Design and Analysis of a Hybrid Power System for Port Hope Simpson, Labrador

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Abstract:
This paper presents the design and analysis of a hybrid power system for Port Hope Simpson (PHS), Labrador, using HOMER and MATLAB simulink. Port Hope Simpson (PHS) is one of the remote communities in Newfoundland and Labrador that rely heavily on fossil fuels for electricity generation. Presently, the electric need of PHS is met with three diesel generators rated, 725 KW, 550 KW and 500 KW which consumes more than 836,760 litres of fuel annually.. The operating costs of running the three generators are currently $1.62M per year. Hence, a new system is being proposed to reduce the operating cost of the system and transportation challenge faced during winter. Homer was used to design a new system which incorporates wind turbines, Solar PV and energy storage technologies with the existing three generators, while MATLAB was used to check the dynamic response of the system. The proposed system added 1,414 kW of PV, 1,571 kWh of battery capacity and 1,600 kW of wind generation capacity. This reduce the operating costs to $695,083/yr as against the $1.62M per year. The investment should have a payback of 2.87 years and an IRR of 34.8%. By optimizing the use of renewable resources and minimizing operational expenses, the hybrid power system can offer long-term economic benefits to the community.

1. INTRODUCTION

Generating clean, reliable, and cost-effective energy is one of the critical challenges facing the globe in this century, especially in rural areas [1]. Integrating a different mix of hybrid renewable energy sources is the most powerful and effective solution to this challenge. The implementation of a hybrid power system offers several advantages. Firstly, it enables the utilization of clean and abundant renewable energy sources, reducing the dependence on fossil fuels and decreasing greenhouse gas emissions. Secondly, integrating multiple energy sources improves the system's overall reliability and stability, ensuring a consistent power supply even during low renewable energy generation periods.

Most remote or off-grid communities in Newfoundland (NL) rely on diesel generators for their electricity and heating fuel for their heat. According to a 2016 report, 95% of the province's on-grid electricity generation capacity is from hydropower (7,703MW). However, in off-gird communities throughout NL, the situation is quite different; 21 of the 27 communities are exclusively dependent on diesel generation with an installed capacity of 39MW. 15 out of these 27 off-grid communities are Indigenous [2]. One of such remote communities is Port Hope Simpson. The reliance on diesel generators in Port Hope Simpson poses several challenges. Maintenance costs and the emission of environmental contaminants are among the concerns associated with this electrification solution. To address these issues and pave the way for a sustainable and resilient energy system, this research explores the utilization of renewable energies, specifically solar and wind, to meet the power needs of Port Hope Simpson. This paper presents a detailed analysis of the proposed hybrid power system, considering its potential to improve the energy supply, reduce operating costs, and minimize environmental impact compared to the current diesel generator and wind turbine setup.

Several studies have investigated the optimization and combination of hybrid renewable energy to solve the power generation challenge in rural communities [3] [4]. These systems integrate multiple renewable energy sources, such as photovoltaic (PV) systems, wind turbines, and diesel generators, to overcome the limitations of individual technologies and ensure a stable power supply. The techno-economic analysis of different types of hybrid energy generation for desert safari camps in UAE using HOMER was conducted by [5]. Simultaneous exploitation of different renewable energy sources to power off-grid applications with solar PV, wind, and battery storage was demonstrated more efficiently. The design and analysis of a hybrid power system for Francois, Newfoundland, was investigated in another study [6]. The design includes a PV system/diesel generator/battery using Homer Pro software. The result shows that the standard operation settings, varying irradiance, various load demands, and different wind speed conditions can accurately replicate the system's behavior in different scenarios. However, the study does not employ other renewable resources such as windmills and small Hydro power plants. Moreover, the design and analysis of a hybrid power system for McCallum, Newfoundland, was investigated by [7]. The study used floating Solar PV to solve the problem and land constraint. The study showed a 70% reduction in diesel fuel consumption.
The design and optimization of hybrid power systems require a comprehensive analysis that considers load profiles, resource availability, system sizing, and economic feasibility. Numerous case studies and research papers have explored the design and analysis of hybrid power systems in similar geographical and climatic conditions. However, it is important to adapt these findings to the specific requirements of Port Hope Simpson and bridge any existing gaps through further research. In this study, a hybrid renewable energy system was design for Hope Simpson to reduce total dependency on the existing diesel generators.

2. SITE DETAILS

Port Hope Simpson (PHS) is one of the remote communities in Newfoundland and Labrador that rely heavily on fossil fuels for electricity generation. It is located in southeastern Labrador on the side of Alexis River (Salmon River), with a

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population of 403 in 2021 [8]. The pictorial view of PHS is shown in Figure 1. To meet its energy needs, PHS relies on a set of diesel-powered generators, which are highly polluting and very expensive to operate. There are currently four installed diesel generators with a total generation capacity of 2,325KW in PHS, which consumes more than 836,760 liters of fuel annually [8]. The ever-increasing high cost of diesel and transportation due to the frozen Labrador Sea and icebergs during winter is a significant challenge for the people of Port Hope Simpson. Hence, the government of Newfoundland and Labrador has to continuously subsidize electricity for domestic use by 75%, which cannot be sustained for long. Consequently, an alternative hybrid method of electricity is needed.

Figure 1: Pictorial view of Port Hope Simpson

The PHS power system is being operated and maintained by NL Hydro. Hence, Data of the annual load profile and Annual Diesel consumption as well as the single line diagrams needed for the design of the hybrid power system for PHS were gotten from NL hydro. Figures 2 and 3 shows the single line diagram of PHS. The year 2022 data from PHS showed that the community used 899,875 Litres of diesel annually, an average of 9136.42 kWh of electricity consumed per day and a peak load of 729.86 kW in the same here.

The PHS power station houses three diesel-powered generators with a capacity of 725 KW, 545 KW and 430 KW, respectively, as shown on the single line Diagram below, and they operate N-1 Philosophy. Meaning two works at a time, and one is on standby.

Fig 2: Daily Load profile of PHS

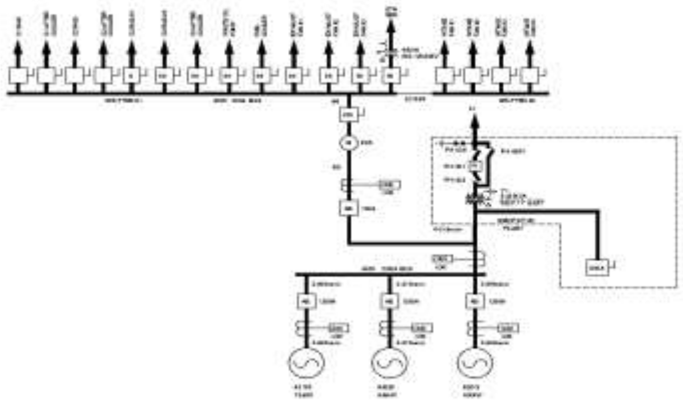


Fig 3: Single Line Diagram for Existing Power System at PHS and its respective feeders

3.1 BASE SYSTEM

The electric needs of Port Hope Simpson, NL, Canada are met with 1,775 kW of generator capacity. This consists of three generators rated 725 KW, 550 KW and 500 KW. The operating costs of running the three generators are currently $1.62M per year. Hence, a new system is being proposed to reduce the operating cost of the system.

3.2 PROPOSE SYSTEM

The proposed hybrid system consists of wind Turbines, Solar Panels, Storage systems (Batteries), power conditioning and a controller, as shown below. We propose adding 1,414 kW of PV, 1,571 kWh of battery capacity and 1,600 kW of wind generation capacity. This would reduce the operating costs to $695,083/yr as against the $1.62M per year. The investment should has a payback of 2.87 years and an IRR of 34.8%.

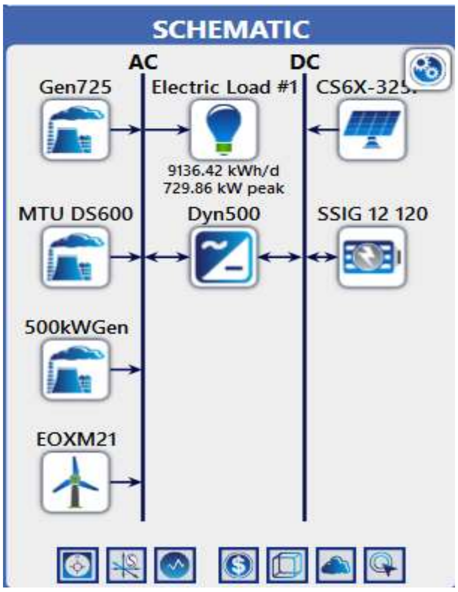


Fig 4: Schematic of the proposed optimisation variables for the system from HOMER Pro software

3.3 RESOURCE ESTIMATION

Prospective available renewable energy sources enormous in PHS are solar and wind are enormous in this location. The latitude and longitude (52.5433° N, 56.3002° W) of the study location was used to estimate the available solar irradiation and the average wind speed with the help of HOMER Pro software. The software was used to estimate the daily solar irradiation; average wind speed; and ideal sizing of the system through the latitude and longitude.

3.4 SOLAR PV ARRAY

The Annual daily solar irradiation available in PHS is shown in Fig. 5 (HOMER software). The Highest daily solar irradiation found is 4.970 kWh/m2/day in the month of May while the lowest was 0.740 kWh/m2/day in December. The P.V. used in this study is Canadian solar Max Power CS6X-325P with a rating of 2950 KW. The modeled solar P.V. array in HOMER Pro software gives D.C. power output directly. Photovoltaic systems are cost-effective in small off-grid applications, providing power to homes in developing countries, off-grid cottages and motor homes in industrialized countries, and remote telecommunications, monitoring, and control systems worldwide. Details information about the PV panels used in the work is shown in the table 1 below.

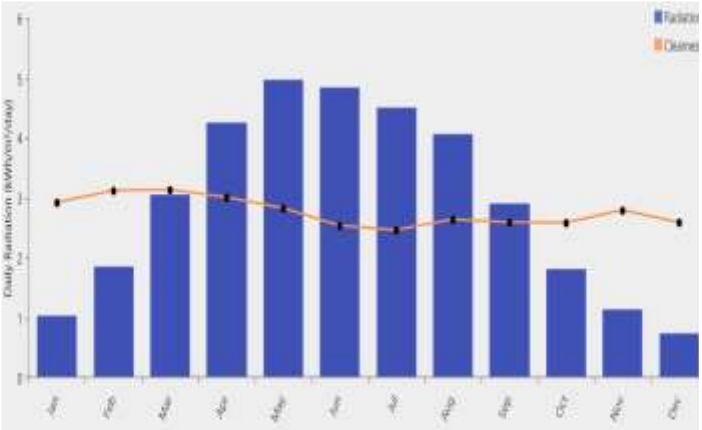


Figure 5: Solar irradiation

Manufacturer	Canadian Solar
Model	CanadianSolar MaxPower CS6X 325P
Panel type	Flat plate
Rated Capacity (KW)	0.325
Efficiency	16.94
Operating temperature (°)	45
Temperature coefficeint	-0.41

Table 1: PV panel specification

3.4 WIND RESOURCES

The need to incorporate renewable energy like the wind into the power system is to make it possible to curtail the environmental impact on the conventional plant. The specification of the wind turbine used in this modeling is 100 kW EXO M-21 AC wind turbine developed by Eocycle. The average wind speed and profile curve for the wind turbine are shown in figures 8, respectively. The highest wind speed was found in the month of December as 5.670 m/s while the lowest wind speed was 4.20 m/s.

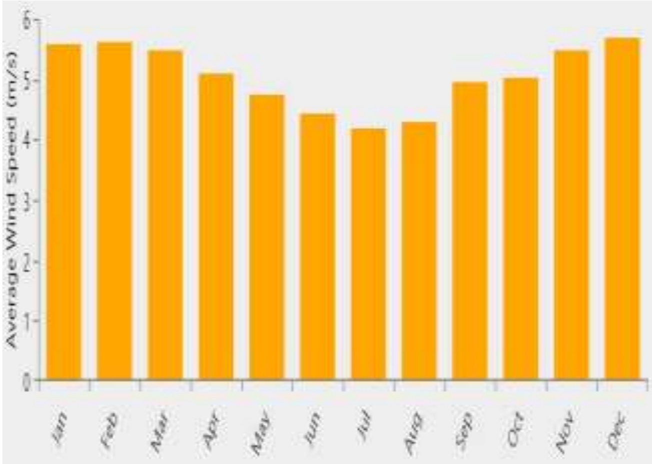


Figure 6: Wind speed data

3.5 BATTERY INFORMATION

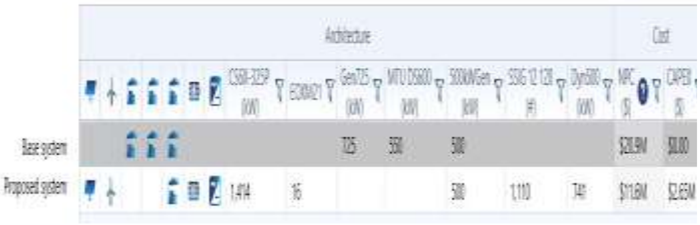
Trojan SSIG 12 V batteries were used for the storage and distribution of electricity generated from PV panels. The nominal capacity of the batteries is 1571kwh, expected life of 2.83 years and storage depletion of 156 kwh/yr.

4. RESULT

In this study Homer and MatLab were used for the design optimization and simulation of a suitable and workable hybrid power system for Port Hope Simpson. Several options are available for different sizes of the components used, components to be added to the system which seem sensible, and cost functions of components used in the system. HOMER's optimization and sensitivity analysis algorithms evaluate the system configuration possibility. Different ranges of fuel prices and wind speeds are considered in the modeling. The system cost calculations account for capital, replacement, operation and maintenance, fuel, and interest costs.

Figure 7 shows the values of each optimization variable. It shows a set of all likely variables in the system configuration. All possible configurations are simulated and sorted according to net present cost (NPC). This simulation's sensitivity variables are P.V. arrays, wind speed, and diesel price. The total number of likely sensitivity variables, including converter and battery. Solar, Wind, and Diesel are simulated with HOMER as renewable resources. Emissions, System control variables, Economics, and Constraints were also checked during the hybrid simulation. From the optimisation results, the highlighted variable with the one diesel generator, PV array and Wind turbine gave us the best result, in term of cost reduction and return on investment when compared with other variables with 2 or 3 generators.

Figure 7: Optimisation results of different variables from Homer Pro



	Architecture								Cost	
	CS6X-325P (kW)	EO30W21	GenT25 (kW)	MTU DS800 (kW)	500kWGen (kW)	SSIG 12 128 (#)	DynX00 (kW)	NPC ($)	CAPEX ($)
Base system			725	550	500			$20.9M	$0.00
Proposed system	1,414	16			500	1,110	741	$11.6M	$2.65M

Figure 8: base system and proposed system

Difference in Net present Cost = Base system – Proposed System

= $20.9M - $11.6M

Difference in Net Present cost = $9.3M

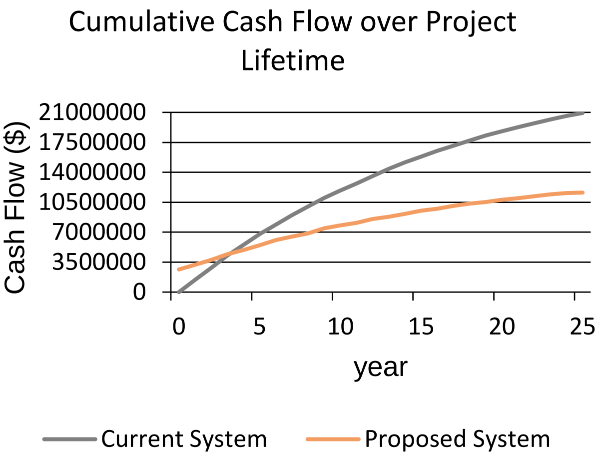


Figure 9: Plot of the base system and the proposed system

The simulation result from Homer of PHS shows the total net present cost of the proposed system to be $11, 631,730.00M as against the $20,931,810.95M of the based system. This shows a difference of $9.3M. The operating cost of the system also reduces from $1.62M to $695,083.30M, which is an annual savings of $924,084. The levelized Cost of Energy is $0.2698 and the return on investment is 31.2%.

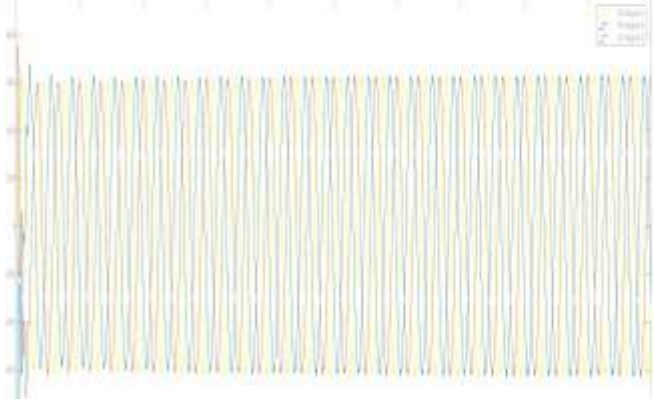


Fig 11: Signal response of the MATLAB Simulink

The above figure 10 and 11 shows the simulation of hybrid power systems that integrate wind, solar, and generator power sources. This hybrid power system is imperative for designing efficient and reliable energy solutions. It ensures that these systems effectively balance renewable energy sources with backup generation, meeting the energy needs of diverse applications while reducing the environmental impact.
Simulating the hybrid power system involves modeling each component individually and then integrating them into a comprehensive system model. Wind turbines capture energy from the wind, solar panels generate power from sunlight, and the generator provides a supplementary power source. The simulation considers various parameters, including local weather conditions, load demand, and energy storage systems. MATLAB Software was used in designing this system.

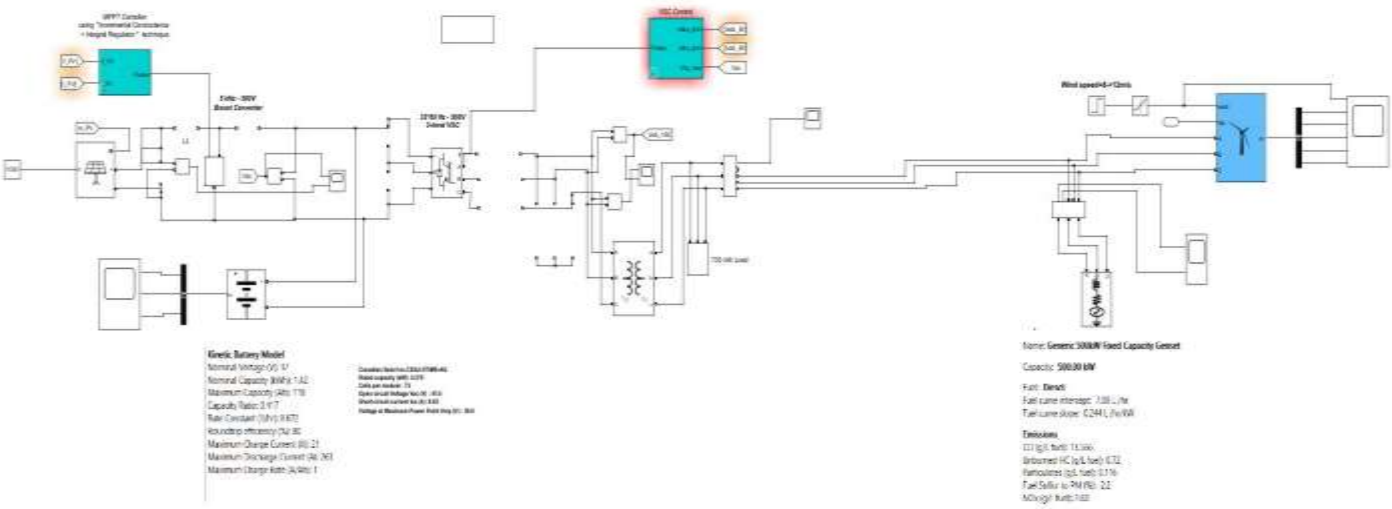


Fig 10: MATLAB Simulink simulation for the proposed hybrid system

5. RECOMMENDATION:

Based on the research presented in this paper, it is highly recommended to proceed with the implementation of the proposed hybrid power system for Port Hope Simpson, Labrador. The integration of solar panels alongside the existing wind turbine and diesel generator setup offers significant advantages, including improved energy reliability, reduced operational costs, and a reduced environmental impact.

The comprehensive resource assessment conducted in the region indicates the presence of viable wind and solar resources, making the hybrid system a feasible and sustainable solution for meeting the community's energy needs. The simulations and performance evaluations carried out in this study demonstrate the potential economic benefits of the hybrid system compared to the current setup. The reduction in operational expenses and greenhouse gas emissions will not only contribute to environmental conservation but also lead to long-term cost savings for the community.

6. CONCLUSION

The design and analysis of a hybrid power system for Port Hope Simpson, Labrador, offer a promising solution to address the region's energy challenges. By integrating solar panels with the existing wind turbine and diesel generator set. The implementation of a hybrid power system in Port Hope Simpson holds several significant advantages. Firstly, it reduces the community's reliance on fossil fuels, leading to a reduction in greenhouse gas emissions and promoting environmental conservation. Secondly, the integration of energy storage systems and intelligent controls ensures a stable and reliable electricity supply, even during periods of low renewable energy generation.

The economic analysis reveals potential cost savings compared to the current system, further supporting the viability of the hybrid solution. By optimizing the use of renewable resources and minimizing operational expenses, the hybrid power system can offer long-term economic benefits to the community.

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