 May	7.9	9.2474	1	7.9	0.899	7.1
11 Jun.	8.33	4.9815	1	8.33	0.856	7.13
17 Jul.	7.96	6.9300	1	7.96	0.876	6.98
16	7.53	14.693	1	7.53	0.953	7.18
15 Sep.	6.77	25.951	1.083	7.34	1.083	7.33
15 Oct.	5.65	37.764	1.284	7.26	1.252	7.08
14	4.27	47.05	1.496	6.39	1.383	5.91
10 Dec.	3.74	51.148	1.657	6.2	1.477	5.53

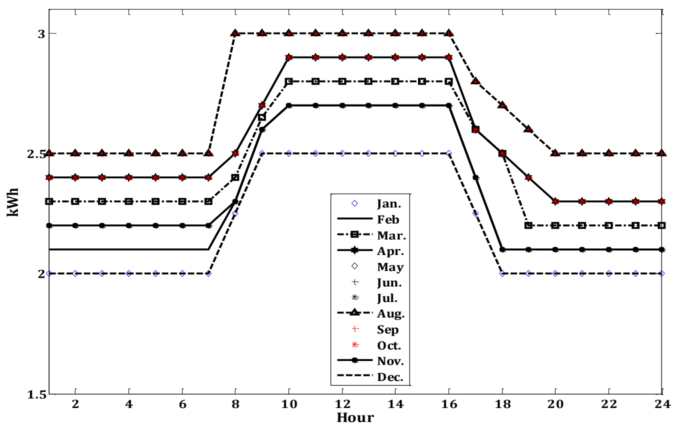

Fig. 3. Average Hourly electrical loads

It can also be noted also that;

1- OSCA is inversely proportional to PV module efficiency. (high PV module efficiency means decrease OSCA and vice versa)
2- The monthly best tilt angle gives the lower OSCA from all selected PV modules. Related with latitude angle.
3- For lower PV module efficiency the percentage differences in OSCA is little then as PV module efficacy will increase, the difference in OSCA increase

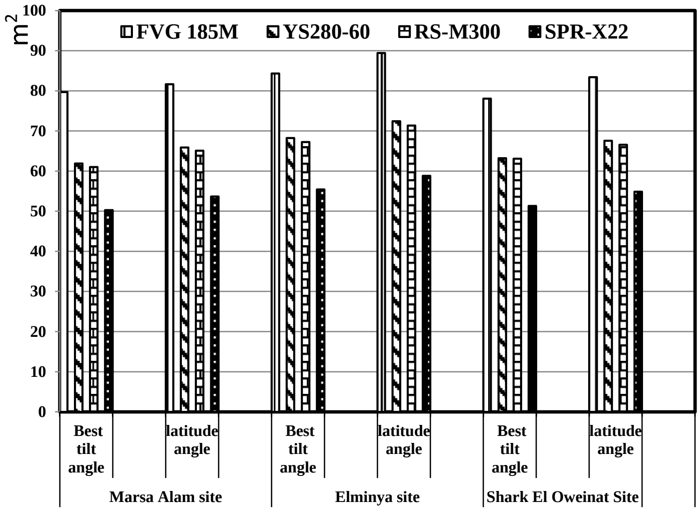

Fig. 4. OSCA (m^2) for selected Sites using selected PV modules and monthly best tilt angle and latitude angle.

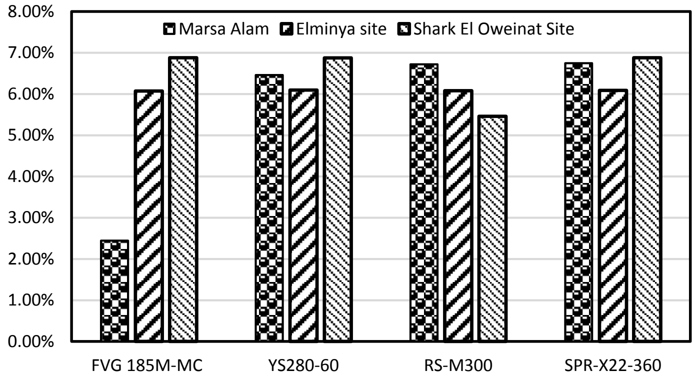

Fig. 5. Percentage area differences between best tilt angle and latitude angle for selected PV modules

SPR-X22-360 solar module is the optimum choice because it gives smaller solar area required.

Table 6. The characteristics of the selected PV modules

PV module / Item	FVG 185M-MC	YS280-60	RS-M300	SPR-X22-360
Number of cells	72	60 (6*10)	60 (6*10)	96
Module efficiency	14.6 %	18.03 %	18.3%	22.2%
Maximum power (P_{max}), W	185	280	300	360
Voltage at P_{max} (V_{mp}), V_{dc}	37.5	32.1	32.6	59.1
Current at P_{max} (I_{mp}), A	4.95	8.72	9.19	6.09
Short-circuit current (I_{sc}), A	5.4	9.45	9.64	6.48
NOCT, ºC	47 ±2ºC	45 ±2ºC	44 ±2ºC	47 ±2ºC
Maximum system voltage (V_{dc})	700	1000	1000	1000
Module active area, m^2	1.729	1.6335	1.6368	1.629668
Maximum series fuse rating, A	7	15	15	15
Open circuit voltage (V_{oc}), V_{dc}	44.5	39.2	39.9	69.5

Table 7. Energy balance program results for selected PV modules and monthly best tilt angle and latitude angle

Solar cell type		FVG	YS280-60	RS-M300	SPR-X22-360
Marsa Alam site	OSCA with Best tilt angle, m^2	79.7	61.9	61	50.262
	OSCA with latitude angle,m^2	81.65	65.9	65.1	53.654
Elminya site	OSCA with Best tilt angle, m^2	84.3	68.25	67.25	55.4299
	OSCA with latitude angle,m^2	89.42	72.41	71.34	58.805
Shark El Oweinat Site	OSCA with Best tilt angle, m^2	78.04	63.195	63.1	51.3232
	OSCA with latitude angle,m^2	83.41	67.541	66.545	54.8542

VI. CONCLUSION

Optimal solar cell areas estimated for three sites in Egypt, depending on the tilt angle that determined and the amount of solar insolation on panel surfaces and other conditions. Conventionally the fixed best tilt angle is equivalent to latitude of the location at which panel is installed. The value of optimal tilt angle at defined location depends on local atmospheric conditions, altitude of nature of region. As efficacy of Solar panels increases, the optimum solar cells area required will decrease.

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