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Maximum power analysis of photovoltaic module in Ramadi city

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Abstract
Performance of photovoltaic (PV) module is greatly dependent on the solar irradiance, operating temperature, and shading. Solar irradiance can have a significant impact on power output of PV module and energy yield. In this paper, a maximum PV power which can be obtain in Ramadi city (100km west of Baghdad) is practically analyzed. The analysis is based on real irradiance values obtained as the first time by using Soly2 sun tracker device. Proper and adequate information on solar radiation and its components at a given location is very essential in the design of solar energy systems. The solar irradiance data in Ramadi city were analyzed based on the first three months of 2013. The solar irradiance data are measured on earth's surface in the campus area of Anbar University. Actual average data readings were taken from the data logger of sun tracker system, which sets to save the average readings for each two minutes and based on reading in each one second. The data are analyzed from January to the end of March-2013. Maximum daily readings and monthly average readings of solar irradiance have been analyzed to optimize the output of photovoltaic solar modules. The results show that the system sizing of PV can be reduced by 12.5% if a tracking system is used instead of fixed orientation of PV modules.

Keywords: Irradiance; Renewable energy; Ramadi city; Anbar University; Soly2 sun tracker.

1. Introduction
The global demand for energy is rapidly increasing with increasing human population, the traditional energy used are coal natural gas, nuclear energy, oil etc. Due to the crisis of traditional energy sources we need to find out the other source of energy. Solar energy is a good option and the electricity produced is clean and silent [1]. Photovoltaic power is an established technology and has recently experienced rapid growth over the last ten years [2]. A solar cell basically is a p-n semiconductor junction. When exposed to light, a dc current is generated. PVs offer several advantages such as: high reliability, low maintenance cost, no environmental pollution, and absence of noise [3]. An accurate knowledge of the solar radiation data at a particular geographical location is important for solar energy system design [4]. The amount of sunlight received by any surface on earth will depend on several factors including, geographical location, and time of the day, season, local landscape and local weather. The Earth's surface is round and the intensity will depend on the distance that the light has to travel to reach the surface. The radiation received by a surface will have two components one which is direct and will depend on the distance the rays travel (air mass). The energy which is harvested from the natural resources like

sunlight, wind, tides, geothermal heat etc. is called renewable energy. As these resources can be naturally replenished, for all practical purposes, these can be considered to be limitless unlike the tapering conventional fossil fuels. The global energy crunch has provided a renewed impulsion to the growth and development of clean and renewable energy source [5]. Globally, technological advances, economies of scale and demand for various sectors to find solutions to the problem of global warming, have positioned the PV as the natural replacement for nuclear energy and fossil fuels. PV energy is exceeding growth projections made in the beginning so that it can be said that any power generation technology has grown as fast as it has passed through the solar energy during the last decade [6]. PV functionality depends upon the absorption of sunlight with a semiconductor material, most commonly a silicon P-V diode, providing a medium in which incident photon can be converted to energy, usually in the form of heat [7]. When absorbed a photon transfers energy to an electron in the absorbing material and if the magnitude of incident photon energy is greater than the electron's work function, the photon may raise an electron's energy state or even liberate an electron. Once liberated the electrons are then free to move around the semiconductor material influenced, temperature and electric field. Among the proposed solutions for improving the efficiency of PV conversion is the solar tracking technique.

This paper aims to analyze the real measured solar irradiance, ambient temperature in Ramadi city for three months (i.e. January, February, and March-2013). The paper is organized as follows: the next section discusses the real data of solar irradiance in Ramadi city and it taken from the sun tracker system. Section 3 presents the system sizing which is the power output that can be extracted by using PV modules. Section 4 shows the results with a practical PV system sizing example, and section 5 gives the conclusions of the paper.

2. Solar radiation

Full description of solar radiation involves measurements of direct and diffuse radiation several times an hour for a statistically significant time period. This level of data is expensive to obtain, or exists only for limited locations, and due to its volume also inherently requires a computer program to analyze and use. Full statistical data analysis during the winter time is analyzed by using Matlab software. The analysis is used for determining the lowest level of sun irradiance which incident the surface of earth at the specified location. Actual solar radiation can varies from its maximum value during sunny days to the lowest value at dusty or cloudy weather case. The aim is to determine:

1) Total measured power during the first three months of year.
2) The maximum PV power based on statistical measured data.
3) Variation of solar intensity during this period.

The calculation of the average sun irradiance (w/m^2) for each month and picks the month with the average value closest to the average, keeps realistic day-to-day variation of solar radiation. Average solar radiation per month: Gives average power density per day in a particular month for a particular angle (usually either horizontal or vertical latitude). Statistical analysis of radiation provides an indication of the amount of the storage data in the data logger of sun tracker system. The experimental set-up is located at the renewable energy research center in Anbar University. By using the solar tracker system, the available data on solar radiation are obtained. The meteorological data include temperature, global solar irradiance, and direct solar irradiance. The estimation of daily solar irradiance has been reviewed in most of the researches based on the duration of sunshine; the actual data readings were taken hourly and daily basis from the 1st of January, 2013 until the 31th of March, 2013.

2.1 Solar irradiance analysis of January

The overall performance of solar cell varies with varying Irradiance and temperature. With the change in the time of the day the power received from the Sun by the PV panel changes. With the increasing solar irradiance the maximum power point varies. Temperature plays another major factor in determining the solar cell efficiency. The monthly average data of solar irradiance are shown in Figure 1. This figure shows the average change of solar irradiance with time during daytime hours for the whole month of January. Note that the maximum power is about 700 w/m^2 at quarter past twelve O'clock for both global and direct irradiance. The maximum power range is between 10:00am-2:00pm afternoon, which has an average of 650w/m^2 for 4-hours. This result is expected because the month of January is sometime rainy, cloudy, partial cloudy, dusty or sunny in Ramadi city and the weather particles inhibit solar radiation. In general, it can be notice that the direct solar irradiance higher than global solar irradiance because the direct sensor measures the maximu incident solar irradiance with angle of zero, at this case the direct solar tracker sensor tracks the sun movement during the day time. However, the overcast conditions can cause a reduction in direct solar irradiation as it notice in Figure 1 between 11:10 am and 1:10 pm with reference to the global sensor. The global solar irradiance higher than direct solar irradiance because the contribution of diffuse irradiation from behind the sensor is lost (difference irradiance between direct and global solar irradiance = gains of solar energy if a solar energy system tracks the sun). As a result, the maximum value of the monthly-average direct solar irradiance was 690 w/m^2 at 12:00 in January, other global solar irradiance was 700 w/m^2 at time same. From the same figure, the temperature is more than 18 °C in the range of 12:00-5:00pm.

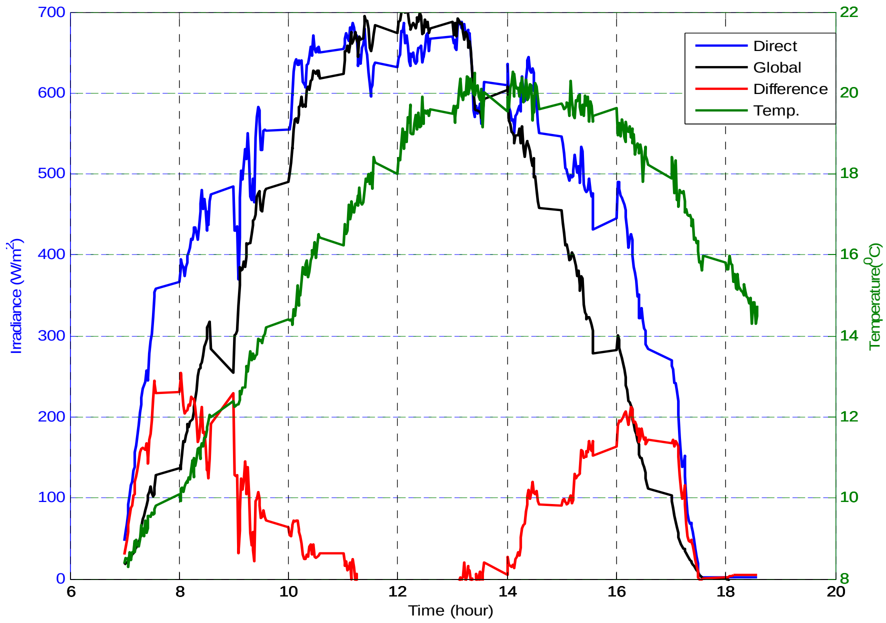

Figure 1. Average monthly irradiance for January-2013 (the average for each two minutes)

In Figure 2 the maximum solar radiation range is between 11:00 am to 3:00 pm afternoon, which has about 650 w/m^2 for direct and global solar irradiance. The global solar irradiance was more than the direct solar irradiance in the time range from 12:00 am to 2:00 pm. The maximum temperature is 20 ºC at 2:00 pm.

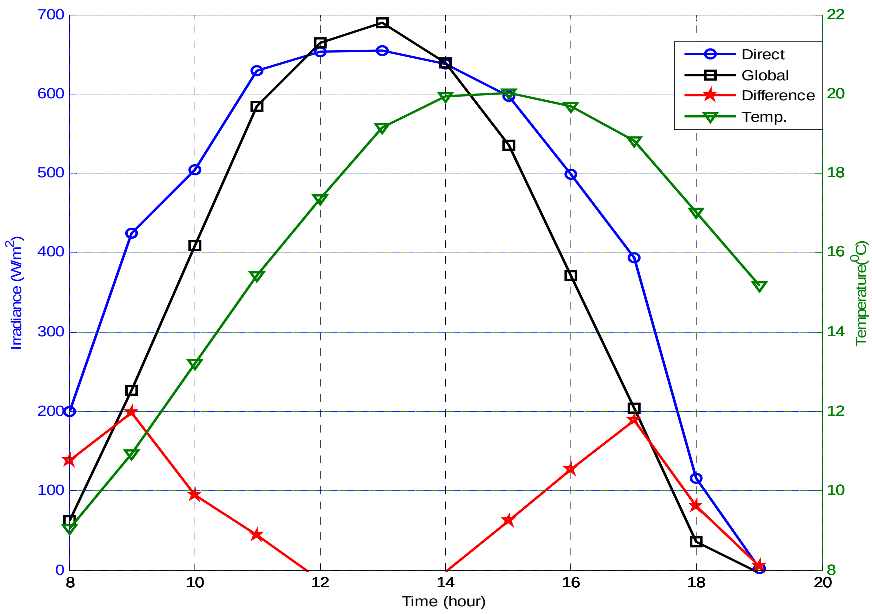

Figure 2. Hourly average irradiance for January-2013

2.2 Solar irradiance analysis of February

Figure 3 shows the solar irradiance characteristics in February. It has approximately the same solar irradiance characteristics of month of January, because approximately the weather is the same. The Direct Solar Irradiance (DSI) and Global Solar Irradiance (GDI) are increased. Bands of clouds can be observed when the curves reduced instantaneously and therefore the DSI and GSI are dropping when the cloud moves to shade the sensor. Also different kinds of clouds can be detected: The drop in DSI signal at about 9:00 am is not accompanied by increasing DSI. Whereas a between 9:30 am and 11:30 am seems a clear sky which increases DSI and GSI, a thin and light cloud cover (cirrus clouds), which increases global solar irradiance because of low optical thickness and forward scattering of the sunlight during the afternoon nearly no sudden decrease of DSI signal can be observed such as between 11:15 am and 1:15 pm. Note that the maximum power is about 710 w/m^2 at 12:00 O'clock. The maximum power range is from 10:00 am to 2:00 pm afternoon, which has an average range of 640 w/m^2 for 4-hours.

In Figure 4 the maximum solar power range is between 9:30 am-2:00 pm, which has more than 600 w/m^2 for direct solar irradiance, other global solar irradiance was more than 600 w/m^2 at time range 10:00 am-1:30 pm. From the same figure, the maximum temperature is 23°C at 2:00 pm.

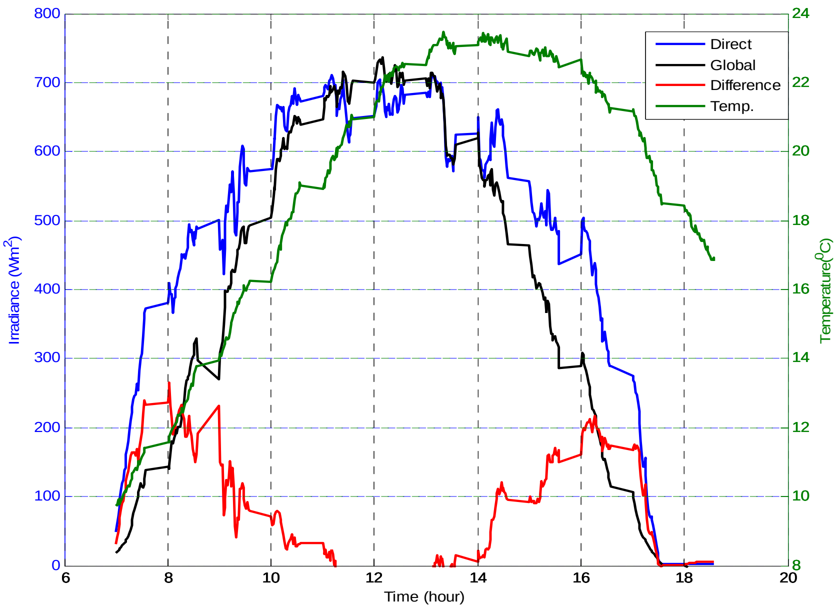

Figure 3. Average monthly irradiance for February-2013 (the average for each two minutes)

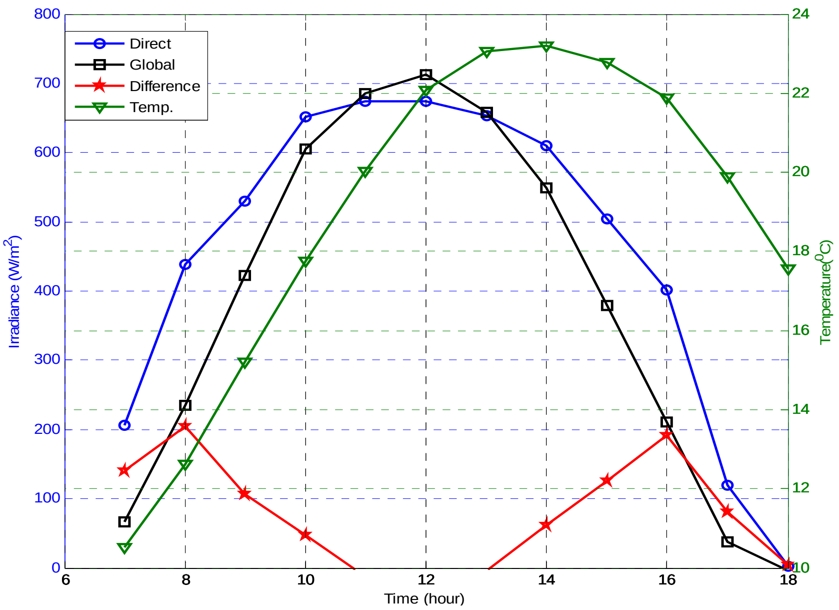

Figure 4. Hourly average irradiance for February-2013

2.3 Solar irradiance analysis of March

In Figure 5 note that the maximum solar power is near to 500w/m^2 from 10:00 am-3:00 pm for direct solar irradiance. The maximum irradiance range is between 9:00 am-3:15 pm, which has an average of 600 w/m^2, and note that the global irradiance greater than direct irradiance in this time range. The case of this variation in reference to the first two months of this year is the cloudy weather for most days of March as well as dust in some days. The maximum average temperature is 26.5 ^{0}C at 2:20 pm, and it considers optimal degree where it near the standard test condition.

In Figure 6 the global solar irradiance has more values than direct solar radiation in the time range between 9:30 am-4:30pm afternoon, which has 400 w/m^2 for seven hours. The maximum radiation is less than 500 w/m^2 in all time range of this month. The maximum global solar irradiance occurs at 1:00 pm which is 720 w/m^2.

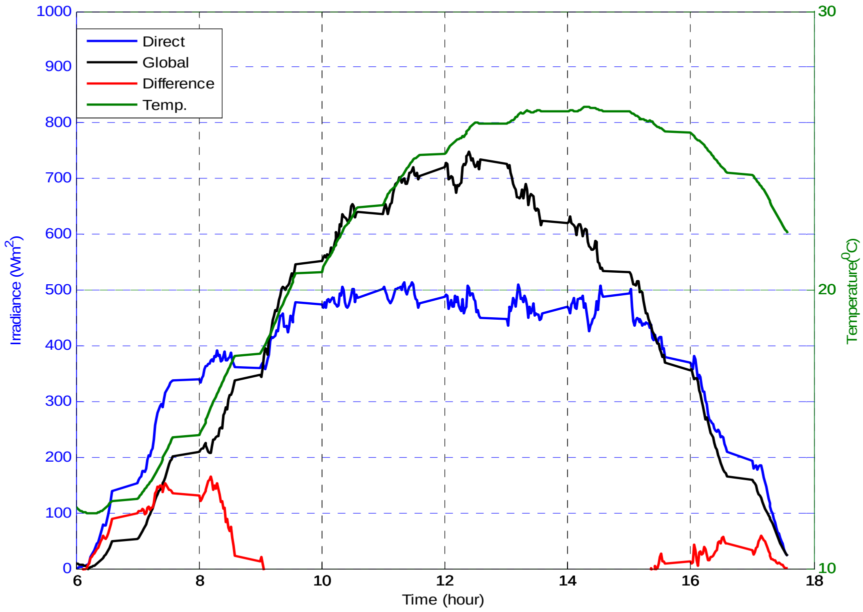

Figure 5. Average monthly irradiance for March-2013 (the average for each two minutes)

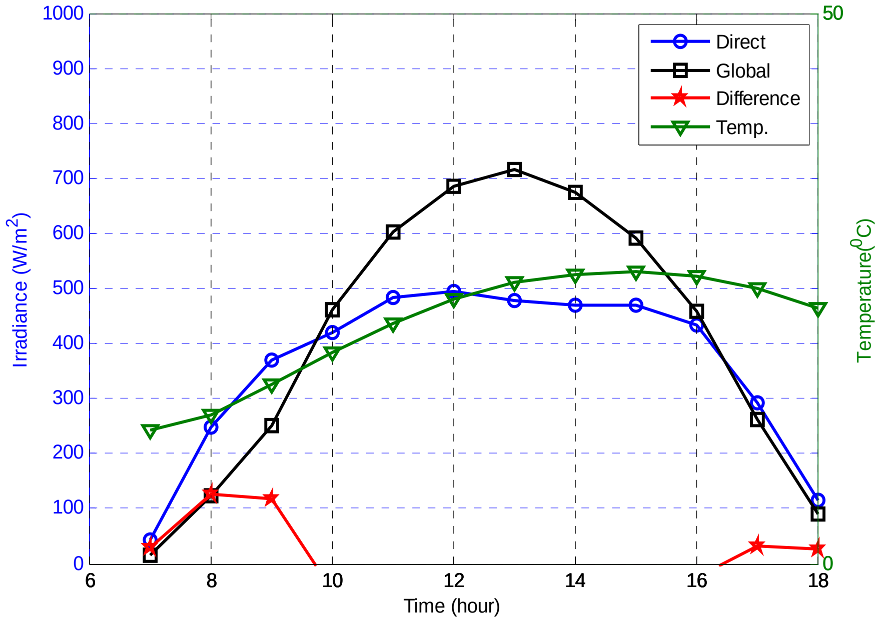

Figure 6. Hourly average irradiance for March-2013

According to Table 1 the maximum value of the monthly-average direct irradiance in January, February and March was recorded to be 5466.6 w/m²/day in February. The minimum value of direct was 4313.4 w/m²/day observed during March. The temperature increases slowly from 16.3°C on January to 21.6°C on march. The maximum value of the monthly-average daily global irradiance is 4927.5 w/m²/day in March. The minimum value of global irradiance is 4421.8 w/m²/day observed during January.

Table 1. Hourly average direct, global irradiance and temperature for the first three months of 2013

Month / Hour	January			February			March		
	Direct w/m²	Global w/m²	Temp. °C	Direct w/m²	Global w/m²	Temp. °C	Direct w/m²	Global w/m²	Temp. °C
7:00	200.48	62.77	9.04	206.37	66.45	10.51	42.36	13.9	12.09
8:00	424.64	226.27	10.91	438.81	234.2	12.61	248.78	122.99	13.49
9:00	504.40	409.37	13.21	530.16	422.76	15.2	369.99	251.84	16.21
10:00	628.63	584.35	15.41	651.83	604.63	17.75	419.07	461.95	19.12
11:00	652.53	664.41	17.36	674.7	686.07	20.03	482.12	603.69	21.87
12:00	654.31	689.09	19.15	673.37	712.25	22.07	495.53	685.26	24.04
13:00	637.05	639.03	19.92	654.03	657.81	23.05	477.26	716.08	25.54
14:00	596.75	534.96	20.01	609.82	548.41	23.21	469.05	673.25	26.28
15:00	498.61	371.19	19.68	504.83	379.2	22.79	469.97	591.36	26.48
16:00	393.12	204.27	18.82	402.05	210.62	21.87	433.39	457.26	26.06
17:00	116.12	36.06	17	118.89	37.361	19.88	291.14	260.55	24.96
18:00	1.642	0	15.16	1.697	0	17.56	114.65	89.34	23.14
Total	**5308.3**	**4421.8**		**5466.6**	**4559.7**		**4313.3**	**4927.5**	
Average direct irradiance for 3-months= **5029.4 w/m²**									
Average global irradiance for 3-months= **4636.3 w/m²**									

3. Sizing of a photovoltaic system

In the design of a solar power system (photovoltaic systems), there are certain things that need to be considered and one of them, which seems to be the most important is solar sizing (load calculation). This calculation outlines the sizing of a solar PV system. PV systems are commonly used to supply power to small, remote installations (e.g. telecoms) where it is not practical or cost-efficient to run a transmission line or have alternative generation such as diesel generating sets. This calculation should be done whenever a solar PV power system is required so that the system is able to adequately cater for the necessary loads. The result can be used to determine the ratings of the system components (e.g. PV arrays, battery, inverter capacity etc.) [8]. For this design to be accurate, the following steps needs to be treated carefully:

- Estimate the solar irradiance available at the site based on measurement.
- Array tilt.
- Load estimation of the system.
- Calculate the required battery capacity based on the design loads.
- Estimate the output of a single PV module at the proposed site location.
- Calculate size of the PV array.
- Calculate the size of the inverter.

3.1 Estimate the solar irradiance

Solar irradiance represents the amount of radiant energy coming from the sun that is not absorbed nor back-scattered by the atmosphere and hence reaches the surface of the earth measured in watts per meter squared (w/m²) [8]. There are many ways to measure the solar irradiance (solar insolation) of a given area, one of the ways is by using Soly2 sun tracker device, which already used in the university of Anbar site.

3.2 Tilting of PV array

To maximize generation of solar irradiance the interception of solar irradiance has to be maximized. For maximum interception of solar radiation, the solar PV modules should be kept perpendicular to the sun rays. Sun changes its position throughout the day, hence the position of the PV modules should also be changed throughout the day, i.e. sun tracking is required. Since precise tracking is not possible also the cost of the system increases due to costly tracking equipment moreover it requires maintenance; therefore fixed mounting of solar PV modules is advised and preferred [9]. For a clear day, the intensity of solar radiation at a given location is symmetrical around the solar noon time of the location. Also the radiation intensity is maximum at noon. Therefore the solar PV modules are oriented to maximize solar radiation interception at noon time. It can be shown that if the PV modules are to be fixed throughout the year, at a fixed angle, the optimum tilt of solar PV modules should be equivalent to the latitude angle of the location. Also, if the modules installation is done in the northern hemisphere the orientation should be south facing and if the PV modules are being installed in southern hemisphere, then the PV modules should be installed north facing [10].

3.3 Load estimation

System design is based on the size of the load. The operating voltage selected for a PV standalone system is usually the voltage required by the largest loads [11]. Energy demand is given by watt–hour per day by:

$$E_d\,(wh) = \sum_{i=0}^{n} N_i I_i V_i H_i \tag{1}$$

where N_i =number of i^{th} load, I_i and V_i are the current and voltage drawn by the i^{th} loads, H_i = Daily duty cycle of the i^{th} load (hrs/day).

The load demand in ampere-hour is given by:

$$E_d\,(Ah) = \frac{E_d\,(wh)}{\eta \quad Vs} \tag{2}$$

where η = power conversion efficiency, V_s = nominal system voltage, a system voltage of 220VDC is used in this design.

Corrected ampere hour load is given by:

$$E(Ah) = \frac{E_d\,(Ah)}{\eta_w \eta_b} \tag{3}$$

where η_w = Wire efficiency= 98%, η_b = Battery efficiency= 75% [12].

3.4 Battery sizing

About the battery bank, there are many factors like maximum depth of discharge, temperature correction, rated battery capacity and battery life should be considered in the designing of PV system [11]. For deep cycle battery, the maximum depth of discharge is 80%. Many designers took it less than 80%. Temperature correction is needed because at low temperature battery efficiency decreases. Temperature correction factor is taken to be 0.9. Required battery capacity in ampere-hour (Ah) is given by:

$$B_{rc} = \frac{E(Ah) \times D_s}{(DOD)_{\max} \times \eta_t} \tag{4}$$

where, D_s =battery autonomy or storage days, $(DOD)_{\max}$ = maximum battery depth of discharge, η_t = temperature correction factor. For non-critical loads and areas with high solar irradiance, 5 to 7 days of autonomy are acceptable. For critical loads or areas with low solar irradiance, 7 to 14 days of autonomy or greater should be used [13].

The batteries in parallel are calculated by:

$$B_p = \frac{B_{rc}}{B_{sc}} \tag{5}$$

where, B_{sc} = capacity of selected battery (Ah). Batteries in series is given by:

$$B_s = \frac{V_s}{V_b} \tag{6}$$

where, V_b = nominal battery voltage, V_s = Nominal system voltage. The total batteries are:

$$B_T = B_p \times B_s \tag{7}$$

3.5 Estimation of the output power

Ramadi city has high insolation, the primary step towards the installation of the solar PV module is an estimation of how much area will be covered by a solar PV module to generate certain amount of energy. In other words, how much energy can be generated from the unit area of the module [14].

The PV module output can be estimated based on the following factors.

- Efficiency of a solar PV module.
- Solar insolation at the desired location.

The efficiency of a solar PV module can be calculated by:

$$Efficiency = \left(\frac{W_p / m^2}{1000 w / m^2} \right) \times 100\% \tag{8}$$

where W_p = The peak power rating of the module per meter square.

Modules are rated at standard test conditions of 1000 w/m^2. If the solar insolation of the area is known, then the output of the PV module can be calculated by:

$$Output(Kwh/m^2/day) = Eff.\ of\ Module \times Ave. Dialy\ Radiation\ (Kwh/m^2/day) \tag{9}$$

3.6 Sizing calculation of PV array

It is possible to calculate the total number of solar modules required for PV system. If the year-round reliability is required, then it is best to use the lowest requirements or "smooth" the data. The peak power of the module can be found in the module specifications in the nameplate of module. It can be also get close enough to the required power by dividing the modules wattage by the peak power point voltage, [8]. The steps can be summarized as:

- **Process 1**: Total average amp-hours per day from the system loads work form.
- **Process 2**: Multiply process 1 by 1.25 to compensate for loss from battery charge/discharge.
- **Process 3**: Note the average sun hours per day in Ramadi city.
- **Process 4**: Divide process 2 by process 3. This is the total solar array amps required.
- **Process 5**: Note the optimum or peak amps of solar module used. See module specifications.
- **Process 6**: To get the total number of solar modules in parallel. Divide process 4 by 5.
- **Process 7**: Round off to the next highest whole number.
- **Process 8**: Number of modules in each series string to provide DC Battery voltage.
- **Process 9**: Total number of solar modules required. Multiply process 7 by 8.

3.7 Inverter size calculation

The size of inverter depends on what appliances or tools are planning to use and their power requirements, which called the load. It is important to know how many continuous watts the appliances require to run, this is calculated using the load calculation work form, add up the wattage of specific items which will (or potentially can) operate simultaneously to determine the minimum continuous watts are needed, how many different appliances are planning to run at the same time, and also how much of surge or power draw, they have when first starting up, as with some larger appliances like the freezer [14].

4. Results

The solar module of 130W is used in this paper with a technical specifications as given in Table 2. While Table 4 summarizes the system sizing of PV for home applications as an example.

Table 2. Specification of Solara PV model

Parameter	Solara (Germany)
V_{max} (Volt)	17.8
I_{max} (Ampere)	7.3
V_{OG} (Volt)	21.7
I_{SG} (Ampere)	8.18
P_{out} (Watt)	130

Note: *The data are based on measurements made in a solar simulator at Standard Test Conditions (STC), which are:(1)Illumination of 1 kW/m^2 at spectral distribution of AM 1.5. (2) Cell temperature of 25ºC*

The energy demand in Table 3 is calculated by using equation (1). Using the analyzed data in Ramadi city as the location, the following results were gotten:

The size of required inverter depends on maximum continuous load. It is recommended from Table 4 to use an inverter size equal to 3000W, (maximum two working loads at the same time multiplied by 1.25 to protect the inverter from continuous overload problem (Steam Iron 1200W+Washing machine 1200W= 2400W*1.25=3000W). while the expected optimum value of inverter with minimum loss can be approximated by: (1*1000 +5*40 +2.5*55 +1*75 +1*65 +1*275 +2*100= 1952W). If the inverter is required to be used for covering the surge current coming from motors like Pumps, then the optimum value of inverter may be calculated as:

Inverter size=((1*1000)+(1*275)+(1200)+(1*1100))*2=7150W

Note that the inverter size depends on the user choice. If the low inverter value is used then some loads cannot be run at the same time. While if a big inverter capacity is used, then the loss of the system will increase.

Table 3. Loads collected to be used by the system

Appliances	No. of units	Wattage	Daily runtime h/day	Energy demand Wh/day
Air-condition	2	1000	7	14000
Tube lights	10	40	7	2800
Fan	5	55	12	3300
Television	2	75	12	1800
Computer	1	65	8	520
Steam Iron	1	1200	1/2	600
Refrigerator	2	275	20	11000
Washing machine	1	1200	2	2400
Exhaust fans	2	100	24	4800
Pump	1	1100	1	1100
Other appliances		100	2	200
Total				42520

From the calculations of previous steps, the total number of modules for direct solar irradiance in the three months is 98 modules as given in Table 4. The other values for both direct and global solar irradiances for the first three months for PV modules are summarized in Table 5. From this table, it can be seen that the direct solar radiation needs less number of solar modules than global solar radiation, and hence the system performance can be improved by using the solar tracker. The solar tracking system can reduce the total number of PV modules from 112 to 98, i.e. 12.5% ((112-98)/112) in January. In February, the total number of PV modules is reduced by 25% (112-84/112). In March the difference between direct and global radiation is inverted, there are 14 additional modules for direct design. The difference, comes from the fact that the weather is either dusty of cloudy most of days. The total power saving for three months based on direct solar radiation is 12.5%.

Table 4. Result obtained from the system sizing

Load Estimation	Total estimation load of the system (eqn. (1))	42520W/day,	
	Corrected Ampere hour load at η=0.8, 220V, η_w=0.98, η_s=0.75 (eqs.(2, 3))	328.69Ah/day	
Battery Sizing	Required battery capacity in Ampere hour (eqn.(4)). DOD=0.8, η_t=0.9	456.52Ah at D_s=1day	3195.64Ah D_s=7days
	Capacity of selected battery (Ah)	150Ah	
	Batteries in parallel (eqn.(5))	3.04 ≅ 3	≅ 22
	Batteries in series (eqn.(6)) V_b =24V, V_s=220V	10	10
	Total batteries	30	220
Array Sizing	Design month	3-month	
	Efficiency of a solar PV module used (Solara). Power=130W, area=65*147cm^2 =0.9955m^2. (eqn.(8))	13.06%	
	Output of a single PV module used (Solara) In 3-month (Direct irradiance) 5029.4*0.1306=656.8Wh/m^2/day)	656.8 Wh/m²/day	
	Average sun hours per day (Calculated at 1000W/m^2=5029.4/1000)	5.0294 hours	
	Total solar array amps required	48.03A at D_s=1	336.21A at D_s=7
	Peak Amps of solar module used (for Solara-130W)	7.3	
	Total number of solar modules in parallel required	≅ 7	≅ 49
	Number of solar modules in each series string to provide DC battery voltage (240VDC/17.3V=13.87)	13.87 ≅ 14	
	Total number of solar modules required	98	686
Inverter size	Continuous current Surge current	1952W 7150W	

Table 5. Number of PV modules for both direct and global solar radiation

	January	February	March
No. of PV modules (Direct solar radiation)	98	84	112
No. of PV modules (Global solar radiation)	112	112	98
No. of PV modules (Direct solar radiation) For 3-months	98		
No. of PV modules (Global solar radiation) For 3-months	112		

5. Conclusion

This study analyzed the direct, global solar irradiance and temperature in Ramadi city, for the first 3-months of 2013 (January, February and March). It is the first paper that introduces complete practical data for real solar irradiance in Ramadi city and even in Iraq. The real solar irradiance is of important in the design and optimization framework for the maximum power of a photovoltaic module. It is found that the monthly-average daily for direct solar irradiance 5308.3, 5466.6 and 4313.3 w/m² for 3-months respectively, other the monthly-average daily for global solar irradiance 4421.8, 4559.7 and 4927.5 w/m² for 3-months respectively. The average temperature is below 25 ^{0}C for 3-months. The solar tracking system can reduce the PV system size by about 12.5% for the whole three months.

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