



Techno-Economic and Environmental Optimization of a Hybrid PV–Diesel–Battery System for the Faculty of Engineering in Sorman, Libya

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Abstract—This paper consolidates three supplied studies addressing the design, simulation, and evaluation of a hybrid renewable-energy system for the Faculty of Engineering in Sorman, Libya. The integrated framework combines photovoltaic (PV) generation, battery energy storage (BESS), a diesel generator, bidirectional power conversion, and utility-grid support, with HOMER Pro used for simulation, optimization, and sensitivity analysis. The source studies identify strong solar availability at the site and report a principal optimized configuration comprising a 92.5-kW PV array, a 34-kW autosized diesel generator, 98 strings of 1-kWh lead-acid batteries, and a 38.5-kW converter. For the reported simulation case, annual generation is 158,558 kWh, including 155,868 kWh from PV and 2,689 kWh from the generator, with 0% unmet electrical load and 36,080 kWh/year of excess electricity. The reported renewable fraction is 97.7%. The supplied studies also contain alternative design values, including a 200-kW PV case, 40 battery strings, and a 25-kW converter; these are retained as alternative source scenarios rather than silently merged with the primary optimization case. Because the source documents contain inconsistencies in load-audit values and economic indicators, the manuscript explicitly identifies these data-quality limitations and treats the numerical HOMER outputs as model-dependent results requiring validation before implementation.

Index Terms—hybrid renewable energy system, photovoltaic, battery energy storage, diesel generator, HOMER Pro, techno-economic optimization, Sorman, Libya.

I. INTRODUCTION

The transition toward lower-carbon electricity systems has accelerated as photovoltaic generation and battery storage have become increasingly competitive and widely deployed. The International Energy Agency reports continued strong expansion of renewable electricity and identifies solar PV and system integration as central elements of the transition [1]. IRENA likewise reports that solar PV remained among the lowest-cost sources of new utility-scale generation in 2024 and that battery-storage costs have fallen substantially over the past decade [2], [3]. These developments are particularly relevant to educational facilities in regions with strong solar resources and constrained or unreliable grid supply.

The three supplied studies address this problem at the Faculty of Engineering in Sorman, Libya. They investigate grid-connected and hybrid configurations containing PV generation, batteries, a diesel generator, converters, and the utility grid, with HOMER Pro used to assess feasibility, life-cycle economics, and sensitivity to system assumptions. Recent literature similarly uses HOMER-based optimization to compare hybrid architectures according to net present cost (NPC), cost or levelized cost of energy (COE/LCOE), renewable fraction, unmet load, and emissions [4]–[8].

The objective of this integrated paper is therefore to consolidate the three source studies into one technically coherent manuscript while preserving their figures and equipment-load table. Where the source documents report different parameter sets, the differences are explicitly identified rather than treated as interchangeable measurements.

II. RELATED WORK AND THEORETICAL FRAMEWORK

Recent studies show that hybrid PV–storage–diesel systems are commonly evaluated through a combination of resource assessment, hourly load modeling, component sizing, dispatch simulation, sensitivity analysis, and economic comparison. Yadav et al. demonstrated the use of HOMER for techno-economic assessment of hybrid systems with multiple storage technologies, emphasizing the influence of uncertain techno-economic parameters on NPC and COE [4]. A 2022 study of a PV/diesel/battery system in Iraq showed that dispatch strategy can materially affect reliability, renewable fraction, cost, and emissions [5]. Grid-connected hybrid systems have also been studied for institutional facilities, where HOMER-based sensitivity analysis is used to quantify the effect of solar resources, prices, and other economic variables [6].

For the present application, PV generation supplies daytime demand and charges the battery when surplus energy is available; the battery provides temporal energy shifting and backup capability; the diesel generator provides firm generation when renewable and stored energy are insufficient and the grid provides an additional supply path in the grid-connected architecture. This hybridization reduces dependence on any single source but makes the result sensitive to the load profile, solar resource, battery assumptions, fuel price, component costs, and dispatch rules.

Recent case studies further demonstrate that HOMER-based designs are highly site dependent. Comparative analyses in 2024 reported trade-offs between economic cost, renewable penetration, excess generation, and emissions for different

hybrid architectures [7], [8]. Consequently, numerical outputs from the Sorman model should be interpreted as scenario-specific optimization results rather than universal performance values.

III. SITE CHARACTERIZATION AND LOAD MODELING

The study site is the Faculty of Engineering, University of Zawia, in Sorman, Libya. The supplied studies characterize the site as a coastal location at approximately 32.75668° N and 12.57159° E. For climatological context, the 1991–2020 normal annual mean temperature for Sorman is 20.6 °C; this externally sourced climate value is distinct from the approximately 22 °C temperature reported in the supplied simulation study. The latter is therefore retained only as a source-model input, not as an independently verified Sorman climate normal.



Fig. 2. Solar global horizontal irradiance (GHI) resource profile.

The supplied equipment audit contains lighting, computers, printers, air-conditioning equipment, laboratory equipment, projectors, and miscellaneous loads. The table below is reproduced from the source data. Importantly, the reported air-conditioning entry dominates the table and produces a total daily energy value of 1,397,749 Wh/day, whereas the same source study reports an annual scaled average load of 165.59 kWh/day and a 30.09-kW peak load. These values are not internally consistent. The equipment table should therefore be treated as a source audit requiring verification, while the reported HOMER load profile and simulation outputs should be retained as the model case until the original metered data are checked.

Load Component	Qty	V	Power (W)	h/day	Energy (Wh/day)
Lights	13	220	15	7	1,365
PCs & Workstations	15	220	300	6	27,000
Printers & Plotters	8	220	800	1	6,400
Air Conditioners	25	220	8,952	6	1,342,800
Laboratory Equipment	4	220	1,335.5	2	10,684
Projectors	3	220	250	2	1,500
Others (Sound/Coffee)	8	220	500	2	8,000
Total	—	—	—	—	1,397,749

TABLE I. EQUIPMENT-BASED DAILY ENERGY AUDIT REPRODUCED FROM THE SUPPLIED STUDIES.

The adopted demand model indicates pronounced seasonal variation, with summer demand increasing because of air-conditioning use. The daily load profile is therefore an

important input to component sizing and dispatch. The supplied load-profile figures are retained below.



Fig. 3. Daily, seasonal, and yearly electric-load profile used in the HOMER model.

IV. SYSTEM ARCHITECTURE AND COMPONENT MODELS

The integrated HOMER architecture comprises five functional elements: PV generation, BESS, diesel backup, bidirectional power conversion, and utility-grid connection. The source studies also contain alternative schematic representations and component-definition screens; all supplied figures are retained later in this paper.

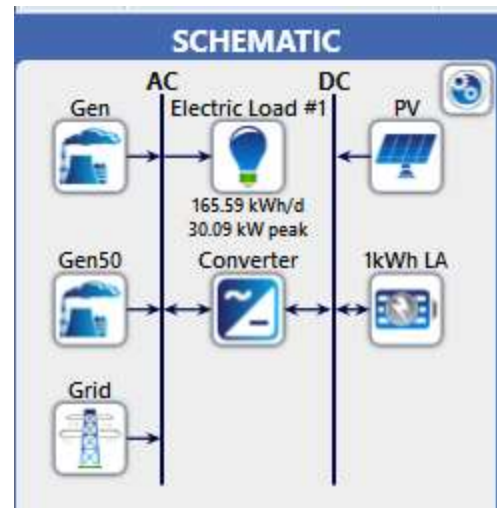


Fig. 1. Designed grid-tied PV system (HOMER Pro model).

The principal component assumptions reported in the detailed Sorman study are summarized as follows:

- PV array: generic flat-plate modules rated at 1 kW per module, connected to a 36-V DC bus, with a 25-year lifetime and an 80% derating factor.
- BESS: generic 12-V lead-acid batteries, 1-kWh nominal capacity, 83.4-Ah maximum capacity, 80% round-trip efficiency, and approximately 10-year lifetime in the detailed Sorman model; 98 strings are reported for the optimized configuration.
- Diesel generator: autosized between 25 and 34 kW in the detailed model, with a 45% minimum-load ratio.

- Converter: Leonics MTP 413F, rated at 38.5 kW in the detailed optimized configuration, with approximately 96% inverter efficiency and 94% rectifier efficiency.
- Grid connection: utility supply is retained as an additional source in the grid-tied architecture.

HOMER evaluates candidate configurations by simulating their hourly operation and then ranking feasible solutions according to the selected economic objective and constraints. The source studies describe load-following and cycle-charging dispatch strategies. In load-following operation, the generator supplies the deficit when renewable and stored energy are insufficient; in cycle charging, generator output can exceed instantaneous load so that surplus power charges the battery. Recent research confirms that dispatch selection can materially change NPC, renewable fraction, fuel use, and emissions [5], [8].

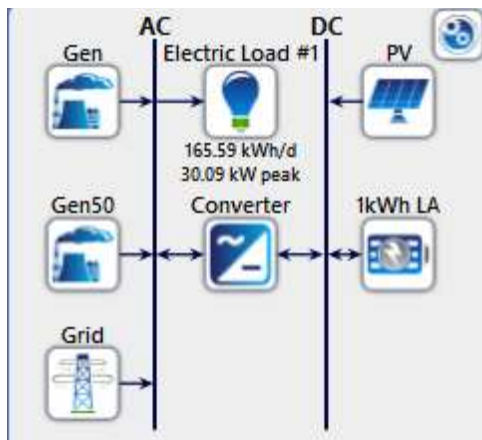


Fig. 4. Block representation of the PV system model.



Fig. 5. PV panel specification used in the source model.



Fig. 6. Energy-storage/converter specification screen retained from the source model.



Fig. 7. Diesel-generator specification used in the source model.



Fig. 8. Converter specification used in the source model.

V. MATHEMATICAL FORMULATION AND OPTIMIZATION

The HOMER formulation can be represented conceptually as an optimization problem in which the decision vector contains component sizes and operational variables. The primary economic objective is minimization of total net present cost subject to electrical reliability, component, and dispatch constraints. A generic representation is

$$\min \text{NPC} = f(\text{CAPEX, replacement, O\&M, fuel, grid purchases, salvage})$$

subject to power-balance, battery state-of-charge, converter-capacity, generator operating, and allowable unmet-load constraints. The PV power relationship can be represented in the standard form $P_{PV} \propto G_T [1 + \alpha_P (T_C - T_{STC})]$, where G_T is incident irradiance and α_P is the temperature coefficient. Battery operation is constrained by state of charge, charge/discharge limits, and minimum allowable storage level. These relationships are implemented internally by HOMER; the supplied studies report the resulting optimization outputs rather than providing a complete equation-by-equation derivation.

VI. INTEGRATED SIMULATION RESULTS

The principal optimized configuration reported in the detailed Sorman study consists of a 92.5-kW PV array, a 34-kW autosized diesel generator, 98 strings of 1-kWh lead-acid batteries, and a 38.5-kW bidirectional converter connected to the local utility grid. The HOMER case reports annual electricity production of 158,558 kWh/year, comprising 155,868 kWh/year from PV and 2,689 kWh/year from the generator. The component values sum to 158,557 kWh/year, leaving a 1-kWh reconciliation difference; this is treated as a

reporting/rounding discrepancy rather than silently changing the HOMER-reported total, The reported unmet electric load is 0%, while excess electricity is 36,080 kWh/year, corresponding to 22.76% of the HOMER-reported annual production, i.e., $36,080/158,558 \times 100$.

The source material also reports a renewable fraction of 97.7%. This value is broadly consistent with the dominance of PV generation in the reported production mix, but the exact definition of renewable fraction in the HOMER case should be retained from the project file because renewable-fraction calculations can depend on the treatment of grid imports, battery flows, and excess electricity.



Fig. 9. Battery details and storage parameters.

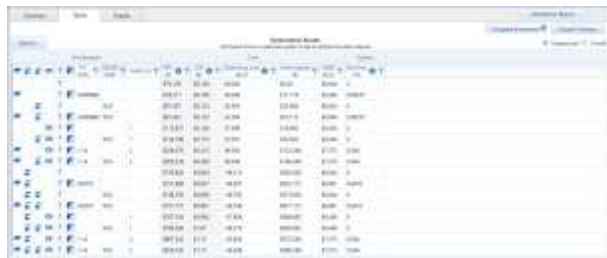


Fig. 10. Sensitivity cases and optimization results.



Fig. 11. Base-case and proposed-system economic values.



Fig. 12. Net present cost by cost type.



Fig. 13. Net present cost by component.



Fig. 14. Monthly electric production.

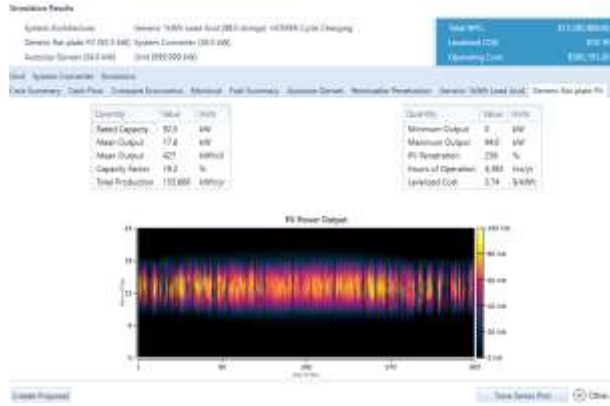


Fig. 15. PV power output.

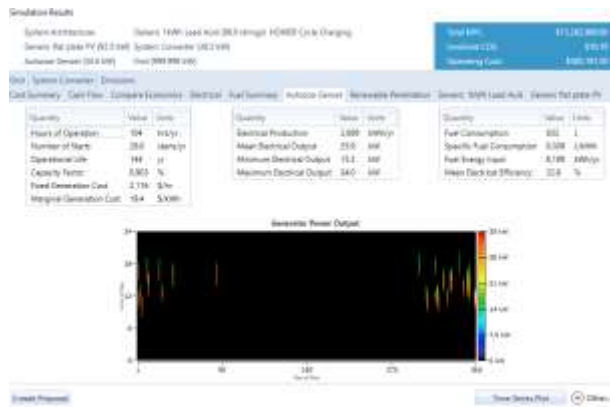


Fig. 16. Generator power output.

VII. ALTERNATIVE SOURCE SCENARIO AND DATA CONSISTENCY

One of the supplied studies reports a different grid-tied design based on a predictive load model: 200 kW of PV, a 25-kW converter, and a 36,800-Ah battery bank arranged in 40 strings. That study also reports a 10.96% reduction in the cost of energy relative to an average monthly 2023 grid rate. These values are not numerically identical to the 92.5-kW/34-kW/98-string optimized configuration in the detailed Sorman study. Rather than choosing one set without explanation, the present manuscript treats the 92.5-kW configuration as the primary optimization case and the 200-kW configuration as an alternative scenario generated under different load/cost assumptions.

The source documents also differ in reported solar GHI (4.55 versus 5.32 kWh/m²/day). These values are retained as source-model inputs because the study site has now been defined as Sorman, the final GHI used for publication should be taken from one frozen, site-specific meteorological dataset rather than combining the two source values. Converter rating (25 versus 38.5 kW), battery string count (40 versus 98), and battery technology descriptions. These differences may result from different simulation versions, load models, component libraries, or sensitivity cases. Before procurement or publication of a final engineering design, the original HOMER

project file, hourly load data, meteorological dataset, component cost database, fuel price, grid tariff, and economic assumptions should be frozen to a single version and rerun.

VIII. ECONOMIC EVALUATION

The detailed Sorman study reports an NPC of USD 15,282,900 and a COE of USD 10.19/kWh under its stated sensitivity constraints, together with a reported payback threshold of approximately 0.052 years. These figures are reproduced because they are part of the supplied simulation results, but they require particular caution. A payback period of 0.052 years corresponds to approximately 19.0 days (using 365 days/year) and is unusually short for a PV–battery project; it should therefore be independently checked against the cash-flow assumptions, tariff definition, project lifetime, discount rate, capital costs, and salvage/replacement treatment before being interpreted as a real-world financial result.

The broader literature supports the use of NPC and LCOE/COE as key comparison metrics, but also shows that results are strongly affected by local prices and resource assumptions [4], [5], [7]. IRENA's recent cost assessment reports a global weighted-average LCOE of approximately USD 0.043/kWh for newly commissioned utility-scale solar PV in 2024 and continued declines in battery-storage costs [3]. Such global benchmarks should not be substituted for the Sorman model's local economics, but they provide a useful external reasonableness check on technology-cost assumptions.

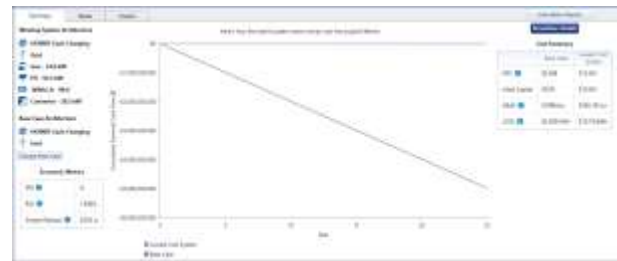


Fig. 17. Proposed-system performance over the project lifetime.



Fig. 18. Difference between the proposed and base systems.

IX. ENVIRONMENTAL AND RELIABILITY IMPLICATIONS

The hybrid architecture reduces dependence on diesel generation by assigning PV the dominant annual energy contribution and retaining the generator primarily as a firming

source. The supplied extended study identifies reductions in CO₂, SO₂, and NO_x as an environmental benefit of replacing conventional fossil-fuel generation with solar-storage operation. However, the source documents do not provide a complete numerical emissions inventory for the primary Sorman case. Therefore, this integrated paper does not invent annual emissions-reduction values.

From a reliability perspective, the reported 0% unmet load indicates that the modeled configuration satisfies the reliability constraint used in the HOMER simulation. Battery storage can provide short-duration buffering, while the diesel generator and grid provide additional supply paths. The resulting resilience is nevertheless model-dependent and should be verified against actual grid outage duration, battery degradation, generator availability, and protection/control requirements.

X. DISCUSSION

Three findings emerge consistently across the supplied studies. First, Sorman has a favorable solar resource, making PV an appropriate primary generation technology. Second, hybridization with storage and firm backup can improve continuity of supply and reduce dependence on a single generation source. Third, the economic outcome is highly sensitive to the load profile and model assumptions. These findings agree with recent HOMER-based studies in which PV, storage, and dispatch strategy materially affect cost, reliability, and emissions [4], [5], [7], [8].

The main technical limitation is data consistency. The equipment audit, scaled average load, peak load, and annual consumption reported across the source documents cannot all describe the same physical operating condition. The equipment-table total is 1,397,749 Wh/day = 1,397.749 kWh/day, equivalent to approximately 510,178 kWh/year if repeated for 365 days. By comparison, the reported scaled average load of 165.59 kWh/day corresponds to approximately 60,440 kWh/year. These values differ by a factor of about 8.44 and therefore cannot represent the same unmodified load basis. Accordingly, the next engineering step should be a metered load campaign, ideally with at least 15-min or 1-h resolution, followed by a single auditable HOMER input dataset.

The second limitation is economic traceability. The reported NPC, COE, and payback depend on a specific HOMER cost database and sensitivity assumptions that are not fully reproduced in the source material. A publication-grade final study should include capital cost, replacement cost, O&M, diesel price, grid tariff, discount rate, inflation, project lifetime, and battery replacement assumptions in a single table so that the optimization can be independently reproduced.

XI. RETAINED SOURCE FIGURES

To satisfy the requirement that the supplied visual material be preserved, all figures embedded in the three source documents are retained in this integrated manuscript. Figures 1–18 originate from the first supplied study and Figures 19–24 from the extended study. The captions have been standardized to IEEE-style numbering and wording; the underlying image content has not been altered.



Fig. 19. Monthly average solar GHI resource data.

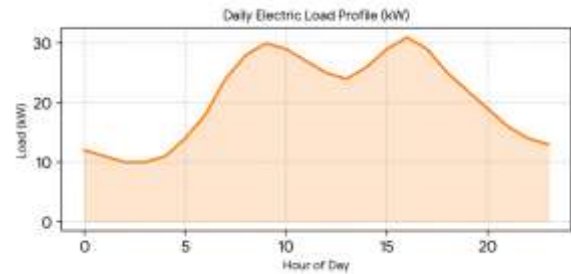


Fig. 20. Daily electric-load profile of the facility.

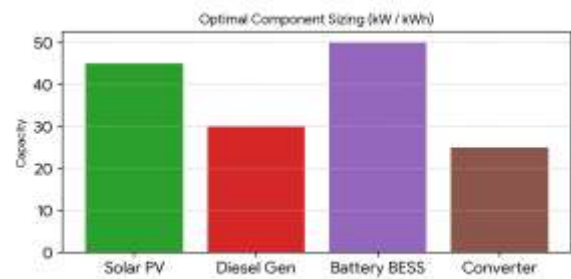


Fig. 21. Optimal component sizing and system architecture.

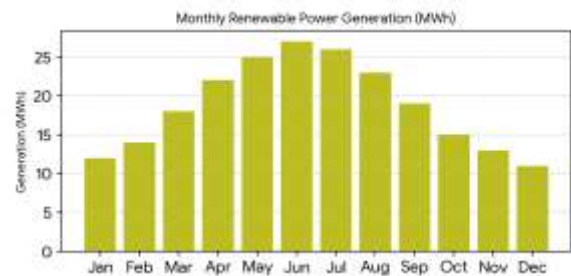


Fig. 22. Monthly renewable power generation.

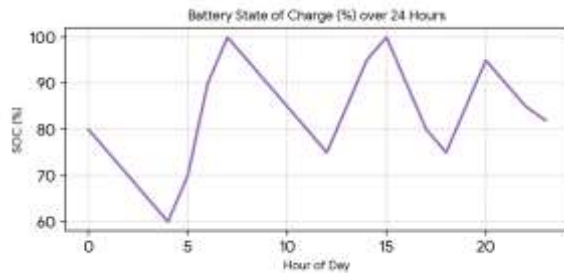


Fig. 23. Battery state of charge over 24 h.

Numerical validation note: The manuscript distinguishes three categories of numbers: (1) values directly reported by the supplied HOMER/source studies, (2) values obtained by arithmetic reconciliation of those reported values, and (3) external Sorman climate values used only for site characterization. No unverified HOMER performance, economic, or emissions result has been substituted for a source result. The 92.5-kW PV, 34-kW generator, 98 battery strings, 38.5-kW converter, NPC of USD 15,282,900, COE of USD 10.19/kWh, and 0.052-year payback remain source-reported scenario outputs and should be re-run in HOMER for the Sorman site before being presented as final design values.

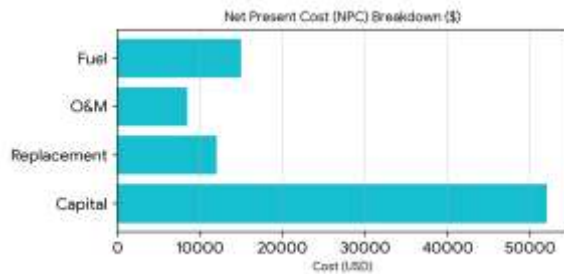


Fig. 24. Net present cost breakdown.

XII. CONCLUSION

This integrated study consolidates the supplied technical, economic, and environmental analyses of a hybrid PV–diesel–battery system for the Faculty of Engineering in Sorman. The primary HOMER optimization case reported in the detailed study consists of 92.5 kW of PV, a 34-kW autosized diesel generator, 98 strings of 1-kWh lead-acid batteries, and a 38.5-kW converter connected to the utility grid. The HOMER-reported annual generation is 158,558 kWh/year, with 0% unmet load, 36,080 kWh/year of excess electricity, and a reported renewable fraction of 97.7%. The listed PV and generator outputs sum to 158,557 kWh/year, so the 1-kWh difference is explicitly retained as a source-reporting reconciliation issue.

The study supports the technical rationale for PV-centered hybridization in Sorman, but it also demonstrates why rigorous data governance is essential. Differences in GHI, load-audit totals, PV capacity, battery strings, converter rating, and

economic indicators across the supplied studies must be resolved before the results are treated as a single field-ready design. Future work should therefore validate the hourly load profile, confirm the meteorological dataset, rerun HOMER using a frozen cost/tariff database, quantify emissions using the final fuel and dispatch results, and evaluate battery degradation and grid-outage scenarios.

XIII. REFERENCES

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Editorial note: All numerical values identified as “reported” originate from the supplied source studies. No unsupported numerical results were added. The manuscript explicitly flags internal inconsistencies so that they can be resolved from the original HOMER project and measurement records.