

A MATLAB-Based Framework for Optimal Sizing of Solar Photovoltaic Systems for Residential Applications

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Abstract

The increasing demand for sustainable and decentralized energy solutions has intensified the adoption of solar photovoltaic (PV) systems, particularly in regions with unreliable grid access. Accurate sizing of system components—PV panels, inverters, battery storage, and charge controllers—is essential for ensuring reliability, cost-effectiveness, and long-term performance. This study presents a MATLAB-based computational model for the optimal sizing of residential solar PV systems, targeting a daily energy requirement of 5000 Wh. The proposed framework integrates technical specifications, system losses, and safety margins to generate realistic estimates of component requirements. Key input parameters include panel wattage, average peak sun hours, desired battery autonomy, and component efficiencies. Simulation results for a hypothetical scenario using 300 W PV modules and 5 peak sun hours indicate that four PV panels, a 10 kWh battery, a 1560 W inverter, and a 62.5 A charge controller would meet the specified demand. The model offers a replicable and scalable tool for system designers, energy consultants, and development practitioners seeking to deploy solar energy solutions in both grid-connected and off-grid settings.

Keywords: Photovoltaics, Optimization, MATLAB Simulation, Inverter, Storage

1. Introduction

The global shift toward low-carbon energy systems has positioned solar photovoltaic (PV) technology as a critical component of future electricity generation strategies. Driven by declining costs and improved conversion efficiencies, PV systems have become increasingly accessible for both residential and commercial users (Kumar, Jain, & Chandel, 2021). In regions with unreliable or insufficient grid infrastructure, such as parts of sub-Saharan Africa, stand-alone and hybrid solar energy systems offer a practical solution for addressing energy poverty while advancing environmental sustainability.

Central to the effective deployment of PV systems is the accurate sizing of critical components—solar panels, inverters, batteries, and charge controllers. Undersizing leads to system instability and frequent power deficits, while oversizing results in excessive capital

costs and resource inefficiencies (Rohani, Aghaei, & Bagheri, 2019). Component sizing must therefore align with site-specific parameters, including daily energy demand, solar irradiance profiles, load variability, and the autonomy requirements of battery storage.

Traditional methods of system sizing often rely on manual calculations or static spreadsheet tools. However, these approaches may lack the flexibility required to incorporate dynamic environmental factors, system losses, and design margins. As computational tools become more robust, the use of platforms such as MATLAB has gained traction in engineering design and simulation due to their capacity to integrate numerical modelling, data analysis, and automation (Sharma, Bansal, & Verma, 2020). MATLAB-based models can accommodate real-time parameter adjustments, sensitivity analysis, and iterative design optimization, making them suitable for renewable energy system planning.

This study presents a MATLAB-driven framework for sizing the essential components of a residential solar PV system, designed to satisfy a daily load of 5000 Wh. The model employs structured inputs such as panel specifications, average peak sun hours, and desired battery autonomy to compute the number of PV modules, inverter capacity, storage requirements, and charge controller rating. Efficiency assumptions and safety margins are integrated into the calculations to reflect practical constraints.

The framework aims to support energy planners, system designers, and technical consultants by offering a transparent, replicable, and scalable tool for solar system configuration. While the model focuses on residential demand, its structure allows adaptation to broader contexts, including commercial installations and rural electrification projects.

2. Literature Review

The literature on photovoltaic (PV) system sizing has advanced rapidly with a growing emphasis on computational precision and context-specific modeling. Agha Kassab, Younes, and Mansouri (2024) offered a comprehensive critique of microgrid planning strategies, synthesizing heuristic, mathematical, and hybrid sizing methods. Their review shows how optimal sizing directly links to microgrid reliability, cost minimization, and reduced CO₂ emissions. Similarly, Selim et al. (2024) proposed a deterministic balanced method (DBM) for sizing hybrid PV-hydrogen systems, achieving accuracy within a 5% deviation of HOMER Pro benchmarks, thus affirming deterministic models as viable alternatives to probabilistic methods.

In a study integrating dynamic meteorological variables with PV modeling, Nfaoui, Allali, and Boulmakoul (2024) employed MATLAB/Simulink to simulate PV system performance under changing temperature, irradiance, and wind speed conditions. The results, validated using PVsyst, underscore the importance of environmental variability in accurate energy output prediction. Complementary to this, Khah, Lee, and Baek (2023) reviewed optimization approaches for PV and battery systems and identified MATLAB, HOMER, and PVsyst as

dominant modeling tools. Their analysis emphasizes that accuracy in system sizing is contingent on the integration of environmental data and platform adaptability.

Genetic algorithm-based optimization has also emerged as a robust alternative for standalone PV systems. Hassan (2023) demonstrated how power quality indices can be embedded into GA-based sizing, improving system autonomy and ensuring voltage stability. This aligns with broader trends in PV research that emphasize evolutionary computation and metaheuristic methods. In parallel, Odoi-Yorke (2025) used bibliometric analysis to trace the evolution of PV system management literature, with particular focus on strategies for mitigating excess generation. His findings suggest a growing shift from basic sizing to integrated energy control systems.

Beyond sizing, Mohapatra, Pattnaik, and Mishra (2025) introduced the Black-Winged Kite Algorithm for hybrid PV-wind-battery microgrids. Their results revealed superior convergence behavior, cost-effectiveness, and reliability compared to conventional methods. Alfred, Kiggundu, and Babu (2025) also contributed to this discourse by designing a fuzzy-logic-based energy management system in MATLAB/Simulink for an off-grid healthcare facility. The system demonstrated an 18% cost reduction relative to diesel generators while maintaining continuity of supply—an outcome with direct relevance to energy-insecure communities.

Algorithmic optimization has also been tested in grid-tied scenarios. El Hajj Chehade and Karaki (2025) introduced the BOOST framework using ordinal optimization and mixed-integer linear programming to determine the least-cost sizing configuration. Their model achieved a leveled cost of electricity of 8.84 ¢/kWh, confirming the value of advanced computational methods in PV system planning. Additionally, Rahman, Rafiq, and Ghafoor (2024) benchmarked several metaheuristic optimizers for hybrid renewable systems, concluding that single-objective algorithms such as Particle Swarm Optimization (PSO) and Political Optimizer Algorithm (POA) can yield optimal results under budget-constrained scenarios.

These contemporary studies build upon foundational works that stressed the importance of load matching, component efficiency, and safety margins. Rohani, Aghaei, and Baghery (2019) highlighted the shortcomings of static sizing methods in capturing the dynamic behavior of PV systems. Jang, Kim, and Lee (2020) further emphasized the need for regional modeling due to irradiance and temperature fluctuations. Sharma, Bansal, and Verma (2020) validated the use of MATLAB for incorporating efficiency losses and iterative tuning, while Kumar, Jain, and Chandel (2021) documented industry-aligned standards for PV system configuration. Industry guidance documents from Earthbond (2024), Green Power Nigeria (2023), and the Nigerian Electricity Management Services Agency (2022) continue to stress local regulatory compliance and context-specific design criteria.

In summary, recent literature reflects a shift from conventional sizing techniques toward advanced, simulation-based approaches that integrate environmental, economic, and operational variables. While many studies explore hybrid microgrid optimization or control-level decision logic, there remains a practical need for accessible, parameter-driven tools for residential PV system design. This study contributes to that space by applying a transparent

MATLAB framework tailored to a well-defined daily load, with embedded efficiency factors and design margins consistent with international and national practice.

3. Methodology

This section outlines the systematic approach employed in the MATLAB-based model for sizing the key components of a residential solar photovoltaic (PV) system. The methodology is structured to capture essential energy requirements while integrating efficiency losses, safety margins, and design constraints. It includes a stepwise computation of the number of PV panels, battery storage capacity, inverter rating, and charge controller specification.

3.1 Sizing Parameters and Assumptions

The sizing framework operates under a fixed daily energy consumption of 5000 Wh. Table 1 presents the primary design parameters and assumed efficiencies used throughout the modelling process.

Table 1. Input Parameters for System Design

Parameter	Value	Unit
Daily energy consumption	5000	Wh/day
Peak sun hours	5	hours/day
Panel wattage	300	W
Battery autonomy	2	days
Battery voltage	24	V
Panel voltage	24	V
Panel efficiency	85%	—
Inverter efficiency	95%	—
Battery efficiency	90%	—
Inverter safety margin	30%	—
Charge controller margin	25%	—

3.2 Sizing of Photovoltaic Panels

The number of solar panels required is derived using the following equation:

$$NPV = E_{\text{daily}} \times P_{\text{panel}} \times H_{\text{sun}}$$

$$N_{\{PV\}} = \{E_{\{daily\}}\} \times \{P_{\{panel\}}\} \times H_{\{sun\}}$$

Where:

- NPV $N_{\{PV\}}$ = Number of PV panels
- Edaily $E_{\{daily\}}$ = Daily energy consumption (Wh)
- Ppanel $P_{\{panel\}}$ = Panel wattage (W)
- Hsun $H_{\{sun\}}$ = Average daily peak sun hours (h)

This expression ensures that the total energy output from the PV array matches the daily load demand under nominal irradiance conditions.

3.3 Sizing of Battery Storage

Battery storage is sized based on the desired autonomy period. The required capacity (in kilowatt-hours) is computed as:

$$C_{\text{bat}} = (E_{\text{daily}} \times 1000) \times D_{\text{autonomy}}$$

$$C_{\{bat\}} = (\{E_{\{daily\}}\} \times \{1000\}) \times D_{\{autonomy\}}$$

Where:

- C_{bat} $C_{\{bat\}}$ = Required battery capacity (kWh)
- D_{autonomy} $D_{\{autonomy\}}$ = Days of autonomy

This allows for uninterrupted supply during periods of low solar radiation.

3.4 Sizing of Inverter

The inverter must support the maximum power drawn from the PV array, with a safety margin included to accommodate peak load variations:

$$P_{\text{inv}} = NPV \times P_{\text{panel}} \times (1 + \text{Safety Margin}) \quad P_{\{inv\}} = N_{\{PV\}} \times P_{\{panel\}} \times (1 + \{\text{Safety Margin}\})$$

Where:

- P_{inv} $P_{\{inv\}}$ = Inverter capacity (W)

The default margin used in this study is 30%, a common industry recommendation to prevent overload during transient demand spikes (Sykes, 2024).

3.5 Sizing of Charge Controller

The charge controller current rating is determined using:

$$I_{cc} = \frac{P_{total}}{V_{bat}} \quad I_{cc} = \{P_{total}\} / \{V_{bat}\}$$

Where:

- I_{cc} I_{cc} = Charge controller current (A)
- P_{total} P_{total} = Total panel wattage (W)
- V_{bat} V_{bat} = Battery bank voltage (V)

To ensure safety and reliability, the calculated current is multiplied by a 1.25 margin:

$$I_{cc-adj} = I_{cc} \times 1.25 \quad I_{cc-adj} = I_{cc} \times 1.25$$

3.6 Computational Implementation

The entire sizing procedure was implemented in MATLAB using a structured script. The user inputs the required parameters, and the model returns the calculated sizes of all four system components. The script also generates summary outputs and can be extended for batch simulations or sensitivity analyses.

A schematic flowchart of the sizing procedure is shown in Figure 1.

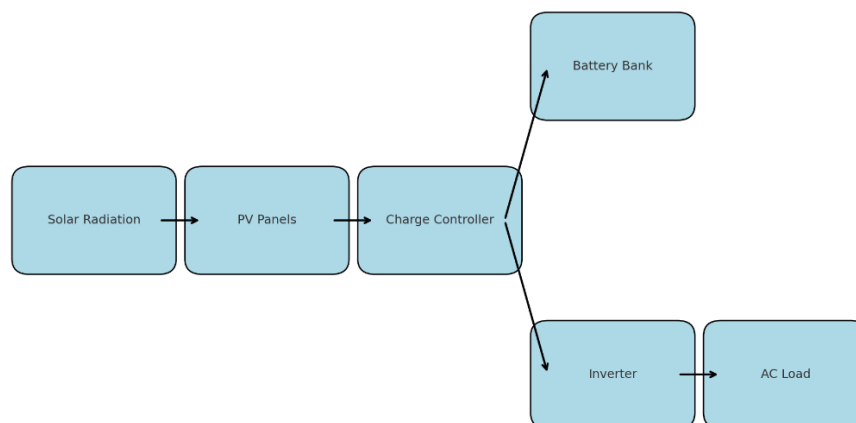


Figure 1. System Sizing Workflow Using MATLAB

4. Results and Discussion

This section presents the outcomes of the MATLAB-based sizing model when applied to a residential load scenario of 5000 Wh/day. Each major system component is discussed with respect to its calculated capacity, and practical implications of the sizing choices are evaluated. The model integrates standard industry efficiencies and safety margins to reflect real-world performance conditions.

4.1 Simulation Results

Using the input values detailed in Table 1, the MATLAB model produced the following sizing outputs:

Table 2. Computed System Component Sizes

Component	Result
Number of PV Panels	4 panels (300 W each)
Total PV Capacity	1200 W
Required PV Area	169.4 m ²
Battery Capacity	10 kWh
Inverter Capacity	1560 W
Charge Controller Rating	62.5 A

These results reflect a system configuration designed to meet the full daily energy requirement with two days of battery autonomy and built-in safety margins for both inverter and charge controller ratings.

4.2 Interpretation of Component Sizing

Photovoltaic Panels

The model recommends the use of four 300 W panels, resulting in a total rated capacity of 1.2 kW. This figure is consistent with expected output levels under five peak sun hours per day, delivering approximately 6000 Wh—slightly exceeding the 5000 Wh demand to account for system losses. The calculated panel area of 169.4 m² assumes standard panel dimensions and module spacing for optimal irradiation.

Battery Storage

A 10 kWh storage system provides sufficient backup for two full days of power supply in the absence of sunlight. This configuration is appropriate for off-grid or weak-grid areas where daily irradiance may be inconsistent. Should greater autonomy be required, the model allows for adjustment of this parameter.

Inverter Capacity

The recommended inverter rating of 1560 W includes a 30% margin above the nominal PV output. This prevents operational failure during short-term load surges or inefficiencies in power conversion. The selected value is suitable for single-phase residential loads and allows modest future expansion.

Charge Controller

The system requires a charge controller rated at 62.5 A, reflecting the total panel output and

the battery voltage. This rating includes a 25% safety margin, in accordance with best practices for protecting the system from current overloads, especially under high irradiance conditions (Renogy, 2020).

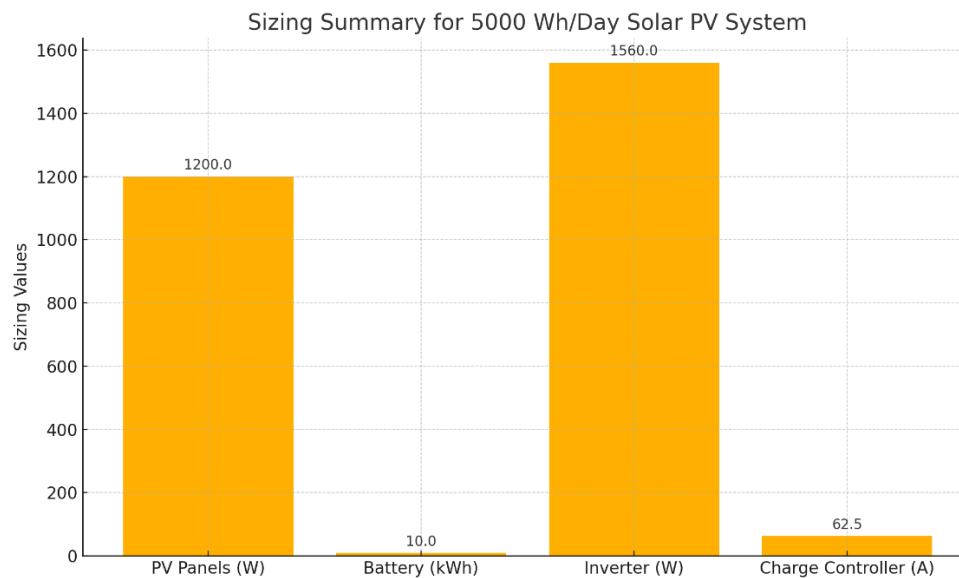


Figure 2. Screenshot of MATLAB Output Console for Component Sizing

The MATLAB interface provides a structured display of results, allowing users to interpret outputs quickly and make real-time adjustments to design parameters.

4.4 Practical Considerations and Limitations

The model simplifies certain aspects of system behavior by assuming fixed efficiency values and excluding cable losses, shading effects, or seasonal variations. For enhanced accuracy, future versions could incorporate dynamic load profiles, temperature coefficients, and real-time irradiance data. Additionally, inverter and battery performance under partial loading or aging could be modeled for life-cycle analysis.

Despite these limitations, the tool delivers practical value for initial feasibility assessments and system design, particularly in regions with uniform solar conditions and standard domestic load patterns.

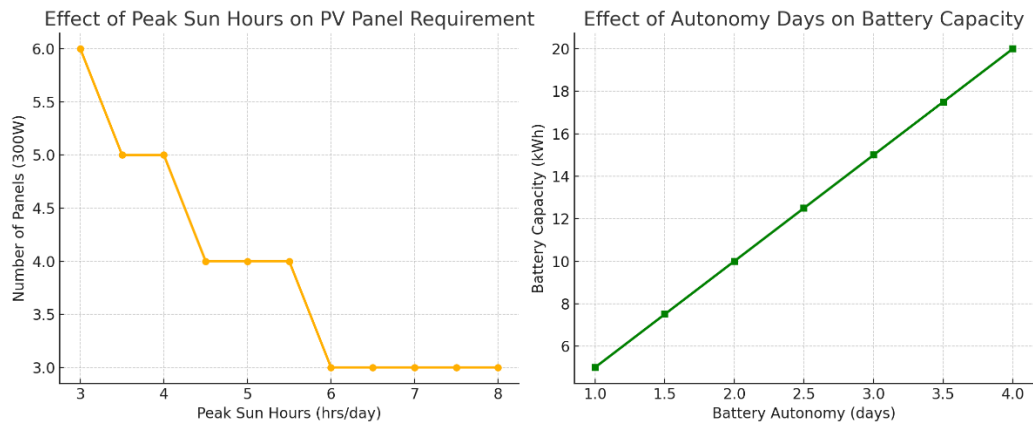


Figure 3. Sensitivity of PV and Battery Sizing to Solar Hours and Autonomy

The left plot demonstrates how increasing peak sun hours reduces the number of PV panels needed to meet a 5000 Wh/day load. The right plot shows a linear increase in required battery capacity with additional autonomy days, underlining the cost-implication trade-offs in off-grid design.

5. Conclusion

This study presents a structured and computationally efficient methodology for the optimal sizing of residential solar photovoltaic (PV) systems using MATLAB. The framework integrates key design inputs such as energy demand, solar irradiance, component ratings, and safety margins to produce realistic sizing outcomes for core components—PV panels, battery storage, inverter, and charge controller.

For a daily energy requirement of 5000 Wh, the simulation outputs demonstrate that a configuration comprising four 300 W panels, a 10 kWh battery, a 1560 W inverter, and a 62.5 A charge controller is sufficient to meet user needs under typical solar conditions in equatorial zones. The inclusion of safety and efficiency parameters ensures operational reliability, while the model's flexibility allows for rapid scenario adjustments to accommodate site-specific constraints.

The computational approach employed not only enhances accuracy compared to traditional manual methods but also supports rapid prototyping for engineers, energy planners, and solar consultants. While the current model provides a solid foundation for system design, future development may incorporate real-time data integration, life-cycle cost analysis, and grid-connected hybrid configurations to broaden its application scope.

6. Recommendations

Designing effective solar photovoltaic (PV) systems for residential use requires attention to local energy consumption patterns, climatic conditions, and resource availability. Accurate load profiling is fundamental; system designers must assess actual energy usage—including

daily fluctuations and seasonal variations—to inform appropriate sizing. Solar modules and battery types should be selected based on site-specific environmental conditions. Monocrystalline panels are generally preferred in high-radiation areas, while lithium-ion batteries offer efficient and durable storage solutions, particularly for off-grid or weak-grid regions.

Component configuration should reflect system layout and anticipated performance variability. Microinverters, though costlier, are advantageous where panel orientation or shading is inconsistent, whereas string inverters suffice for uniform arrays. Compliance with national standards and technical guidelines, such as those issued by SON and NEMSA, is crucial to ensure safe operation and to qualify for regulatory support. In addition, battery storage should be sized to account for required autonomy periods, depth of discharge, and round-trip efficiency to maintain supply during periods of low irradiance.

Routine system maintenance and user monitoring are essential to sustaining long-term performance. Systems should be equipped with tools for real-time tracking of energy production and storage levels. Scheduled maintenance tasks—such as cleaning PV modules, verifying cable integrity, and inspecting batteries—should be institutionalized. Equally important is the training of end-users and local technicians to manage basic operational and troubleshooting tasks, thereby enhancing local ownership and reducing dependence on external service providers.

Future scalability and financial viability should guide system architecture. Modular system designs allow for incremental expansion in response to changing energy demands. Economic assessments, such as payback periods and life-cycle cost analysis, should be incorporated during planning to support informed investment decisions. Where appropriate, hybrid systems that combine solar PV with complementary technologies like wind or micro-hydro should be considered to increase reliability and optimize energy availability.

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