Design and Analysis of a Hybrid Power System for Cartwright, Labrador

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Abstract- **This paper presents a design, analysis and simulation of a hybrid electrical power system for an isolated community named Cartwright in Newfoundland and Labrador, Canada. The design aims to meet a peak energy demand of 902.24kW. In the selected renewable energy supply, the power-sharing ratio is tuned to 30% for solar Photovoltaic (PV) module and 70% for wind turbine power. The system is designed with the advanced HOMER Pro software to assess system performance under different scenarios. The aim of the design and analysis is to identify ideal configurations to propose sustainable solutions that address the energy needs of the community. This paper further displays a modeling and simulation process using the MATLAB/Simulink software. The simulation creates a prediction of the behaviour of the proposed system and reduces errors that may be present in the design process. The electric needs of Cartwright are met with 3,380 kW of solar PV system, 500 kW of generator capacity, 16,395 kWh of battery capacity, and 4,300 kW of wind generation capacity. The economic analysis results indicate operating costs amounting to $1.09M per year. This shows a total Net Present Cost (NPC) of $30,256,680 and a Levelized Cost of Energy (LCE) of $0.352/kWh.**

Index Terms— Levelized Cost of Energy, Net Present Cost, Photovoltaic, Renewable Energy Supply.

I. INTRODUCTION

A hybrid energy system is unique in serving the power demand by using diverse energy sources rather than a single unstable power generation. Reliable power sources allow us to improve our quality of life by using more advanced technologies. With the surge in global energy demand, almost 80% of the power generation is currently from fossil fuels that are depleting [1].

Power generation from conventional energy resources is the leading cause of carbon dioxide (CO2) emissions that hurt the planet by greenhouse gas emissions that result in boosting the surrounding temperature. Reusing natural energy resources is essential for generating electricity. These renewable sources are integrated with the grid to reduce reliance on conventional generators, offering low-cost power and meeting demand. However, their power supply can be unreliable. To address this, hybrid energy systems and energy storage facilities are recommended to store excess power and ensure consistent supply, reducing distribution costs and providing economic solutions.

Research reflects that shifting the load demand from conventional to renewable energy sources can reduce greenhouse gas (CO2) emissions by 50% [2]. One significant step toward the widespread use of renewable energy sources that can lessen reliance on fossil fuels is the decentralization of the power industry. In recent years, the global growth rates of wind power and photovoltaics (PV) have been 7% and 4%, respectively [3]. Over the previous five years, the average increase was 27% for PV and 13% for wind [4].

Power plants have limitations and increasing the capacity could lead to bigger costs, so hybrid systems enable them to meet the demand load on existing energy infrastructure. Power conversion stages for renewable energy (REN) grid integration must be dependable and efficient, especially considering the growing requirement for high control ability and flexibility from the grid side [5].

The fluctuation and sporadic nature of individual energy sources can be lessened by combining numerous sources. Diversification of energy sources can lead to cost savings, especially in areas with varying availability of solar and wind resources. Hybrid systems can also reduce the need for extensive grid infrastructure in remote locations [6].

The main challenge to RES like solar or wind is the inconsistency of always generating power. Smart solutions are proposed to utilize power from RES at the peak generation of individual RES. This can help supply power to remote communities where grids are too far [7].

II. LITERATURE REVIEW

In the present era, the exponential rise in electricity creates a huge gap between consumption and production of power from conventional sources like fossil fuels. The primary drivers of the decline in the use of fossil fuels for transportation and energy generation were changes in the global climate and rising carbon footprints. Wind, solar, and water energy sources can replace conventional energy resources as they are abundant in nature and lead toward a sustainable society.

The crucial factor in a hybrid power system is the penetration of the energy, which is the ratio of the actual energy supply and energy demand per annum. The penetration level has a direct relation with the cost, and it is classified into three (low, medium, and high) levels [8].

In recent years, multiple studies have been conducted on stand-alone power supplies. This paper evaluates the performance, and optimization of an off-grid hybrid energy system integrating solar, wind, diesel generator, and battery using Homer software for Cartwright. Similar research in Klia Sepang Station by Shezan and other researchers [9]. They concluded that their system reduced the NPC by 29.65% and green gas emissions by 16 tons. In the same domain, Mahbub and their colleagues researched in McCallum using the same system and introduced Floating Solar Photovoltaic modules (FSPV) in their design [10]. They concluded that only one 150 kW generator was used even though they had the availability of three and the load was shifted towards a new FSPV energy generation plant that saved 70% of fuel consumption, compared to a diesel generator. Erasmus and Tabet researched the African area, Cameroon, using the same hybrid system and concluded that the PV/DG/hydro/BS configuration serves as the best optimal solution in meeting load demands and design constraints [11].

In this research work, we will design a hybrid power system for Cartwright, Newfoundland and Labrador, Canada. The wind speed is quite effective in the selected location and the wind turbine model can be integrated. We will integrate a wind turbine energy resource that helps in reducing greenhouse gas emissions and makes the system more fit economically. To cater to the problem of fluctuation and inconsistency of RES, the energy storage system is used. This paper offers a reliable, cost-effective power solution to the Cartwright community using Homer software.

III. SITE DETAILS

The research area that we selected for the hybrid system model is Cartwright, in Newfoundland and Labrador Canada. It is a remote area located at 53°42.5'N and 57°0.9'W. Cartwright is a small, less populated area in the province of Newfoundland and Labrador, Canada with a total population of 439. The community is located on the eastern side of the entrance to Sandwich Bay, along the southern coast of Labrador. It is a cold area, and the main industry of the Cartwright is the crab fishery. Due to extreme weather conditions, and lack of proper electricity provision, the hybrid system is the better option in such conditions. Fossil fuels-based generators are used to generate power, and integration with a smart hybrid system resolves energy shortage issues.

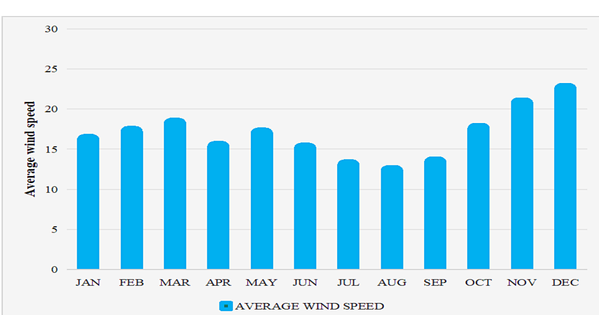

Fig. 1. Average Wind Speed in m/s versus Month.

Cartwright has four generators connected to a microgrid, which is in use for generating electricity. The proposed wind farm will be situated close to this plant at 0.98 km from the existing diesel plant, while the proposed solar system site location is 0.5 km from the existing diesel plant, for easy incorporation into the existing grid within the facility

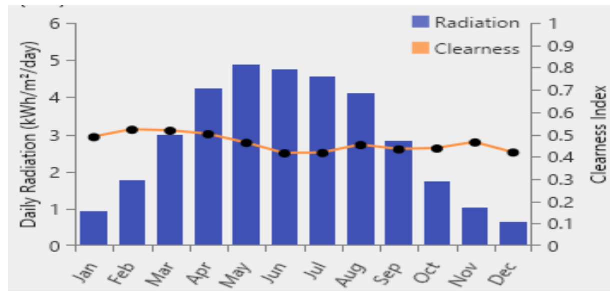

Fig.2. Monthly Average Solar Irradiance and Clearness Index in Cartwright, Canada.

From the climate data presented, it can be observed that the available solar resources are not as abundant as the wind resources. It can be intercepted from Fig. 1 that the peak wind speed occurs between December and January, while the lowest wind speed occurs between July and September. The monthly average wind speed of the curve is 5.97 m/s in Cartwright, Canada. Fig. 2 represents the monthly average solar irradiance and clearness index, and it can be concluded that the clearance index varies between 0.4 to 0.5 throughout the year, and the radiation is maximum in May and June.

IV. WIND AND DATA SOURCES

Wind data for twelve months was downloaded from the Government of Canada Historical Climate Data website. This website provides reliable access to historical weather and climate data, and related information for locations across Canada [12]. The data accuracy on this site, including wind speed and direction, can be trusted, giving one confidence in research and analysis.

The solar data for this project was obtained from the Solar Global Horizontal Irradiation (GHI) Resource page on the Homer Pro software. HOMER Pro imports and utilizes solar resource data from external sources to perform its simulations and optimizations. These external sources include NASA's POWER Data, the National Renewable Energy Laboratory's (NREL) National Solar Radiation Database (NSRDB) and other weather stations. Solar data was fetched from these online databases based on the geographic coordinates of specific locations in Canada.

V. EFFECTS OF CLIMATE ON BATTERY STORAGE

Cartwright's cold climate may pose some effects on the battery storage of a hybrid system. Cold weather reduces the charge/discharge efficiency of the batteries by slowing down their inner chemical reactions. That is, less energy will be stored during a colder period. Additionally, cold climates slow the charging of batteries and thus may challenge matching energy demand with available supply from sources such as solar and wind energy [13].

To remedy this situation, housing the batteries in temperature-controlled or insulated enclosures can help regulate the temperature around the battery system, hence reducing the effect of cold weather on its performance. Experimental results illustrate that the preheating approach has strong robustness and high reliability, which can effectively preheat low-temperature batteries under different conditions without needing a complicated battery model [14].

VI. SYSTEM DESIGNING

The hybrid system was designed using renewable energy resources, battery storage, and the existing diesel generators in Cartwright. The system was analyzed and evaluated on Homer Pro software by selecting each specific model of energy resource. The resources were selected with precise calculations, and demand applications.

The load of 12,811.12 kWh per day with a peak of 902.14 kW is connected to the AC bus whereas solar module CS6X-325P was connected to the DC bus along with the Trojan SIG-12 255 battery storage system. The inverter was used in between AC and DC, and the design selection proposed to use an Eaton1000 converter with 100 percent efficiency. The existing generator was fueled by diesel, and it has the type of CAT-500 that was able to generate 500 kW power. The power-sharing ratio is tuned to 30% for solar power and 70% for wind power.

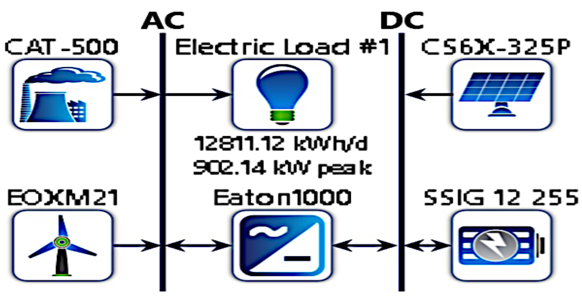

Fig. 3. Schematic Diagram of the Hybrid Power System.

In PV modeling, the Maximum Power Point Tracking (MPPT) is implemented based on the Perturb and Observe algorithm. To assess if the battery can supply or not, its state of charge assessment is modelled. All designs are integrated into the proposed hybrid model and connected with the Energy Management System (EMS). The complete design of Simulink is shown in Fig. 4.

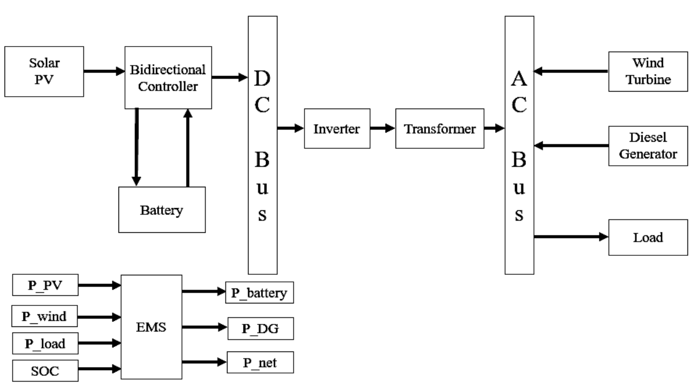

Figure 4. Block Diagram of Complete Hybrid System Simulink Model

VII. RESULTS AND DISCUSSION

The optimized results were observed based on the simulation of the hybrid energy system in Cartwright, Newfoundland and Labrador, Canada. The designed solar-wind hybrid power system was implemented using the available renewable energy resources in Cartwright. The Homer software recommended a system architecture that could reduce the cost to an optimal value. Optimized findings displayed several hybrid power system configurations where fuel consumption was significantly higher than with the first solution. Therefore, it was preferable to choose the option with lower fuel consumption, ensuring a higher fraction of renewable energy sources.

The results from Homer Pro software indicate the optimized size of each component. The solar PV system increased from 0.325 kW to 3,380 kW, while the wind turbines were boosted from the estimated 5 units to 43 units to economically dispatch power. The system converter was recommended to be upgraded from 1 MW to 2.71 MW, with a total storage capacity of 16,395 kWh. From the optimization results, the solar panel can generate 15,978 KWh/day. It can remain functional for 4,372 hours/year giving the levelized cost of a solar PV system of 0.0616$/KWh. The optimized configuration of the hybrid system is displayed in Table I.

TABLE I: OPTIMUM CONFIGURATION OF THE HYBRID SOLAR-WIND POWER SYSTEM

Component	Name	Optimized Size
Generator	CAT-500kW-60Hz-PP	500 kW
PV	Canadian Solar MaxPower CS6X-325P	3,380 kW
Storage	Trojan SSIG 12 255	16,395 kWh
Wind turbine	Eocycle EOX M-21	43 ea.
System converter	Eaton Power Xpert 1000 kW	2,711 kW

The wind turbine can provide a total production of 4,691,454 KWH/year. Again, it can work for about 3,994 hrs. /year giving a levelized cost of 0.0567$/KWh. The diesel generator optimization results are presented in Fig. 6

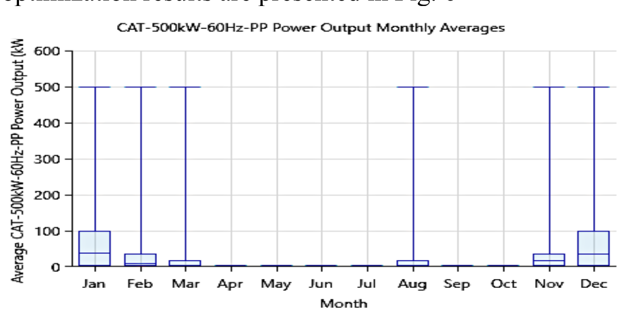

Fig. 6. Diesel Generator Optimization Results

Electrical Consumption and Production

The optimization findings showed that the real average yearly daily energy consumption is higher than 12,817 kWh/day. However, at the start of the research, it was estimated to be 12,811 kWh/day. It was also discovered that the actual peak load was lower than the projected 902.24 kW, at 888 kW.

The energy production by each power-generating component of the system is presented in Fig. 7 and Table II.

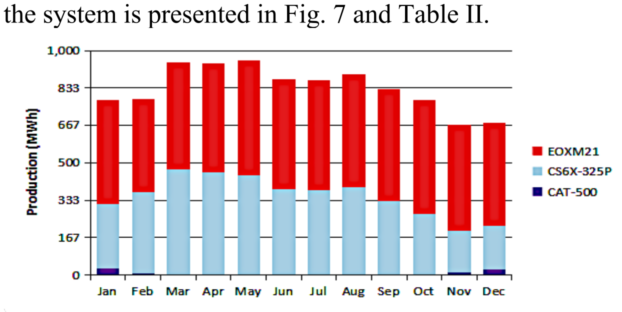

Fig. 7. Actual Electric Power Production in Cartwright

TABLE II: DETAILS OF ACTUAL ELECTRIC POWER PRODUCTION IN CARTWRIGHT

Component	Production (kWh/yr)	Percent (%)
CAT-2500kW-60Hz-CP Canadian Solar MaxPower CS6X	4,149,614	41.5
CAT-500kW-60Hz-PP	75,612	0.756
Eocycle EOX M-21 [100kW]	5,772,450	57.7
Total	9,997,676	100

The annual power from the wind farm was 5,772,450 kWh/yr. It is equal to 57.7 percent of the total generated power. The solar farm created 41.5 percent of the total generated power which corresponds to 4,149,614 kWh/yr, while the diesel generator produced a total electricity of 75,612 kWh/yr of the total energy produced. The results show that demand power can be extracted from a solar-wind hybrid system with negligible load on diesel-generated. Homer determined that the optimized system produced 4.8 GWh of excess electricity annually. The excessive electric load will be 2,815 kWh and a capacity deficiency of 4,660 kWh. The optimized system output is displayed in Table III.

TABLE III: EXCESS ELECTRICITY PRODUCED AND CAPACITY SHORTAGE OF THE SYSTEM

Quantity	(kWh/yr)
Excess Electricity	4,828,299
Unmet Electric Load	2,815
Capacity Shortage	4,660

Optimization Results from the Energy Storage System

The optimized value of the storage capacity of Trojan SSIG 12 255 batteries by the Homer Pro software is 16,395 kWh. The optimized annual throughput of the system calculated by software is 1,881,254 kWh/yr. The required number of Trojan batteries as determined is 5,310 batteries connected in a string of 30 batteries. So, the total number of strings is 177.

The Eaton Power Xpert 1000kW analysis shows the optimized required capacity is 2,711 kWh using Homer Pro software. The mean output of the converter system is 289 kW with a maximum output of 846 kW.

The optimized system cost is $1.09 million per annum in total operating expenses. Table IV displays the overall Net Present Cost of the system. Fig. 8 shows the NPC of all components.

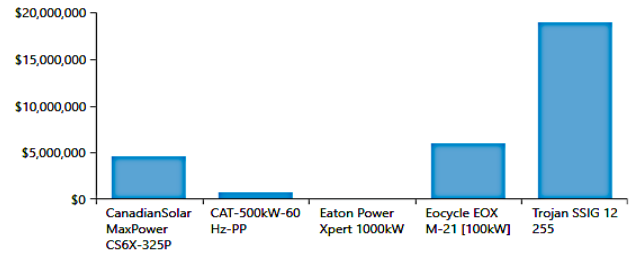

Fig. 8. Net Present Cost for the Hybrid System.

It can be observed that the NPC is maximum against Trojan battery and minimal against converter. The overall impact of the diesel generator cost is low, whereas the net present cost of wind, and solar is high.

TABLE IV: TOTAL NET PRESENT COST OF THE SYSTEM

Name	Capital ($)	Operating ($)	Salvage ($)	Total ($)
Solar CS6X-325P	2.70	1.91	0.00	4.61M
CAT-500kW-60Hz-PP	0.00	73105	-78471	599042
Eaton Power Xpert 1000 kW	93519	32364	0.00	.25883
Eocycle EOX M-21	4.73	1.58M	-307242	6.00M
Trojan SSIG 12 255	2.90	9.57M	-263199	19.0M
System	10.4	13.3M	-648912	30.4M

For the economic aspect, looking at the cost summary of the hybrid system, the total cost to build a hybrid power system, considering the capital, replacement, operating and maintenance, fuel, and salvage costs is around $29.6 million.

VIII. CONCLUSION

Renewable energy resources are the new approach to generate clean energy and replacing conventional energy resources due to their intermittence and abundance in nature. The hybrid system is designed using renewable energy resources, battery storage, and an existing diesel generator in Cartwright, Canada to reduce the power generation from diesel generator. The objective of this project was to alleviate the burden of power production from conventional resources and analyze the impact wind-solar hybrid power system. The system is analyzed and evaluated on Homer Pro software and the electric needs of Cartwright are met with 3,380 kW of solar PV system, 500 kW of generator capacity, 16,395 kWh of battery capacity and 4,300 kW of wind generation capacity. The operating costs for the optimized hybrid system results in $1.09M per year. The result shows a total net present cost of $30,256,680 and a levelized cost of energy of $0.352/kWh. The proposed hybrid system mainly relies on wind turbine system to meet the monthly energy production. Solar power contributes to feeding power to make system more reliable, and diesel generators are least among producing power that light up the Cartwright community.

For future studies, we would include a detailed discussion of our MATLAB/Simulink results. It is our recommendation to try other software and compare the efficiencies. Floating solar systems can be integrated, and more advanced AI algorithms can offer more optimal design and cost.

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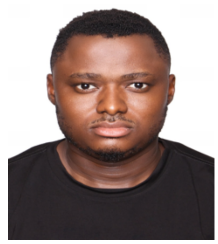

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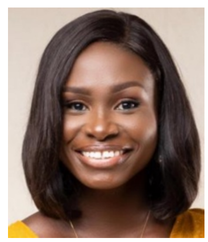
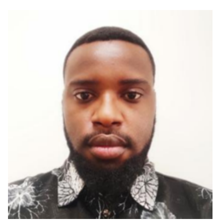


Lynna Otabil holds a BSc. in Electrical / Electronic Engineering from the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana since 2012. She holds over a decade of experience as an expert in Metering and Technical Operations in the electric power utility industry. She is also experienced in power cable designing and testing. Lynna is currently a postgraduate student offering MASc. Energy Systems Engineering in Memorial University of Newfoundland, Canada.



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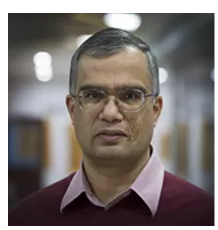

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