Implementation of an On-Grid Solar PV System with Integrated Battery Backup for a Standard Residential Home

Saad Hajjih

May 2025

Contents

List of Figures

List of Tables

Abstract

This paper presents the design, implementation, and analysis of an on-grid solar photovoltaic (PV) system with integrated battery backup tailored for a standard residential home in Amman, Jordan. The proposed system is engineered to meet a daily energy demand of 36 kWh using a PV array rated at 8.28 kW and a lithium-ion battery bank providing 73.7 kWh of usable energy. A hybrid inverter ensures seamless integration between PV generation, storage, and the utility grid. A MATLAB-based simulation over 30 days, including a full-day grid outage, demonstrates the system's autonomy, efficiency, and reliability. A detailed cost analysis validates the feasibility of the solution.

1 Load Profile and Site Conditions

The residential site at coordinates 31.9951389°N, 35.9400000°E has an average daily energy consumption of 36 kWh and a peak demand of 6.5 kW. Solar resource data from NASA and the Global Solar Atlas show an average peak sun hour (PSH) of 5.891. The optimal fixed tilt angle for maximum energy yield is 29°, with seasonal adjustments of 47° in winter, 32° in spring/fall, and 17° in summer.

2 System Sizing

A1	Inverter efficiency	97.6	Percent (%)
A2	Battery Bus voltage	48	Voltage (V)
A3	Inverter AC voltage	220	Voltage (V)
A4	Daily energy consumption	36	kWh/day
A5	Maximum AC power requirement	6.5	kW
A6	Monthly avg energy consumption	1080	kWh/month
A7	Peak Sun Hours	5.891	Hours (h)
A8	Total amp-hour demand per day	703.125	Amp-hours (Ah)
B1	Days of storage desired (autonomy)	2	Days
B2	Allowable depth of discharge limit	0.9	(decimal)
B3	Required battery capacity	1562.5	Amp-hours (Ah)
B4	Amp-hour capacity for selected batteries	100	Amp-hours (Ah)
B5	Number of batteries in parallel	16	—
B6	Number of batteries in series	1	—
B7	Total number of batteries	16	—
B8	Total battery amp-hour capacity	1600	Amp-hours (Ah)
C1	Total energy demand per day	36	kWh/day
C2	Battery round trip efficiency	0.85	(decimal)
C3	Required array output per day	42.35	kWh/day
C4	PV module max power voltage (STC)	41.5	Voltage (V)
C5	PV module guaranteed power output (STC)	460	Watts (W)
C6	Peak sun hours at design tilt	5.891	Hours (h)
C7	Energy output per module per day	2710	Watt-hours (Wh)
C8	Module energy output at operating temp	2439	Watt-hours (Wh)
C9	Modules required to meet energy requirements	18	—
C10	Modules per string (rounded up)	6	—
C11	Strings in parallel (rounded up)	3	—
C12	Total modules to be purchased	18	—
C13	Nominal rated PV module output	460	Watts (W)
C14	Nominal rated array output	8280	Watts (W)

Table 1: System Design Parameters and Component Sizing

2.1 PV Array and Battery Sizing

The design includes 18 Canadian Solar CS3W-460MS modules, each rated at 460 W, yielding a total array capacity of 8.28 kW. The daily energy requirement, accounting for system losses and battery efficiency, necessitates approximately 42.35 kWh/day of PV output. A lithium-ion battery bank comprising 16 SE-G5.1 Pro-B batteries provides 81.92 kWh of nominal capacity and 73.73 kWh of usable energy (90% DoD). The system is designed for 2-day autonomy.

2.2 Inverter and Charge Controller

The Deye 7.6K-SG01LP1 hybrid inverter supports a peak load of 6.5 kW and includes dual MPPTs for optimal solar harvesting. It accepts up to 10.4 kW of PV input and interfaces with 48 V battery banks. Features such as built-in MPPT charge control, smart battery management, and Wi-Fi monitoring enhance system functionality.

2.3 Cable Sizing

Cables are sized based on voltage drop calculations. After applying the formulas and assuming cable lengths:

Section	Current (A)	Voltage (V)	Length (m)	Voltage Drop (V)	Formula Result	Recommended Cable Size
PV Modules → Battery Bank	127.3	48	10	1.92	$\approx 11.45\,\text{mm}^2$	16 mm²
Battery Bank → Inverter	150.5	48	3	1.92	$\approx 8.1\,\text{mm}^2$	16–25 mm²
Inverter → AC Load	29.55	220	10	8.8	$\approx 1.16\,\text{mm}^2$	4–6 mm²

Table 2: Cable Sizing and Voltage Drop Calculations for System Connections

3 protection and auxiliary equipment

Protection Point	Device Type	Rating / Action
PV Array → Inverter (DC)	DC-rated breakers or PV-specific fuses	16 A per string
Battery → Inverter	DC-rated MCCB or battery fuses	250 A
Inverter → AC Load	Standard AC breakers	40 A

Table 3: Electrical Protection Devices and Ratings for System Safety

Protection devices are essential for ensuring system safety and reliability. Each PV string is protected with DC-rated breakers or PV fuses rated at 16 A, while the battery-to-inverter connection uses a 250 A DC-rated MCCB or fuse to manage high current levels. On the AC side, a 40 A breaker protects the inverter output to the load. These devices are typically installed in combiner boxes, which may also include additional protection components such as surge protection devices (SPDs), and IP68-rated enclosures, providing full protection against dust ingress and prolonged water immersion.

3.1 Types of Combiner Boxes

Combiner boxes come in various types, each designed to cater to specific solar panel installation requirements. Understanding the different types can help you choose the right one for your PV system:

3.1.1 Standard Combiner Boxes:

These are the most common type, designed to combine multiple DC inputs from a solar array into a single output. They are ideal for standard solar installations where simplicity and efficiency are key.

3.1.2 Disconnect Combiner Boxes:

These boxes offer the added functionality of disconnecting the solar array at a single point. This feature provides an extra layer of safety, allowing for quick and easy shutdowns during emergencies or maintenance.

3.1.3 AFCI Combiner Boxes:

Arc Fault Circuit Interrupter (AFCI) combiner boxes are designed to detect arc fault signals and interrupt the circuit before faults can develop into fires or short circuits. This makes them an excellent choice for installations where fire safety is a primary concern. In some areas AFCI combiner boxes are a requirement according to code standards in certain jurisdictions, although this is more relevant for residential installations as opposed to utility-scale solar plants.

3.1.4 AC Combiner Boxes:

These boxes are equipped with an integrated AC Molded Case Circuit Breaker (MCCB) for AC input. They are generally used for applications like aggregating AC circuits from inverters in larger systems or handling multiple inverters. They also include Type 2 AC Surge Protection Devices (SPD) for overvoltage protection on inverters, making them suitable for systems that require robust AC protection.

For this system, a Voltacon 9-in/1-out solar PV combiner box is selected, featuring integrated DC fuses, surge protection devices (SPDs), and a DC isolator. It aggregates power from nine PV strings, each comprising two 460 W modules, into a single, protected DC output for the inverter. Each string is individually protected with 16 A fuses to guard against overcurrent, while the integrated SPD offers defense against voltage surges from lightning or grid anomalies. The built-in DC isolator enables safe shutdown and maintenance of the PV array. Housed in a durable, IP65-rated enclosure, the combiner box is well-suited for outdoor installation in demanding environmental conditions.

4 simulation, performance and cost analysis

4.1 System Overview

Component	**Value**
Simulation Duration	30 Days (May 2025)
Daily Load Demand	36 kWh
Total Load (Month)	1,080 kWh
PV Daily Production	42.35 kWh
Total PV Energy	∼1,270.5 kWh
Battery Capacity	1600 Ah @ 48 V = 76.8 kWh
Usable Battery (90% DoD)	69.12 kWh
Inverter Efficiency	97.6%
Battery Efficiency	85% (round-trip)

Table 4: Simulation and System Parameters

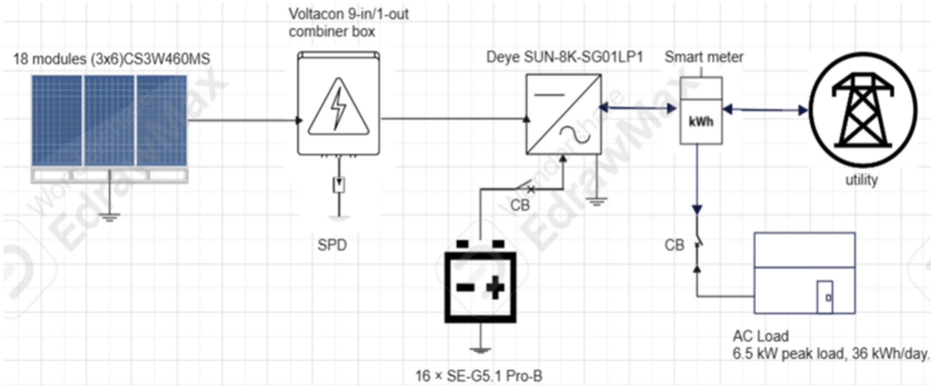

Figure 1: Integrated Solar PV System with Inverter, Battery Bank, and Grid Connection

4.2 single line diagram

4.3 Performance Analysis

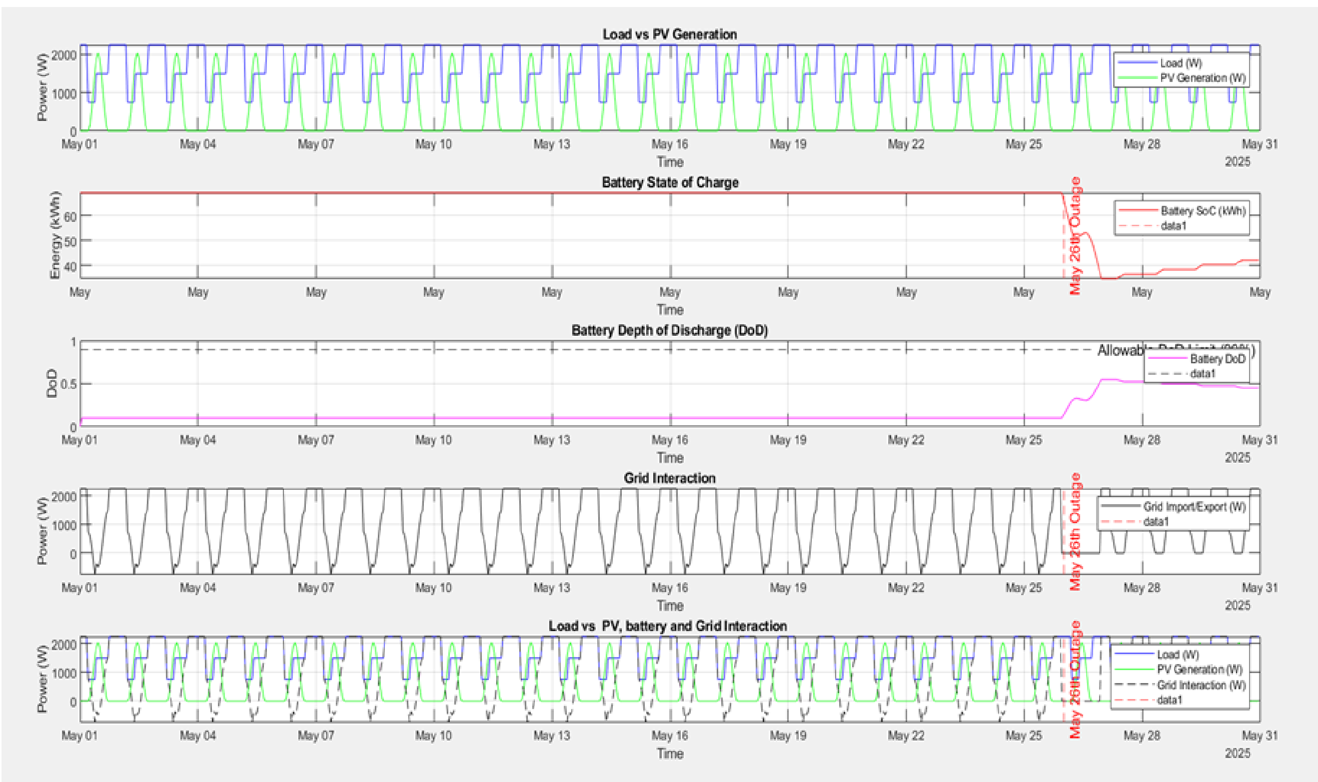

Figure 2: System Performance Simulation using MATLAB

4.3.1 Load vs PV Generation

Most days, photovoltaic production matches the demand closely. On average, photovoltaic energy generates approximately 6.35 kWh/day more than is consumed, allowing potential export to the grid or additional battery charging.

4.3.2 Battery State of Charge (Soc)

On normal days, the battery remains near full capacity as a result of a consistent surplus of photovoltaic energy. During the 26 May outage, the state of charge (SoC) drops significantly, confirming the system's dependence on the battery; however, it maintains energy without full depletion.

4.3.3 Depth of Discharge (DoD)

During the outage, the Depth of Discharge (DoD) remains safely below 90% , preserving battery health and ensuring system reliability. Although some energy is lost during the charging and discharging process due to the battery's 85% round-trip efficiency, these losses do not affect the overall operation of the system.

4.3.4 Grid Interaction

During normal days, excess solar energy is exported to the grid during midday hours, while grid imports typically occur at night to meet the load. In the outage period, the system operates without any grid interaction, and the battery seamlessly supplies the entire load, demonstrating its effectiveness and autonomy.

4.3.5 Combined View

On 26 May , during the simulated outage event, the combined output from the PV system and battery successfully met the load demand. Although the battery experienced significant discharge, it did not fully deplete, indicating that the system is appropriately sized for such contingencies.

4.4 Cost Analysis

The solar PV system is designed with 16 SE-G5.1 Pro-B lithium batteries and 18 CS3W-460MS solar panels. The total equipment cost, including batteries, PV modules, combiner box, and inverter, is approximately 31255 JD. Adding installation and miscellaneous expenses estimated at 20% of equipment cost (about 6251 JD), the total system cost comes to roughly 37506 JD. This budget covers all major components and installation for a reliable 2-day autonomy solar energy system.

Component	Unit Cost (JD)	Qty	Subtotal (JD)
SE-G5.1 Pro-B Battery (5.12 kWh)	1,560.00	16	24,960.00
CS3W-460MS PV Panels (460W)	257.85	18	4,641.16
Combiner Box (Voltacon)	–	1	391.91
Inverter (SUN-8K-SG01LP1)	–	1	1,262.02
Total Equipment			**31,255.09**
Installation & Misc. (20%)	–	–	6,251.00
Total System Cost			**37,506.09 JD**

Table 5: Cost Breakdown of System Components and Installation

5 Conclusion

In this project, I designed and simulated an on-grid solar PV system with battery storage for a typical residential home with a daily energy consumption of 36 kWh. Using MATLAB, I modeled the system for a full month (May 2025) and included a full-day grid outage on May 26 to test the system's autonomy and reliability. The setup includes 18 solar panels producing about 42.35 kWh/day and a battery bank of 16 SE-G5.1 Pro-B lithium-ion batteries. These batteries offer a total of around 81.92 kWh of storage at 48V, with about 73.73 kWh usable, considering a 90% depth of discharge . During the grid outage simulation, the batteries handled the entire load without going below the DoD limit, proving that the system is well-sized and reliable for backup scenarios. From a cost perspective, the full system — including panels, batteries, inverter, combiner box, and installation — comes to roughly 37,506 JD. I made sure to select components that are efficient and compatible, like the Deye SUN-8K hybrid inverter and Voltacon combiner box, which helped optimize performance and safety. Overall, the results showed that the system can easily meet daily energy demands, cover short-term outages, and even export surplus energy on normal days.

References

[1] Canadian Solar. Hiku cs3w-ms module datasheet. https://static.csisolar.com/wp-content/uploads/sites/3/2021/07/15113025/CanadianSolar-HiKu_CS3W-MS_v5.592_F9_J2_NA.pdf, 2021. Accessed: 2025-08-04.

[2] Deye. Sun 5-6-7.6-8k-sg01lp1 hybrid inverter datasheet. https://flipbook.pagepreserve.com/deye-sun-5-6-7-6-8k-sg01lp1-us-data-sheet#page1, 2025. Accessed: 2025-08-04.

[3] Deye ESS. Se-g5.1 pro and se-g5.3 battery datasheet. https://deyeess.com/wp-content/uploads/2023/08/SE-G5.1-Pro-SE-G5.3.pdf, 2023. Accessed: 2025-08-04.

[4] Global Solar Atlas. Global solar atlas - site details. https://globalsolaratlas.info/detail?s=31.995133,35.939885&m=site&c=31.995265,35.939369,11, 2025. Accessed: 2025-08-04.

[5] NASA Langley Research Center. Power data access viewer. https://power.larc.nasa.gov/data-access-viewer/, 2025. Accessed: 2025-08-04.