



INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

TECHNO-ECONOMIC EVALUATION OF A HYDRO-PV HYBRID ENERGY SYSTEM FOR A PAPER MILL FEEDER USING HOMER PRO

1ISHTPREET SINGH, 2BALJEET SINGH, 3PREETINDER SINGH

1STUDENT, 2ASSISTANT PROFESSOR, 3ASSOCIATE PROFESSOR

1GNDE COLLEGE LUDHIANA,

2GNDE COLLEGE LUDHIANA,

3GNDE COLLEGE LUDHIANA

Abstract

The increasing electrical demand of industrial facilities and the need to reduce dependence on conventional electricity sources have created interest in renewable-based hybrid energy systems. This paper presents a techno-economic evaluation of a Hydro-PV hybrid energy system designed for a Paper Mill Feeder using HOMER Pro. The study considers an annual electrical demand of 800,000 kWh/year, an average daily demand of 2,191.78 kWh/day, an average electrical demand of 91.32 kW, and a peak demand of 150 kW. Four configurations are evaluated: grid-only, hydro-only, Hydro-PV-Converter, and Hydro-PV-Battery-Converter systems. The hydroelectric unit has a rated capacity of 49 kW and produces approximately 383,463 kWh/year, corresponding to 47.93% of the annual feeder demand. The comparative analysis demonstrates that integrating photovoltaic generation substantially increases renewable electricity production, while battery storage improves the ability of the system to utilize surplus renewable energy. The Hydro-PV-Converter configuration achieves an annual production of 836,404 kWh, with an NPC of ₹18.53 million and an LCOE of ₹1.81/kWh. The Hydro-PV-Battery-Converter configuration produces 1,017,581 kWh/year and is identified as the best overall hybrid configuration, although its NPC and LCOE are higher at ₹37.03 million and ₹3.62/kWh, respectively. The results demonstrate the importance of coordinated generation and storage sizing for industrial renewable-energy applications.

Keywords: Hydro-PV Hybrid System, HOMER Pro, Paper Mill Feeder, Techno-Economic Analysis, Battery Storage

1. INTRODUCTION

1.1 Background

The continuous development of industrial activities, urbanization, population growth, and increasing use of electrical equipment have resulted in a steady increase in electricity demand. Industrial feeders require a dependable electricity supply because interruptions or inadequate generation capacity can affect production, equipment operation, and overall process continuity. Conventional electricity systems can provide continuous supply, but dependence on conventional sources also results in recurring electricity expenditure and continued reliance on non-renewable generation. The thesis considers renewable energy as an alternative approach for reducing dependence on conventional electricity while maintaining an adequate energy supply.

Solar photovoltaic and hydroelectric generation have different operational characteristics. Solar PV generation is dependent on solar radiation and daylight availability, whereas hydroelectric generation depends on the availability of suitable water resources and hydraulic conditions. Hydropower can provide relatively consistent renewable generation when the resource is available, while PV generation can contribute significant energy during periods of solar availability. Combining these sources can therefore provide a more diversified renewable-energy supply than relying on either source independently.

The use of a hybrid renewable system becomes particularly relevant for an industrial feeder having a significant annual energy requirement and a defined peak demand. The Paper Mill Feeder considered in this study consumes approximately 800,000 kWh/year, with an average daily demand of 2,191.78 kWh/day, an average electrical demand of 91.32 kW, and a peak demand of 150 kW. These values form the common load basis for all configurations evaluated in the study.

HOMER Pro is used in the study for modelling, simulation, optimization, and comparison of the proposed renewable configurations. The software evaluates energy generation, storage operation, electricity utilization, and economic indicators on an hourly basis over a complete year. The principal indicators considered include renewable contribution, unmet load, excess electricity, Net Present Cost (NPC), and Levelized Cost of Energy (LCOE).

1.2 Research Problem

The primary research problem is the mismatch between the available renewable generation capacity and the electrical requirements of the Paper Mill Feeder. The selected hydroelectric generator has a rated capacity of only 49 kW, while the feeder peak demand is 150 kW. Although the hydro generator can produce approximately 383,463 kWh/year, it cannot independently satisfy the complete annual feeder requirement of 800,000 kWh/year or the peak demand. The hydro-only configuration therefore leaves an annual energy requirement of approximately 416,537 kWh/year.

The research problem is consequently not simply to install renewable generation, but to determine an appropriate combination of hydroelectric generation, PV generation, battery storage, power conversion, and grid support. Increasing renewable capacity can increase renewable-energy utilization but may also increase system investment. Similarly, battery storage can improve operational flexibility by storing excess renewable generation, but its inclusion increases system cost. Therefore, the appropriate configuration must be evaluated by simultaneously considering technical performance and economic feasibility.

1.3 Research Objective

The main objective is to model and evaluate a Hydro-PV hybrid renewable-energy system for the Paper Mill Feeder using HOMER Pro. The work specifically aims to evaluate hydroelectric and solar PV generation, examine the influence of battery storage and power conversion, and compare alternative system configurations.

A second objective is to perform a techno-economic comparison using annual energy production, renewable contribution, unmet load, excess electricity, NPC, and LCOE. The purpose is to identify a configuration that

provides a suitable balance between renewable-energy utilization, electricity supply capability, storage flexibility, and lifecycle cost. The thesis explicitly identifies the development and analysis of a Hydro-PV hybrid system and the techno-economic comparison of renewable configurations as the principal objectives.

2. LITERATURE REVIEW

2.1 Hybrid Renewable Energy System Studies

The literature reviewed in the thesis demonstrates that hybrid renewable systems are generally evaluated using a combination of technical, economic, and reliability criteria. Mostofi and Shayeghi investigated hybrid systems involving hydropower, wind, PV, and hydrogen storage and highlighted the importance of reliability, reserve requirements, and system cost during sizing. Ye et al. investigated a microgrid incorporating wind, solar, hydro, batteries, and power electronics, emphasizing both energy balance and dynamic performance.

Okedu and Uhumwangho demonstrated the usefulness of HOMER for comparing renewable configurations containing PV, wind, hydropower, batteries, and converters. Aziz et al. further emphasized that economic parameters alone are insufficient and that technical and environmental indicators should also be considered. Kamran et al. examined a hybrid renewable system for rural areas incorporating canal micro-hydro, PV, wind, and diesel generation, showing the influence of component sizing and water-resource conditions on system economics.

Further studies summarized in the thesis considered different forms of renewable generation and storage. Kumar et al. evaluated renewable technologies from technical, economic, social, and environmental perspectives. Javed et al. discussed pumped-hydro storage as a mechanism for addressing renewable intermittency. Ullah et al. proposed a multi-criteria framework incorporating economic, reliability, ecological, social, and geographical factors. Zhu et al. considered load-carrying capability and profit in hybrid hydro-PV operation. These studies collectively demonstrate that renewable system design requires more than simply maximizing renewable capacity.

2.2 Research Gap and Relevance to Present Study

The literature further indicates the importance of storage, dispatch, resource complementarity, and site-specific system sizing. Bhayo et al. examined solar-battery systems with pumped-hydro storage and observed that storage can reduce excess power, although reliability requirements can influence LCOE. Sadhukhan et al. emphasized energy balance and cost-based optimization, while Sattar et al. investigated canal-based micro-hydel resources using HOMER Pro. Sharma et al. focused on optimal battery dispatch in a pico-hydro PV microgrid, showing the significance of storage operation under renewable and load uncertainty.

The research gap identified in the thesis is that many existing studies focus on remote electrification, diesel displacement, grid extension, renewable penetration, or reduction of unmet load. The present work instead applies a comparative techno-economic assessment to a Paper Mill Feeder with a defined industrial load profile. Four configurations are assessed using a common annual load of 800,000 kWh/year and a peak demand of 150 kW. This provides a direct comparison between grid-only operation, hydro-only operation, Hydro-PV operation, and Hydro-PV operation with battery storage.

3. METHODOLOGY

3.1 Study Location and Electrical Load

The study is conducted for the Paper Mill Feeder at Dulay, Punjab, India. The location used in HOMER Pro is specified at 30°47.2' N latitude and 75°50.9' E longitude. The revised feeder load profile is maintained consistently across all simulated configurations to ensure a meaningful comparison. The feeder has an annual energy requirement of 800,000 kWh/year, average daily energy demand of 2,191.78 kWh/day,

average demand of 91.32 kW, and peak demand of 150 kW. The load is represented as an AC primary load with a 60-minute time step.

The load factor calculated in the thesis is approximately 60.88%. The annual load profile is an important input because component sizing and system economics depend directly on the amount and timing of electricity demand.

3.2 System Configuration and Component Modelling

The proposed system includes hydroelectric generation, solar PV, battery storage, a bidirectional converter, and grid connection. The hydro generator is connected to the AC bus, while the PV array, battery, and converter are associated with the DC side. The selected hydroelectric generator is a Natel FreeJet FJ 7A with a nominal capacity of 49 kW. It produces approximately 383,463 kWh/year, has a mean output of about 43.8 kW, and a capacity factor of 89.3%.

The selected PV module is Vikram Solar 325 Eldora VSP.72.325.03. The proposed PV capacity is 325 kW in the system design. The PV system has an annual production of approximately 634,118 kWh/year and a capacity factor of 22.28%. Its average daily production is reported as approximately 1,737.31 kWh/day.

Battery storage is included to absorb excess renewable electricity and supply energy during periods when renewable generation is insufficient. The selected battery is Exide Technologies A602/3270 SOLAR. The design information reports approximately 1,012 kWh of storage capacity and a calculated autonomy of approximately 11.08 hours at the average feeder demand. The converter is a Sungrow Power Supply SG30KU bidirectional AC/DC converter rated at 300 kW.

3.3 Simulation and Comparative Evaluation

The system is simulated in HOMER Pro for 8,760 hours using a one-hour time step. Four configurations are investigated: (1) Grid Only, (2) Hydro Only, (3) Hydro-PV-Converter, and (4) Hydro-PV-Battery-Converter. Each configuration is evaluated using the same feeder load profile.

The principal technical indicators are annual electricity production, renewable fraction, unmet load, and excess electricity. Economic performance is evaluated through NPC and LCOE. The comparison is intended to determine whether additional PV and battery investments provide sufficient technical advantages to justify their higher system costs.

4. RESULTS AND DISCUSSION

4.1 Paper Mill Feeder Load Characteristics

The Paper Mill Feeder represents the common electrical demand against which all system configurations are evaluated. The annual electrical consumption is 800,000 kWh/year. The average daily energy requirement is 2,191.78 kWh/day, corresponding to an average electrical demand of 91.32 kW. The maximum demand is 150 kW. Maintaining these values across all cases makes the comparison independent of changes in the load profile.

The difference between average and peak demand is important for system sizing. The 49 kW hydro generator is smaller than both the average demand and the peak demand. Consequently, hydroelectric generation can provide a renewable base contribution but cannot independently satisfy the complete feeder requirement.

4.2 Hydroelectric Generation

The hydroelectric component is modelled using a 49 kW Natel FreeJet FJ 7A generator. Its annual production is 383,463 kWh/year, which corresponds to approximately 47.93% of the annual feeder demand. The reported mean output is 43.8 kW and the capacity factor is 89.3%.

The high capacity factor indicates relatively consistent generation over the simulated year. However, the difference between annual hydro production and annual feeder consumption is 416,537 kWh/year. Therefore, the hydro-only configuration cannot supply the complete feeder demand. The hydro generator nevertheless provides a substantial renewable contribution and serves as the principal renewable base source in the studied system.

4.3 Solar PV Integration

Solar PV is introduced to complement hydroelectric generation. The fundamental advantage of combining PV with hydro is that the two resources have different operating characteristics. Hydro generation provides relatively continuous renewable output, whereas PV contributes during periods of solar availability.

In the Hydro-PV-Converter configuration, the technical results show a total production of 836,404 kWh/year. The renewable generation associated with this configuration is reported as substantially higher than the hydro-only configuration. The system also has 148,066 kWh/year of excess electricity and 152,838 kWh/year of unmet load in the comparative electricity-generation table.

The economic result of Case 3 is particularly notable. Its NPC is ₹18.53 million and its LCOE is ₹1.81/kWh. Although PV increases the investment relative to the hydro-only arrangement, the reported LCOE is the lowest among the studied configurations.

4.4 Battery-Assisted Hydro-PV Configuration

Battery storage is incorporated to improve the ability of the hybrid system to utilize excess renewable generation. The battery does not generate electricity; rather, it stores electricity produced during periods of surplus and makes that energy available when renewable generation and load do not coincide.

The final comparative results identify the Hydro-PV-Battery-Converter configuration as the most comprehensive hybrid arrangement. The configuration produces approximately 1,017,581 kWh/year, compared with 836,404 kWh/year for the Hydro-PV-Converter case and 383,463 kWh/year for the Hydro-only case. The battery therefore supports a higher annual system production and eliminates the reported unmet load in the comparative table.

The comparative component table reports 49 kW hydro capacity, 300 kW PV capacity, 2,024 kWh battery storage, and a 300 kW converter for the final Hydro-PV-Battery-Converter configuration. These values are the configuration values used in the final comparative assessment of the thesis.

4.5 Comparative Configuration Analysis

The four configurations provide progressively different combinations of reliability, renewable contribution, storage capability, and cost.

Case	Configuration	Annual Production (kWh/year)	Annual Load (kWh/year)	Excess Electricity (kWh/year)	Unmet Load (kWh/year)
Case 1	Grid Only	800,000	800,000	0	0
Case 2	Hydro Only	383,463	800,000	0	416,537
Case 3	Hydro-PV-Converter	836,404	800,000	148,066	152,838
Case 4	Hydro-PV-Battery-Converter	1,017,581	800,000	217,273	0

The table demonstrates a clear increase in annual renewable-system production as PV and battery storage are incorporated. Case 2 has insufficient production to meet the annual load. Case 3 increases annual production but still records unmet load. Case 4 has the highest annual production and no unmet load in the reported comparative results.

4.6 Economic Evaluation

Economic evaluation is based primarily on NPC and LCOE. The grid-only case has the highest NPC of ₹81.81 million and an LCOE of ₹8.00/kWh. The Hydro-only case reduces the NPC to ₹9.24 million and LCOE to ₹4.02/kWh. Case 3 has an NPC of ₹18.53 million and the lowest reported LCOE of ₹1.81/kWh. Case 4 has an NPC of ₹37.03 million and an LCOE of ₹3.62/kWh.

Case	Configuration	NPC (₹ million)	LCOE (₹/kWh)
Case 1	Grid Only	81.81	8.00
Case 2	Hydro Only	9.24	4.02
Case 3	Hydro-PV-Converter	18.53	1.81
Case 4	Hydro-PV-Battery-Converter	37.03	3.62

The results show that the lowest-cost configuration is not automatically the technically best configuration. Hydro-only has the lowest NPC among the renewable configurations, but it cannot satisfy the full feeder requirement. Case 3 has the lowest LCOE, while Case 4 provides the best balance between renewable generation, storage, and supply capability and is consequently ranked as the best overall hybrid configuration.

5. FUTURE SCOPE

Based strictly on the future directions identified in the uploaded thesis, the following areas can be considered for further investigation:

1. **Integration of additional renewable sources:** Wind energy can be incorporated into the Hydro-PV system to investigate whether an additional renewable source can improve overall renewable-energy utilization and reliability.
2. **Additional hydroelectric generation:** Increasing or supplementing hydro generation can be investigated to determine its effect on annual renewable production and the ability to meet feeder demand.
3. **Advanced battery technologies:** Different energy-storage technologies can be evaluated to improve storage efficiency, operational flexibility, and renewable-energy utilization.
4. **Comparison of battery chemistries:** Lithium-ion and flow-battery technologies can be studied and compared with the existing storage arrangement in terms of lifecycle performance, storage efficiency, and overall lifecycle cost.
5. **Improved system optimization:** Future investigations can examine alternative combinations of renewable generation and storage to further balance energy availability, reliability, renewable utilization, and economic performance.

6. CONCLUSION

This paper presented a techno-economic assessment of a Hydro-PV hybrid energy system for a Paper Mill Feeder using HOMER Pro. The study considered an annual electrical demand of 800,000 kWh/year, an average demand of 91.32 kW, and a peak demand of 150 kW. Four configurations were compared using common load conditions.

The 49 kW hydroelectric generator produced approximately 383,463 kWh/year, corresponding to 47.9% of the annual feeder requirement. Although hydro generation provided a substantial renewable contribution, it was insufficient to satisfy the complete feeder demand. Integration of PV increased annual generation, while the addition of battery storage provided greater flexibility for managing surplus renewable electricity.

The Hydro-PV-Converter configuration achieved an annual production of 836,404 kWh/year, NPC of ₹18.53 million, and LCOE of ₹1.81/kWh. The Hydro-PV-Battery-Converter configuration achieved the highest annual production of 1,017,581 kWh/year and zero reported unmet load, with an NPC of ₹37.03 million and LCOE of ₹3.62/kWh. Although Case 4 does not have the lowest economic cost, it provides the strongest overall technical performance and the best generation-storage balance. The thesis consequently identifies the Hydro-PV-Battery-Converter system as the best overall hybrid configuration.

REFERENCES

- [1] M. M. Al-Sawalha *et al.*, “Optimal power management of a stand-alone hybrid energy management system: Hydro-photovoltaic-fuel cell,” *Ain Shams Engineering Journal*, vol. 15, no. 12, 2024.
- [2] A. S. Aziz *et al.*, “Feasibility analysis of PV/Wind/Battery hybrid power generation: A case study,” *International Journal of Renewable Energy Research*, vol. 8, no. 2, pp. 661–671, 2018.
- [3] E. K. Bawan *et al.*, “Comprehensive analysis and optimal design of hybrid renewable energy system for rural electrification in West Papua, Indonesia,” *IEEE Access*, vol. 13, pp. 66250–66275, 2025.
- [4] B. A. Bhayo *et al.*, “Energy management strategy of hybrid solar-hydro system with various probabilities of power supply loss,” *Solar Energy*, vol. 233, pp. 230–245, 2022.
- [5] W. Chen *et al.*, “Coordinated optimization scheduling of wind, solar, hydro and methane power generation with adjustable methane,” *Frontiers in Energy Research*, vol. 13, 2025.
- [6] T. da Luz *et al.*, “New Benders decomposition and rolling horizon optimisation approaches to design isolated microgrids for Amazon region,” *Electric Power Systems Research*, vol. 221, 2023.
- [7] U. A. Dodo *et al.*, “Grid-connected hydro-solar hybrid systems for low-carbon energy transition: A techno-economic assessment,” *Environment, Development and Sustainability*, 2026.
- [8] Y. Fang *et al.*, “Two-tier configuration model for the optimization of enterprise costs and user satisfaction for rural microgrids,” *Mathematics*, vol. 12, no. 20, 2024.