Design and Analysis of Hybrid Power System for Rigolet, Labrador

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Abstract— ***This paper focuses on hybrid electricity generation systems as an alternative to solo dependency on diesel generators for remote location such as Rigolet island, Labrador. The potential of extracting PV (photovoltaic) and wind energy to generate electrical power along diesel generators is scrutinized in this study. This paper provides effective modeling, sizing, and system architecture to reduce carbon footprint and operational costs. To make the most economical and reliable system design, this paper employs the optimization feature of the HOMER Pro. This software is used for the steady state analysis of the systems. In addition, MATLAB Simulink is used to represent the hybrid system for dynamic simulations. The stability and power output of the system are analyzed under varying load conditions. Overall, this paper covers simulation results and comprehensive system details.***

Keywords— ***Hybrid System, Wind Turbine, PV Solar Panels, Diesel Generators, HOMER Pro Software, and Simulink MATLAB***

I. INTRODUCTION

Electrical energy is very crucial element for the development of any society. As the consequence, energy demand is increasing exponentially. But it is challenging to make a reliable and efficient power system for any remote and isolated community like Rigolet. They mostly depend on diesel generated power systems for their electricity demand. Diesel generator's size changes depending on the demand of electrical energy. When required, they can be either portable, modular, or fixed [1]. Another aspect to consider for diesel generators is that they possess a high power-to-weight ratio. This makes them an excellent power source for various systems. But they have limitations, including higher costs for diesel-based power generation, fuel price volatility, transportation cost for diesel, diesel storage facility, and a significant increase in CO_2 emissions [2].

A hybrid power system could be one of the best alternatives for Rigolet. A hybrid power system is a system that produces energy from different types of sources including either renewable or non-renewable sources. Renewable energy provides a solution that can decrease operational costs. It is done by lowering reliance on fossil fuel and lowering the emissions rate. Although, wind energy is one of the most common forms of renewable energy, only wind-based power systems can be unstable due to variable wind speeds and terrain limitations. Hence, combination of different renewable energy sources ensures a stable and sustainable energy system [3]. In hybrid systems, photovoltaic energy can be utilized during sunny days while wind energy can be harnessed during cloudy and windy conditions. Also, both can be turned on parallel as well as diesel generator can be used for backup. Design is selected based on various factors such as wind speed, solar irradiance, and water source availability, etc. The purpose of the project is to design and analysis of a hybrid power system for Rigolet, Labrador. Through the project a system will be developed which conjugates conventional systems with solar and wind turbine.

II. LITERATURE REVIEW

The power generation system is a matter of concern for the Inuit community in Rigolet, Labrador. The region relies on diesel plants operated by Newfoundland and Labrador Hydro [4]. While hybrid power generation system would be more efficient for the community because of decarbonization and more sustainability. This system leads to the use of alternative fuel instead of fossil fuel. Advancement of technologies such as power electronics-based onboard grids, batteries, high-power fuel cells, PV panels, wind turbines and all-electric propulsion systems [5].

In present days, some of the hybrid power generation systems are dependent on renewable sources, for example: solar photovoltaics (PV) and wind farm (Fig. 1). From modest off-grid systems of a few kilowatts, usually intended for low voltage DC and AC, hybrid energy systems have also increased in capacity to higher megawatt systems that are extending to medium voltage grid-connected systems [6]. Sustainable energy production problems can be solved by hybrid renewable energy systems depending on wind and solar power technology. Advancement of technology and wide range of research influence to increase the dependence on renewable energy sources.

Figure 1: Wind Power Plant [7]

A study shows the energy generation of Benban Solar Park in Egypt. The capacity of plants is 1,600 MW. This plant produces approximately 3.8 terawatt-hours (TWh) of electricity and helps to offset about 1.2 million tons of greenhouse gas emissions annually. The economic feasibility study indicates a cost of 8.1 USD cents per kilowatt-hour at a 12% interest rate. The payback period of the plant is 10 years [8].

Renewable energy can be derived from different types of sources, including hydro, wind, solar, and geothermal. While these are the most common forms of clean energy, they are not the only ones. Installation cost of solar energy is comparatively high, but after installation it provides continuous energy supply. Despite all, solar panels appear to be the most practical and viable option given the country's geological limitations. A university in Ouargla, Algeria made an optimal design for a grid-connected rooftop system based on the software like Ecotec, ArcGIS, and the Homer optimizer. This study found that the cost of energy is reduceable if energy yield is increased [9].

In a study a new nanomaterial called SurfaShield G was sprayed and tested on a 150 W monocrystalline photovoltaic panel, compared to uncoated panels with the same characteristics. The transmission of the coated surface showed an improvement of 1.8% and 6.1% compared to the uncoated surface, respectively, when both surfaces were clean and dusty (Fig. 2). Over three months, the coated panel generated 0.35% more maximum power and 0.1% more efficiency with no dust in the panel. After dust accumulation, these improvements rose to 20% in power and 2.3% in efficiency. This shows the effectiveness of SurfaShield G in enhancing panel performance, especially under dusty conditions [10].

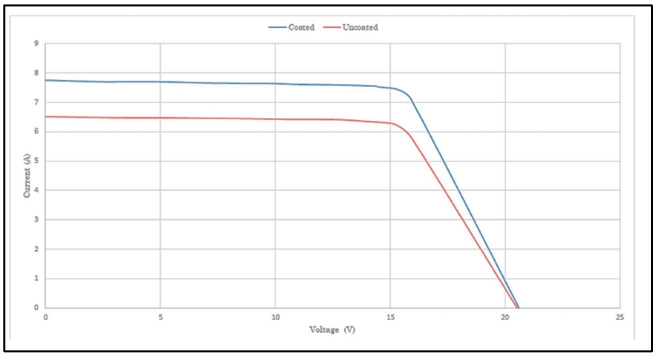

Figure 2: I-V curves for dusty coated and uncoated panels

In a research, researchers developed an enhanced PV system in India. With the help of PV system v 6.70 modeling software, the researchers could predict the potential electricity generation of the new design. A comprehensive evaluation, considering costs, payback period, and input output energy, was carried out to measure the performance of the newly developed system. It has been illustrated by the analysis that the new system is more effective than the previous one [11].

III. METHODOLOGY

A. Site Selection

Rigolet is a remote and coastal area located 160 km Northeast of Happy Valley-Goose Bay at the entrance of Hamilton Inlet in Labrador. The town is the southernmost officially recognized Inuit community in the world. There is no road access with the rest of the Labrador. In the summer, CAI Nunatsiavut Marine offers a passenger ferry service and in the winter the snowmobile trail provides access to the community by snowmobile trail. The population of Rigolet was 327 in 2021, living in 125 of its 134 total private dwellings. The total land area is 5.27 square kilometer having population density was 62 in 2021 [12].

Figure 3: Project Layout and Map

Rigolet is dependent on isolated electricity systems and this service is provided by NL Hydro (Newfoundland and Labrador Hydro). The system was installed in 1998, and their on-site fuel storage capacity was 813,530 Liter's. The means of transportation fuel was ship. In 2021, They had 3 sets of generators having capacity 1,320 KW (Kilowatt). The gross electricity generation was 2,907,334 kWh/yr (Kilowatt hours per year), and annual fuel consumption was 835,064 Liter's. They had 185 customers having consumers demand 2,823 MWh/yr, and net peak was 651 KW [13]. Due to the geographical location (Fig. 3), there is good potential of wind (Fig. 4, Fig. 6) and PV (Fig. 5) based electricity generation. Average wind speed and solar radiation over there is very suitable for operating these systems and meeting the local energy demand. So, the proposed site is suitable for developing hybrid renewable system consisting of wind and PV system along with diesel generator.

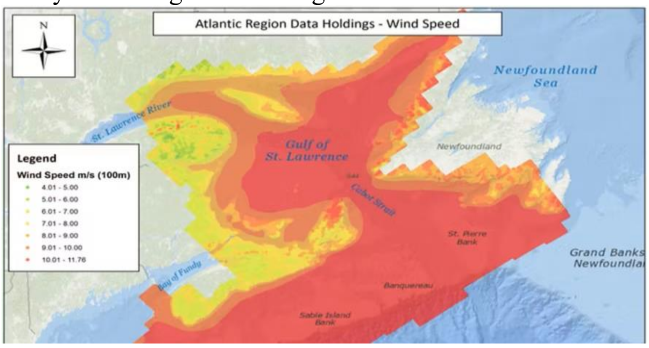

Figure 4: Wind Speed Map of Rigolet Island, Labrador [14]

During the winter, solar irradiance in Rigolet is comparatively less than the summer (Fig. 5). Other factors such as sky clearness and wind temperature can impact solar irradiance. Wind speed in winter is suitable for running the wind turbine. Thus, the average energy production remains constant even in the winter. To keep constant electricity production, a diesel generator will provide a backup in the winter.

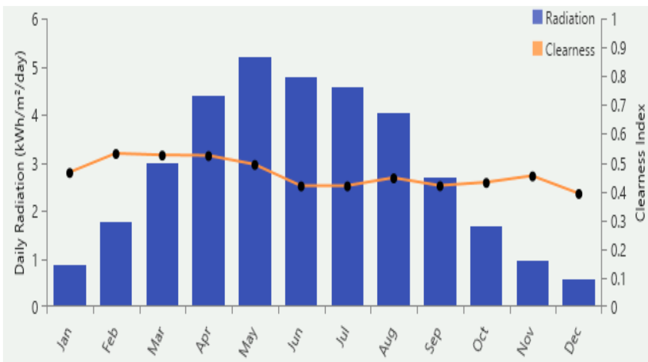

Figure 5: Solar Irradiance of Rigolet

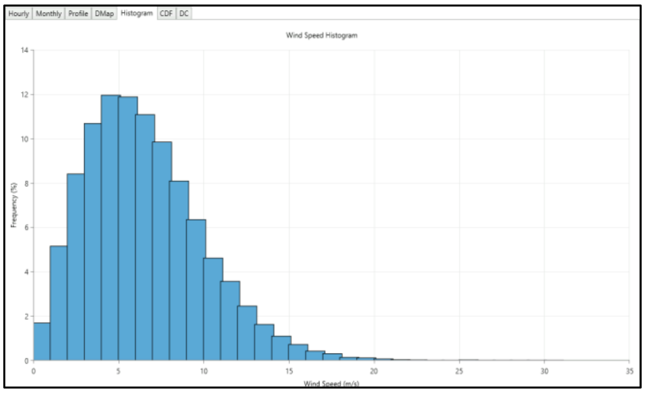

Figure 6: Windspeed in Rigolet area

B. *Load Data*

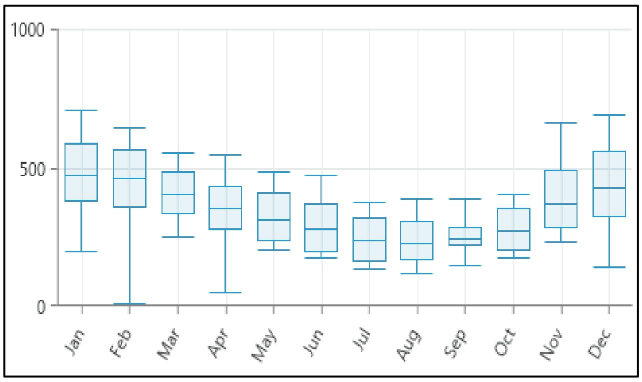

Figure 7: Monthly Load

During winter, the load or electricity demand will be the highest due to space heating. But in the summer, there will be no space heating. As a result, the electricity demand is declined. Solar irradiance for the location is shown in Figure-5 and the daily average irradiance is 2.87 kWh/m²/day. For our location, the daily energy demand is 8129.98 kWh/d, with a peak of 706.74 kW in a day. The following Figure-7 shows monthly load data for a year.

C. *System Design in HOMER Pro*

For system optimizing and finding the most viable option for the mentioned island, techno-economic analysis is necessary. To do this analysis, HOMER Pro is very useful software. This system design consists of a wind turbine, photovoltaic (PV) array, battery system, diesel generator and inverter to supply the load.

We design the system with one existing single diesel generator, wind turbine, PV array, converter and pack of lead-acid battery (Fig. 8) [15-19].

Table 1: System component cost given in Canadian Dollar

Component	Capital Cost ($)	Replacement Cost ($)	O&M Cost ($)
CAT-410kW	0	55,000	0.15 / hour
WES 18 [80kW]	62,000	52,500	20 / year
CS6U-340M	400	300	10 / year
SG750MX	50,000	43,000	15 / year
SAGM 12 205	600	500	10 /year

Based on HOMER optimization, for our system the components required-

Table 2: System components list and quantity

Component	Quantity	Combination
CAT-410kW	1	Parallel with AC bus
WES 18 [80kW]	38	Parallel with AC bus
SG750MX	1	Parallel with AC-DC bus
CS6U-340M	2535	15 in series 169 in parallel
SAGM 12 205	1200	30 in series 40 in parallel

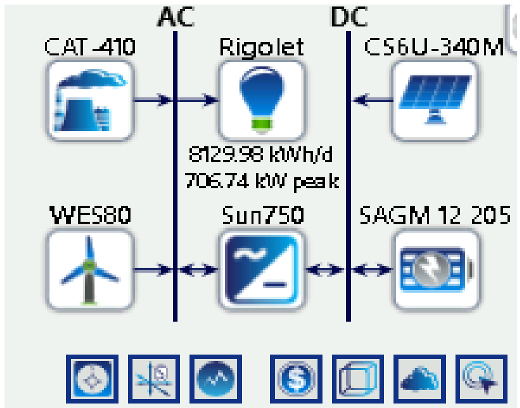

Figure 8: Proposed system in HOMER

As our location is in a remote area so only one way to transport these components via ferry. So, our selected wind turbines blade diameter is good enough to carry those with regular ferry.

IV. RESULTS AND DISCUSSION

A. *HOMER Pro*

HOMER suggestion for our project is- we will get 10.1% total energy output from PV, and we select 340W module so we required total 2535 PV module which will produce 861 kW in peak and mean total output will be 2897 kWh/day. Yearly production will be 1,057,449 kWh/year. We will add 13 modules in series to get the DC bus voltage 360V (Fig. 9 -12). From wind turbine, the output will be 88% of total generation. Because the location is windy, so the percentage output is more from the wind turbine. We select a wind turbine of 80 kW rated and needs total 38 sets of this. Total rated output will be 3040 kW, and mean will be 1049 kW. Yearly production will be 9,191,799 kWh/year. All the WT will be connected in parallel to the AC bus.

In the case of Battery, we choose 12V and 219Ah battery and we will use total 1200 battery. We add 30 batteries in series which will make the DC bus voltage 360V and synced with PV bus voltage (see Table 1, 2).

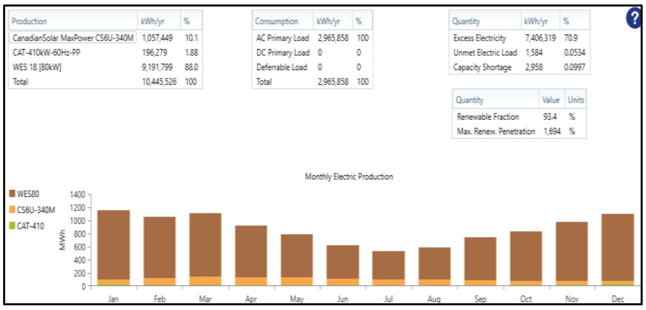

Figure 9: Monthly electrical summary

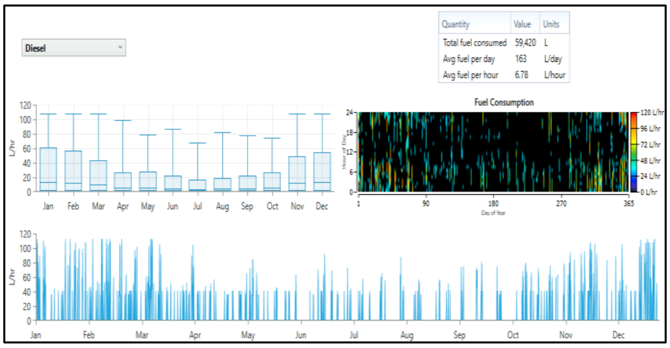

Figure 10: Monthly use of fuel

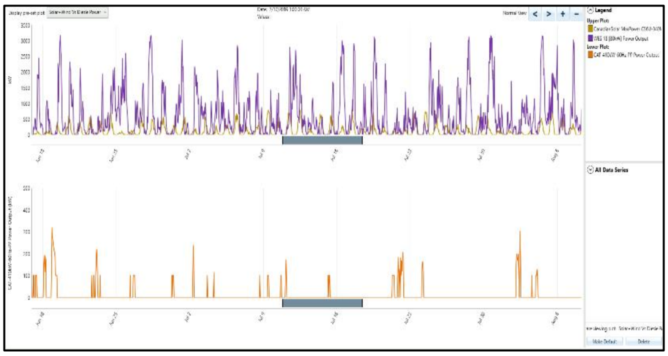

Figure 11: Solar, wind vs generator output in summer

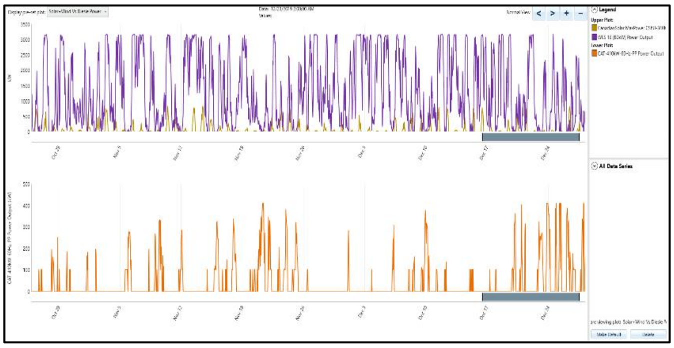

Figure 12: Solar, wind vs generator output in winter

B. *MATLAB Simulation Model*

To get a better understanding we analyze our system through the MATLBA Simulink. We used MPPT controller to utilize our PV systems output and added wind turbine and diesel generator. There we used the same parameters which we used for our HOMER simulation.

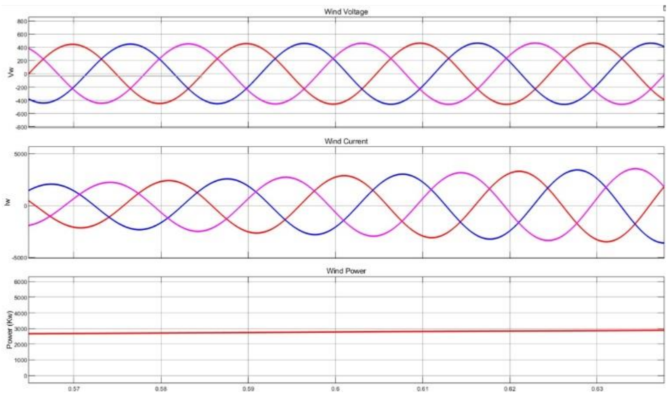

Figure 13: Output of the wind turbine system

This figure illustrates the analysis of the wind turbine's performance, showing waveforms for voltage, current, and power output. The voltage and current plots display consistent three-phase sinusoidal patterns, indicating stable operation across phases, with peak voltage values close to 600 V and peak current values around 500 A. Despite potential variations in wind conditions, the power output remains steady at approximately 3000 W, suggesting that the system includes effective regulation mechanisms to maintain reliable energy production, which is essential for applications that demand a stable power supply.

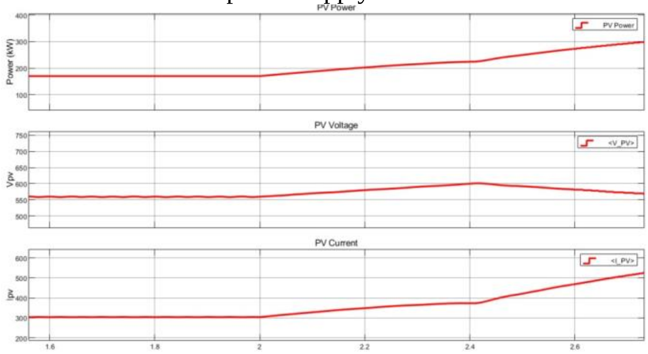

Figure 14: Power, voltage, and current output of the photovoltaic (PV) system

From the above figure, the PV voltage remains relatively stable, fluctuating around 600 V, with minor variations. Meanwhile, the PV current and power show a gradual increase, with power reaching up to approximately 400 kW. This trend indicates that the PV system effectively scales its output based on available sunlight, maintaining consistent voltage while adjusting current to meet energy demands. Such performance stability is essential for reliable power generation in variable environmental conditions.

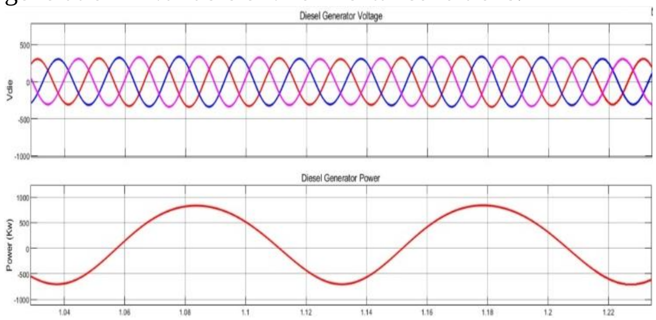

Figure 15: Voltage and power output of diesel generator

The diesel generator voltage exhibits a stable three-phase sinusoidal pattern, with peak values reaching approximately ±500 V. This consistent sinusoidal output demonstrates the generator's steady operation, which follows a sinusoidal pattern with peak values around ±1000 kW, reflecting the generator's dynamic response to load demands. This fluctuation in power output is characteristic of load-following diesel generators, ensuring adaptability to varying power requirements (Fig. 15).

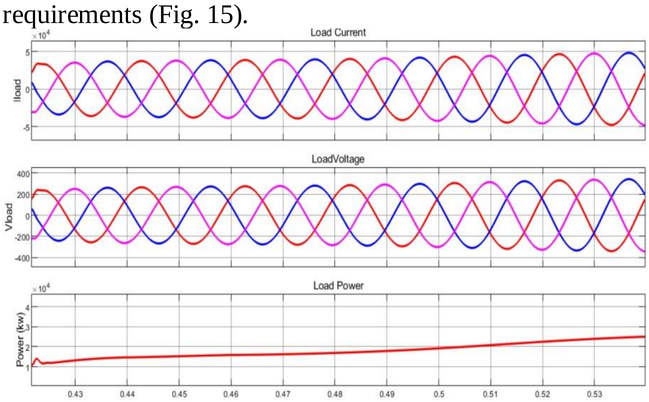

Figure 16: Load voltage, current and power curve

The current and voltage plots display stable three-phase sinusoidal waveforms, with current peaks around ±50,000 A and voltage peaks at approximately ±400 V, indicating a balanced and consistent load operation. In the bottom plot, the load power shows a gradual upward trend, eventually reaching around 10,000 kW, reflecting the system's capability to meet increasing energy demand while maintaining steady current and voltage levels (Fig. 16).

C. *Design of Data Logger SCADA System*

We implemented Supervisory Control and Data Acquisition System (SCADA) to monitor wind and solar system remotely. For that purpose, we used two different Arduino, one is Arduino Uno, and another is Arduino esp8266 Wi-Fi module to send our measured data to cloud and there's two sensors we used ACS712 current sensor and 25V Arduino voltage sensor (Fig.17). In case of cloud, we selected an open source platform "Thingspeak". The could systems allow us to live monitoring of data and logged all the data in each 15sec.

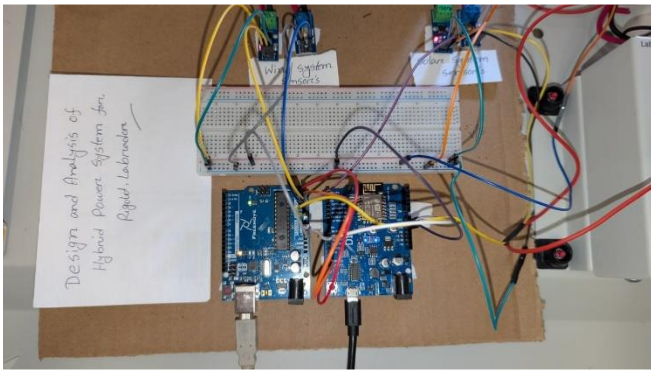

Figure 17: SCADA system setup

This SCADA has been tested on FESTO- 46120 Solar/Wind Energy Training System which included demo wind turbine and solar system (Fig. 18). Arduino Uno log all the measured data from current and voltage sensor and send data to the cloud system through the Arduino esp8266 Wi-Fi module. The open-source platform has the options to read, write and visualize the data set.

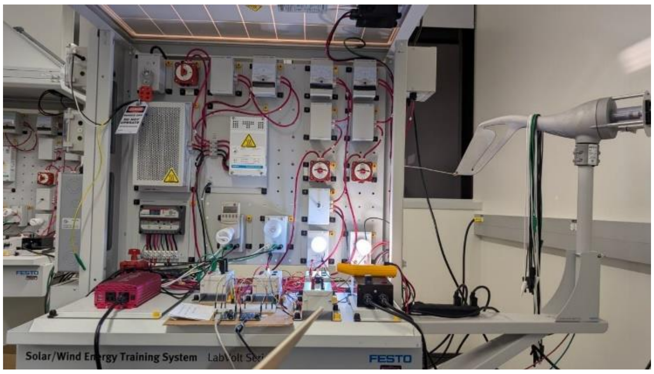

Figure 18: Solar/Wind energy training system

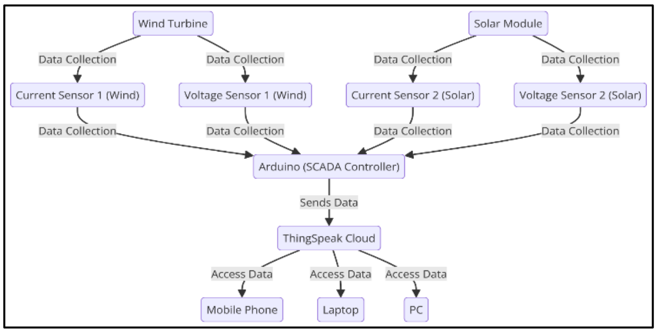

Figure 19: Block diagram of data logger system

The data logger system consists of two current and voltage sensors and each of the voltage and current sensor of wind and solar system. The sensors collect data from wind turbines and solar panels and send them to the Arduino microcontroller (Fig. 19). Then the microcontroller analyzes all data sets and sends those data to the Thingspeak could to store and review later. Following Fig. 20, shows the cloud interface.

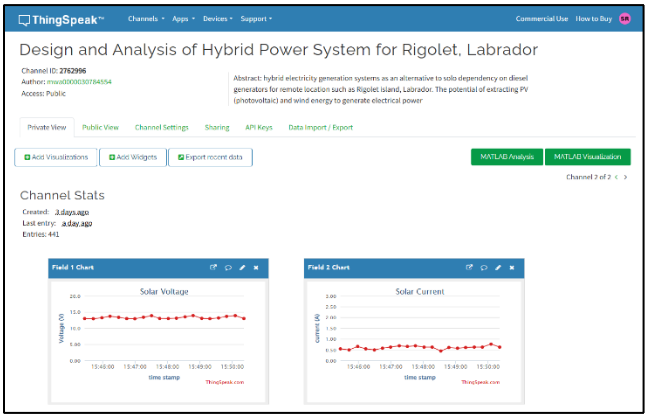

Figure 20: Interface of Thingspeak cloud system

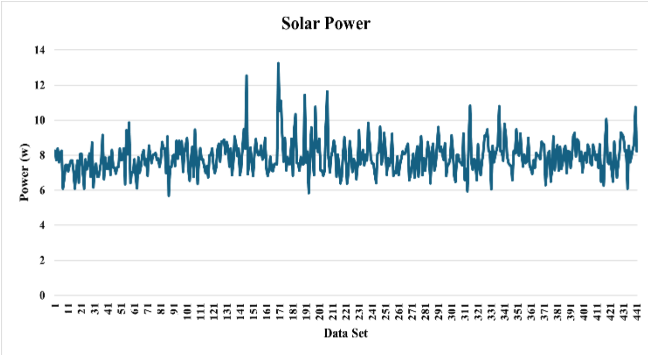

Figure 21: Solar power output based on cloud data

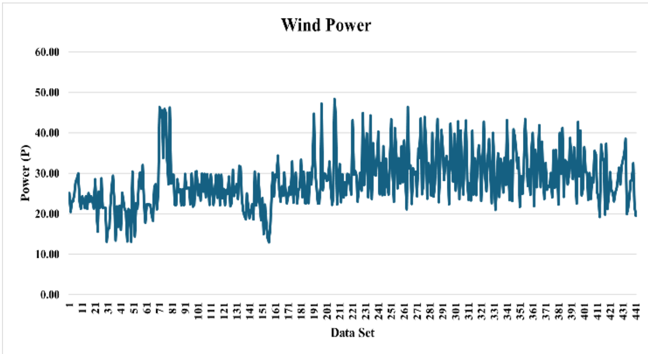

Figure 22: Wind power output based on cloud data

Fig. 21 and Fig. 22, represents the output of solar/wind training energy system which captured through the cloud system. The plot has been created based on 443 data values and shows the average solar power 7.8W and wind energy rises to 28W.

V. CONCLUSION

Our proposed hybrid power system, incorporating wind turbines, solar panels, and a diesel generator, is designed to reduce this reliance on fossil fuels and lower emissions. The wind turbine is projected to supply 88% of the total energy, with solar panels contributing 10.1% and the diesel generator covering the remaining 1.9%. As Rigolet's current energy system demands 835,064 liters of diesel annually to generate

2,823 MWh, leading to CO_2 emissions of 2,238 metric tons per year. So, this hybrid approach not only ensures a reliable power supply throughout the year, even with seasonal fluctuations in solar irradiance, but also offers a substantial reduction in CO_2 emissions and operational costs. Implementing this solution represents a transformative step towards a cleaner, more resilient energy infrastructure for Rigolet.

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