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RESEARCH ARTICLE

Optimal Sizing and Techno-Economic Analysis of a Hybrid Power System for Postville

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ABSTRACT

Providing reliable and sustainable electricity to remote communities poses a significant challenge. Techno-economic feasibility of an off-grid hybrid renewable energy system for Postville, a remote Northern Labrador, Canada community, is presented in this paper. The study integrates solar photovoltaic panels, wind turbines, battery storage, and diesel generators into a hybrid system, analyzing various components and optimizing using advanced Homer Pro software. Simulation results demonstrate that the most optimized hybrid structure ensures a stable power supply while minimizing diesel generator operation, reducing fuel consumption. Economically, this system offers substantial cost savings, alleviating the financial burden on the community. The designed system consists of 435 kW PV, 500 kW wind turbine, 455 kW diesel generator, and 815 kWh batteries. The proposed system will generate power with a net present cost of $5.57 million. This research also contributes to the broader goal of creating sustainable energy solutions and improving the quality of life in remote communities.

Keywords: Diesel backup, hybrid system, solar power, wind energy.

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1. Introduction

Energy systems play an increasingly important role in our daily lives, and the increasing energy consumption crisis is a significant concern for all countries [1]. Access to affordable and reliable energy is essential to the sustainability of our daily activities and economy. Traditional fossil fuels provide the most electricity in developing countries [2]. The substantial reliance on non-renewable resources like coal, oil, and natural gas leads to significant emissions of greenhouse gases [3]. In isolated areas, beyond the environmental worries related to greenhouse gas emissions, additional challenges arise when providing fossil fuels. These remote regions typically rely on imported fossil fuels for electricity generation due to limited local fossil fuel availability, leading to considerably higher oil costs on islands due to transportation expenses [4], [5].

In recent years, renewable energy resources have been used to generate electricity to address these challenges [6]. Numerous renewable energy resources are available, including wind, biomass, solar, and ocean energy. Hybrid renewable energy systems are affordable, environmentally sustainable, adaptable, and reliable [5]. Solar and wind are the most economical renewable energy sources [7]. Combining wind turbines and solar photovoltaic panels with backup devices such as diesel generators and battery storage is becoming increasingly popular. Combining these two technologies decreases fossil fuel consumption and CO_2 emissions and improves overall system reliability [8], [9]. Various research projects have been conducted on stand-alone power supplies in recent years.

Shezan *et al*. [6] evaluated the performance of an off-grid hybrid energy system combining wind, diesel, battery, and PV technologies using Homer software for a Klia Sepang Station. The findings indicated that the optimized system outperformed conventional power setups, reducing the net NPC and CO_2 emissions by approximately 29.65% and 16 tons, respectively.

Mahbub *et al*. [10] designed a hybrid power system for the McCullum in Newfoundland and Labrador using Homer Pro software. Challenges such as lack of flat surfaces and unsuitability for a hydropower plant led them to introduce floating solar photovoltaic modules (FSPV) in their design. As a result of incorporating FSPV, only one generator of 150 kW was required from the available three. The new FSPV energy generation plant can save nearly 70% of fuel consumption compared to a diesel generator. It has also been shown that switching from diesel generators to renewable resources substantially reduces greenhouse gas emissions.

Fig. 1. Location of Postville in northern labrador, Canada. (Source: Captured from Postville Inuit community government).

Erasmus *et al*. [11] compared the performance of various hybrid configurations integrating PV, wind, small hydro, batteries, diesel, and inverters using Homer software for Cameroon, Africa. The PV/DG/small hydro/BS configuration emerged as the most economically feasible option, effectively fulfilling load requirements and design limitations. Although structures based solely on renewables have no emissions, they can be expensive for local communities and unreliable.

Baig *et al*. [12] analyzed the integration of WT, BS, and PV resources for a remote location in Pakistan using Homer software. They found that micro-grid systems primarily based on solar panels would offer more significant economic benefits than incorporating wind resources. The lower wind speed and abundant solar radiance in the region make adding wind turbines inefficient in the model design.

The combination of PV, WT, DG, and BS is analyzed by Farivar *et al*. [13] for Kish Island in Iran. Their findings indicate the DG-BS system is the most cost-effective option but has environmental disadvantages. They concluded that the WT-DG-BS hybrid System stands out as a promising choice, offering a notable reduction in carbon dioxide emissions and competitive economic indicators.

The primary objective of this study is to design an optimal hybrid power system using Homer software for Postville in Newfoundland and Labrador, Canada. This system combines renewable energy sources like solar, wind, and battery storage with existing diesel generators to supply community power needs. Battery backup is used to ensure power supply even in adverse weather conditions. The paper's structure follows: Section 2 presents a description of the Postville site and power consumption data, Section 3 provides detailed descriptions and technical details of each designed energy component, the schematic configuration of the hybrid power system used by Homer is described in Section 4, a detailed analysis of the simulation results is given in Section 5 in terms of economic and electrical aspects and in Section 6, a summary of the entire paper is provided.

2. Site Data and Description

The study is based on data collected from Postville, Canada. Postville is located about 40 km (25 m) from Kaipokok Bay and roughly 180 km from the north of Happy Valley-Goose Bay.

Fig. 1 shows the location of Postville (54° 54′ 37″ N, 59° 48′ 8″ W), a town with 188 inhabitants in northern Labrador, Canada [14]. There is no road connecting Postville to the rest of the world, so it can only be reached by sea or air [15]. The community is not linked to the grid. Consequently, it relies on three diesel generators with a total power output of 1067 kW to produce electricity, which results in annual consumption of over 500,000 litres of diesel fuel [16]. In Newfoundland and Labrador, average diesel prices over the past year were 1.65 Canadian Dollars without considering the fuel transfer fees [17].

In this study, the NASA Surface Meteorology and Solar Energy database is used to obtain renewable energy resources data, which can be imported into Homer Pro through multiple options [18]. Fig. 2 shows the community's monthly average global horizontal radiation [18]. The scaled annual average of solar irradiation is 2.87 kWh/m^2/day, and the average clearness index is 0.408 for the considered location.

The monthly average wind speeds at 50 m heights in Postville, displaying variations from 9.14 m/s in December to 7.07 m/s in May, is shown in Fig. 3. The annual average wind speed is recorded as 7.81 m/s at 50 m height.

The load profile for the Postville has been provided by Newfoundland & Labrador Hydro for every 15 minutes. Fig. 4 illustrates the average load demand for each month of the year. There is a fluctuation in the load demands throughout the day and over the year. In this study area, the average daily electrical consumption is 4683.2 kW/day, random variation is 10.608%, and peak demand is 401.71 kW.

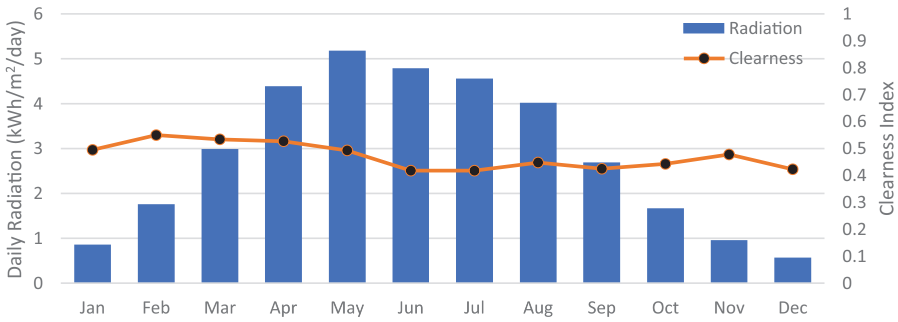

Fig. 2. Monthly average solar irradiance and clearness index in Postville, Canada.

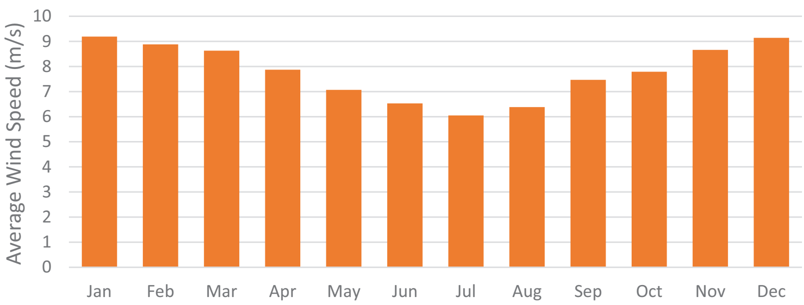

Fig. 3. Monthly average wind speed in Postville, Canada.

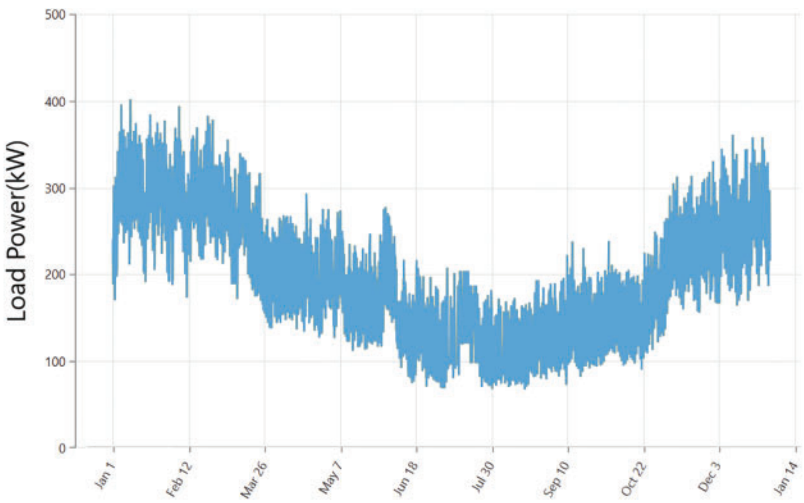

Fig. 4. Average load demand for each month of the year.

3. Description of Energy System Components

3.1. *Photovoltaic*

Photovoltaic (PV) energy systems are commonly known to produce DC electric power from sunlight [19]. There are a variety of PV technologies available today. However, the characteristics and parameters of PV modules provided by manufacturers often differ from their actual performance under real operating conditions. It is crucial to assess these parameters in real working conditions for accurate modeling and simulation of PV systems [20]. The power produced by the PV system depends on factors such as sunlight, temperature changes, and the type of cell technology used [19].

In this study, The PV module (model: Canadian solar Max Power CS6X-325P) was selected. Table I summarizes the specifications of the selected PV module, CS6X-325P. In this research, an initial capital cost of $200/kW for a PV module was assumed. The replacement cost was set at $120/kW, and O&M expenses were assumed to be $6 per year [21].

TABLE I: Technical Information About Selected PV

Technical data	Value
Manufactory	Canadian solar max power
Model	CS6X-325P
Max rated power	325, W
Cell per module	72
Max power voltage	37, V
Max power current	8.78, A
Temp coef of V_{oc}	−0.31, %/℃
Temp coef of I_{sc}	0.053, %/℃
Lifetime	25, years

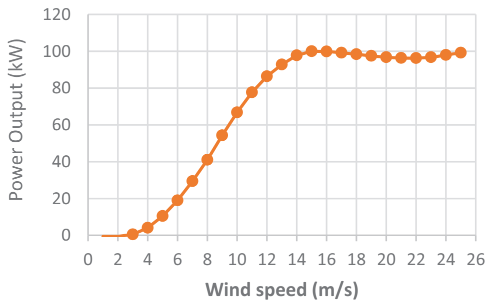

Fig. 5. Power curve graph of the selected wind turbine.

TABLE II: Technical Information About Selected Wind Turbine

Technical data	Value
Manufactory	Northern power
Model	NPS100C-21
Cut-in wind speed	3, m/s
Cut-out wind speed	25, m/s
Rated wind speed	15, m/s
Lifetime	20, years

3.2. *Wind Turbine*

A wind turbine transforms the mechanical energy from the wind into electrical energy [22]. The output of wind turbines depends primarily on the power output curve, the wind speed data, and the tower height [1]. Power curves for wind turbines are discrete forms used to compute power output [1]. The power curve profile of the NPS100C-21 is also shown in Fig. 5.

The wind turbine selected for this study is Northern Power Systems (model: NPS100C-21) due to its suitability in cold temperatures. The selected wind turbine with AC voltage output is configured with rotor diameters of 20.7 m and hub heights of 37 m [23]. Wind turbine module details are illustrated in Table II [23], [24]. In this study, a \$350,000/kW initial capital cost was assumed for a wind turbine module, with a \$320,000/kW replacement cost and \$300 in annual operating and maintenance (O & M) expenses.

3.3. *Diesel Generator*

Diesel generators are increasingly common in remote areas due to their reliability and ability to meet on-demand electricity needs [22].

The capacity of the DGs is typically designed to match the requirement for maximum power usage [13].

The fuel curve illustrates the quantity of fuel the generator consumes to generate electricity [25]. HOMER generates an efficiency curve by inputting the fuel curve data. HOMER assumes the curve is linear [22]–[25].

In this study, the 455 kW generator is chosen from the three available diesel generators on the island to satisfy a peak load demand of 401.71 kW. Due to the diesel generator's availability at the location, its initial cost is zero. Maintenance and replacement costs are considered to be \$10/op.hr and \$25,000/kW, respectively. Canada has a current diesel price of 1.90 (\$/L), which fluctuates based on global markets [17]. Table III shows the details of selected generators and diesel fuel [26].

TABLE III: Technical Information About Selected DG

Technical data	Value
Manufactory	CAT
Model	455, kW–60, Hz-PP
Fuel type	Diesel
Capacity	455, kW
Fuel curve intercept	19.8, L/h
Fuel curve slope	0.231, L/h/kW
Lower heating value	43.2, MJ/kg
Density	820, kg/m^3

TABLE IV: Technical Information About Selected Battery

Technical data	Value
Manufactory	Northern power
Model	NPS100C-21
Cut-in wind speed	3, m/s
Cut-out wind speed	25, m/s
Rated wind speed	15, m/s
Rotor diameter	20.7, m
Number of blades	3
Lifetime	20, years

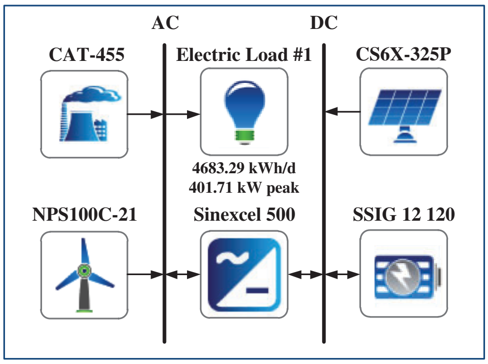

Fig. 6. Schematic diagram of the hybrid power system.

TABLE V: Optimal Results of Hybrid Power System for Selected Location

Configuration	NPC (\$)	COE (\$)	O & M (\$/year)	Capital cost (\$)
Case A	5.357 M	0.252	257.576	2.25 M
Case B	5.92 M	0.268	282.690	2.27 M
Case C	6.85 M	0.310	220.737	3.99 M
Case D	7.82 M	0.354	232.522	4.81 M
Case E	9.97 M	0.451	687.901	1.08 M
Case F	13.3 M	0.603	1.03M	7.765

3.4. *Converter*

A bidirectional converter is used to manage the energy flow between the DC and AC components [27]. Inverter efficiency determines how much DC power is converted to AC power, and rectifier efficiency is the ratio of DC power to applied AC power [25]. The converter selected for this research is Sinexcel 500 kW. According to the manufacturer data, the inverter has an efficiency of 97.67% and a life of 10 years [28]. For this research, an assumption of \$90,000/kW for initial capital cost, \$60,000/kW for

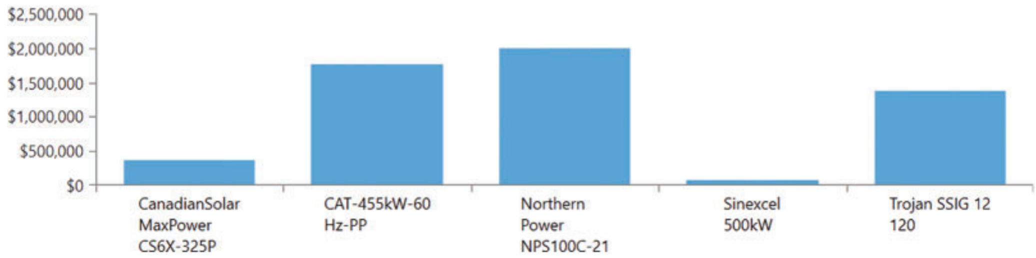

Fig. 7. Detailed description of the net present cost for hybrid PV/WT/DG/BS system.

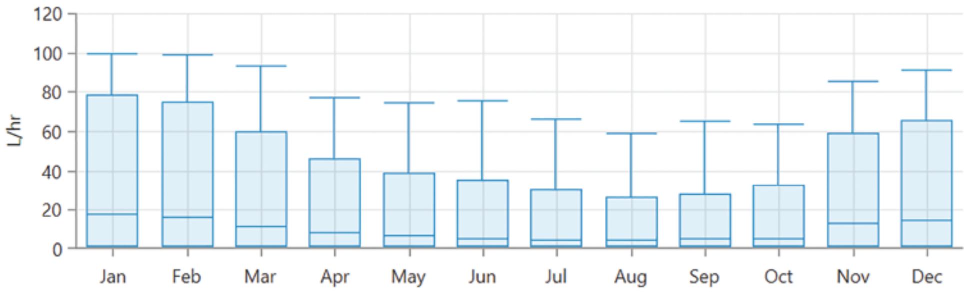

Fig. 8. Fuel cost summary for hybrid PV/WT/DG/BS system.

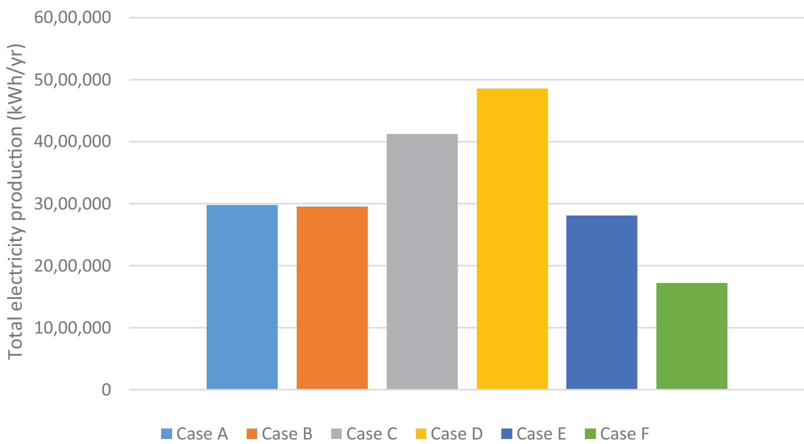

Fig. 9. Total power generated by different structures.

replacement cost, and $30.00 for annual operating and maintenance was made.

3.5. *Battery*

In engineering, energy storage involves saving energy in a usable form for future energy generation needs [29]. Several battery storage models exist, the most prevalent types being Lead-Acid Flow, Vanadium Redox, and Lithium-Ion [27]. The battery storage Trojan (model: SSIG 12 120) was selected in this study. Table IV provides detailed information about the proposed battery storage. The initial capital, replacement, and annual operating and maintenance costs were considered $240.00, $220.00, and $10.00, respectively.

4. Hybrid Power System Design Using Homer Pro Software

The HOMER Pro is an optimization tool developed by the National Renewable Energy Laboratory (NREL) in the United States for various fields [30].

Input data such as resource data, technical and economic parameters of components, load data, and other project-specific details are used in HOMER simulation [31].

HOMER aims to identify the most economical equipment configuration to fulfill the electricity demand consistently [30].

In this study, renewable energy and traditional energy sources are combined to form hybrid energy systems. A schematic of the hybrid energy system for the selected community is shown in Fig. 6. In this schematic, a wind turbine, diesel generator, and AC load are interconnected using an AC bus. In contrast, PV panels and a battery are connected through a DC bus. Additionally, a converter is bridged between both the AC and DC buses.

5. Simulation Results

The purpose of this section is to present the results of the Homer Pro optimization. The most optimized system has been determined based on two primary considerations: economics and technical. All six optimized configurations

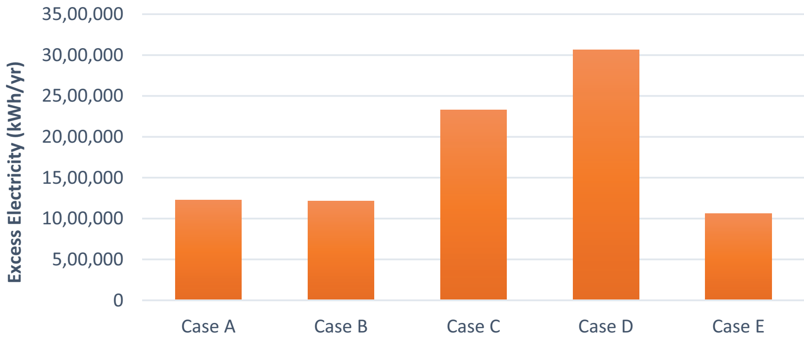

Fig. 10. Surplus electricity production by different structures.

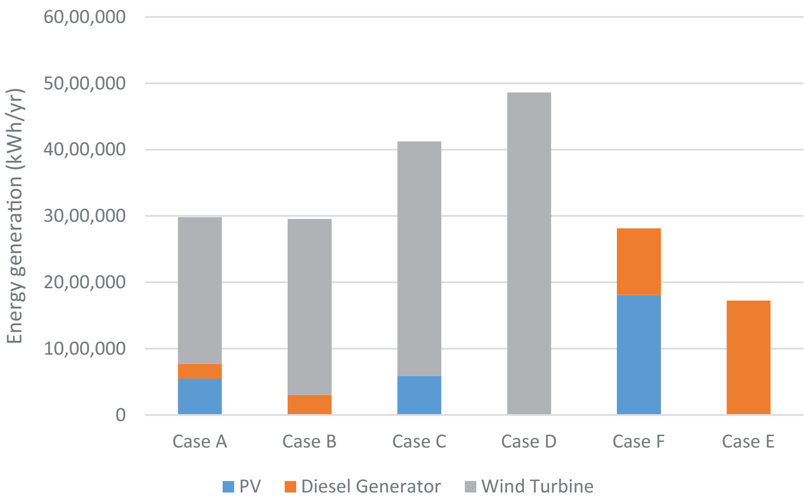

Fig. 11. Energy generation by different components of each case.

of the system will be discussed depending on their economic, electrical, and emission characteristics.

5.1. *Economic Analysis*

The economic evaluation primarily relies on factors such as net present cost (NPC), Operating Expenses (OE), Cost of Energy (COE), and the Initial Capital (IN) investment. Table V indicates all optimized configurations with optimum cost analysis.

5.1.1. *Case A: PV/Wind Turbine/Diesel Generator/ Battery Hybrid System*

Simulation results show that the case A is the most cost-efficient and optimized configuration. This structure consists of a 435 kW PV module, five wind turbines (100 kW every), a diesel generator with a capacity of 455 kW, and a power converter with a 306 kW rating. As Table V demonstrates, this system is associated with the lowest economic expenses, with an NPC of $5.57 million, a COE of $0.252 million, and annual O&M costs of $257,546. Fig. 7 demonstrates the detailed net present cost for each component.

As depicted in Fig. 7, wind turbines and diesel generators cost more than other components. There is a total consumption of 77,245 l of fuel per year. Fig. 8 shows the fuel cost summary for the mentioned system.

5.1.2. *Case B: Wind Turbine/Diesel Generator/Battery Hybrid System*

In Table V, it is shown that the case B configuration is a second economic configuration. The system consists of six generic 100 kW wind turbines, a diesel generator with a 455 kW power output, and a power converter with a 205 kW power output. The overall NPC for the system amounts to $5.92 million, and COE is at $0.268 per kilowatt-hour (kWh). In contrast to the preceding system setup, this scenario incurs a greater fuel expense, amounting to $171,420 per year. This contrast is because more diesel fuel is consumed, and renewable energy sources are used less in this scenario.

5.1.3. *Case C: PV/Wind Turbine/Battery Hybrid System*

It is observed from Table V that the third alternative scenario involves a PV, wind turbine, and battery hybrid system featuring 466 kW of solar PV modules, 8 wind turbines with 100 kW power output, and a 440 kW inverter. The cost of initial capital for this system is notably higher compared to the previously discussed hybrid systems, amounting to $3.99 million. This difference arises from the absence of a diesel generator in this scenario, which is already present in the location. According to Table V, it's evident that this system provides a full 100% contribution of renewable energy and incurs no fuel costs.

5.1.4. Case D: Wind Turbine/Battery Hybrid System

In this scenario, the hybrid system comprises 11 wind turbines with 100 kW power output, 453 kW of inverters, and a total of 3660 batteries. As described in Table V, the NPC is equal to $7.82 million, and the system's operational expenses total $232,522. The capital investment for this system stands at $4.81 million, with a total fuel consumption of zero.

5.1.5. Case E: PV/Diesel Generator/Battery Hybrid System

In this particular situation, the hybrid system includes 1436 kW worth of solar PV modules, a 455 kW diesel generator, and 388 kW of inverters. The Net Present Cost (NPC) amounts to $9.97 million, and the operational costs for the system amount to $687,901. The initial capital investment for this system is $1.08 million, and it consumes a total of 337,864 l of fuel per year.

5.1.6. Case F: Diesel Generator/Battery Hybrid System

The case F configuration comprises the basic case architecture, consisting of a single 455 kW diesel generator, 30 batteries, and a 3.14 kW converter. The initial capital cost for this configuration is significantly lower at $7.765, primarily because the diesel generator already exists in the community. However, in contrast, the Net Present Cost (NPC), Cost of Energy (COE), and operating expenses are notably higher compared to the other configurations, standing at $13.3 million, $0.603, and $1.03 million, respectively. The diesel generator and battery system have an annual fuel cost of $941.247.

5.2. Electrical Analysis

It is reported that 1709401 kWh of electricity is consumed annually in Postville by the Homer Pro. Fig. 9 shows the overall power generated by various configurations. Among all configurations, wind turbine and battery system generates the highest electricity output, producing approximately 4,861.365 kWh/year, while the case A which is the most economic configuration system generates the smallest amount, with around 2,981.030 kWh/yr. Evaluating different hybrid energy systems with respect to their surplus electricity production is shown in Fig. 10. Based on Fig. 10, it's evident that the wind turbine and battery hybrid system configuration exhibits a higher degree of excess electricity generation.

In the most cost-efficient and optimized system consisting of PV, wind turbine, diesel generator and battery, the wind turbine plays a primary role in electricity generation, contributing 2,209.711 kWh/year, constituting 74.1% of the total power production. The PV system contributes 547,565 kWh/year, making up 18.4% of the total generation, and the diesel generator contributes only 223,754 kWh/year, representing a mere 7.51% of the total generation (Fig. 11). This suggests that the diesel generator primarily serves as a standby power source to back up the hybrid power system. Furthermore, the renewable energy fraction stands at 86.9%, highlighting that the majority of electricity is derived from renewable energy sources.

6. Conclusion

The study proposes and analyzes the techno-economic feasibility of an off-grid hybrid renewable energy system for a remote location in Canada. The primary objective is to reduce the community's dependence on conventional energy resources, enhance energy security, reduce costs, and contribute to global efforts to combat climate change. The study utilizes HOMER Pro software to assess different system configurations, considering technical feasibility, economic viability, and environmental impact. This software allows for optimizing and adjusting system components and operation modes. This research's key conclusions and findings are as follows:

- Optimized Configuration: This study identifies the PV, Wind Turbine, Diesel Generator and Battery Configuration as the most cost-efficient and optimized system. It combines renewable and conventional energy sources and minimizes fuel consumption while providing a stable power supply. It offers substantial cost savings and reduces greenhouse gas emissions.
- Economic Feasibility: While some configurations, like wind turbine and battery system, offer higher renewable energy fractions and lower emissions, they come with higher initial capital costs. The PV, Wind Turbine, Diesel Generator and Battery Configuration balances cost-effectiveness and sustainability.
- Energy Generation: Wind turbines and photovoltaic panels play a crucial role in electricity generation, with wind turbines contributing the majority of power in the PV, Wind Turbine, Diesel Generator and Battery Configuration. This indicates the effectiveness of wind energy in the region.
- Energy Security: The hybrid system enhances energy security for Postville by reducing dependence on imported diesel fuel and providing backup power during outages.

The research demonstrates that the proposed hybrid renewable energy system, particularly the PV, Wind Turbine, Diesel Generator and Battery Configuration, is a technically feasible, economically viable, and environmentally friendly solution for providing reliable electricity to Postville. This system reduces costs and contributes to a cleaner and more sustainable energy future, aligning with global sustainability goals. The study's findings can serve as a valuable reference for similar remote communities facing energy challenges worldwide, contributing to the broader goal of improving the quality of life in isolated regions while addressing climate change concerns.

Conflict of Interest

The authors declare that they do not have any conflict of Interest.

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