

Comparative Analysis of Manual Solar System Design and PVsyst Outputs for Residential Loads

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Abstract

Off-grid solar energy systems are increasingly adopted for residential use as a sustainable alternative to fossil fuel-based electricity. Accurate design of these systems is essential to ensure reliability, efficiency, and cost-effectiveness. This study compares manual sizing calculations with PVsyst simulation outputs for residential off-grid systems. The manual approach focuses on determining the required number of PV modules, inverter capacity, and battery storage while accounting for surge loads. PVsyst simulations are then used to model the same system under environmental and operational conditions. Results reveal that while PVsyst provides valuable long-term performance insights, it tends to underestimate inverter requirements and battery usability in off-grid applications. Manual design, in contrast, ensures reliable surge load handling and more realistic storage capacity estimates. The study concludes that a hybrid approach—integrating manual engineering methods with PVsyst simulations—offers a more reliable pathway for residential off-grid solar system design.

Keywords: Solar Energy; System Manual Design; Residential Solar Design; PVsyst Simulation; Battery Sizing; Surge Load

Introduction

The growing demand for reliable and sustainable electricity has accelerated the adoption of residential solar photovoltaic (PV) systems as an alternative to conventional grid supply [1]. In areas with frequent grid outages or limited access to centralized electricity, careful PV system design is critical to ensuring continuous power availability [2]. Key design considerations include inverter size, bat-

tery capacity, and solar panel configuration, which play a critical role in determining power delivery efficiency and long-term system reliability [3, 4].

Manual design methods provide a basis for estimating residential load demand, selecting inverters capable of handling continuous and uninterrupted loads, and calculating battery autonomy based on depth-of-discharge (DoD) requirements [5]. However, these methods often rely on simplistic assumptions that may not fully reflect site-specific dynamic conditions. Advanced simulation tools such as PVsyst overcome these limitations by incorporating detailed environmental datasets, component specifications, and modeling system behaviour under realistic operational scenarios.

Libya was selected as a case study due to its suitability for off-grid solar deployment. Its harsh climate and prolonged grid outages make solar a reliable alternative. These conditions allow for more accurate residential load estimation and provide a practical environment for evaluating inverter performance, battery storage, and solar panel production under realistic operational challenges.

Research Aim

This study aims to compare manual sizing methods and PVsyst simulation outputs for residential off-grid solar energy systems, with the goal of identifying discrepancies and developing a hybrid design methodology that ensures reliable and efficient system performance.

Research Objectives

R01. To perform manual calculations for sizing PV modules, inverter capacity, and battery storage, including surge load requirements for residential loads.

R02. To simulate the same system using PVsyst software with equivalent design inputs.

R03. To compare manual and PVsyst results in terms of inverter sizing, battery usability, and PV array sizing.

R04. To identify discrepancies between manual and PVsyst-based approaches in off-grid system design.

R05. To propose a hybrid design methodology that integrates manual calculations with PVsyst simulations for more reliable residential solar system performance.

Research Questions

RQ1. How do manual calculations of PV modules, inverter capacity, and battery storage compare with PVsyst simulation results for the residential system?

RQ2. Does PVsyst accurately account for surge load requirements and usable battery capacity in off-grid system design?

RQ3. Can a hybrid approach that combines manual sizing with PVsyst simulation improve the reliability of off-grid solar energy system design?

Methodology

The proposed off-grid solar energy system is designed to meet the electrical energy requirements of a residential site while maintaining flexibility for future expansion. The main components include:

- **Hybrid Inverter:** A 10.00 kVA inverter, sized to accommodate a peak surge load of 9,570 W, ensuring reliable operation of appliances with high startup currents such as air conditioners and pumps.
- **System Voltage:** A nominal 48 V DC bus, selected to reduce current levels, improve efficiency, and minimize transmission losses.
- **Battery Bank:** The storage system is built from 12 V lead-acid batteries connected in series (4 per string) to achieve 48 V DC.

Two such 48 V, 225 Ah Battery Banks are connected in parallel, providing a total theoretical capacity of 21.6 kWh. At 80% depth of discharge (DoD), the usable storage is approximately 17.3 kWh, which is sufficient to meet the daily household energy demand with a small margin. In total, the battery banks consists of 8 Batteries, Each group is composed of 4 units.

The system is intended to power common residential loads, including lighting, refrigeration, air conditioning, and entertainment devices. To ensure scalability, additional inverters and battery banks can be integrated as needed, allowing the system to adapt to higher loads or extended autonomy requirements.

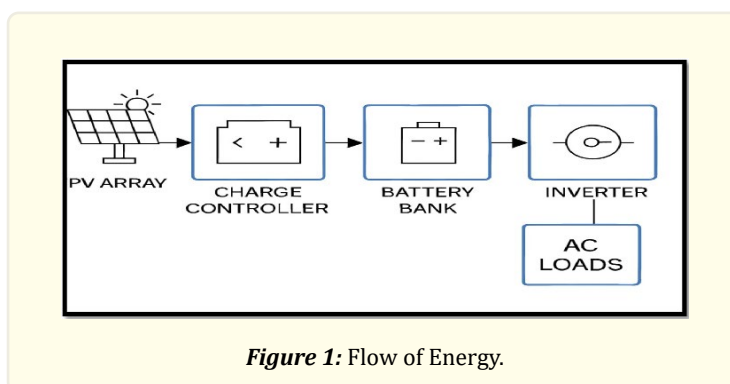


Figure 1: Flow of Energy.

Load Assessment

To determine the total energy demand, a load analysis was conducted based on the site data from the Excel file.

Device	Power (W)	Daily Use (h)	Energy (Wh)
On Load	3,530	5	17,650
Lighting	400	4	1,600
TV	110	3	330
AC - 12 BTU	1,200	4	4,800
AC - 18 BTU	1,650	4	6,600
Refrigerator (Fridge)	170	10	1,700
Water Pump (0.5 HP)	0	0	0
Total Daily Energy			15,030 Wh

Table 1: Load Assessment.

Battery Bank Sizing: To calculate the required battery bank size, we used the following steps:

Step 1: Adjust for System Efficiency

Assuming an 80% system efficiency:

$$\text{Front Head Energy} = \text{Total Load Energy} / \text{Efficiency} = 15,030 / 0.8 = 18,036 \text{ Wh/day.}$$

This is the upstream energy that must be supplied by the battery bank.

Step 2: Required Ampere-Hours (Ah)

$$\text{Suggested Required Ah} = 18,036 / 48(\text{VDC}) = 375.75 \text{ Ah.}$$

Step 3: Preferred Required Ah (at 80% DoD)

Preferred Required Ah = $375.75 / 0.8 = 469.6875$ Ah.

Assuming;

Days of Autonomy	1
Temperature Compensation	1
Design Margin (DM)	1

Step 4: Number of Batteries

Using 12 V, 225 Ah lead-acid (48V, 225 Ah):

No. of Batteries = $469.6875 / 225$ (V SYSTM) = $2.08 \rightarrow 2$ Units.

Conclusion: 2 batteries are recommended to ensure sufficient capacity and margin.

- Total Battery Capacity: $2 \times 10,800 = 21,600$ Wh.
- Usable Energy (80% DoD): $21,600 \times 0.8 = 17,280$ Wh.
- Autonomy at 3,530 W Load: $17,280 \div 3,530 \approx 4.90$ hours.

Inverter Sizing

The inverter must support both continuous and surge loads.

Continuous Load, Total: 3,530 W.

Surge Load

- **Surge devices:** 12 BTU AC (1,200 W), 18 BTU AC (1,650 W).
- **Surge factor:** ~3 Times.
- **Surge power:** $(1,200 + 1,650) \times 3 = 8,550$ W.
- Additional margin $\rightarrow 9,570$ W (from Excel of manual calculations).

Inverter Rating

Inverter selected = 105% at Maximum possible load.

=105% of (9750) = $10,048.5$ W.

Use a 10 kVA hybrid inverter to handle surge and support battery charging.

PV Panel Sizing: To generate 18,036 Wh/day, with 5.5 peak sun hours (PSH):

Required PV Output = $18,036 / 5.5 = 3,279.27$ W.

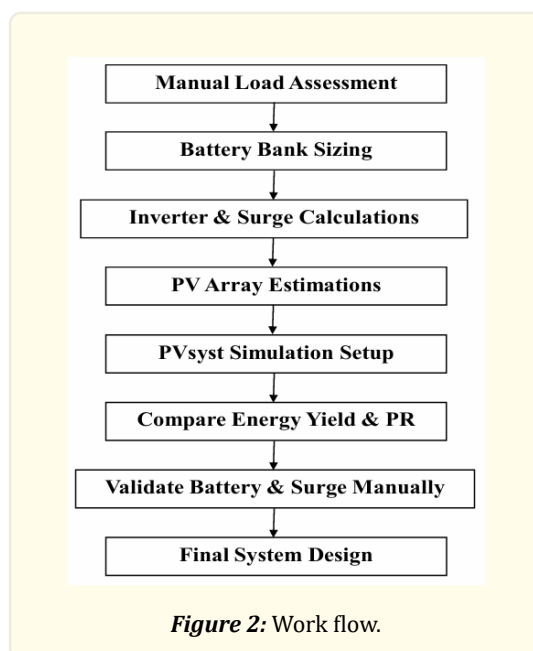
Using 377 W monocrystalline panels:

Number of Panels = $3,279.27 / 377 = 8.86 \rightarrow 9$ panels

- **Total PV Capacity:** $9 \times 370 = 3,330$ Wp.
- **Expected Daily Production:** $3,330 \times 5.5 = 18,315$ Wh (meets demand with margin).

Workflow Module for Manual Design and PVsyst Simulation Comparison

A hybrid approach to solar system design combines the reliability of manual calculations with the forecasting power of software like PVsyst. Manual methods ensure accurate sizing for surge loads and battery life, while PVsyst offers valuable predictions for energy yield, PR, and long-term performance. This balance helps avoid overdesign or under design, optimizing cost and efficiency—especially in harsh environments like Libya. Future work will apply this workflow to validate the residential site design and improve simulation accuracy for battery and surge load behaviour.



PVsyst Simulation Results

The PVsyst simulation was conducted for the residential load using the same demand profile and system parameters as the manual design. The modeled system consisted of 10 monocrystalline panels rated at 370 Wp each (total 3.7 kWp) and a lead-acid battery bank configured as 8 units in series-parallel, yielding 48 V and 450 Ah nominal capacity.

Metric	Manual Design (80% DoD)	PVsyst Simulation (80% DoD)
Daily load (user needs)	15.03 kWh/day	15.03 kWh/day
PV array	3.70 kWp (10 × 370 W)	3.70 kWp (10 × 370 W)
Battery type & conFigure	12 V lead-acid, 4 in series × 2 strings (8 units total)	12 V lead-acid, 4 in series × 2 strings (8 units total)
Nominal battery capacity	48 V × 450 Ah = 21.6 kWh	48 V × 450 Ah = 21.6 kWh
Usable battery energy (80% DoD)	17.3 kWh	17.3 kWh
Inverter / charger	10.05 kVA (sized for 9,570 W surge)	4.8 kW (default selection)
Annual energy from solar (E _{user} / yr)	~5,480 kWh/year (manual est.)	4,857.8 kWh/year
Performance Ratio (PR)	~78–80% (assumed)	67.2% (reported)
Solar Fraction (SF)	100% (design target)	88.6% (reported)

Table 2: Simulation Vs Manual result.

Manual Vs PVsyst

Battery Capacity

Both approaches model a bank of 8 *lead-acid batteries* (48 V, 450 Ah). At 80% DoD, the usable storage is approximately 17.3 kWh in both cases, showing close agreement when the same assumption is applied.

Inverter Sizing

PVsyst applies a default 4.8 kW inverter, which is insufficient for the 9,570 W surge load. In contrast, the manual design specifies a 10.05 kVA hybrid inverter, correctly sized to handle startup currents from appliances such as air conditioners and pumps.

Annual Energy and PR

PVsyst reports an annual delivered energy of 4,857.8 kWh, with a performance ratio (PR) of 66.22%, reflecting lead-acid inefficiency and conservative assumptions. The manual design estimates a slightly higher annual energy (~5,480 kWh) and assumes a more realistic PR of 78–80%, consistent with well-optimized off-grid systems.

Solar Fraction

The manual design achieves the target of 100% solar fraction, while PVsyst reports 88.6%, indicating partial reliance on unmet load or curtailed energy.

Limitations of PVsyst in Off-Grid System Sizing

PVsyst is widely used for solar PV analysis, but its off-grid design capabilities remain restricted. In versions 6 and 7, the software does not allow direct *inverter selection* or modelling of start up currents and surge demands. Instead, users can only adjust the *number of PV modules, MPPT inputs, and battery banks*. This contrasts with PVsyst's grid-connected mode, which includes a full inverter database with rated power, efficiency curves, and overload behaviour.

As a result, off-grid simulations may underestimate inverter requirements, particularly for inductive loads such as air conditioners and pumps. Manual calculations are therefore indispensable to determine both *continuous and transient power needs*, ensuring reliable sizing of inverters and batteries.

Conclusion

This study compared manual sizing with PVsyst simulations for a residential off-grid solar system with a daily load of 15.03 kWh. The manual method determined that a 48 V, 450 Ah battery bank (two parallel strings of four 12 V, 225 Ah batteries), a 10.05 kVA hybrid inverter, and a 3.70 kWp PV array would reliably supply the load, providing 17.3 kWh usable storage at 80% DoD and safely handling surge demands up to 9,570 W.

The PVsyst simulation, while valuable for modeling annual energy yield, performance ratio, and solar fraction, showed limitations in off-grid applications. It reported a PR of 66.22%, an undersized 4.8 kW inverter, and a lower solar fraction (88.6%) compared to the manual design's 100% target.

The key finding is that PVsyst alone cannot guarantee reliable off-grid system sizing, especially in contexts without grid backup. A *hybrid approach*—using manual calculations for critical component sizing and PVsyst for performance forecasting—provides a more robust framework for designing residential off-grid solar systems.

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