Direct Use of Solar PV System Generation with Minimum Batteries Capacity

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Abstract. The aim of this work is to present a specialist design of solar PV system to provide load at (8a.m. to 2p.m.) as daily energy consumption, by expanding in solar panels numbers with reducing battery numbers, consider the cost of batteries proportionally to solar panels cost. The specialist design depended on load consumption (6) hours between (8 a.m. – 2 p.m.) at sunshine day to supply power to load directly from the PV system generation with little contribution battery energy. The results show specialist design can be useful for this situation of covering load consumption in (6 hours) band benefit to used PV system to reduce the solar PV systems cost, was the performance analysis of this system from April to October.

1. Background
Solar PV systems are utilized based on the type of electric appliances used by the users. This information is gathered through a site survey. The loads total energy requirement per day of (kilowatt-hour per day) is estimated by using the calculation equations for sizing solar PV system [1, 2].

The sizing of the solar PV system is very useful to conceive an optimal power and economic solar PV system and optimization of the existing solar PV system with regard to tilt angle and orientation of the panels will be apply, with respect to the amount of produced power and economic profitability [1, 3].

Solar photovoltaic system design can be built in a multi-step calculation, list all connected loads (watts) with operating hours then calculate the total energy requirement of the system (total loads consumption), estimation of the number of solar panels, battery bank and cost estimation of overall system [3,4].

The actual power output of a solar panel depended on peak power rating, and operating factor, the power used at the end user is less due to lower combined efficiency of the solar PV system [2, 5].

The amount of energy storage is important to use the energy from the loads when sunlight is absent. The solar photovoltaic systems required rechargeable batteries. There are various commonly available rechargeable batteries but the batteries with high depth of discharge are used in solar photovoltaic systems [5, 6].

While the battery stores the energy generated from the solar panels and uses this energy to provide loads, but the capacity of batteries less than the lifetime of a number of factors, the most important is the number of cycles of charging and discharging [2, 4].

Energy payback period is a commonly used indicator in the life cycle assessment of photovoltaic solar systems to justify the initial use of energy to produce components of photovoltaic systems, and the time of energy recovery is the proportion of total embodied energy incurred in the manufacture of photovoltaic systems and the annual energy produced by photovoltaic systems [2, 6].
In order to calculate the daily consumption power of all the loads with an hourly time step was constructed, this gave a good understanding of how often the loads are used during the two different periods of the days [3, 5].

Depending on the specific applications, batteries storage bank is calculated based on the batteries specifications such as the batteries storage capacity (the minimum batteries) for off-grid applications, batteries have to fulfill the discharging rate has to be larger than or equal to the peak power of loads capacity, the batteries storage capacity has to be large enough to supply the longest day time energy used and to be able to use energy during the longest cloudy period time [2, 8].

The gross energy requirement \( (E_G) \) of an energy conversion device with the energy output \( (E_O) \), can be decomposed in two parts the direct input of energy during operation \( (E_D) \), and indirect energy requirement \( (E_I) \), the energy used by the loads can be calculated by the Eq.1:[7,9] 
\[
E_G = E_D + E_I
\]

Where:
\( E_G \): Gross energy requirement
\( E_D \): Direct input of energy
\( E_I \): Indirect energy requirement

Solar panels and batteries can be calculated using basic equations that depend mainly on the total daily load capacity. One principle is that the solar panels charge the batteries during the day and the batteries process the load at night as in the solar street lighting system. The capacity of storage batteries can be calculated according to the following equation:
\[
CB(Ah) = \frac{E_{load}}{\eta_{inv} \times V_B \times DOD \times DOA}
\]

Where:
\( CB \) : Total battery capacity (Ah)
\( E_{load} \) : Total load Energy (Wh/day)
\( \eta_{inv} \) : Inverter efficiency
\( V_B \) : Battery voltage (V)
\( DOD \) : Depth of discharge (%)
\( DOA \) : Day of autonomy

While, daytime operating loads there is a direct use of solar generation energy through the Inverter to supply load without passing through the storage battery. Therefore, the needing for battery will depend on the level of energy generated from the solar panels instantaneous. When the generated energy is less than the load requirement will be the battery to compensate for the energy shortage, and when the energy generated his higher than the load requirements will drop to charge the battery.

2. Related Work
Sizing the photovoltaic solar systems at a specialist design for providing load consumption about (13.2 kWh) in a day as the maximum current (10 A), the daily operation about (6 hours) between (8 a.m. – 2 p.m.).

The system is designed according to the requirements (off – grid) photovoltaic systems, in two approach (traditional, modify) design.

Table 1. Sizing result for major component of (traditional, modify) design

| Design Approach | PV Power (kWp) | No.of modules (80W) | No. of batteries (12V/200Ah) |
|-----------------|---------------|---------------------|-----------------------------|
| Traditional     | 3.92          | 49                  | 12                          |
| Modify          | 4.32          | 54                  | 4                           |
The system is designed according to the requirements (off – grid) photovoltaic systems, array contain about (4.32kWp) consists of (54) solar panels size (80 Watts), the specialist design has more than the classic design with in a quantity (8 panels), the increasing ratio about (10 %), and (4 battery) size (200 Ah/12 V) less than classic design with in a quantity (8 battery) the decreasing ratio about (66%).

The specialist design shall be abilities for covering the load’s variables within the design scale of the photovoltaic systems with the minimum storage battery.

The photovoltaic systems can be supplying the generating energy from the solar Panels to loads directly through the inverter without using energy stored in the battery when there is an enough in solar generation rates, depending of solar irradiation rates, storage battery is need for limited time during the morning and afternoon periods.

3. Results and Discussion

Solar irradiation rates normally change with time in Baghdad city as shown in a figure 1, and accordingly will be had changed in energy generation from PV system depended on PV solar system efficiency and weather condition.

The first operation step of the system will begin from sunrise to produce power for charging the batteries; the State of Charge (SOC) depended on solar irradiation rates.

Sometimes in cascading cloudy days, there is not enough energy in batteries to keep load continue working, Contrariwise in the summer there is enough time for batteries charging from sunrise to (8 a.m.) about three hours and solar irradiation rate are enough to load consumption from PV system generation directly, the generation energy rates from a solar PV system will vary throughout the year as shown in a figure 2.

![Solar irradiation (kWh/m²/day)](image)
A short time between sunrise and (8 a.m.) during months winter then the energy generation rates will be low, show in a figure 3 – section (A).

Loads start operating at (8 a.m.) and consuming the energy in this time the lowest of solar irradiation leads to a generation from solar panels will not be enough to meet the loads’ consumption therefore the compensation of missing energy will be supplied from the batteries until the solar irradiation increasing to value that making the generating energy from solar panels system to covering the load consumption, show in a figure 3 – section (B).

**Figure 2.** PV system generation energy rates.

**Figure 3.** PV system generation energy with load consumed energy and battery discharge energy for clear day
The next situation for a PV system, the solar panel generation will cover the load consumption directly and the power generation will overstep until gone to batteries charging and compensates the energy which consumption at (8 a.m.) time figure 3 – section (C).

The covering and overstep time about (3 – 4 hours) and can increase the energy generation by increasing the solar panel numbers.

After afternoon the power generation will be decreased until (2 p.m.) because a decrease in solar irradiation rates and compensation will be from a battery bank figure 3 – section (D).

At (2 p.m.) time the loads will be off, and all energy generation will go to the battery bank for a clear day as shown in a figure 3 – section (E)

In the cloudy day, there is a change in performance system shown in a figure 4, the curves shown there is energy generation of PV system with synchronization batteries used for providing load although the cloudy situation.

![Figure 4. PV system generation energy with load consumed energy and battery discharge energy for cloudy day](image)

one day has a daily solar irradiation rates about (4.8 kWh / m² /day) showing a good performance for system between time (8 a.m. – 2 p.m.), the surplus PV energy generation providing battery charge current but the battery discharge current will compensates the shortage of PV energy generation, figure 5 l explain the system performance for one day, the curves shown the low contribution from battery energy to consumed loads except at (8 a.m. – 9 a.m.).
Figure 5. PV system generation and battery (charge and discharge) current

At the time for providing power to the load from battery’s energy arranged at system voltage (48 V) without solar PV generation shown in the figure 6.

The curve refers to the battery’s capacity can be enough for consumption load for about (3 hours) when no energy generation from the PV system.

Figure 6. load energy consumption load and battery voltage without PV solar generation
The yearly summary of PV solar system and battery performance shown in the figure 7, the ratio of energy provides for load from a PV system can cover the consumption load in most months, except for the winter months there is the participation ratio from batteries bank contribution to provide consumption load in beginning at morning and after afternoon.

![Figure 7. yearly PV solar system performance (PV direct used and battery use)](image)

4. Conclusion
Determine the load energy for each hour during the day should be used instead of the daily total energy as the basis of the design, and estimation the PV modules energy generating depending on the Solar irradiation per hour of the average three winter months then calculate subtract between the load energy and modules generator for each hour, the sum of the all the values subtract for each hour is represented the \( E_{load} \) in battery calculation equation.

The direct use of the solar energy generated to must be gotten out of the calculation of the storage battery and to limit the need for storage batteries to compensate for the missing energy from the generation of the panels, but the rate must be based on the intensity of solar irradiation for three month’s winter accounts in the total capacity of the solar panels for the basic values of battery recharge and maintain the depth of the discharge so as not affecting the battery life.

PV solar system for specialist design was can provide loads with minimum battery capacity decrease ratio about (66%) with increasing PV ratio about (10%) will result reduces the cost of PV solar system.

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