A Novel Software Tool for Sizing Off-Grid PV System and PV/Diesel Hybrid System

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Abstract. The design of graphical user interface programming is for sizing the components of a stand-alone PV system and PV-Diesel hybrid power system based on Iraq conditions. This software program presents as a guideline tool for photovoltaic system integrated depends on the input data by the user to give correct results according to the weather condition of solar radiation of Iraq, with less time and effort. A stand-alone solar system design model applied firstly, on a software program is to provide the load with energy 300Wh/day. Secondly, as an experimental application, to identify the appropriate factors that must be entered in the program from average solar irradiation and safety factor, by test the performance of the photovoltaic solar system, where the generation energy rate by the solar module was 381Wh and the consumption energy rate was 250.33Wh during the working period. The system will suffer from a lack of power generation if solar irradiation is not high enough or in case of weather conditions change.

Keywords: Renewable energy, Stand-alone PV System, Hybrid PV-Diesel System, Design of Solar Power System, Solar System Design Program.

1. Introduction
Iraq is located in the Middle East between latitude (29° 5' and 37° 2’ N), and longitude (38° 45’ and 48° 45’ E) [1]. Iraq receives more than 3000 hours of solar radiance per year in Baghdad [2]. The increase in the percentage of air pollutants and their negative effects led to the reliance on renewable sources of energy [3]. Solar energy is the most reliable and important energy resources to compensate for the restricted availability of the conventional energy source. Solar energy can be directly converted to electrical energy via photovoltaic (PV) technology and is considered as an environmentally friendly source of electricity. A standalone power system is independent on the main grid electricity. PV system is an interdisciplinary field, which involves a large variety of applications and can protect urban and rural areas from pollution by avoiding CO₂ emissions. Generally, a standalone photovoltaic solar system majorly included: photovoltaic solar modules, DC-DC solar charge controller, DC-AC inverter, storage batteries, loads, and other accessories like cables, frame for solar modules, connectors, etc., the previous components with adding diesel generator as a backup source will be a hybrid PV-Diesel system, see Figure 1 [4]. Using a diesel generator as a standby source will make utilization of hybrid systems more attractive [5]. The hybrid PV-Diesel system design provides power to the loads and to charging batteries when the solar irradiation is not available and the battery storage system is low and incapable to provide the loads [6]. There are many software and simulation programs is designed and most of these programs are complex and needs time to learn [7, 8]. In this paper, a new software program is designed to facilitate the sizing process of the system components (modules, storage, charge controller, DC-AC inverter, and diesel generator (DG), don’t need more time to learn and more compatible with Iraq conditions.
2. Software Design Methodology

The software program developed by employing GUI (graphical user interface) platform is based on visual studio and for creating a database by using Microsoft SQL Server. The overall process of input and output data for this software design tool summarized in the block diagram in Figure 2, explains the input and output information from this software program under the name of program is University of Baghdad_Solar System Design Tool (UOB_SSDT).

3. System Sizing

The properly photovoltaic system sizing is essential to achieve sustainable and reliable system design. The system sizing will be determined the size of each component existed in the photovoltaic system.

3.1 Load Assessment

Generally, load power refers to the electrical or thermal energy demand. Serving load is the primary purpose of any power system [9]. In the state of load analysis, a system designer should also discuss all the potential energy resources that can meet the capacity needs by the consumer and educate the customers about energy efficiency. The steps for load estimation are:

1. List all the alternative current (AC) electrical appliances that should be supplied by the designed power system.
2. Enter the items number of appliances.
3. Enter the operating wattage for one appliance.
4. Enter the number of hours per day for each item used.
5. Specify the number of days per week.
6. Multiply steps 2, 3 and 4 to calculate the daily energy requirement for 7 days a week.
7. Multiply steps 2, 3, 4 and 5 divided by 7 days a week to calculate the average daily energy requirement per day [10].

3.2 Photovoltaic Module Sizing
To estimate the actual power of the photovoltaic array by equation (1) [9].

\[ P_{PV} = \frac{E_{L,ave}}{P_{SH} \times \eta_c \times \eta_{inv} \times \eta_{batt}} \times SF \]  \hspace{1cm} (1)

Where the \( \eta_c, \eta_{inv}, \eta_{batt} \) is the efficiency of the charge controller, inverter and battery respectively, SF is the safety factor for compensating the losses due to temperature, dust, mismatch, and wire losses [17]. \( E_{L,ave} \) is the average daily energy demand, and PSH is the peak sun hour.

In hybrid PV–Diesel system the energy demand will be multiplied by a fraction (n), this fraction can be defined by the PV to DG ratio [9]. The final equation (2).

\[ P_{PV} = \frac{n \times E_{L,ave}}{P_{SH} \times \eta_c \times \eta_{inv} \times \eta_{batt}} \times SF \]  \hspace{1cm} (2)

3.3 Charge Controller Sizing
The estimated solar charge controller rating (SCCR) depends on the output from PV array and battery voltage by equation (3) [11].

\[ SCCR = Isc \times N_p \times SF \]  \hspace{1cm} (3)

3.4 Battery Storage Sizing
The required storage batteries capacity is a function for many parameters like the maximum depth of discharge (DOD), autonomy days (AD) and the efficiency of an inverter and battery. The AD is the number of days that the batteries are able to supply the required load without recharging by photovoltaic modules or diesel generator. The battery capacity can be determined by using equation (4) [15].

\[ C_{Bat, nom} = \frac{E_{d, daily} \times AD}{DOD \times SV \times \eta_{batt} \times \eta_{inv}} \]  \hspace{1cm} (4)

Where \( E_{d, daily} \) is the daily energy demand and SV, is the DC-bus system voltage.

3.5 DC-AC Inverter Sizing
The calculated size of inverter in system design depends on the power of loads, the inverter size (IS) is calculated by equation (5) [16].

\[ IS = \text{Total power} \times SF \]  \hspace{1cm} (5)

Where the total power of loads will use to find the inverter size.

3.6 Diesel Generator Sizing
To obtain a good diesel utilization with long service life, the generator must be operated at optimum load. The estimating of diesel generator size (\( S_{dg} \)) can be found by the equation (6).

\[ S_{dg} = S_{max, dem} \times f_{over} \]  \hspace{1cm} (6)
Where $S_{\text{max}_{\text{dem}}}$ is the maximum required power during battery charging and $f_{\text{over}}$ is oversize factor. The number of hours required in h/day for cover the load and charge the battery depends on PV to DG ratio by following equation (7) [9].

$$h = \frac{\left(1-n\right) \times E_{\text{L-ave}}}{\text{Total Power}}$$  \hspace{1cm} (7)

A model was applied to design a stand-alone PV solar system using UOB_SSDT. Figure 3 shows the main interface of the photovoltaic system design tool. It contains access information such as project name, designer or user name and the date. Also, it contains the type of system presented by the stand-alone PV system and hybrid PV-Diesel system. This window contains files that designed and saved for retrieval when needed to open it.

![Figure 3. Main form in software program.](image)

The second window has been designed as a home interface, it allows for easy navigation of the system components in this software design tool. It is containing the design information (Irradiation, System voltage and Safety factor). The peak sun hour (PSH) and SF in a software program used ($5.7 \text{ kWh/m}^2/\text{day}$), and ($1.15$) respectively as default value. Also, it contains a diagram explain the type of current and includes components of the selected system such as the load analysis, PV Array, Inverter, Battery Bank, and DG for hybrid PV-Diesel system as shown in Figure 4.5. The solar irradiation data was obtained from Photovoltaic Geographical Information System (PVGIS) website. In Baghdad city, the suitable tilt angle for orientation PV array in the winter season is $(45^\circ – 48^\circ)$, and for the summer season is $18^\circ$, the optimal tilt angle through the year is $33^\circ$ for fixed photovoltaic modules and according to the latitude of Baghdad. In this program can input the average (daily, monthly and yearly) solar irradiation for system design.

![Figure 4. The home form in stand-alone PV system](image)

![Figure 5. The home form in a hybrid PV-Diesel system.](image)

Figure 6, shows the load profile window, the user can input the used loads power based on design system through input type of device, power of the device, quantity and the number of days in a week.
to view the actual load. From power and energy screen the user can know the values of the amount of energy demand and the power peak demand. These values are important in any sizing system.

**Figure 6.** The load profile form.

In software program, there are types and models of photovoltaic modules available in Iraq stores and Iraq companies can be chosen from a combo box. For new data specifications and new types of module, the checkbox used as manual input for adding it manually as shown in Figure 7. The sizing solar charge controller, it is consist of two types of a charge controller are PWM and MPPT to calculate the current size. In addition, it contains the combo box to choose the charge controller model and the manual input property for adding a new model as shown in Figure 8.

**Figure 7.** The PV modules form.  
**Figure 8.** The charge controller form.

For sizing a battery storage capacity, it depends on the total daily energy consumption and battery capacity required. In addition, there is a list of batteries types available in Iraq stores and Iraq companies can be chosen it from the combo box or through enter the battery capacity at STC, battery voltage and it is price manually as shown in Figure 9. For inverter sizing, it includes three important parameters, firstly the short circuit current ($I_{sc}$) of the module which will be imported automatically when selecting the PV module, secondly is the safety factor for inverter and thirdly is the value of peak power required from the load power profile window. The three parameters determine the size and number of the inverter. In addition, the property of the combo box and manually input are existed in the interface as shown in Figure 10.

**Figure 9.** The battery storage form.  
**Figure 10.** DC-AC inverter form.

When the selected system is hybrid PV-Diesel system the diesel generator interface will be. The
fraction of energy contributed by photovoltaic (PV to DG ratio) and the power of diesel generator is presented in this interface as shown in Figure 11.

Figure 11. The diesel generator form.

Figure 12. show the result interface for stand-alone PV system in the software program, the result presented by the energy of loads, power of PV modules, total number of modules and how many series and how many parallels based on the system voltage. In addition, the program will calculate the charge controller current and the number of it, also, will calculate the power of inverter and the number of it. The program will calculate the total capacity of batteries in (Ah), the total number of batteries, how many in series and how many in parallel based on the system voltage. In addition, it contains the total cost of each component and initial capital cost as an approximate value. By press on button Calculate, all of the above results will calculate. The Figure 13, for hybrid PV-Diesel system results if it selected that will be influenced on the number of PV modules due to contribution ratio, also, it calculated the power of the generator, the number of hours to supply the loads and charging battery and diesel generator price to calculate the initial capital cost.

4. Experimental System Design
An empiricist system for stand-alone photovoltaic system is designed to verify from the result of software program on between experimental work. The system is producing energy to turn on the lamps load with (300Wh/day) as the night light. The period of work was for a week from months (January, February, March, April). Table 1 shows the standard parameters adopted in the PV system design.
Table 1. The standard parameters adopted in the photovoltaic system design.

| Parameter                                      | Value |
|------------------------------------------------|-------|
| Peak sun hour (h)                              | 5.7   |
| DC voltage bus (system voltage) (V)            | 12    |
| Safety factor                                  | 1.3   |
| Efficiency of inverter                         | 0.9   |
| The efficiency of the charge controller        | 0.9   |
| Efficiency of battery                          | 0.85  |
| Days of autonomy                               | 1     |
| Depth of discharge                             | 50%   |

The structure is adjusted with the optimal tilt angle 33° to the south as an annual system, installing the PV module on the frame with the height of structure 1.06m, Figure 14 shows the installed PV module. Table 2 shows the specification of solar module. Then connect the other parts of the solar system charge controller, inverter and battery storage with loads board then connected it with the PV module (an improper sequence order can damage the controller). With apparatuses for measuring presented by: power meter, for measuring the kilo-watt-hour of loads, three apparatuses of digital multi meter for measuring the battery voltage, PV voltage, PV current, as shown in Figure 15, see Figure 1 (b) as a block diagram for system.

Table 2. The specification of mono-crystalline module at STC from ISTAR SOLAR manufacture.

| Model | IS 100P |
|-------|---------|
| Peck Power | 100W |
| Current At Maximum Power (Imp) | 5.62 |
| Short Circuit Current (Isc) | 6.15 |
| Voltage At Maximum Power (Vmp) | 17.8 |
| Open Circuit Voltage (Voc) | 22 |
| Normal Operation Cell Temperature | 25°C |
| Dimensions | 1200*540*40 (+/-2mm) |
| Power Tolerance | +/-3% |

Figure 14. Installed PV module as a stand-alone PV system with solar power meter.  
Figure 15. Other components of PV solar system with apparatuses for measuring.
To extraction the performance of the solar photovoltaic system more clearly, the load was fixed on (300Wh/day). In addition, the panel was cleaned daily to exclude losses due to dust. And to know the reason for the difference between actual production by PV solar module and design production with actual loads consumption, therefore the solar irradiation, produced a capacity of the solar module and energy consumption loads were measured.

5. Results and Discussion

The intensity of solar radiation for months (January, February, March and April) in work periods previously at a tilt angle (33°) degree was (2.96, 3.61, 4.62 and 5.25) respectively. The highest average daily solar irradiation during the work period was in April (5.25 kWh/m²/day) due to the number of daylight hours during the week of this month was longer than the rest of the months, and the weather was sunny with few clouds in most days. The average of solar radiation through four months was (4.11 kWh/m²/day), as shown in Figure 16.

![Figure 16. The intensity of solar radiation for months with work periods.](image)

The produced power from the PV module changes directly proportional with the value of solar irradiation. Most of the energy generated from the solar panel in the three months of February, March and April was within design limits and covered the demand energy to loads, the Figure 17 and Figure 18 summarized the data of experimental work for generation and consumption energy during the week respectively. The load energy of the solar system has been proven to be (300Wh/day) throughout the working period as a constant daily load. The highest rate of generated energy during the week was (473.8Wh) on March due to the increase the weekly rate of solar irradiation, while the highest rate of consumption energy was (292Wh) on April, because of the compensation the shortage of generation due to clouds and rain to meet the required load for energy by energy stored in batteries in days at high solar radiation rate.

![Figure 17. Generation energy for a week per month of four months.](image)

![Figure 18. Consumption energy for a week per month of four months.](image)
From Table 3, the difference between practical and theoretical in generating power due to losses caused by heat losses and DC cable losses. In addition, to decrease the solar irradiation due to weather conditions. Moreover this effects on the difference between the daily required load in design (300Wh) and actually average consumption load during the months (250.33Wh) as well as equipment losses represented by charge controller, storage battery and DC-AC inverter or due to defects in components. The conversion efficiency is the output consumption energy to input generation energy and the rate of DC-AC energy conversion efficiency was (0.665) very close to the theoretical efficiency which comprises the efficiency of charge controller, inverter and storage battery (0.9, 0.9 and 0.85) respectively with error percentage equal to -3.5%.

To evaluate the photovoltaic installation performance and it is involved losses like (components losses, temperature losses, DC and AC cable losses, dust and snow losses, losses at weak radiation) by using the performance ratio (PR). The performance ratio for the designed system was approximately 61% that’s mean 39% is wasted energy, the incident solar radiation is not converted to useful energy due to heat losses, conduction losses, and other components losses. With taking the solar module efficiency (0.153) the performance ratio is calculated from formula in equation [18].

$$PR = \frac{[\text{UsefulEnergy (kWh)/ (Irradiance (kWh/m2))}\times \text{PVarea (m2)}}{\text{PV module Efficiency}}] \times 100 \quad (8)$$

Table 3. The weekly average of ambient temperature, experimental and theoretical generated energy in watt-hour, error percent, consumption energy in watt-hour, and with conversion efficiency respectively arrangement in the table.

| Month | Ta (Cº) | Eexp. (Wh) | Etheo. (Wh) | Error (%) | Econs. (Wh) | ηconv. |
|-------|---------|------------|-------------|-----------|-------------|--------|
| Jan.  | 11.6    | 246.3      | 327.7       | 24.8      | 181         | 0.735  |
| Feb.  | 9.11    | 379.7      | 400.8       | 5.2       | 234         | 0.616  |
| Mar.  | 14      | 473.8      | 440         | -7.7      | 294.3       | 0.621  |
| Apr.  | 20.29   | 424.2      | 458.3       | 7.4       | 292         | 0.688  |

6. Conclusion
The software program is developed to acts as a guideline tool the final result depends on data entered by the user. Also, it facilitates the design process for systems with the possibility of saving and printing the results. Due to changes in weather conditions throughout the year, especially solar radiation and temperature, are heading towards increasing solar panels in stand-alone PV system to increase the generation capacity to cover the loads during the interruption of power processing during winter months and to avoid increasing the depth of battery discharge more than 50% to avoid costly losses. Or the user can use an alternative source of renewable energy as a backup generator as the hybrid system to cover this gap in the working of the solar system during the winter months and to charge the battery storage.

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