Comparison between two calculation methods for designing a stand-alone PV system according to Mosul city basemap

1 Introduction

PV is a manner of procreating electrical power by changing solar radiation to DC electricity using semiconductors that induct in PV technology. PV generation uses solar panel compounded of many solar cells. Because of the growing demand of clean energy sources, the fabrication of PV modules has developed considerably in recent years [1]. PV is one of the essential universal trends connected to gaining energy from renewable energy sources (RES) [2]. PV inability has important effect on the safety, accuracy, and energy balance of PV devices [3]. PV systems are growing rapidly, starting from low capacity to high capacity around 40,000 MW at the end of 2010. More than 100 countries use PV system [4]. PV is a technology that credibly converts sunlight to DC electricity. Variable kinds of PV modules accredit on the rating scale of the power. Solar cell is a fabric cited by famous semiconductors like silicon [5]. Changeability in the temperature will affect the solar module efficiency, and because of these mutations this technology is facing big defiance in its power finesse rendition. Reintegrated of clean energy is considered a screed route [6]. Efficiency is a very significant signal for PV systems [7]. The requirement to decrease the environmental effect of conventional fossil fuels, as well as the depletion of these resources and the intense increase in fossil fuel prices, is the cause for the rising use of RES [8]. PV technology is very well suited to supply the stand-alone locations. It has good reliability [9]. Are obtained from calculation solar program by software package according to the longitudinal and latitude site in formation for a certain loads are given various premiums about the PV generation [10].

2 Literature review

Angga Romana, Eko Adhi Setiawan, and Kumianto Joyonegoro (2018) studied the design of solar PV system according to two methods: Australia/New Zealand Standard and manual methods. The two methods take constant values for DC voltage bus (48 V) and oversupply coefficient (2). They concluded that Australian design method is better than the manual method [11].

Preeti Bhatt and Arunima Verma (2014) studied the design of solar PV system. They made a comparison between congenital and nano PV system they take (200 V) for bus voltage but did not include the dirt factor
tilt angle, inverter efficiency, and oversupply coefficient in the calculations of solar PV system design for conventional and nano types. They concluded that nano PV system cannot be used for high power load on computation of its low conversion efficiency and the design for three phase load requirement of the whole building [12].

Ayaz A. Khamisani (2019) studied the design of off-grid solar PV system. He included the system losses in the calculations and he depended on the PWM charge controller instead of MPPT charge controller in the design of the charger. Solar PV system (off-grid) type systems more agreeable to areas where the consumer opts not to be supply back the energy that generated at this end and the electrification is yet to be accomplished [13].

3 The uniqueness of this work

PV models have nonlinear characteristics of voltage–current relationship, and therefore, there is only unique point for stand-alone solar PV system as compared with the other previous design; in this work all practical environmental conditions are included in the design according to calculation solar program, and all main practical environmental conditions are taken from this program and compensated in the mathematical method. These practical conditions gave true sizing of PV modules, batteries, charge controller, and inverter as compared with previous works.

4 Stand-alone/off grid solar PV system

PV systems are considered a simple application for the customers to connect their loads to the grid [14]. Battery storage system is used in off-grid PV systems for providing the electricity during cloudy days and at night. The weather changes and the year round conditions must be considered at designing these systems [15]. When sun does not appear for many continuous days, back-up generators are required such as diesel, gasoline, and petroleum. The advantages of stand-alone PV systems are to give adequate energy to a household and powering the place which are distant from the grid [16]. Off-grid systems have further ingredients and these systems are considered expensive and comparatively costlier than grid direct system [17]. Table 1 illustrates the PV system components.

<table>
<thead>
<tr>
<th>Particular</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV modules</td>
<td>ATERSA</td>
</tr>
<tr>
<td>Batteries</td>
<td>STECA TAROM</td>
</tr>
<tr>
<td>MPPT controller</td>
<td>KHUN</td>
</tr>
<tr>
<td>Inverter</td>
<td>VICIRO</td>
</tr>
</tbody>
</table>

Table 1: PV system components

Figure 1 represents the stand-alone PV system.

5 Materials and methods

Many materials and two calculation methods are suggested in this work.

5.1 Materials

Materials used in this work are given in Table 2.

5.2 Methods

Calculation solar program is an implementation that determines the energy during 24 h, requested of a household and depending on the numerator that represented by batteries required and number of PV modules [18]. The implementations included the presumptive wattage of each appliance. Calculation solar program the appliances are collected to gather into four categories called
entertainment, cleaning, air-conditioning, and lighting
energy requested for each category is determined sepa-

rately then displayed [19]. The forerunner version ditto
numerates the rating of the inverter and the charge con-
troller that required by the solar system [20]. These are
necessary components for a solar system. In addition,
the full clone takes within the account the system effi-
ciency, depth of discharge, and offline verses online
usage [21]. Solar are rate of the peak sunshine hours,
there are three various estimation manners. The estima-
tion manners annexing use of air mass formula, half-
sine model and NASA solar insolation data [22]. The
mechanism for calculating the area and panel tilt angle
was included.

The proposed model is said to perform better at
energy prediction than software tools such as PV watts,
PV system, or ret screen. The approach was validated on
two 5 MW PV plants in the same district of Mosul-Iraq
[23]. Method to curriculum the demeanor of a PV appa-
ratus as a prosthesis to the equivalent circuit model. In
some implementation a very prompt and cushy approach
to a solar panel demeanor is required [24]. Daytime tem-
perature and global horizontal insolation (GHI) are the
two core parameters affecting the PV plant output. Accor-
ding to these parameters, Mosul can be classi-

fied into 15 climatic zones [25]. From National Renewable Energy
Laboratory (NREL) Mosul is classi-

fied into various climatic zones. Finally, the results show a decisive study to select
the best PV technology for various climatic zones of Mosul [26].

Table 2: Materials of suggested PV system

<table>
<thead>
<tr>
<th>Name/type</th>
<th>Shapes</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solar panel: ATERSA A-100M</strong></td>
<td><img src="https://example.com/solarpanel.png" alt="Solar panel" /></td>
<td>Product warranty 10 years, $P_{max}$ (100 Wp), $V_{max}$ (18.95 V), $I_{max}$ (5.28 A), $V_{oc}$ (22.21 V), $I_{sc}$ (5.79 A), panel efficiency (15.07%)</td>
</tr>
<tr>
<td><strong>Regulator: STECA TAROM 245 PWM.</strong></td>
<td><img src="https://example.com/regulator.png" alt="Regulator" /></td>
<td>System voltage 12 V/24 V, input $I_{sc}$ (45 A), maximum output current at load (45 A), maximum self-consumption (14 mA), charge voltage of the boost (14.4 V) and (28.8 V), floating case end of charge voltage (13.7 V) and (27.4 V), equalization charge (14.7 V) (29.4 V). Deep discharge protection (SOC/LVD) &lt; 30% SOL/11.1 V (22.2 V/44.4 V)</td>
</tr>
<tr>
<td><strong>Battery: KHUN 100 AH TUBULAR-PLATE.</strong></td>
<td><img src="https://example.com/battery.png" alt="Battery" /></td>
<td>Model type LPTT 12100H, warranty 5 years, rated capacity 100 Ah, inverter support 10KYA-900 VA, nominal voltage 12 V, tall tubular technology, depth of discharge 80%</td>
</tr>
<tr>
<td><strong>Inverters: VICTRON MULTIPLUS C 24/2000/50-30.</strong></td>
<td><img src="https://example.com/inverter.png" alt="Inverter" /></td>
<td>1,600 W constant output and 4,000 W peak current for 24 V battery voltage. Combination of inverter with transfer switch and 50 A battery charger. Provides pure sine wave at 50 Hz. VE.Bus communication port allows extensive possibilities in terms of connection, configuration, and controlling of victron multiplus devices. Supports three-phase operation (three units of the same model needed). Supports parallel operation – up to six units can be connected parallel to increase system power if needed. Inverter efficiency 94%</td>
</tr>
<tr>
<td><strong>Appliances: Television, refrigerator, microwave oven, computer, and lighting</strong></td>
<td><img src="https://example.com/appliances.png" alt="Appliances" /></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Consume appliances per day

<table>
<thead>
<tr>
<th>Appliances</th>
<th>Hours (h)</th>
<th>Power (W)</th>
<th>Energy (W h/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer</td>
<td>5</td>
<td>300</td>
<td>1,500</td>
</tr>
<tr>
<td>Television</td>
<td>3</td>
<td>70</td>
<td>210</td>
</tr>
<tr>
<td>Microwave oven</td>
<td>0.8</td>
<td>800</td>
<td>640</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>8</td>
<td>195</td>
<td>1,560</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>3,910</td>
</tr>
</tbody>
</table>
From basemap the installation is situated: unnamed road, Mosul, Iraq; the coordinates: 36.541461, 43.19386. PV array is bought according to the following peculiarity: inclination: 73°. Disorientation belonging the south: 6°. AC with a voltage of 230 is used in this system [27].

6.1 Consumption

The energy consumption is determined from appliances and lighting per day. Tables 3 and 4 show the appliances and lighting consumption per day.

Table 4: Lighting consumption

<table>
<thead>
<tr>
<th>Type</th>
<th>N°</th>
<th>Hours (h)</th>
<th>Power (W)</th>
<th>Energy (W h/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorescent lamp</td>
<td>2</td>
<td>5</td>
<td>11</td>
<td>110</td>
</tr>
<tr>
<td>Fluorescent tube</td>
<td>2</td>
<td>5</td>
<td>30</td>
<td>300</td>
</tr>
<tr>
<td>Bulb</td>
<td>2</td>
<td>5</td>
<td>60</td>
<td>600</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>1,010</td>
</tr>
</tbody>
</table>

Table 5: Performance ratios

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery depth of discharge</td>
<td>80%</td>
</tr>
<tr>
<td>Battery losses coefficient</td>
<td>5%</td>
</tr>
<tr>
<td>Wiring loss coefficient</td>
<td>5%</td>
</tr>
<tr>
<td>Loss coefficient of DC/AC conversion</td>
<td>6%</td>
</tr>
<tr>
<td>Self-discharge coefficient of battery</td>
<td>0.5%</td>
</tr>
<tr>
<td>Autonomy system</td>
<td>3 days</td>
</tr>
<tr>
<td>Performance ratio</td>
<td>81.9%</td>
</tr>
</tbody>
</table>

6.2 Theoretical total daily energy 4,920 W h/day

Theoretical energy per day is 4,920 W h/day; the parameters given in Table 5 are used by the calculation of yield (performance ratio) [28–33].

Table 6 represents the calculation of PV modules number.

7 Regulator specifications

The specifications of the regulator are given in Table 7.

8 Batteries calculations

Energy, depth of discharge, bus voltage, and days of autonomy are entered in the batteries calculations.
- Nominal voltage of battery: 24 V.
- Depth of discharge: 80%.
- Days of autonomy: 3 days.
- Daily real energy: 6,007 W h/day.
- Battery capacity calculated helpful: 751 A h.
- Actual capacity batteries calculated: 1,252 A h.

Battery specifications are given in Table 8.
9 Inverter charger

The choice of inverter charger is given in Table 9.

The elements that obtained from the calculation solar program are summarized in Table 10.

10 Mathematical calculations

The mathematical calculations are obtained according to the theoretical total daily energy:

10.1 PV sizing

Total load (W h) = 3,910 + 1,010 = 4,920 W h.

Total power = \( \frac{\text{Total load}}{\text{Sun Arc Rate}} = \frac{4,920 \text{ W h}}{6.5 \text{ h}} = 756 \text{ W}. \)

Power of PV module = 100 W.

Then,

No. of PV modules = \( \frac{\text{Total power}}{\text{Power of PV module}} = \frac{756 \text{ W}}{100 \text{ W}} = 7.56 \approx 8 \text{ pcs.} \)

10.2 Battery sizing

Required battery capacity = \( \frac{\text{Total energy}}{\text{DC voltage}} \times \frac{\text{Day of autonomy}}{\text{Depth of discharge}} \times \text{Temperature correction factor} \)

\[ = \frac{4,920}{24} \times \frac{3}{0.6 \times 0.95} \times 0.57 = \frac{615}{0.57} = 1,078 \text{ A h}. \]
10.3 Inverter sizing

\[
\text{Inverter sizing} = \frac{\text{Total energy} \times f_o}{\text{Energy (W h)}} \times f_o,
\]

where \(f_o\) is the oversupply coefficient.

\[
= \frac{4,920}{6} \times 1.7 = 1,394 \text{ W}.
\]

The elements obtained from the mathematical calculations are summarized in Table 11.

### Table 10: Stand-alone PV components (calculation solar program)

<table>
<thead>
<tr>
<th>Units</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Module type – ATERSA A-100M MONOCRISTALINO</td>
</tr>
<tr>
<td>1</td>
<td>Regulator type – STECA TAROM 245 PWM</td>
</tr>
<tr>
<td>2</td>
<td>Battery type – KHUN 100 AH TUBULAR-PLATE</td>
</tr>
<tr>
<td>1</td>
<td>Type of inverter – VICTRON MULTIPLUS C 24/2000/50-30 (MPPT built-in)</td>
</tr>
</tbody>
</table>

### Table 11: Stand-alone PV components (mathematical calculations)

<table>
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<tr>
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<th>Elements</th>
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</tr>
</tbody>
</table>

### 12 Presumptions

The presumption effects of the practical conditions are:
- Dust particles are litters in the midair and are readily carried by the wind; these dust particles generated from industrial ambient cause 80% softening in the PV electrical output. Also the effect of dust and sighting will decrease the efficiency.
- The poor solar irradiant and inclination angle will lead to the fakir PV systems, also the wrong angles will cause a poor received of radiation.
- Day of autonomy can be expressed by the time that the load can be met with the batteries alone unrested any solar inputs, embarking from full charged battery state, this may perform to sorely low average state of charge premium over broad periods of the year which is fully damaging for batteries bank.

### 13 Conclusion

The comparison results of two methods appear that the number of PV modules, batteries, and inverter are equally for same provenance and specifications of solar PV system components depending on the real cautions of calculation solar program and the theoretical mathematical calculations. Stand-alone PV system is more reliable than the on-grid PV system because of using battery storage system that gives more stability for this system. Days of autonomy have a large effect on the number of the batteries, which in turn will effect on the total cost of the system.

### 14 Future prospects and drawback

Stand-alone PV system is expected to grow very quickly from now to 2030. The drawbacks of these systems are very high initial cost, especially the storage back and the dust in the weather.

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References

[2] Malek A, Caban J, Wojciechowski L. Charging electric cars as a way to increase the use of energy produced from RES. De Gruyter | Published online; 2020 March 8.
[11] Roman A, Setliawan EA, Joyonegoro K. Comparison of two calculation methods for designing the solar electric power system for small islands. Published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0. E3S Web of Conferences. Berline: DE Gruyter; 2018.

