Design and Analysis of a Hybrid Power System for Black Tickle, Labrador

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***Abstract*—Over the years, there has been a tremendous increase in the use of renewable energy systems as an alternative source of power especially for distant communities (rural areas). This is as a result of its significant increase in effectiveness as well as a constant reduction in price. Black-Tickle, having an all-year-round population of about 120 people is a part of the three diesel-dependent communities in NunatuKavut's Southeast coast (the other two being Norman Bay, and St. Lewis) [1]. This diesel dependency and continuous burning of diesel is not only too expensive but also has a huge negative impact on the climate and environment for the people of Black-Tickle to live in consistently.**

The Hybrid Power System presented in this paper consists of a Photovoltaic system, which is Solar powered, a wind turbine, and batteries for energy storage that serve as a second alternative power to the diesel plant currently in Black-Tickle, Newfoundland and Labrador. It will greatly reduce the amount of diesel that the community currently uses for power generation.

The sizing of the system is carried out using the HOMER Pro software. System dynamic modeling is created in MATLAB/Simulink. Outcomes from the design and simulation have been included.

Keywords – hybrid power system, solar PV, wind, diesel generator, HOMER Pro, MATLAB, Black Tickle.

I. Introduction

Using a hybrid energy system is a dependable way to meet one's electrical needs. Diverse energy sources can also be used to address the unstable power generation from renewable energy sources. Its use can boost the quantity of energy that is released from the energy sources, and the availability of power is expanding for rural areas without grid connectivity.

A hybrid energy system should ideally have many energy-producing components, such as wind-solar, solar-diesel-electric, or wind-diesel power. Also, hybrid energy sources include places to store energy. Reduced reliance on fossil fuels and increased usage of renewable energy sources are two advantages of the hybrid energy system. As renewable energy systems are less expensive than fossil fuel-based power generation units, this will result in the production of environmentally beneficial energy and lower long-term power generation costs.

The power plant's ability to produce energy may reach a point where it can no longer do so when the load demand rises. Making hybrid energy systems on top of already-built energy infrastructure lowers the price of building new power plants and has a smaller negative impact on the environment.

The province of Newfoundland and Labrador is situated in the furthest east in Canada. In Newfoundland and Labrador, there is an abundance and diversity of natural resources of all types.

II. Literature Review

To significantly reduce fuel prices and pollution, much research on renewable energy sources has been conducted in several countries [2]. The use of renewable energy for power conversion is currently verifiably feasible in terms of both technology and cost [3].

Using Abuja, Nigeria, as a case study, Samuel et al. used a system elimination method with numerical simulation to confirm and optimize recently reported results highlighting the advantages of photovoltaic-diesel-battery hybrid integrated power systems for commercial centers [4].

Since Newfoundland and Labrador is so strongly linked with hydropower, individuals outside the province might be surprised by Black Tickle's reliance on diesel. Even while hydroelectric projects make up the majority of the province's grid, up to 25% [5] of the electricity in the province is produced by the Holyrood Thermal Generating Station, which burns oil. Along with the contentious Muskrat Falls hydro project, there is also the enormous Churchill Falls hydro-generating station that supplies energy to Quebec [5]. Off-grid areas like Black Tickle are not connected to the renewable grid in the province. Since Indigenous Peoples make up the bulk of isolated communities in Labrador, "off-grid energy advocacy needs to be focused on their rights because these policies and projects have an impact on them," according to Mercer [5]. Wood stoves are an instant fix that may serve as a bridge to green energy while preserving significant cultural aspects of the energy system, even though they may not be as emission-free as wind or tidal power [5].

Islands' unique conditions and limited natural resources cause their electricity distribution networks to be cut off from the grids on the mainland. It is clear that Small Island Developing States (SIDS), which must deal with this circumstance, incur considerable environmental and financial costs as a result of their reliance on pricey old diesel generators to produce power [6, 7] therefore, it's crucial to find a solution to the problem of converting the energy infrastructure of islands into renewable energy systems. The development of auxiliary hybrid renewable energy systems, which integrate two or more renewable energy systems with diesel generators, is an acceptable strategy to reduce environmental pollution and the intensity of fossil fuel use [6, 7].

It may not be sufficient to eliminate petrol or diesel power plants as a backup unit. Renewable energy facilities also require some sort of energy storage device to balance out variations in the availability of natural resources [8]. With regards to solar modeling, the "PVWatts" model of HOMER Pro uses a few key variables to characterize the nameplate capacity, array orientation, mounting type, and system losses in the data on the sun irradiance at Black-tickle throughout the year.

This study is taxed with designing and analyzing a hybrid power system for Black-Tickle, Labrador consisting of the existing diesel generators in Black Tickle, a wind turbine, as well as a solar PV system connected to batteries for energy storage.

III. SITE DETAILS

Black Tickle is a small community in Newfoundland and Labrador, with a land area of 9.43km^2. Black Tickle airport serves the town of Black Tickle because it is not reachable by road. Data received from NL Hydro included the load profile of Black Tickle and a single-line diagram of the Black Tickle diesel plant and substation. A master spreadsheet of 2021 Generation and Consumption Data for Newfoundland and Labrador's Isolated Electricity System was also obtained from the Open Data Newfoundland and Labrador website.

Upon studying the data received from NL Hydro, it was discovered that Black Tickle's isolated power system consists of 3 fossil-diesel power generators with a total capacity of 1,005kW [9, 10]. The generators have different ratings (455kW, 300kW and 250kW) [9]. The generators are tied to a common bus serving a three-phase power transformer rated at 333kVA and a station service transformer rated at 30kVA [9].

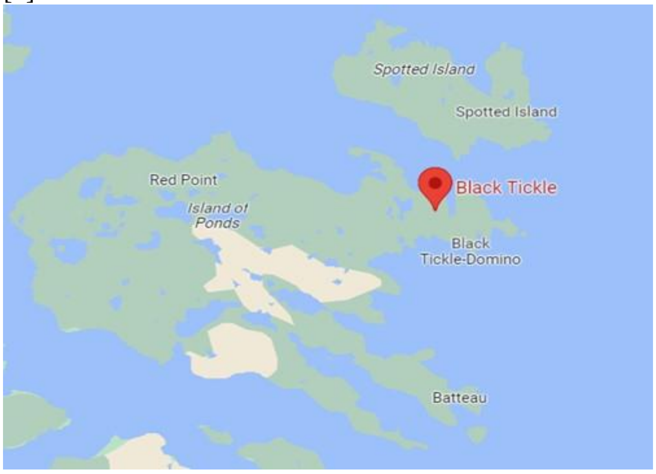

Figure 1 Geographical location of Black Tickle

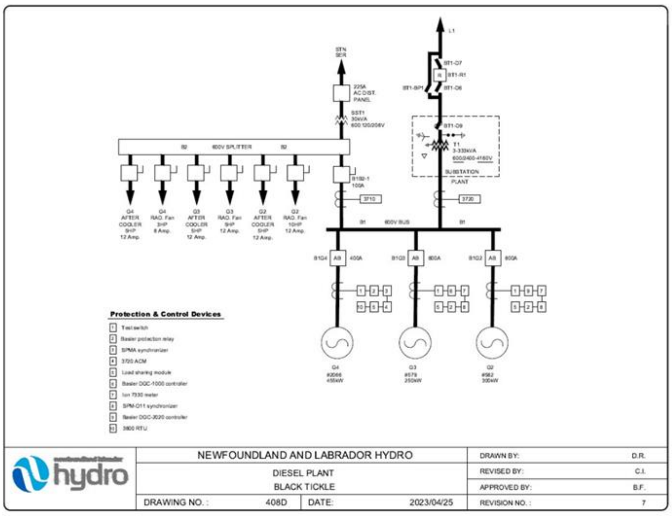

Figure 2 Diesel plant single line diagram of Black Tickle [9]

The peak load for the year 2021 was 237kW [10]. In the same year 326,753 litres of fossil-diesel fuel was consumed in generating an energy of 1,116,466 kWh and this served 91 customers in that year (2021) [10]. The fuel is transported to the island by ship [10].

The number of solar PV modules and wind turbines needed to meet the overall energy demand are ascertained based on the total amount of renewable energy sources, such as sun irradiation and wind speed. At Black Tickle, the yearly average solar radiation available is 2.97 kWh/m^2/day. Similar to that, the annual average wind speed is 6.84 m/s.

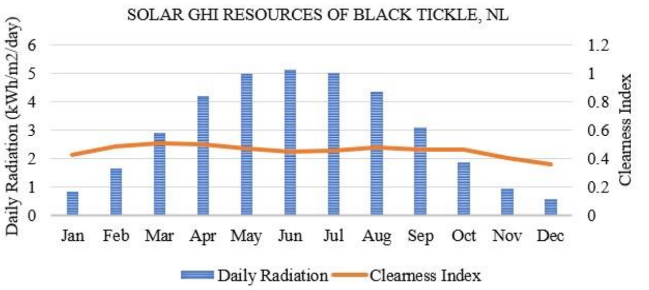

Figure 3 Available Solar GHI Resources of Black Tickle, NL

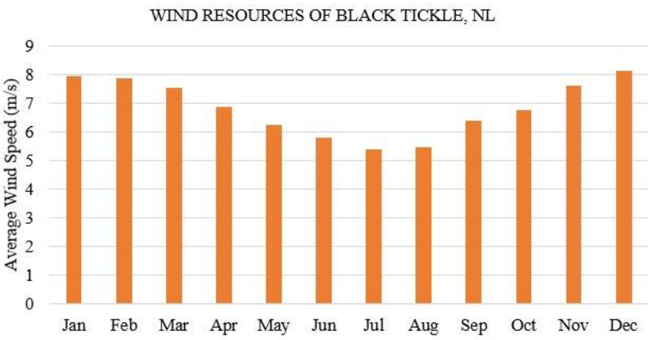

Figure 4 Available Annual Wind Resources of Black Tickle, NL

IV. SYSTEM DESIGN USING HOMER PRO

A diesel generator and renewable energy sources are both included in the hybrid system's architecture. The suggested system is created in the Homer Pro software, which includes a wide range of equipment, and choosing each one yields a workable solution. The daily load is 3120.55kWh, and the peak load on the AC bus is 238.95kW. The "CanadianSolar MaxPower CS6-325P" solar panels on the DC bus also has a 0.325kW rating, and a "Trojan SSIG 12 255" flooded lead-acid is used for energy storage. The battery string size is intended to provide a DC voltage of 360V at a rating of 12V for each battery. The "Leonics MTP-4117H" AC – DC – AC converter, which has a 300kW power rating and is linked for the conversion from DC to AC, is placed between the AC and DC buses.

Additionally, the outcome of developing the hybrid power system is broken down into three sections: net electricity output, system economic analysis, and the fuel needed for the diesel generator. The proposed system's cash flow, where the capital cost is the whole sum required to implement the planned hybrid power system. It can pay for the yearly maintenance fee, operating costs, and the scrap value at the end of the working life. Salvage is often received from the simulation after 25 to 30 years, which is a significant amount of time. Additionally, there is the cost of gasoline since diesel generators need fuel to produce power, and the hybrid system's running and maintenance costs are included in that.

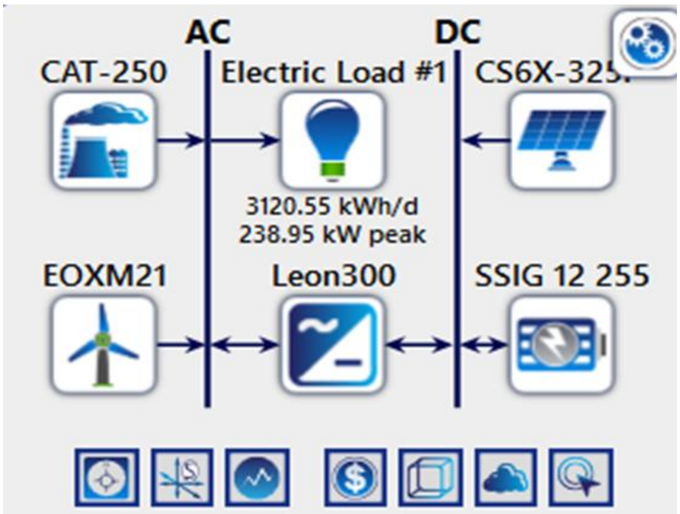

Figure 5 Hybrid Power System Schematic on HOMER Pro

V. HOMER PRO SIMULATION RESULTS/OUTCOME

For optimal results, the program considers a number of variables, including cost, architecture, and the percentage of renewable energy sources. However, the lowest cost of energy per kWh was achieved when 92.1% of the energy used was renewable and diesel generators generated the remaining 8% to meet demand. While alternative optimized solutions also offer similar applications of renewable energy.

Optimized findings display several hybrid power system configurations where the fuel consumption is significantly higher than the original option. Therefore, it is preferable to choose the option that uses the least amount of fuel, which means a large proportion of renewable energy sources. Key characteristics of the major components that make up the optimized system are as follows:

A. Solar PV System

The Solar Panel recommended in this project is the "CanadianSolar MaxPower CS6X-325P". The overall rated capacity of the solar PV system that is intended to be at Black Tickle, NL site is 417kW of the solar PV array; the solar PV system can produce 1,196 kWh/d of power and 436,637 kWh annually. All through the year, the solar PV system is operational for 4,387 hours/yr, which might result in a levelized cost of 0.107 $/KW for a solar PV system.

Table 1 Characteristics of Solar PV Array System

Quantity	**Value**	**Units**
Rated capacity	410	kW
Mean Output (power)	49.8	kW
Mean Output (energy/day)	1,196	kWh/d
Capacity Factor	12.1	%
Total Production	436637	kWh/yr
Minimum Output	0	kW
Maximum Output	434	kW
PV Penetration	42.6	%
Hours of Operation	4,387	hrs/yr
Levelized Cost	0.107	$/kWh
Clipped Production	0	kWh

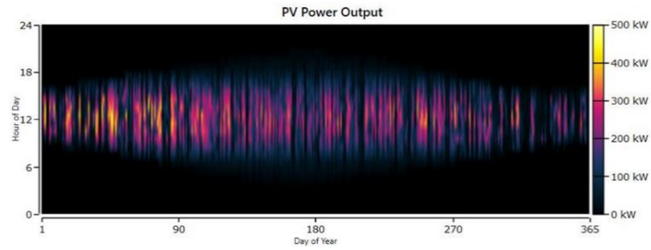

Figure 6 Solar PV System Simulation Results on HOMER Pro

B. Battery Bank Energy Storage

Another important device is the battery backup system for the hybrid power system. It can make up for the little variance brought on by changes in renewable energy sources. In addition, battery backup supplies the vital load in cases of power outages. The battery backup system's size is chosen such that, in the event that renewable energy generation is not possible, it can deliver electricity for a set period of time. Similar to that, when electricity is generated from renewable sources, the battery backup system is also refilled. The battery suggested in this project is the Trojan SSIG 12 255.

Table 2 Characteristics of Battery Bank Energy Storage

Quantity	**Value**	**Units**
Autonomy	10.1	hr
Storage Wear Cost	0.257	$/kWh
Nominal Capacity	1,482	kWh
Usable Nominal Capacity	1,186	kWh
Lifetime Throughput	888,960	kWh
Expected Life	2.71	yr
Average Energy Cost	0	$/kWh
Energy in	366,513	kWh/yr
Energy Out	293,640	kWh/yr
Storage Depletion	481	kWh/yr
Losses	73,353	kWh/yr
Annual Throughput	328,300	kWh/yr
Batteries	480	Qty
String Size	30	Batteries
Strings in Parallel	16	Strings
Bus Voltage	360	V

Figure 7 Battery Bank Simulation Results

C. Diesel Generator

The electricity generated by the Diesel Generator set at Black Tickle is slightly decreased with the installation of a hybrid power system. All of the power was formerly generated by three Diesel Generator sets with respective capacity of 250kW, 300kW and 455kW. However, after modelling the hybrid power system, it was ascertained that for continuous delivery of electricity throughout the year in black Tickle, a maximum of 250 kW Diesel Generator set is required in addition to the wind and solar renewable energy sources.

D. Wind Turbine

The wind turbine used for this project is the EOX M-21 wind turbine with a rating of 100kW. 7Nos. wind turbines are used in this hybrid system. The capacity of each unit is 100kW of AC electricity production. In order for the Simulink model to produce the greatest power from the wind turbine, we kept the generator speed at 1pu, the pitch angle at 0, and the base wind speed at 12m/s.

Table 3 Characteristics of Wind Energy System

Quantity	**Value**	**Units**
Total Rated Capacity	700	kW
Mean Output	113	kW
Capacity Factor	162	%
Total Production	990,690	kWh/yr
Minimum Output	0	kW
Maximum Output	425	kW
Wind Penetration	96.6	%
Hours of Operation	4,146	hrs/yr
Levelized cost	0.0725	$/kWh

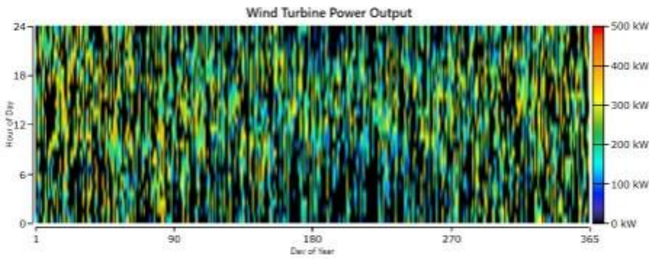

Figure 8 Wind Turbine Simulation Result

E. Converter

In the Homer design, a "Leonics MTP-4117H (300kW)" inverter has been suggested. To maintain the energy flow between AC and DC electrical components, a hybrid system needs a converter an electronic power device. It has a rectifier to change DC into AC and an inverter to change AC into DC. Here, an inverter with a capacity of around 300kW is employed.

VI. TOTAL ELECTRICITY PRODUCTION

The result below describes how the hybrid energy system's net electrical output was produced. The wind turbine system produces the most electricity, close to 990,690kWh/year, or approximately 63.8% of the total amount produced annually. Next in line is the solar photovoltaic system. It contributes close to 436,637kWh/year, or approximately 28.1%. The diesel generator produces only 125,990kWh/year, or only 8.11% of the total amount produced annually, and the final few remaining percentages of the electricity requirement are satisfied by battery backup systems. However, a hybrid system still uses some extra electricity to create power.

Table 4 Composition of total electricity production

Production	**kWh/yr**	**%**
Wind Energy	990,690	63.8
Solar PV Energy	436,637	28.1
Diesel Generator	125,990	8.11
Total	1,553,317	100

VII. ECONOMIC EVALUATION

Regarding the financial side, it will cost around $4.5 million to establish a hybrid power system, considering the cost of repairing, maintaining, and running all the equipment. In a hybrid power system, the equipment's useful life is calculated as 25 years, after which the salvage value of the individual parts is deducted. Overall, the system will have a straightforward payback period of roughly 3.7 years and a return on investment of about 28.7%.

VIII. SIMULATION OF THE SYSTEM DYNAMIC ON MATLAB

Electrical dynamic modeling is crucial to study since it enables us to comprehend how a system would function in real life. We might better grasp how a PV system will operate and adapt to environmental changes with the use of a dynamic model. We may simulate the system under different operating situations that the hybrid power system might encounter with the aid of this dynamic model. For the hybrid system, our renewable energy sources include solar panels and wind turbines. The battery is constantly being charged by these sources. The voltage of the solar power system is controlled by a dc-dc boost converter, and the output of the boost converter is supplied into the battery.

Depending on the difference between the mechanical torque from the wind turbine and the electrical torque from the generator, the mechanical system either accelerates, decelerates, or maintains a constant speed. The generator's output is routed into a two-level rectifier, which converts the wind turbine's ac voltage to dc. The dc-dc boost converter, which controls the voltage, receives the rectifier's output next. The battery is then given the output. The battery is linked to a universal bridge, which transforms the battery's dc output into ac so that it may power our ac load.

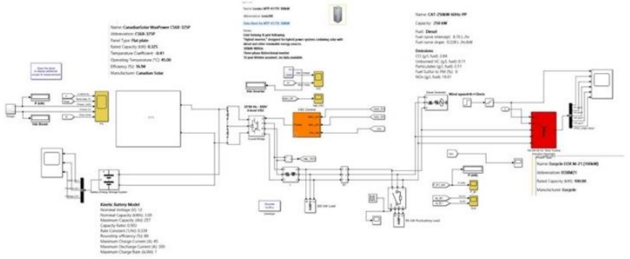

Figure 9 MATLAB/Simulink design for the Hybrid Power System

The two renewable energy sources; PV modules and wind turbines as well as the existing diesel generator make up the intended power generation sources for the hybrid energy system for Black Tickle, NL.

With a 360V nominal voltage, the PV modules are linked to the DC bus. The goal of the batteries is to serve as a storage medium for electricity that would deliver steady power to the load. A DC-DC boost converter connects the solar module to the DC bus. The ac bus is linked to the wind turbine. The converter connecting the wind turbine subsystem to the dc bus to charge the battery conditions the output. The load is linked to the diesel generator. The electronic DC-DC converter known as the maximum power point tracker, maximizes the PV array's compatibility with the battery bank or utility grid.

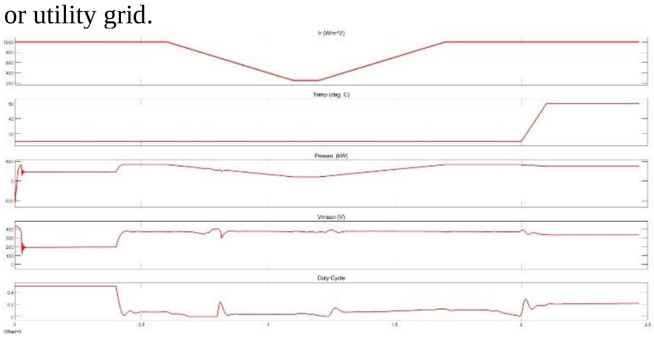

Figure 10 Simulink waveforms of the Hybrid System

IX. CONCLUSION

This research looked at a hybrid power generating system that fairly generates electricity for Black Tickle in Newfoundland and Labrador by combining solar panels, wind turbines, and diesel engines with battery banks, and inverter units. The HOMER simulation program from the NREL has been utilized as a tool for simulation and optimization. The PV/wind/diesel hybrid system with battery storage was selected among the many available solutions based on the study of the findings and certain critical characteristics, including a high renewable penetration, a low yearly diesel consumption, and a low Levelized energy cost. A dynamic simulation of the hybrid system was carried out in MATLAB/Simulink following the HOMER study. The dynamic model included PMSG wind turbines and solar panels that employed MPPT to harvest the greatest amount of power. We were able to completely understand the system's operation in a variety of modes, settings, and situations thanks to the dynamic model, as well as how the system will react to changes in environmental factors like temperature and irradiance, among others.

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