Feasibility Assessment of Offsetting Diesel Generator in an Islanded Microgrid

by

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B.Sc., Islamic Azadi University , 2009

M.Sc., Amirkabir University of Technology, 2013

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We acknowledge and respect the Lək̓ʷəŋən (Songhees and Esquimalt) Peoples on whose territory the university stands, and the Lək̓ʷəŋən and W̱SÁNEĆ Peoples whose historical relationships with the land continue to this day.

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Abstract

The presented work endeavors to mitigate the reliance on existing diesel generators by integrating hybrid renewable energy systems to fulfill the energy demands of a small community residing in Meziadin Lake, Canada. Utilizing HOMER Pro 3.16.2 software, the research employs a range of analyses, encompassing Net Present Value (NPV), Cost of Energy (COE), emissions, energy production, and operational costs. The simulation outcomes indicate that the combination of solar energy, batteries and the existing diesel generator represents the optimal solution, demonstrating superior performance with NPC and COE of \$3.26M and \$0.1815/kWh, respectively. Our model has a renewable fraction of 82% and results in 47.5% reduction of NPC and COE, as well as 89.1% decrease in annual carbon dioxide emission compared to the baseline system.

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A special mention goes to my wife, Ghazal, for her unwavering support, patience, and understanding during this challenging yet rewarding journey. Her encouragement, sacrifices, and belief in me have been a constant source of inspiration.

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Dedication

This thesis is dedicated to my cherished family and beloved wife, Ghazal. To my family, whose boundless love, unwavering support, and enduring patience have sustained me throughout this academic journey. Your encouragement and belief in my abilities have fueled my determination to succeed.

To my dear wife, Ghazal, your unwavering support, understanding, and sacrifices have been the cornerstone of my achievements. Your love has given me the strength to overcome challenges and pursue my dreams with unwavering determination. This thesis is a testament to our partnership, love, and shared commitment to each other's dreams.

Reza Rahbar

CHAPTER 1

Introduction

Meziadin Lake, located in the pristine landscapes of British Columbia, Canada, faces the challenge of relying on diesel generators for its energy needs[1]. However, the environmental, social, and economic costs of this reliance are increasingly evident. The goal of this thesis is to present a sustainable solution that reduces the community's fossil fuel dependency by harnessing local renewable energy sources (RES) . This transition not only supports environmental and economic well-being but also represents an essential step towards energy security, reconciliation, and self-determination, especially for Indigenous Peoples [2]. The proposed solution, a hybrid microgrid, is at the core of this endeavor, offering a path to offset diesel generator usage and pave the way for a more sustainable and self-reliant energy future.

Meziadin Lake, British Columbia, Canada, is situated at Latitude 56.03333° and Longitude -129.16667°, hosting a population of 20 inhabitants. Its average AC type commercial consumption is standardized to 2,419.80 kWh/day, with the peak load registering at 407.44 kW, resulting in a load factor of 25%. Loads in Meziadin Lake reach their peak in January. The existing diesel generator has a capacity of 500 kW. Additionally, the fuel price is $0.43/L [1]. Figure 1.1 demonstrates the location of the proposed area on map.

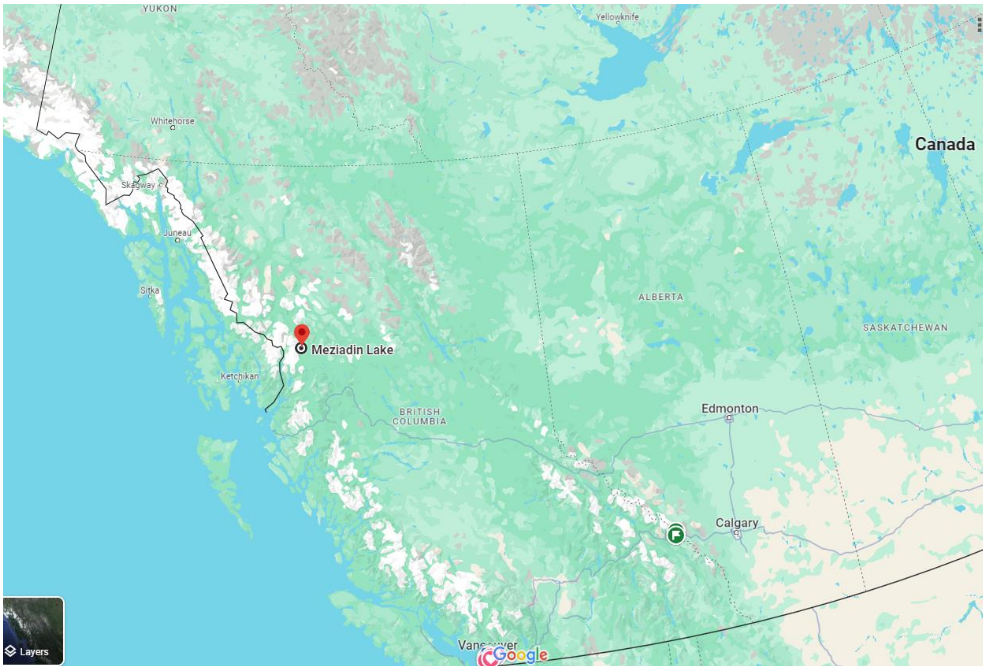

Figure 1.1 Meziadin Lake Location

A microgrid is a versatile solution that integrates both renewable and conventional energy sources on a small scale, ensuring reliable power supply from generation to demand. Operating either independently or connected to the main grid, microgrids manage diverse energy inputs and storage while overseeing functions like monitoring and automation. By situating distributed energy resources (DER) close to demand centers, microgrids minimize transmission losses, offering grid operators greater control over power distribution. Particularly beneficial for remote areas, microgrids provide a cost-effective alternative to extensive grid infrastructure, overcoming barriers like environmental constraints. These advantages have fueled the global adoption of microgrid technology [3-8].

The global annual renewable capacity additions have increased by almost 50%, almost reaching 510 gigawatts (GW) in 2023, the fastest growth rate in the past two decades [9]. Canada is a world leader in the production and use of energy from renewable resources (RES). RES currently provide 18.9% of Canada's total primary energy supply [10].

The province of British Columbia is no exception in this matter. The province is aiming to become a global leader in the usage of RES in the 21st century. About 94.1% of total generated power in British Columbia is supplied from hydropower, while the sum of wind, solar and tidal energy comprises about 3.0%. As of 2022, British Columbia had 702 Megawatts (MW) of wind and 303 MW of solar installed on its grid [11].

Microgrids have become a cornerstone in connecting the power produced by RES. Microgrids provide an independently controllable process that comprises different aspects of generation, transmission and distribution of power and energy utilization systems, consisting of distributed generators, load, battery storage, and safety control schemes, which can operate as an on-grid or standalone unit [12].

Accordingly, executing simulation analysis by optimization software such as the Hybrid Optimization Model for Multiple Energy Resources (HOMER Pro) has become a hot topic in this field. Study on designing a hybrid power system, simulated and optimized by HOMER PRO in Canada has been carried out by Patel. K. et al., who designed a hybrid power system for the remote location of Francois, located on the southern coast of Newfoundland, Canada. In this work, the authors studied a hybrid power system by incorporating PV panels, diesel generators, and a battery backup system [13]. Baral et al. simulated a hybrid islanded microgrid system including PV, diesel generator, a battery, and a converter in Bhubaneswar, India [14]. Sitanggang studied a hybrid microgrid system including PV, wind turbine, battery, converter and diesel in Wetar Island, Indonesia [15]. Al-Badi et al. evaluated different scenarios including a PV, battery, fuel cell in Al Mazyouna, Oman [16]. Islam et al. compared different scenarios including a diesel generator, PV, wind turbine and battery in Cumilla, Bangladesh [17]. Ionescu et al. proposed a hybrid microgrid system including a diesel generator, PV and wind turbine in Dobrogea region, in Romania [18].

The diverse geographical and infrastructural specifications of each place mandate execution of local studies to tailor the best design for each location. This may be even more highlighted in case of indigenous communities, where population distribution in scattered, small-sized communities with simpler infrastructure is more common. Also, the generally lower annual income of smaller communities may translate to higher financial impact of lowering costs of power generation, leading to overall higher improvement in quality of life.

1.1 *Contributions and Outline*

This chapter briefly introduces the geographical details of the target site and the importance of shifting to renewable energy sources (RES). The role of microgrids in managing power generation, transmission, distribution, and energy utilization is discussed. The use of HOMER Pro for simulation analysis and model optimization is also highlighted.

In the second chapter, background knowledge will be provided by conducting a literature review, mainly focusing on studies about the application of HOMER Pro for optimizing proposed hybrid microgrid systems both globally and in Canada. The gaps in the existing literature will be discussed in detail, and it will be highlighted how these gaps are bridged by our study.

In the third chapter, the site description, including electrical load data and local meteorological features, will be provided. The proposed hybrid microgrid model and its components (PV system, battery, converter, and diesel generator) will be detailed. The HOMER Pro optimization function, including energy balance calculations, system feasibility evaluation, and cost minimization, will be elaborated on, along with the mathematical formulation implemented by HOMER Pro, specifically how the net present cost (NPC) is minimized and the total cost of each component is calculated.

In the fourth chapter, the results of our optimized simulation will be presented, beginning with a comparison of the financial aspects between the baseline model and our proposed model. A detailed cost breakdown will be provided, and the specific features of each system component will be discussed. Environmental aspects, including a comparison of pollutant emissions, will also be elaborated upon. Lastly, a detailed graph depicting the system's operation breakdown by component on a sample day will be included.

In Chapter five, the conclusions of our study will be presented, with the characteristics of each component of our proposed model and its ultimate financial and environmental impact on the selected community detailed. How further exploration may be pursued to augment HOMER Pro's capabilities in addressing the intricate technical nuances inherent in microgrid systems will be discussed.

CHAPTER 2

Literature Review

Microgrids represent a transformative approach to energy distribution, offering localized, resilient, and sustainable solutions to meet the evolving needs of communities and industries. In the pursuit of energy sustainability, microgrids have emerged as pivotal systems, capable of integrating renewable energy sources, enhancing energy efficiency, and ensuring reliable power supply[19] .

The importance of microgrids in achieving energy sustainability cannot be overstated. With the increasing demand for clean energy and the pressing need to mitigate climate change, microgrids offer a promising avenue for reducing carbon emissions, promoting energy independence, and bolstering energy security. By enabling the integration of renewable resources such as solar, wind, and hydroelectric power, microgrids contribute to the transition towards a low-carbon future while fostering economic development and social equity.

However, the successful implementation of microgrid projects hinges on thorough planning, analysis, and assessment of feasibility. Conducting feasibility studies is crucial to evaluate the technical, economic, and environmental viability of microgrid deployment in specific contexts. These studies help stakeholders identify optimal system configurations, assess potential risks and challenges, and make informed decisions regarding investment and resource allocation [3-7].

In this context, HOMER Pro emerges as a valuable tool for optimizing microgrid systems. HOMER Pro is a sophisticated software platform that enables users to simulate, design, and analyze microgrid configurations with precision and efficiency[20]. By leveraging advanced algorithms and modeling capabilities, HOMER Pro empowers researchers, engineers, and policymakers to explore various scenarios, optimize system performance, and assess the economic viability of microgrid projects. Its intuitive interface and powerful optimization features make it an indispensable tool for navigating the complexities of microgrid design and operation [5, 8].

In the following sections of this literature review, the theoretical underpinnings of microgrid technology will be delved deeper into, the existing literature on microgrid feasibility studies will be explored, and the role of HOMER Pro in facilitating the optimization of microgrid systems will be examined. Through this exploration, insights into the challenges and opportunities associated with microgrid implementation will be aimed to be gained, contributing to the advancement of sustainable energy solutions.

Jyoti Ranjan Baral et al. [14], studied an islanded mode microgrid system optimized by HOMER Pro in the city of Bhubaneswar in 2022. This city is in Odisha, India (20.2961° N, 85.8245° E) with a tropical savanna climate. The authors used synthetic data for the community group load profile available in the software with daily load consumption of 165.59 kWh, daily peak of 23.31 kW and peak load in June. Their proposed system consisted of PV, battery, diesel generator and converter with the power ratings of 53.6, 144, 26 and 24 kW, respectively. Their model has net price cost (NPC) of $378K and cost of energy (COE) of 0.484 $/kWh with an initial cost of $233K. Renewable fraction of their proposed model equals to 83.9%, consuming 4082 liter of fuel per year. They concluded that HOMER Pro was successful in proposing a hybrid microgrid system which met the demands of the small target community. Furthermore, the paper suggests that this design concept could be expanded to a grid-connected system, with a focus on economic optimization. However, there are some inconsistencies in their methodology, as the authors have claimed to have implemented a 48 V DC bus in the abstract but have not mentioned or provided any explanation on this matter in the methodology.

Ruly Bayu Sitanggang [15] studied an islanded mode microgrid system optimized by HOMER Pro in Wetar subdistrict, Southwest Maluku Regency, Maluku Province, with coordinates 7°47'00.87" S 126°16'52.13" E in 2022. Ruly simulated the hybrid islanded microgrid using diesel generator, PV, battery, converter and wind turbine. He used the load profile available in the software with daily load consumption of 1375.77 kWh, daily peak of 107 kW and compared the efficacy of implementing three different types of batteries, lead-acid, Li-ion and Vanadium Redox Flow Batteries (VRFB). He reported the NPC for the model with lead-acid battery is $1.73M, while for both Li-Ion and VRBF equaled to $1.39M. However, the lower capital cost of Li-Ion compared with VRBF ($879K vs $1M) led to slight difference in cost of energy among the two models (0.213$/KWh vs 0.214$/KWh). Therefore, he concluded that Li-ion was the most cost-efficient choice. The final proposed system consisted of PV, Lithium-ion battery, diesel generator, wind turbine and converter with the power of 209 kW, 893 kW, 400 kW, 27 kW and 96 kW, respectively. The model has NPC of $1.39M and COE of $0.213/kWh considering a capital cost of $879K, with 24,426 liter fuel consumption per year. He concluded that HOMER Pro was successful in proposing a hybrid microgrid system which met the demands of the small target community. Furthermore, the paper suggests that this design concept could be expanded to a grid-connected system, with a focus on economic optimization. His methodology has some inconsistencies though. The author has modelled the system accounting for a wind turbine nominal speed of 11 m/s, which according to the regional wind speed graph he provided in the article (Figure 5. I lwaki Wind Speed Monthly Profile), cannot be met as the regional wind speed is significantly lower than this amount. Also, the diesel life time he accounted for (100,000 hrs, Table 3) is unrealistic (normal values are about 15,000[21]).

Abdullah Al Badi et al. [16], studied the possibility of replacing diesel power plant with renewable energy system and battery/fuel cell system in a remote area in Al Mazyouna, Oman, in 2022. They studied 3 different scenarios. The first design implemented PV and battery, resulting in NPC of $222 M and COE of 0.422 $/kWh having the advantage of being 100% renewable and producing no harmful emissions. The second design implemented a 65 MW PV and 10 MW fuel cell, resulting in NPC and COE of $385 M and 0.731 $/kWh, respectively. Finally, they studied a hybrid microgrid system utilizing PV, fuel cell and battery which lead to NPC of $264 M and CEO of 0.501 US$/kWh. They reported that among the three scenarios, the first one with PV and battery was the most cost effective. However, considering the low price of fuel in Oman, the base diesel only system with CEO of 0.188 US$/kWh was still the most cost effective method of power generation among all models. It should be mentioned that they accounted for a 10 MW load with peak load of 9.4 MW in September. For storage system, battery bank and a combination of fuel cell, electrolyzer and hydrogen tank system were used. For the fuel cell system, the power generated by the system covers the load demand and the excess energy is utilized by the electrolyzer to produce hydrogen which will be stored in a tank. It should be kept in mind that their results are based on the fuel price in a major oil producing country and therefore may not be applicable to most regions in Europe and America.

Wahiba Yaïci et al. [22], studied a hybrid islanded mode microgrid for residential purpose in Ottawa, Canada, in 2022. A Hybrid Renewable Energy System (HRES) is a system which implements a mixture of several renewable energy sources to generate power electricity[23]. They modeled two scenarios to investigate the technical and economic feasibility of using HRES with hydrogen and battery storage alternatives to provide electricity for remote household use. They accounted for a load of 162.24 kWh/day. The first configuration comprised of PV, battery, converter and diesel generator. The optimized model implemented 15 kW PV, a 10 kW diesel generator, 10 kW converter and 20 kW battery, resulting in NPC of $395K and COE of 0.56 $/kWh with 23.3% renewable fraction. The second configuration consisted of a PV, diesel generator, system converters, hydrogen tank and hydrogen storage systems. The optimized model implemented 20 kW PV, 15 kW diesel generator, 25 kW of electrolyzer, 10 kg hydrogen tank and 15 kW converter. This model resulted in a 61% higher NPC compared with the previous model ($639K vs $395K), with COE of 0.9 $/kWh, which seems quite a little high. They concluded that with hydrogen storage being a novel technology, it cannot currently compete with conventional battery storage system regarding cost-effectiveness[22].

MD. Khaled Saifullah et al. [24], studied an islanded mode hybrid microgrid in Chapainawabgonj District in Bangladesh, in 2023. The regional load is about 789 kWh/d with a 79kW peak. The authors investigated the output of the PV, biomass/biogas, and diesel generators to handle the issue of irrigation in off-grid areas and supplying the residential loads (Latitude: 24°22' - 24°57', Longitude: 87°23' - 88°23'). They considered various energy resources such as wind turbine (Xzer7.2), PV (Jinko60/300), diesel generator, biogas generator, and battery. They studied the model as per each single equipment and estimated the NPC and COE accordingly. One salient concern arising from this investigation pertains to the wind speed average, notably recorded at a modest 4.23 m/s. Consequently, incorporating wind energy into the hybrid microgrid appears financially untenable. The ensuing analysis revealed the requisite infrastructure: a 123 kW photovoltaic (PV) system, a 114 kW battery, a 44.7 kW converter, alongside auxiliary generators including a 10 kW diesel generator and a 20 kW biogas generator, in addition to the ostensibly impractical 123 kW wind turbine. The aggregate monetary outlay for this model stands at $980K, culminating in a cost of energy (COE) metric of 0.263 $/kWh. This study is fraught with several noteworthy limitations, chief among them being the incongruity evident in the various figures and outcomes presented. Moreover, a conspicuous absence in the investigation pertains to a comprehensive assessment of power generation capacities across the diverse energy sources considered. Lastly, the geographical constraint of a lower-than-desirable average wind speed exacerbates the fiscal imprudence of deploying a wind turbine, particularly at the substantial 123 kW capacity posited.

Viorel Ionescu [18] studied a hybrid microgrid system for a residential property from Dobrogea region, in Romania, in 2023. The load is11.26 kWh/d with a 3.62kW peak. He utilized PV, wind turbines (WT), diesel generator (DG) and battery on the model. Also, he assessed the case based on economic, technical and environmental point of view. He analyzed 4 different scenarios using renewable energy resources containing the battery module: PV/ WT/DG model (Case 1), WT/DG model (Case 2), PV/DG model (Case 3), DG–only model (Case 4). Based on his studies, case 1 is the optimum scenario with the COE of $0.287k/Wh. This optimized system model's initial capital cost, total NPC, renewable fraction were $20,413 , $48,879 and 98.3%, respectively.

Jawdat Abu-Taha et al. [25] studied the feasibility of installing a microgrid system for Nasser medical complex in Gaza strip in 2023. This hospital is grid connected, supplied by GEDCo with 1.7 MVA, 22kV/400V, medium voltage level, three phase transformers through two feeding lines. The load peak demand at Nasser complex is 1144.52 kW. Moreover, four diesel generators, 400kW, 648kW, and 2*1020kW were used, for an overall energy capacity of 3.0 MW. They studied 4 different scenarios utilizing microgrid:

1) Base case (Grid + Diesel):The grid provides all of the required energy, and the established DGs provide power just in case of a power outage.

2) Hybrid PV system (Grid + Diesel + 250 kW PV): In this situation, the grid, DGs, and a current 250 kW PV system are used to decrease energy bills.

3) Hybrid PV system (Grid + Diesel + 1000 kW PV):In this case the grid, DGs and extending to 1000 kW PV system.

4) Hybrid PV system with Li-Ion batteries (Grid + Diesel + 1000 kW PV +BESS).

Based on their studies the forth scenario has the lowest COE (0.181$/kWh) with $5.9 million NPC and 40.4% PV penetration. The results highlight the advantages of a PV-diesel hybrid with battery configuration, such as optimal load management, improved diesel efficiency, reduced maintenance, and decreased diesel and battery capacities. When compared to the base case, it illustrates that by integrating BESS and PV solar, Nasser Medical Complex can substitute costly diesel with low-cost solar energy, reaching up to a 45% fuel savings, a 19% lowering in levelized cost of energy (LCOE), and a 26% internal rate of return (IRR).

Md. Kamrul Islam et al. [17] investigated the performance of a standalone microgrid in Cumilla, Bangladesh, consisting of wind, solar, diesel generators, a converter, and a battery storage system in 2021. Their target was a residential community with 165.44 kWh/d load and 47.57 kW peak. They used HOMER Pro to model and assess this microgrid and conducted three case studies. Case 1: DG set, case 2: Without Wind Turbine, case 3: With Wind turbine. Based on their study case 3 had the lowest NPC ($791k) and COE ($1.01 $/kWh) with a renewable fraction of 88.5%. The research highlights the capability of the proposed scheme to efficiently assess the cost of different configurations for long-term operation at a specific location.

Zia Ullah et al. [26] proposed an optimal planning and analysis approach for the hybrid solar/wind microgrid system integrated with battery energy storage to maximize the technical, cost, and environmental benefits using HOMER Pro in Sewan city in Pakistan (26° 25′ 10.58″ N, 67° 51′ 17.7″ E) in 2023. The load was a rural household consuming 98.15 kWh/d with 15.4 kW peak. They compared 4 different scenarios, as described in the following.

Case 1: PV, wind, converter, and battery.

Case 2 : PV, converter and battery.

Case 3 : wind, converter and battery.

Case 4: only Diesel generator.

Based on their studies, optimal energy alternative to preserving the load demand of the addressed area is the first scenario, which comprises PV, wind turbine (WT), battery, and converter. The system has the best economic behavior with the lowest total NPC ($226476.1) and LCOE of 0.3523$/kWh, which were found to be 59.51% and 59.47% less than the base-model (only diesel) alternative. The case study results show that the proposed 100% RE-based hybrid system comprising 51kW PV, 4×6 kW WT, 186×1kWh battery packs, and 20 kW inverter is the most sustainable, cheapest electricity service, and eco-friendly energy supply alternative for the rural population in Pakistan when compared with standalone single renewable-based or diesel-based energy systems.

Ramchandra Bhandari et al. [27] explored the feasibility of establishing a self-sufficient hybrid energy system to power a university campus in Kansoe, Ghana, with a primary focus on the LCOE of the system in 2018. The study meticulously estimates renewable energy sources and conducts load analysis to develop a functional Hybrid Energy System (HES). Emphasizing sustainability and the utilization of local resources, the study designs a hybrid system combining PV panels, batteries, and bio-oil generators powered by Jatropha oil, tailored to the region's available resources. The total peak load was considered 160.43 kW. The calculations indicate that a system consisting of a 1241 m^2 PV field, a 73 kWh lead-acid battery, and three bio-oil generators (165 kVA, 110 kVA, 34 kVA) is the optimal solution for campus electricity supply. This configuration results in an LCOE of 27.89 €ct/kWh, which is 2.1% lower than the cost of public grid energy. However, it requires 104 hectares of land to produce the necessary Jatropha oil. The sensitivity analysis reveals that the imputed interest rate, fuel price, and total investment costs significantly influence the LCOE. For instance, lowering the interest rate from 20% to 5% reduces the LCOE by 37.3%, while an increase in bio-oil price from 0.5 €/L to 0.8 €/L raises the LCOE by 14.7%. Moreover, a 25% reduction in total investment costs results in an LCOE of 22.8 €ct/kWh. As a future recommendation, the paper suggests comparing similar studies conducted elsewhere to understand how local parameters impact sensitivity results for LCOE.

Adrian L. Rey et al. [28] studied the potential of hybrid renewable power systems in a remote area in Philippines in 2017, where extending the grid is prohibitively expensive. These systems offer a promising solution to reduce reliance on fossil fuels, particularly as the cost of fossil fuel increases with distance, along with its associated environmental impact. The study utilizes HOMER Pro software to model a hybrid renewable power system for Calayan Island, Cagayan (Latitude:19° 16.6' N, Longitude: 121°, 29.0' E. The average daily energy demand is 4,202.3 kWh with an average power demand of 175.1 kW at 0.38 load factor. The results indicate that a combination of solar PV, wind turbines, diesel generators, a hydroelectric plant, and batteries is the most cost-effective configuration, with a COE of P11.89/kWh. This COE is notably lower than the true cost of diesel-based off-grid power generation in the Philippines, which can exceed P20/kWh. The optimal hybrid system comprises a 50-kW solar PV array, 50 sets of 10 kW wind turbines, 180 kW and 120 kW diesel generators, 450 units of 2 kWh batteries, a 250-kW hydroelectric plant, and a 150-kW converter. Most of the electricity in this system is sourced from the hydroelectric plant, offering a cost-effective power supply to the local community.

Karankumar Patel et al. [13], designed a hybrid power system for the remote location of Francois, an off-grid island off the southern coast of Newfoundland, Canada, in 2022. Their model incorporates PV panels, diesel generators, and a battery backup system. While other renewable resources like wind turbines and small hydro power plants are available, site constraints make their implementation infeasible. Their target location has an average daily radiation of 2.89 kWh/m^2 and a wind speed of 5.7 m/s. The load demand was calculated using reopt software[29] for the four summer months when the area is populated, resulting in an average daily load demand of 2727.1 kWh with a daily peak electricity demand of 155 kW. The system design was optimized by HOMER Pro software to determine the most cost-effective electrical system size. It features an energy storage system with a nominal capacity of 7225 kAh, of which 5780 kAh is usable. The system also has a 35% electricity surplus for potential future load increases. The dynamic modeling of the system includes a diesel generator with basic control, a solar system with Maximum Power Point Tracking (MPPT), and an Energy Storage System, implemented in MATLAB/Simulink for operational analysis.

Gourav Kumar Suman et al. [30] utilized HOMER Pro to design a microgrid for the Microprocessor and Digital Electronics Laboratory at the Northeastern Regional Institute of Science and Technology, located at 27◦7’33.43” N latitude and 93◦44’23.46” E longitude, Nirjuli, India. The target location has a load of 54 kWh/d with a 15.54 kW peak. The microgrid incorporates a PV array, diesel generators, and battery storage units. Through optimization with HOMER Pro, it is determined that this system represents the most cost-effective solution for the laboratory's load profile. The proposed model comprises 4.84 kW PV, 8 kW battery and 5.38 kW converter with NPC of $92K and COE of 0.364 $/kWh. While the cost of the proposed microgrid is higher than grid electricity, the paper emphasizes the importance of prioritizing environmental protection in the long run. This work establishes that suitably optimized microgrids can easily meet the power demands of various sectors, while also significantly reducing CO2 emissions through the utilization of renewable energy sources. The future research direction involves analyzing the transient behavior of the system during fault occurrences, as the loads may be sensitive to transients resulting from switching and fault clearance.

Anastasios Oulis Rousis et al. [31] studied an islanded mode hybrid microgrid system for two cottages in Kea, Greece, in 2018. The estimated load was 53 kWh and 23 kWh during summer and winter, respectively. The system is comprised of PV, Diesel Generator, converter, and batteries. They reported that the optimal configuration would implement 15.3 kW PV, 17 kW diesel generator and 6.93 kW converter with renewable fraction of 70.6% spending over £56k on net price cost. They did sensitivity analysis on fuel price and PV generation. There are some inconsistencies regarding their results. The authors claimed to have studied the model implementing 2 different types of batteries. However, this would require studying 2 separate scenarios and comparison of the results, which has not been outlined in their article. Also, the cost of energy of their proposed system was not mentioned in their article.

Piyali Ganguly et al. [32] studied the optimal design configuration for a standalone RES with battery storage using HOMER Pro for a small community located in Portland, Victoria, Australia (38° 20′ 0″ S, 141° 36′ 0″ E). They experimented with different values of hourly wind speed, solar irradiation, scaled annual average load and annual capacity shortage. The load was considered 111.46 kWh/d with 29.71 kW peak. Their proposed microgrid consisted of wind turbine, PV, converter, and battery. Based on their study, considering a 0.1% capacity shortage, their system requires 71.5 kW PV, 8 wind turbine generators (3-kW each), 441 cells of 1 kwh lead-acid battery and 25 kW converter with NPC about $700 K and COE of 1.14 $/kWh.

Farzam Farahmand et al [33], studied a hybrid microgrid system in Natuashish, an isolated Inuit community in Newfoundland and Labrador, northern Canada, using HOMER Pro in 2024. They accounted for a load of 17MWh/d with 1.9MW peak. The baseline system consisted of two CAT-500 kV and one CAT-910 kV diesel generators. Their proposed model compromised of a 910-kW diesel generator, 4 wind turbines (each 250 kW), 40 kW PV, 20 kW converter and batteries (66 string size and 219Ah capacity) with NPC and LCOE of $14.6M and 0.182 $/kWh, respectively. While their project is rather straightforward, some inconsistencies remain. The average wind speed and solar radiation data of the site have not been described in the manuscript nor has it been clarified where the data was acquired from. Therefore, it is not clear weather implementing wind turbine was efficient enough. Additionally, there are some incompatibilities between the data provided in the text, the schematic diagram demonstrated in Figure 2 and the data charted in the table VII, which details the final proposed model.

Michela Longo et al [34], studied a hybrid microgrid system optimized by HOMER Pro in Canada's Red Lake, which is part of Canadian isolated northern populations with total population of 4,670 individuals in 2019. The authors simulated the model accounting for 30 MW peak load including both residential and community as well as industrial and commercial load profiles. Their optimized proposed model consisted of 52,082 kW solar, 122 wind turbines each 1.5 MW, 10,595 kW hydropower, 4,267 strings of 24V battery storage and 22,015 kW ABB PVS800-1000 kW converters with total NPC of $675M and COE of 0.60 $/kWh. The major limitation of this study is the absurdly high NPC. Also, there are few inconsistencies between the data charted in tables and the text.

Prasid Ram Bhattarai et al [35], studied an off grid microgrid in Brochet, a community in Northern Manitoba, Canada in 2016. The existing system consisted of two 1015kW and one 600 kW diesel generators with LCOE of $0.622. They used HOMER software to propose an optimized purely diesel generator-based system as well as a hybrid model consisting of wind turbine and diesel generators, resulting in LCOE of $0.487 and $0.492, and total cost of $17M and $16.4M, respectively. A major limitation of their proposed hybrid system lies in the marginal low wind speed of this location, wind speed being lower than 4 m/s 65% of the time, not feasible for power production.

H. R. Hooshangi [36] studied a hybrid microgrid system optimized by HOMER in Aupaluk, Kuujjuaq and Salluit, three separate off-grid remote indigenous communities in northern Quebec, with population of 195, 2375, 1347; loads of 3.4 MWh/day, 41 MWh/day and 15 MWh/day, and peak load of 210 kW, 2700 kW and 976 kW, respectively. His proposed model consisted of wind turbine, converter, battery and diesel generator for each community. HOMER Explorer software simulation demonstrated that the baseline electricity production cost of diesel generators in Aupaluk, Kuujjuaq and Salluit are as expensive as 1.564 $/kWh, 0.682 $/kWh, and 1.042 $/kWh, whereas optimum hybrid wind-diesel-battery system reduces the cost of energy to 0.848 $/kWh, 0.454 $/kWh, and 0.661 $/kWh, respectively.

Mert Temiz et al [37], studied an off grid renewable energy system in Cochrane, located in northeastern Ontario using System Advisor Model (SAM) software[1]. Their proposed system consisted of a wind and solar power to meet the electricity, heat, cooling, and hydrogen needs of remote communities. The system includes an anion exchange membrane electrolyzer, a proton exchange membrane fuel cell, a heat pump, and an absorption refrigeration chiller. Analyzing the system's energy efficiency, the study uses hourly meteorological data to assess performance and feasibility. Key findings highlight the system's unique design and time-dependent analysis, showing energy efficiency of 20%. The system requires a 23 MW wind farm, a 3.17 MW solar plant, a 14.3 MW fuel cell, and a 19 MW electrolyzer, with an annual operational cost of $3.7 million and a capital cost of $95 million. The hydrogen production cost is $4.38/kg, and the levelized cost of electricity is $0.141/kWh. Their proposed model targeted a community of 5321 people. Therefore, aside the complicated local meteorological and financial requirements, their model may not be applicable for scattered remote communities with low population densities.

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[1] The System Advisor Model (SAM) and HOMER Pro are both powerful tools used for energy system modeling, but they have distinct features and are used for different purposes. SAM is designed primarily for the detailed performance and financial modeling of renewable energy projects, while HOMER Pro is designed for optimizing microgrids and distributed energy systems, particularly in off-grid and hybrid systems [38] M. Mahmoud, E. T. Sayed, M. A. Abdelkareem, M. K. H. Rabaia, and A. G. Olabi, "Modeling and simulation of solar photovoltaic energy systems," in Renewable Energy-Volume 1: Solar, Wind, and Hydropower: Elsevier, 2023, pp. 281-295.

As detailed above, the process of simulating and optimizing a hybrid microgrid system is heavily dependent on the local geographical, meteorological, financial and load characteristics. Therefore, each site needs a dedicated study tailored to its features and the results of other sites are hardly applicable to another location. Also, among the studies carried out in Canada, almost all of them focused on northern and eastern regions, including Quebec and Ontario, and not the west coast. The populations they targeted were commonly larger than a few thousand people, without accounting for the scattering or density of the communities in that specific region, which obviously affects the distribution of generated power which has not been detailed in their models. To our knowledge, our study is the first study to address an indigenous community as small as 20 people in British Columbia, Canada, while accounting for all the meteorological parameters affecting the feasibility of the system.

CHAPTER 3

Methodology

3.1 *Site Description*

Our chosen site, the Meziadin lake, is situated at latitude 56.03333° and longitude -129.16667°, hosting a population of 20 inhabitants [1]. Its average scaled monthly load data is demonstrated in Figure 3.1. The AC type commercial loads in Meziadin lake reach their average peak in January with the average consumption standardized to 2,419.80 kWh/day. The peak load registers at 407.44 kW, resulting in a load factor of 25%.

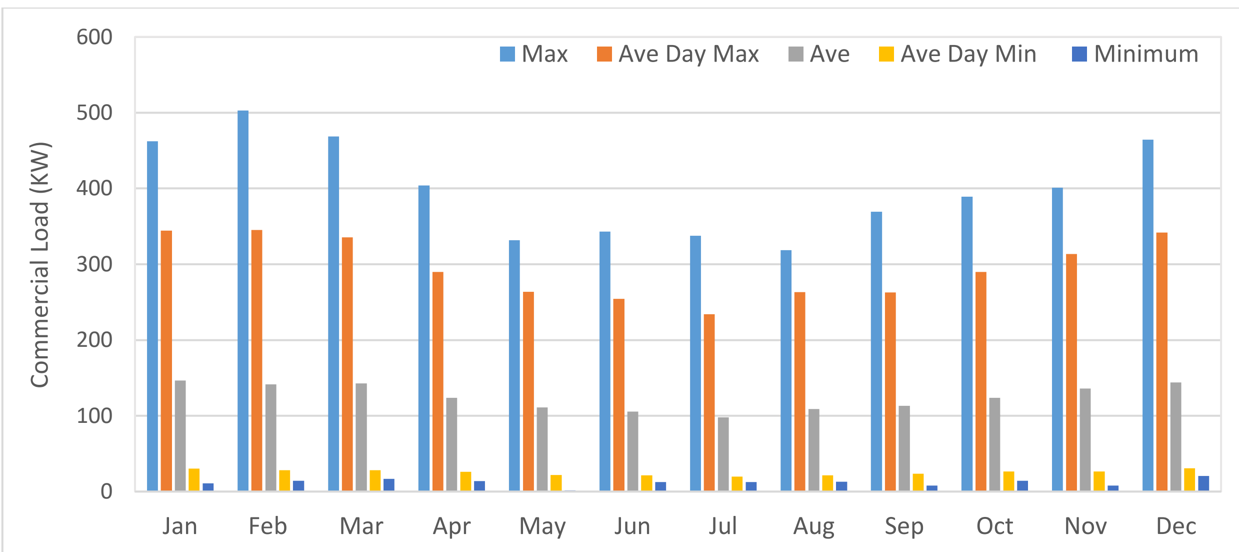

Figure 3.1 Average scaled data of monthly Load in Meziadin Lake (2023)

A discount rate[3] of 4.5% and inflation rate of 2.8% were accounted for based on relevant updated national data [40, 41] for a project lifetime of 25 years. The irradiation data (Figure 3.2) for the site,

[3] The real discount rate is used to convert between one-time costs and annualized costs. HOMER calculates the annual real discount rate (also called the real interest rate or interest rate) from the "Nominal discount rate" and "Expected inflation rate" inputs. HOMER uses the real discount rate to calculate discount factors and annualized costs from net present costs [39] M. Saadeh, M. Muharam, and B. Abu Aldebs, "Economic Analysis Of PPU Hybrid Energy Systems," 2019.

were acquired from the Solar Global Horizontal Irradiance (GHI) from NASA's Prediction of Worldwide Energy Resource (POWER) database [42].

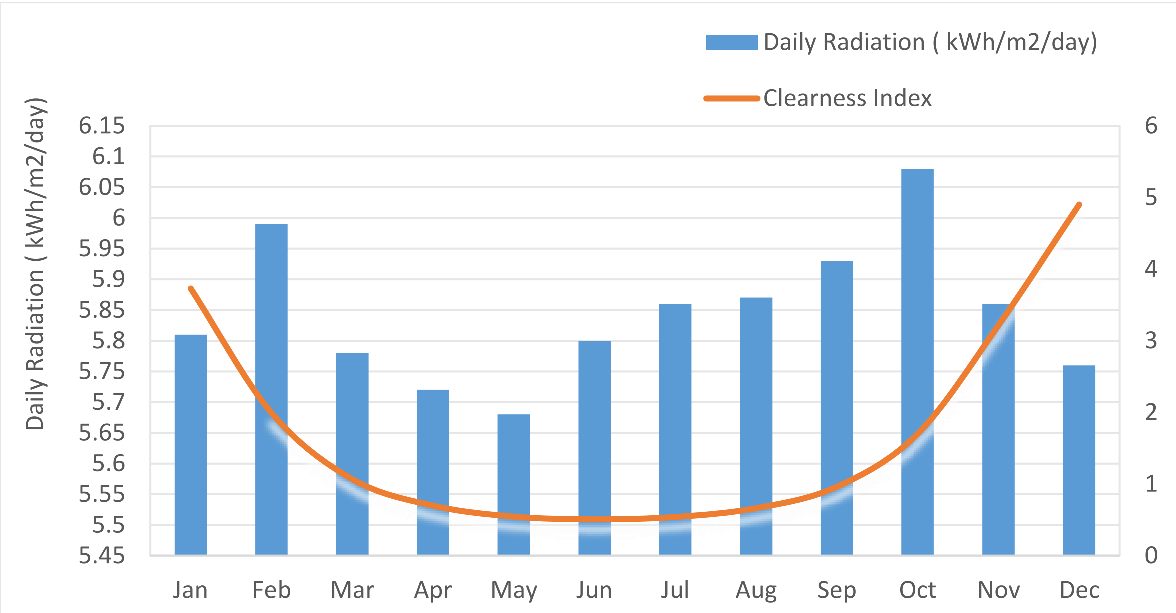

Figure 3.2 Monthly Average Solar Global Horizontal Irradiance (GHI) Data (2023)

According to data from NASA's Prediction of Worldwide Energy Resource (POWER) database [42], the monthly average wind speed at the site is 2.9 m/s, as shown in Figure 3.3, monthly averages below 4 m/s make implementing wind turbine infeasible [43].

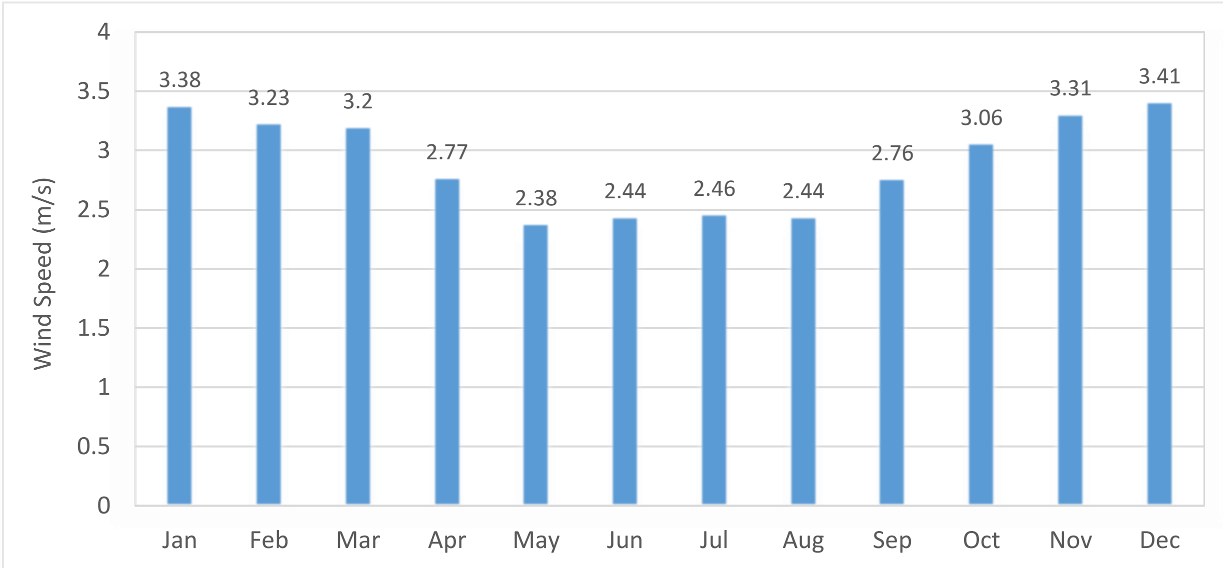

Figure 3.3 Monthly Average Wind Speed (m/s) (2023)

The effects of temperature, also provided by NASA POWER, are accounted for by the software. Due to the unavailability of accessible data, hydro power was not included in our study.

3.2 *Proposed Model*

HOMER Pro version 3.16.2 is used to model the hybrid microgrid. Offsetting the diesel generator and switching to completely renewable energy sources was 1.82 times more costly than opting to a hybrid microgrid system ($5.93M vs $3.26M, Table 3.1) and therefore not cost-effective.

Table 3.1 Cost Comparison of Different Scenarios

	Architecture								Cost			
Scenario	PV	Diesel	Battery	Converter	PV (kW)	500kWGen (kW)	Converter (kW)	Dispatch	NPC	LCOE	Annual Operating Cost	CAPEX
1	x	x	x	x	467	500	330	LF	$3.26M	$0.181	$68,855	$1.86M
2		x	x	x		500	118	LF	$4.40M	$0.245	$209,576	$134.281
3	x		x	x	1048		499	LF	$5.93M	$0.330	$82,541	$4.25M
4		x				500		LF	$6.21M	$0.346	$305,336	$0.00

The schematic of the proposed model is comprised of existing diesel generator, loads along with newly proposed converter, PVs and battery sets as shown in Figure 3.4.

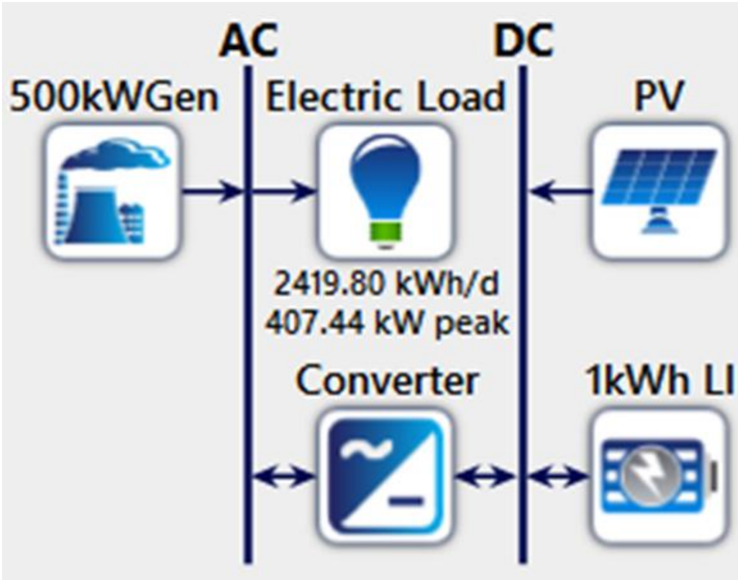

Figure 3.4 Schematic of the proposed Model

Photovoltaic (PV)

A generic 1 kW flat plate PV with capital cost and replacement cost of 2500 $/kW and operation and maintenance fee of 10 $/year for per kW was implemented. The costs and fees are based on the default data of HOMER Pro software. The derating factor and the PV modules' lifetime were defined 80% and 25 years, respectively, which is connected to the DC bus.

Storage

A generic 1 kWh Li-ion battery with specifications charted in Table 3.2 was implemented. The capital cost and replacement fee of the battery is set to $550 with an additional operational and maintenance fee of $10/year. Considering 90 batteries on each string, DC bus voltage is 540 V. The projected lifetime of this battery is set at 15 years.

Table 3.2 Battery Characteristics

Nominal Voltage (V)	6
Nominal Capacity(kWh)	1

Nominal Capacity (Ah)	167
Roundtrip Efficiency (%)	90
Maximum Charge Current (A)	167
Maximum Discharge Current (A)	500
Initial state of charge (%)	100
Minimum State of Charge (%)	20
String Size (Number)	90

Converter

A generic converter system, adhering to the characteristics outlined in Table 3.3, was implemented for utilization in the HOMER Pro optimization process.

Table 3.3 Converter Characteristics

Capacity(kW)	1
Capital ($)	300
Replacement ($)	300
O & M ($)	0
Lifetime (years)	15
Inverter Input Efficiency (%)	95
Rectifier Input Relative Capacity (%)	100
Rectifier Input Efficiency (%)	95

Diesel Generator

Analysis is conducted on a 500-kW generic fixed-capacity Genset, delineated by the subsequent data in Table 3.4Table 3.4.

Table 3.4 Diesel Generator Characteristics

Capacity(kW)	500
Fuel	Diesel
Fuel curve intercept(L/hr)	7.00

Fuel curve slope (L/hr/kW)	0.244
CO(g/L/fuel)	13.566
Unburned HC (g/L fuel)	0.72
Particulates (g/L fuel)	0.116
Fuel Sulfur to PM (%)	2.2
NOx (g/L fuel)	2.6
Lower Heating Value (MJ/kg)	43.2
Density (kg/m3)	820
Carbon Content (%)	88
Sulfur Content (%)	0.4
Initial Capital ($)	0
Replacement (S)	150,000
O&M ($/op. hour)	5.00
Fuel Price ($/L)	0.43[1]
Minimum Load Ratio (%)	30
Lifetime (Hours)	15,000

3.3 *Optimization*

HOMER Pro is a simulation tool that assesses the operation of energy systems. It calculates energy balances at each time throughout the year, compares the electric and thermal demand with the system's energy supply and manages component operation, including generators and batteries. It evaluates the feasibility of system configuration, determines whether they can meet specified electric demand and estimates the lifetime project cost, accounting for various factors like capital, replacement, and fuel expenses. It offers two optimization algorithms, the grid search algorithm which explores all feasible configurations and the HOMER Pro Optimizer, which searches for the least costly system using a derivative-free approach, which means it does not require derivative information in the classical sense to find optimal solutions, most practical in cases such as ours, which information about the derivative of the objective function f is unavailable, unreliable or impractical to obtain [4]. The software simulates numerous variations of possible combinations and sorts them by net present cost, enabling comparison of design options.

[4] Derivative-free optimization (sometimes referred to as black box optimization) is a discipline in mathematical optimization that does not use derivative information in the classical sense to find optimal solutions. Sometimes information about the derivative of the objective function f is unavailable, unreliable or impractical to obtain. For example, f might be non-smooth, or time-consuming to evaluate, or in some way noisy, so that methods that rely on

While determining the exact accuracy and error rate of optimization software such as HOMER Pro is very challenging due to various differences which may occur during implementing the models in real life situations, various studies have validated that HOMER Pro is a robust optimization tool. A recent study which has compared the performance of HOMER Pro with another optimization tool named system advisor model (SAM) based on real life setting results, has shown that the most significant errors which occurred in load and PV production were lower in HOMER Pro versus SAM (4.9-5.3% versus 4.9-7.6%) [46].

The rationale behind the equations used in HOMER Pro stems from the software's goal to model and optimize microgrids, hybrid power systems, and other distributed energy resources. HOMER Pro employs a range of equations to simulate system performance, calculate costs, and assess the feasibility of various configurations. Here’s a breakdown of the rationale behind key types of equations used:

- Energy Balance Equations

These equations ensure that energy supply meets demand at all times. They model the generation from various sources (e.g., solar, wind, diesel) and the consumption by loads. This is critical to ensure that the system operates reliably, without deficits or surpluses of energy.

- Economic Equations

HOMER Pro’s primary purpose is to find the most cost-effective design for a power system. Economic equations calculate the lifecycle cost, including capital, operational, maintenance, and replacement costs. These equations help determine the net present cost (NPC) and levelized cost of energy (LCOE), which are key metrics in evaluating system feasibility.

- Optimization Equations

Optimization equations are used to identify the best system configuration that minimizes cost, maximizes efficiency, or meets specific constraints (e.g., emissions, renewable fraction). These

derivatives or approximate them via finite differences are of little use. The problem to find optimal points in such situations is referred to as derivative-free optimization, algorithms that do not use derivatives or finite differences are called derivative-free algorithms [44] C. Audet and M. Kokkolaras, "Blackbox and derivative-free optimization: theory, algorithms and applications," vol. 17, ed: Springer, 2016, pp. 1-2, [45] J. Larson, M. Menickelly, and S. M. Wild, "Derivative-free optimization methods," *Acta Numerica*, vol. 28, pp. 287-404, 2019.

equations allow HOMER Pro to simulate thousands of potential configurations and select the optimal one [47, 48].

3.4 *Mathematical Formulation*

HOMER Pro aims to minimize the total Net Present Cost (NPC), also referred to as the life-cycle cost. The NPC encompasses all costs incurred by the system, such as installation, operation, and maintenance of components, over its lifetime, subtracting the present value of any revenue generated during the same period. These costs comprise capital, replacement, operation and maintenance (O&M), fuel, and grid power purchasing costs (not applicable here). Revenue considerations include salvage value and grid sales, though in this scenario, grid connection is absent, rendering grid sales revenue zero.

Mathematically, the objective function is denoted by (3.1), expressing the microgrid system's cost, represented by the NPC. The minimization process is subject to constraints outlined by inequalities (3.2)-(3.5)[31].

$$\min\left(C_{NPC,i}\right) = \sum_{\text{all elements}} \left[-R_{0,i} + \sum_{t=0}^{T} \frac{R_{t,i}}{(1+x)^t}\right], \tag{3.1}$$

$$\text{subject to: } \begin{cases} P_{\text{shedding}^5} \leqslant 0.05 \cdot P_{\text{load}}, & (3.2) \\ f_{PV} \geqslant 0.15 \cdot E_{\text{gen}}, & (3.3) \\ r_{\text{load},t} \geqslant 0.10 \cdot P_{\text{load},t} & (3.4) \\ r_{\text{peak load}} \geqslant 0.10 \cdot P_{\text{load}} & (3.5) \end{cases}$$

f_{PV}	PV fraction [%]
E_{gen}	Electricity generation [kWh/year]
$P_{load,t}$	Load in time step t [kWh]

[5] When a microgrid gets disconnected from the main grid due to unexpected events (e.g. faults) and the local generation is smaller than the demand, the microgrid may experience severe and rapid frequency degradation due to the relatively small system inertia level. Effective load shedding is therefore required to curtail a certain amount of load so that the power quality can be maintained at a satisfactory level and the supply to critical loads can be sustained[49] Q. Hong *et al.*, "A new load shedding scheme with consideration of distributed energy resources' active power ramping capability," *IEEE Transactions on Power Systems,* vol. 37, no. 1, pp. 81-93, 2021..

P_{load}	Annual load [kWh]
R_0	Initial investment [$]
$R_{element,i}$	Element lifetime [years]
$r_{load,t}$	Input operating reserve as a percentage of load in the time step t, including the current time step [%]
$r_{peak\ load}$	Input operating reserve as a percentage of annual peak load [%]
$R_{rem,i}$	Remaining life of the component [years]
R_t	Net cash flow for each component (i.e., revenues minus costs incurred) [$]
T	Planning horizon [years]
t	Time of the cash flow [year]
X	Discount rate [%]
i	element

Equation (3.6) applies uniformly across the entire planning horizon for determining costs associated with each element.

$$C_{\text{element},i} = \sum C_{\text{capital},i} + C_{O\&M,i} + C_{\text{replacement},i} + C_{\text{fuel},i} \tag{3.6}$$

The salvage, which represents the only source of revenue following the end of the planning horizon, is given by Equation (3.7):

$$C_{\text{salvage},i} = C_{\text{replacement},i} \cdot \frac{R_{\text{rem},i}}{R_{\text{element}\ i}}. \tag{3.7}$$

$C_{capital,i}$	Capital cost of element *i* [$]
$C_{element,i}$	Cost associated with element *i* over the planning horizon [$]
C_{NPC}	Total net present cost [$]
$C_{O\&M,i}$	Fixed O&M cost of element *i* [$/year]
$C_{replacement,i}$	Replacement cost of element *i* [$]
$C_{salvage,i}$	Salvage cost of element *i* at the end of the planning horizon [$]

Equations (3.8) and (3.9) incorporate the operating reserve, denoted as $r_{\text{load},\,t}$ and $r_{\text{peak load}}$, to guarantee the stability of the power system[6] in response to sudden load spikes or decreases in PV generation. It's worth mentioning that HOMER Pro calculates the minimum operating reserve independently for the AC and DC buses using these equations.

$$L_{res,AC} = r_{load,t} \cdot L_{prim,AC} + r_{peak\ load} \cdot L_{highest\ prim,AC}, \quad (3.8)$$
$$L_{res,DC} = r_{load,t} \cdot L_{prim,DC} + r_{peak\ load} \cdot L_{highest\ prim,DC}. \quad (3.9)$$

$L_{highest\ prim,AC}$	Highest AC primary load for the year [kWh]
$L_{highest\ prim,DC}$	Highest DC primary load for the year [kWh]
$L_{prim,AC}$	Average AC primary load in the current time step [kWh]
$L_{prim,DC}$	Average DC primary load in the current time step [kWh]
$L_{res,AC}$	Minimum operating reserve on the AC bus [kWh]
$L_{res,DC}$	Minimum operating reserve on the DC bus [kWh]
$r_{load,t}$	Input operating reserve as a percentage of load in the time step t, including the current time step [%]
$r_{peak\ load}$	Input operating reserve as a percentage of annual peak load [%]

[6] Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact[50] N. Hatziargyriou *et al.*, "Definition and classification of power system stability–revisited & extended," ibid.vol. 36, no. 4, pp. 3271-3281, 2020.

It's evident now that the optimal solution is the one that yields the lowest total NPC from the project's outset while adhering to all constraints (i.e., inequalities (3.2)-(3.5)). Subsequent sections will illustrate and analyze this optimal design solution.

CHAPTER 4

Results

A summary of the optimized results by HOMER Pro are presented in Table 4.1.

Table 4.1 Optimized Results by HOMER Pro

	Architecture							Cost	
Scenario	PV	Diesel	Battery	Converter	PV (kW)	500kWGen (kW)	Converter (kW)	NPC*	CAPEX**
Proposed System	x	x	x	x	467	500	330	$3.26M	$1.86M
Baseline System		x				500		$6.21M	$0.00

*NPC (Net Price Cost): The present value of all the costs that the system incurs over its lifetime, minus the present value of all the revenue that is earns over its lifetime.
**CAPEX (Capital Cost): Total installed cost of that component at the beginning of the project.

The capital cost of the entire system equals to $1.86 M. The total cost, including capital, replacement, operation and maintenance (O & M), fuel and salvage costs sum to $3.26 M as demonstrated in Figure 4.1. Most of the cost consisted of the capital cost of the PV, followed by battery and replacement cost of the battery. The detailed cost breakdown is outlined in Table 4.2 Components Cost Break Down (per CAD$)

	Capital	Replacement	O&M	Fuel	Salvage	Total
Battery	594,000.0	481,526.8	219,682.7	0.0	-18,387.5	1,276,822.0
Diesel Generator	0.0	115,713.2	96,416.3	397,052.3	-41,808.2	567,373.6
PV	1,166,421.1	0.0	94,904.6	0.0	0.0	1,261,325.6
Converter	98,932.3	77,355.4	0.0	0.0	-21,884.6	154,403.2
System	1,859,353.4	674,595.4	411,003.6	397,052.3	-82,080.2	3,259,924.4

As detailed in Table 4.3Table 4.3, our model results in the renewable produced energy fraction of 82.0% with nearly 123,381 KWh/yr excess produced electricity.

Table 4.3 Electrical Characteristics

Production	Value (KWh/yr)	Unit (%)
Generic flat plate PV	914,790	85.2
Generic 500kW Fixed Capacity Genset	158,848	14.8
Total	1,073,638	100
Consumption	Value (KWh/yr)	Unit %
AC Primary Load	883,226	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	883,226	100
Quantity	Value (KWh/yr)	Unit %
Excess Electricity	123,381	11.5
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value (%)
Renewable Fraction	82.0
Max Renew Penetration	798

The contribution of PV and diesel Generator throughout the year are demonstrated in Figure 4.2. Expectedly, during summer (July to September), demands can be almost fully met with PV output, with the highest amount of PV electric production achieved in August (Figure 4.2 and Figure 4.3). The highest diesel engine output is met in December, paralleling its highest fuel consumption (Figure 4.4).

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The base model has a net price cost (NPC) of $6.21M with a 0.346 ($/KWh) levelized cost of electricity (LCOE), consuming over 417.00 L/year fuel. Our proposed hybrid system reduces the total O&M cost over 25 years from the basic $890,935 to $411,003 (~54% reduction), and the annual operation cost from the basic $305,336 to $68,885 (~77.4% reduction).

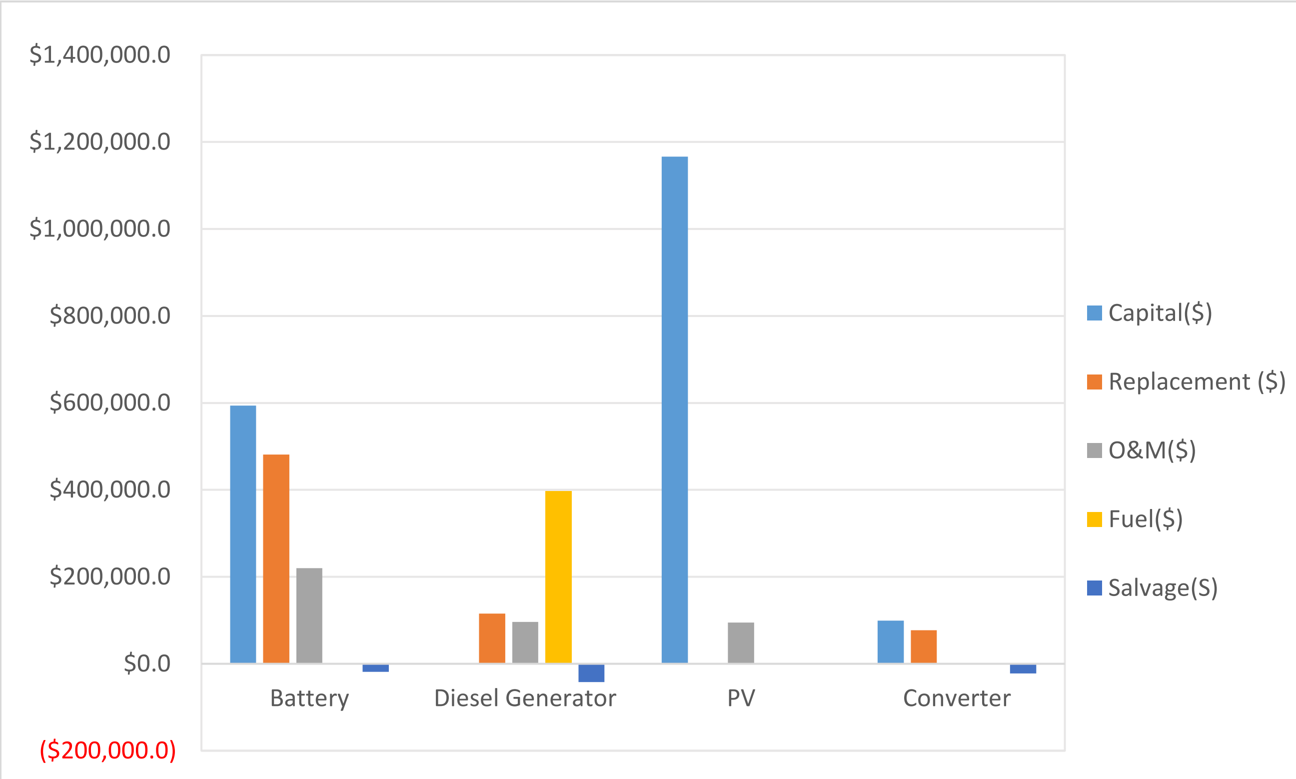

Figure 4.1 Components and Cost Break Down

Table 4.2 Components Cost Break Down (per CAD$)

	Capital	Replacement	O&M	Fuel	Salvage	Total
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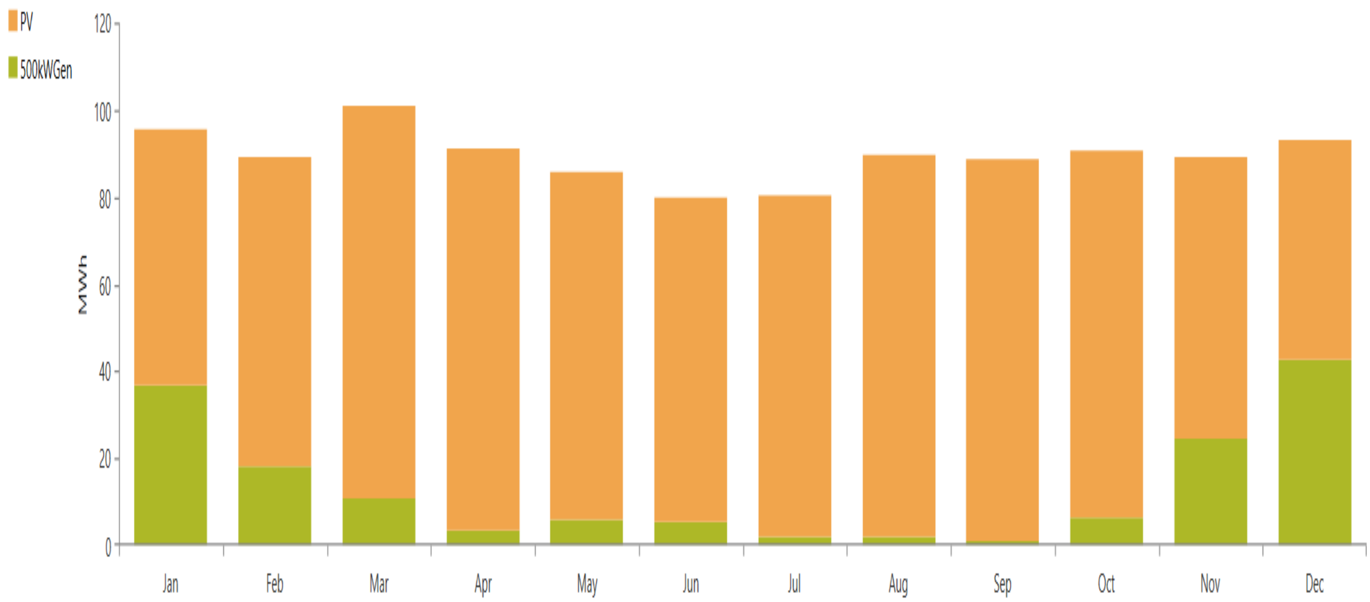

Figure 4.2 Monthly Electrical Production

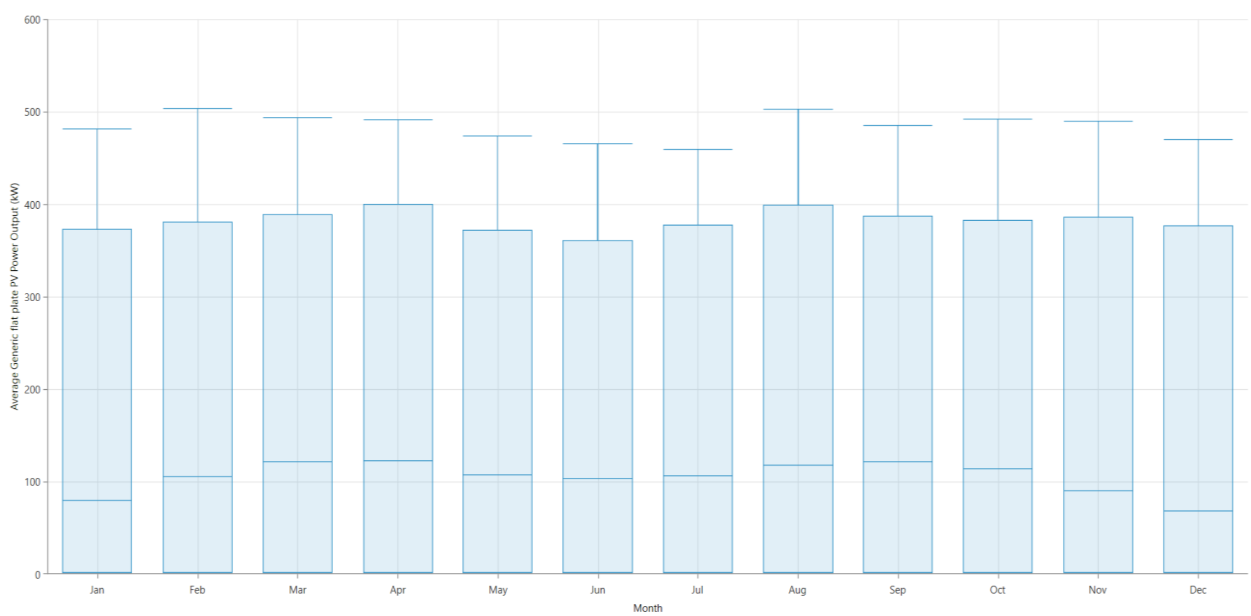

Figure 4.3 Monthly PV Output

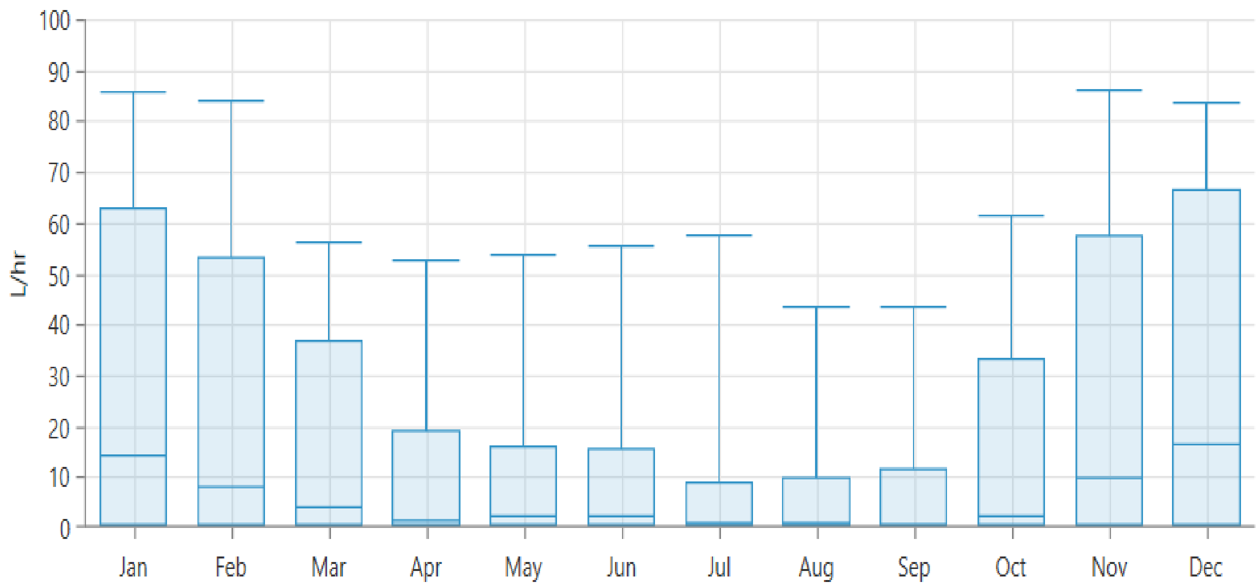

Figure 4.4 Monthly Fuel Consumption

The proposed model depends on merely 948 hrs/yr contribution of the diesel engine with 0.286 L/kWh specific fuel consumption compared with the base 8760 hr/yr which can save $2.95M on net present cost within 25 years. The 89.2% reduction in dependency on diesel engine translates to significant enhancement in self-efficiency of the system. It provides a reliable rural energy access which can secure daily power supply even in emergency situations which access to fuel has been cutoff due to any reason, such as natural catastrophes blocking the transport system. Detailed diesel characteristics are outlined in .

Table 4.4 Diesel Characteristics

Quantity	Value	Units
Hours of Operation	948	hrs/yr
Number of Starts	538	starts/yr
Operational Life	15.8	yr
Capacity Factor	3.63	%
Fixed Generation Cost	18.0	$/hr

Marginal Generation Cost	0.105	$/kWh
Electrical Production	158,848	kWh/yr
Mean Electrical Output	168	kW
Minimum Electrical Output	150	kW
Maximum Electrical Output	325	kW
Fuel Consumption	45,395	L
Specific Fuel Consumption	0.286	L/kWh
Fuel Energy Input	446,686	kWh/yr
Mean Electrical Efficiency	35.6	%

The proposed model requires 12 strings in parallel (string size: 90 batterie) with usable nominal capacity of 864 kWh and annual throughput of 253,155 kWh/yr, with battery characteristics and state of charge demonstrated in , Figure 4.5 and**Error! Reference source not found.** Figure 4.6 respectively.

Table 4.5 Battery Characteristics

Quantity	Value	Units
Batteries	1,080	qty.
String Size	90.0	batteries
Strings in Parallel	12.0	strings
Bus Voltage	540	V
Autonomy	8.57	hr
Storage Wear Cost	0.193	$/kWh
Nominal Capacity	1,080	kWh
Usable Nominal Capacity	864	kWh

Lifetime Throughput	3,240,000	kWh
Expected Life	12.8	yr
Average Energy Cost	0	$/kWh
Energy In	266,053	kWh/yr
Energy Out	240,164	kWh/yr
Storage Depletion	755	kWh/yr
Losses	26,644	kWh/yr
Annual Throughput	253,155	kWh/yr

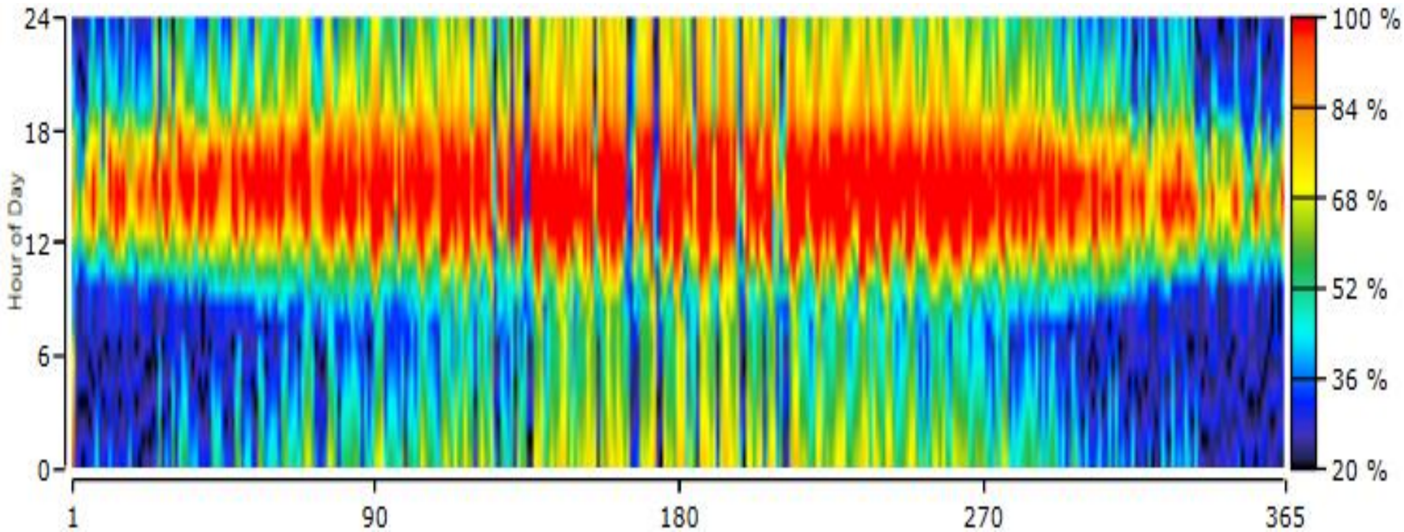

Figure 4.5 State of Charge throughout the Day

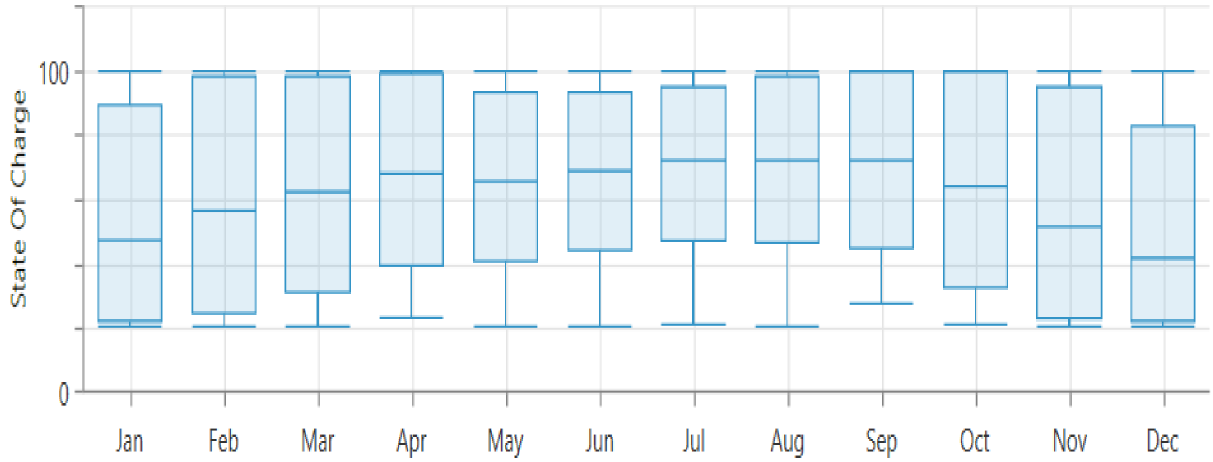

Figure 4.6 State of Charge Throughout the Year

The PV has total production of 914,790 kWh/yr and levelized cost of 0.0678 $/kWh (Table 4.6), with maximum output of 504 kW expectedly reach at 12 to 2 p.m.(Figure 4.7).

Table 4.6 PV Characteristics

Quantity	Value	Units
Rated Capacity	467	kW
Mean Output	104	kW
Mean Output	2,506	kWh/d
Capacity Factor	22.4	%
Total Production	914,790	kWh/yr
Minimum Output	0	kW
Maximum Output	504	kW
PV Penetration	104	%
Hours of Operation	4,380	hrs/yr
Levelized Cost	0.0678	$/kWh
Clipped production	0	kWh

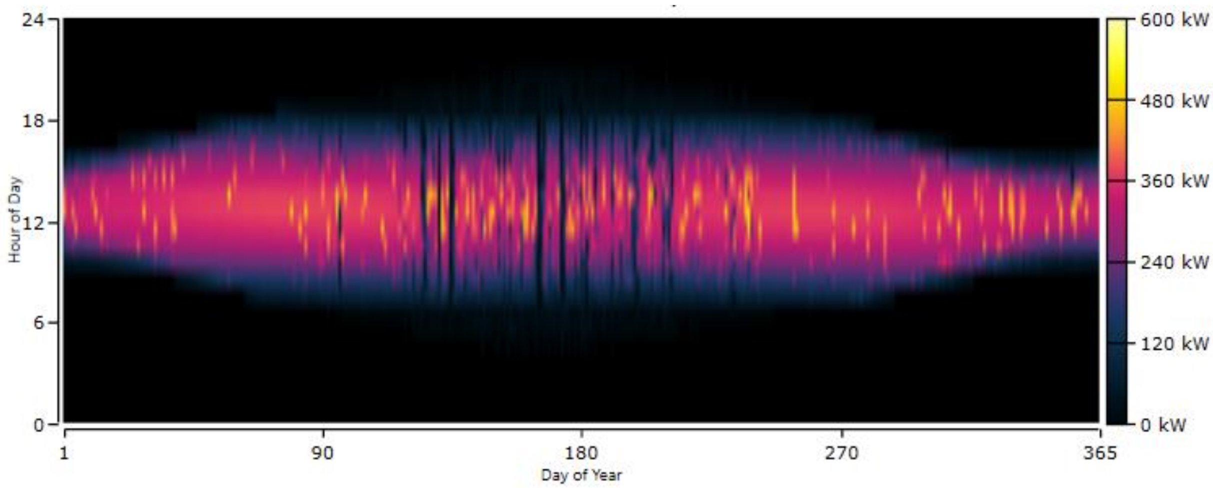

Figure 4.7 PV Power Output

Our model relies on 8,201 hrs/year converter operation, with capacity, mean and maximum outputs equal to 330 kW, 86 kW and 300 kW, respectively. Considering a derating factor of 0.8 and 467-kW PV output, a 330-kW capacity convertor is sufficient Table 4.7.

Table 4.7 Converter Characteristics

Quantity	Inverter	Rectifier	Units
Capacity	330	330	kW
Mean Output	86.0	3.19	kW
Minimum Output	0	0	kW
Maximum Output	300	125	kW
Capacity Factor	26.1	0.966	%
Hours of Operation	8,201	376	hrs/yr
Energy Out	753,766	27,918	kWh/yr
Energy In	793,438	29,388	kWh/yr
Losses	39,672	1,469	kWh/yr

With the proposed model being a hybrid system including a diesel generator, emission of pollutants is inevitable. As detailed in Table 4.8, carbon dioxide holds the first place with a large margin, followed by carbon monoxide and sulfur dioxide in 2nd and 3rd places, respectively. However, our model has resulted in 974,527 kg or 89.1% decrease in annual carbon dioxide emission compared to the baseline, significantly reducing its detrimental effect on the environment.

Table 4.8 Emissions Characteristics

Quantity	Value (Hybrid)	Value (DG only)	Units
Carbon Dioxide	119,036	1,093,563	kg/yr
Carbon Monoxide	616	5,658	kg/yr
Unburned Hydrocarbons	32.7	300	kg/yr
Particulate Matter	5.27	48.4	kg/yr
Sulfur Dioxide	291	2,673	kg/yr
Nitrogen Oxides	118	1,084	kg/yr

Finally, a comprehensive model of daily power generation diagram is demonstrated in Figure 4.8. Excess electricity might have to be dissipated in a dump load, which is usually a simple resistive heater or a bank of light bulbs,

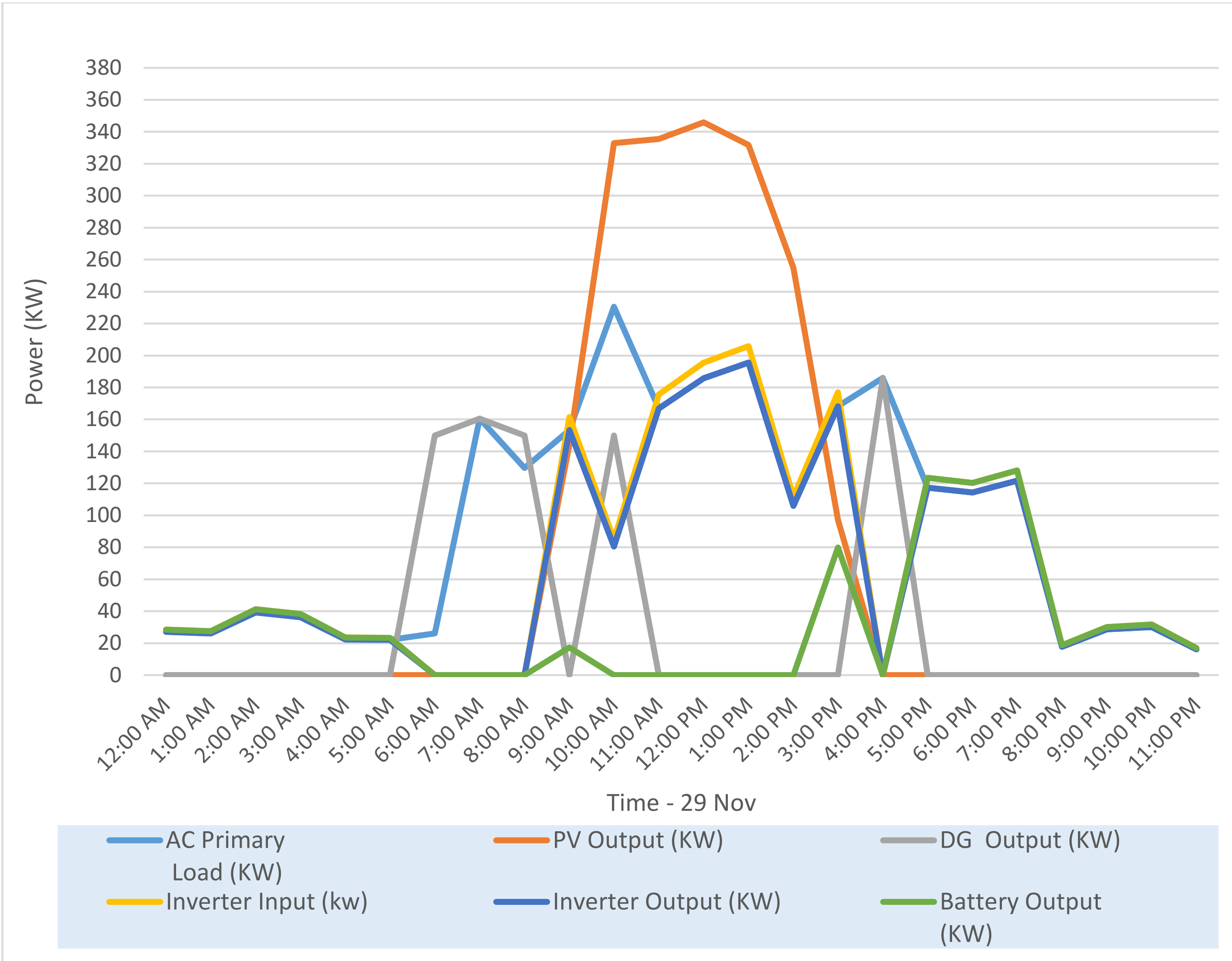

Figure 4.8 Power Generation Diagram

Figure 4.8 depicts the load profile for November 29, illustrating the early morning hours when the battery initially provides the required power until approximately 6:00 AM when it becomes depleted. Subsequently, the diesel generator commences power generation, sustaining operations until 9:00 AM. The surplus energy generated during this period serves to recharge the battery. Concurrently, solar irradiation commences as the day progresses. The peak photovoltaic (PV) generation occurs around noon, reaching approximately 345 kW. PV generation persists until approximately 4:00 PM. Throughout the remainder of the cycle, the charged batteries serve as the primary power source for meeting the load requirements.

CHAPTER 5

Conclusion

In conclusion, the assessment conducted in this study of a potential offsetting diesel generator in Meziadin Lake, Canada, highlights the significant benefits of integrating renewable energy sources into such systems. Through meticulous modeling, it was determined that a hybrid configuration, including the existing 500-kW diesel generator, and the proposed 467-kW solar panel array, 1080 units of lithium-ion batteries, and a 330-kW converter, emerged as the optimal solution for meeting the energy demands of the Meziadin Lake system while minimizing the cost of energy (COE). This hybrid setup not only achieves a competitive COE value of $0.1815/kWh but also demonstrates a substantial reduction in the Net Present Cost (NPC), decreasing from $6.21M to $3.26M having internal rate of return (IRR) of 12% and Return on Investment (ROI) 8.7% with 6.93 years of simple payback. These findings underscore the feasibility and economic viability of integrating renewable energy sources alongside existing diesel infrastructure, paving the way for sustainable energy solutions in remote areas like Meziadin Lake.

5.1 *Future Work*

In prospective research endeavors, leveraging HOMER Pro as a foundational tool, further exploration may be pursued to augment its capabilities in addressing the intricate technical nuances inherent to microgrid systems. The integration of HOMER Pro with supplementary software platforms such as DIgSILENT Power Factory, PSS®E, or specialized modeling frameworks tailored to power network studies holds promise in providing a comprehensive framework for scrutinizing critical facets such as transient stability, voltage stability, and protection coordination within microgrids. By amalgamating the economic optimization attributes intrinsic to HOMER Pro with the advanced simulation and analysis functionalities afforded by these software solutions, deeper insights into the dynamic behavior and performance metrics of microgrids under diverse operational scenarios can be attained. Such an integrated methodological approach promises to facilitate more judicious decision-making in the design, operation, and management of microgrid systems, thereby advancing their reliability, resilience, and sustainability objectives within the contemporary energy landscape.

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