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DESIGN OF A LOW-COST HYBRID SYSTEM FOR A CANADIAN HOME: A CASE STUDY

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***Abstract*—The energy challenge has become the most critical issue in this century, leading to many global conflicts. Solar power is broadly acknowledged as a green technology. A stable and non-outages grid with the lowest cost becomes the target for many people interested in energy, especially after a sharp rise in the regular price of energy. This academic research aims to design a low-cost system for a Canadian home to significantly reduce the power bill of a home in St. Johns, Canada. A house or a small industrial facility can generate enough energy to meet its needs by combining two or three energy sources. In St. John's, Newfoundland, the average yearly wind speed is 6.7 m/s, and monthly average solar radiation exceeds 220 W/m^2. A typical R2000-compliant home uses 68.4kWh per day on average. Many distant dwellings can benefit from hybrid energy systems to generate energy. Photovoltaic and wind power generates electricity by combining solar cells with wind turbines, then integrated into a battery bank. The energy is transferred to an inverter, which produces an alternating current. Before using such energy, significant concerns, such as the input-output relationship, must be considered. A charge controller is required to monitor variations in the energy sources, and a power inverter is needed to convert electric current to alternating current. The economic and geological feasibility is conducted for this case study.**

***Keywords*—Small scale solar system, Small-scale wind turbine, Hybrid-energy system.**

I. INTRODUCTION

As the world's power consumption grows, particularly in developed countries like Canada, the demand for a reliable power supply will continue to drive prices down, making alternative power sources more convenient and practical. One of the essential needs for a hybrid energy system is maintaining a constant power flow by storing excess energy from renewable sources. A hybrid energy system operating on such alternative technologies with a renewable source could be a viable option for small-scale power generation [1-4]. A site-specific analysis is required to analyze the associated cost, component size, and overall economics because the performance and efficiency of a hybrid energy system are largely dependent on environmental circumstances. A hybrid energy system comprises a primary renewable energy source that works in tandem with a secondary non-renewable module and storage units. The desire for cleaner energy and progress in alternative energy technology promise well for their widespread adoption. However, the biggest challenge for such system adoption is the economic aspects which include but are not limited to component pricing, availability in the market and maintenance of renewable energy system [5]. In addition, systems that rely on battery modules for energy storage are subjected to replacing the batteries at regular intervals. The research methodology will follow an all-inclusive study of the energy demands of a typical home in St. Johns, Newfoundland, and Labrador.

A hybrid system will be designed and simulated with the help of Homer in such a way that the proposed hybrid model can deliver close to 70% of the total energy demand through renewable energy sources. The simulated model will be validated on PVSyst with economic aspects and various conditions; the proposed model will be subjected throughout the proposed system's lifetime, keeping the components' availability in mind. This includes but is not limited to system performance during the variation in sun path, system performance during rain precipitation and maintenance cost analysis. Hybrid systems were considered, and each segment's progress was measured based on network illumination data, unique load bends, and local atmospheric conditions. HOMER software was used for this assurance. The main objective of this analysis was to ensure that the financial and environmental calculations were made while obtaining at the same time the best development of the hybrid power arrangement at the lowest rate of fuel necessary for the load demand. The straightforward micro grid approach increases the on-grid zone's use of neighboring renewable energy sources. The development is indicated using HOMER programming related to the scope and nature of energy change technologies used by neighboring renewable energy sources. The Cost of Energy is a significant variable right now. The PV framework's primary purpose is to supply electrical loads with capacity. Depending on the purpose, the load may be AC or DC in type and require power solely during the day, only at night, or consistently throughout the day. The annualized lifecycle coasting method estimates the lifetime cost of the electrical energy produced by a solar PV system. HOMER programming is utilized for framework reproduction and enhancement. This improvement's perception of the remote location's resources shows how the power age depends on various non-conventional energy sources and diesel generators. Therefore, we used HOMER software to obtain the best augmentation of the hybrid energy scheme [5].

II. ENERGY DEMAND

The energy demands in a Canadian home are vastly varied according to seasons. During the summer, energy is used for air-conditioning; during winter, more energy is consumed for heating. This causes a rapidly changing monthly energy demand curve.

A. Load Data – Collection and Analysis

For the project, electric load data was collected from a single-family home in St. Johns, Canada, from 2020-2022 (Table 1). Based on the energy bill collected, the average monthly energy demand was collected and tabulated to plot the monthly average energy demand curve as in Figure 1. An average load demand trend table was created based on the power bill. This load data generates the load curve, which was later imported to Homer. The spike in energy demand from November to April is the winter months in St. Johns. The peak energy demand was during March, and the minor energy consumption was during the month of August. The load assessment is a crucial stage in this study's definition of the sizes of the system parts.

Table I. Annual energy consumption

Month	Monthly Average (kW)	Daily Average (kW)
January	2053	2.76
February	2083	3.10
March	2326	3.13
April	1463	2.03
May	1011	1.36
June	716	0.99
July	551	0.74
August	520	0.70
September	754	1.05
October	710	0.95
November	1212	1.68
December	1796	2.41

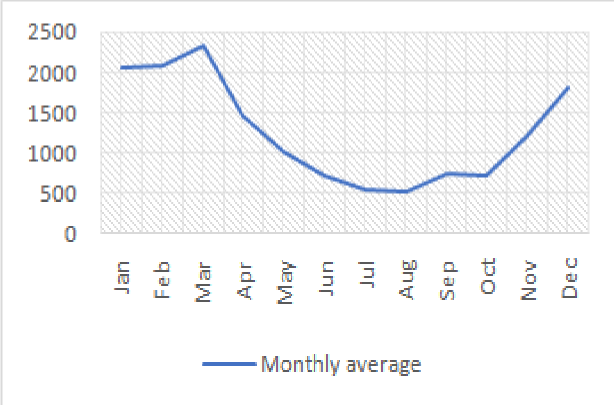


Figure 1. Annual power consumption trend

B. Available Resources at the Proposed Location

The proposed hybrid model system should contribute one or more renewable energy resources. For the location of St. Johns, the renewable energy resources available at the site of the province is

1. Wind energy
2. Solar energy
3. Micro-Hydro

The home under study is on Freshwater Road, St. Johns, Newfoundland and Labrador, Canada. This location has high wind speed and a moderately good amount of solar irradiation as the location is situated in northern hemisphere. But the geographical location doesn't have any flowing water resources like small brooks or other flowing water facilities that can be used to deploy a micro-hydro system. Rerouting the closest water resources is not feasible as it is situated more than two kilometers away as per the data based on research conducted. Hence only two common renewable energy resources can be used for this proposed location. As per the data in the Homer database, the average airspeed at the proposed site is 9.3ms-1, which is comparatively high and the average solar irradiation at the proposed location is 3.14 kWh/m2/day, as shown in Table II and Figure 3.

Table II. Average wind speed in St. Johns, Canada

Month	Average wind speed (ms^{-1})
January	10.86
February	10.73
March	10.31
April	8.92
May	8.33
June	8.29
July	7.94
August	7.62
September	7.68
October	8.89
November	10.08

December	11.12

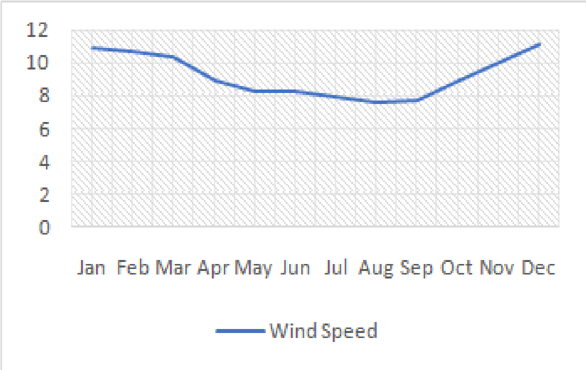


Figure 2. Graphical average wind speed distribution in St. Johns, Canada

Figure 2 indicates the average wind speed during the winter months is higher, which will aid the electricity production using wind turbines during the winter months to meet the overshoot in the demand curve winter months. At the same time, the average solar irradiation is higher from April to late August, when the average daily solar irradiation is more than four kilowatts per square meter.

Table III. Average daily solar irradiation in St. Johns, Canada

Month	Clearness index	Daily irradiation
January	0.434	1.28
February	0.479	2.11
March	0.501	3.31
April	0.465	4.18
May	0.439	4.74
June	0.444	5.14
July	0.437	4.88
August	0.455	4.39
September	0.447	3.31
October	0.426	2.15
November	0.389	1.27
December	0.403	1.02

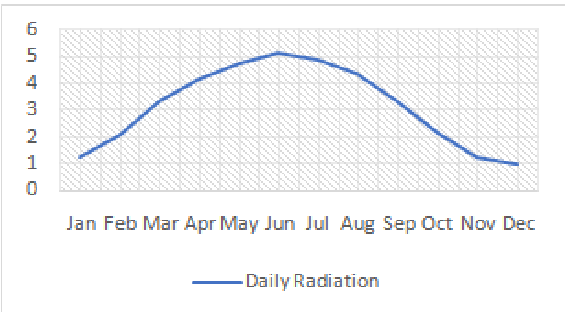


Figure 3. Graphical average daily solar irradiation in St. Johns, Canada.

III. MODEL SIMULATION IN HOMER

Homer software - an industry-standard tool for enhancing micro grid design across all industries is used to design and simulate the proposed hybrid system. HOMER calculates the overall cost of building and running the system during its lifetime while simulating the physical behavior of a power system. Users can interactively compare design solutions based on their technical and financial advantages thanks to its graphical user interface. The three primary functions of HOMER are simulation, optimization, and sensitivity analysis. Chronological simulations are finished over a year for the variety of micro-grid systems that the user specifies. The best system size and control approach with the lowest net current cost is then found using HOMER. The impact of model assumptions and input parameters on system robustness is made through sensitivity analysis.

C. Load Curve in Homer

As per the load data collected, the hybrid system location was set to St. John's, Newfoundland and downloaded the wind and solar data for the site to Homer. The load design data was imported from data collected in Table I and adjusted the load profile hourly to meet the household energy demand curve with peak load during the evening hours and valley load during mid-day, as shown in Figure 4.

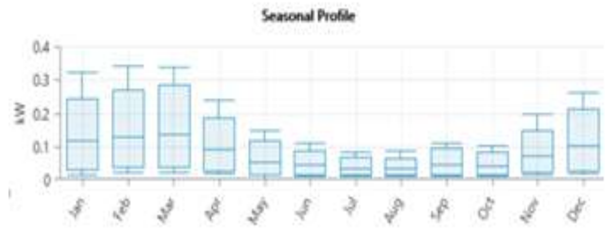


Figure 4.Load design in Homer

D. Hybrid System Components

As per the load data collected, the hybrid system consisting of two two-kilowatt small-scale wind turbines and a one-kilowatt solar panel module with a battery backup was designed and simulated in Homer as shown in Figure 5. Since the power generation is in direct current, the system requires a converter to convert the energy produced in direct current and energy stored in a battery to supply the AC loads of the home. The model parameters were designed to keep the cost of the hybrid system minimum. The proposed system should also meet at least 70% of the total demand by the proposed system. The cost parameter limits other features of the hybrid system, such as hours of autonomy. Hence the proposed system will be able to deliver the bare minimum on the hours of autonomy.

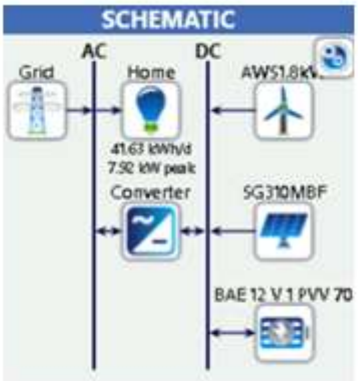


Figure 5. Schematic diagram for the proposed model in HOMER

E. Identification of Low-Cost Materials and Economic Aspects

The cost of the significant components of the proposed hybrid system is listed below. In addition to the cost of components, other miscellaneous investment costs are also to be considered [6-8].

1. 1.8 kW Wind turbine – Australian Wind and Solar 1.8kW - CAD4242
2. 1kW Solar panels – Peimar SG13 - CAD600
3. Lead Acid battery – BAE Secur a 70 - CAD800
4. Converter – SPF 5000 ES sine wave solar inverter – CAD300
5. Tower Wiring Kit – CAD1500
6. Shipping & Delivery – CAD2000
7. 250' Wire Run – CAD600
8. Electrical Contractor – CAD1375
9. Misc. Costs – CAD500
10. Building Permit – CAD500
11. Sales Tax -CAD400

Once the suitable wind turbine was identified, the power curve was obtained from the wind-turbine data sheet, and the power curve was updated in the model, as shown in Figure 13.As per the load data collected, the hybrid system location was set to St. John's, Newfoundland and downloaded the wind and solar data for the site to Homer. The load design data was imported from data collected in Table I and adjusted the load profile hourly to meet the household energy demand curve with peak load during the evening hours and valley load during mid-day, as shown in Figure 4. PV panel orientation is set to zero azimuth with a slope according to the study area's latitude. A straightforward flat plate display is evaluated without considering tracking or temperature effects. The HOMER software was used to access solar radiation data from the Climatological Solar Radiation database of the National Renewable Energy Laboratory. To reflect the reuse of the mounting bracket, the replacement cost is 20% cheaper than the initial cost. The range of capacities was 0 kW to 3 kW. The nominal capacity of the Trojan T-105 battery is 1.35 kWh, and its average lifetime throughput is 845 kWh. To maintain DC bus voltages of 6 V, 12 V, 24 V, or 48 V, the 6 V battery was modelled as a battery bank with battery quantities of 0, 1, 2, 3, 4, 6, 8, 12, 16, and 24 grouped in strings. Once the suitable wind turbine was identified, the power curve was obtained from the wind-turbine data sheet, and the power curve was updated in the model, as shown in Figure 6.

F. Homer Simulation Results

The proposed hybrid system was designed and simulated in Homer. Among the results yielded, one had more practical reliability, providing power from multiple reliable sources simultaneously, grid integration and lower economic cost of installation. Figure 7 signifies the proof of energy delivered by the proposed system is more than 70% of the total demand

can be provided by the proposed renewable energy hybrid system. As per the simulated results the solar module has solar penetration of close to 32% of the total demand, whereas the wind turbines have a wind penetration of 75%.Table IV shows that the total power bill can be reduced by over 80% between May and August as the power purchasedfrom the grid can be reduced to less than 200kWhr on average. Saving a small amount over time has a more significant substantial effect, which can save a considerable amount of money throughout the project's lifetime, estimated to be fifteen years apart from the battery.

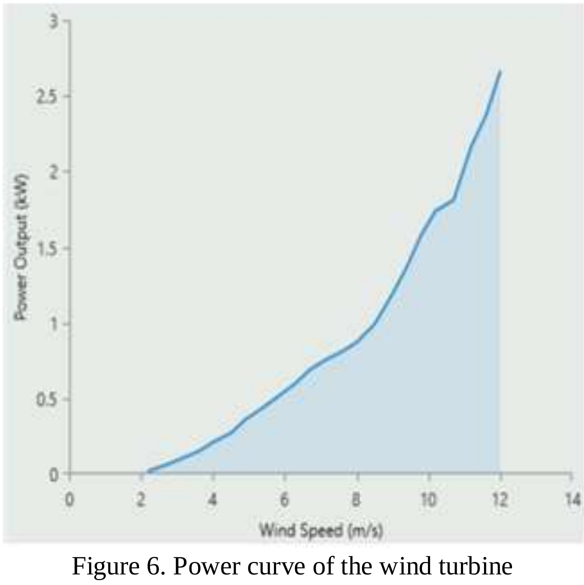


Figure 6. Power curve of the wind turbine

Figure 7. Monthly electricity production

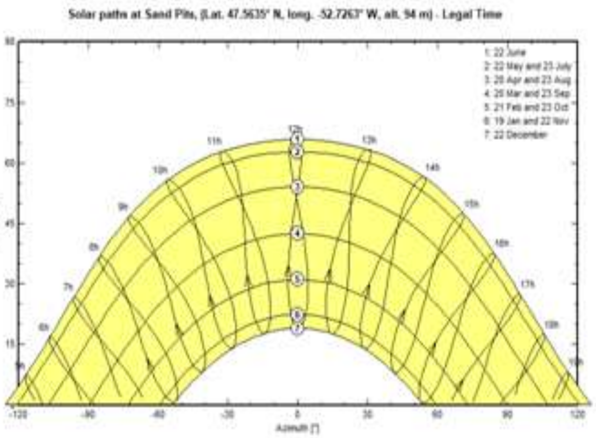


Figure 8. Sun path diagram for St. Johns

Table IV. Grid usage and anticipated power bill

Month	Energy Bought (kWh)	Energy Sold (kWh)	Net Bought (kWh)	Peak Load (kW)	Energy Charge ($)
Jan	1,243	387	856	7	$104.9
Feb	1,247	399	848	8	$104.7
Mar	1,437	463	974	7	$120.5
Apr	735	575	160	5	$44.73
May	372	726	-353	3	$0.90
Jun	214	797	-583	2	$18.41
Jul	137	883	-746	2	$30.44
Aug	145	863	-718	2	$28.69
Sep	264	692	-428	2	$8.20
Oct	223	763	-540	2	$15.86
Nov	565	523	41	5	$30.30
Dec	1,034	409	625	6	$82.92
Total	7,615	7,479	136	8	$387.5

IV. PVSYST SIMULATION AND RESULTS

After choosing the suitable system elements to meet the load power requirements. The PVSyst software application simulates solar and load parameters and is used to design the proposed system. The PVSYST software is the sole foundation for this research project.This software uses models for modelling purposes.

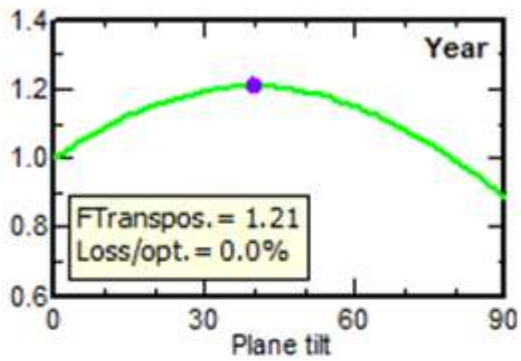


Figure 9. Solar orientation – Plane tilt with fixed axis for St. Johns

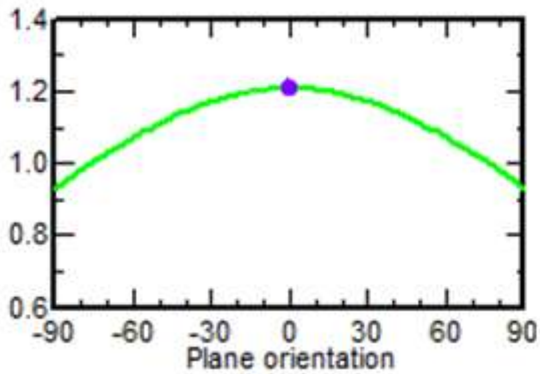


Figure 10. Solar orientation – Plane orientation with fixed axis for St. Johns

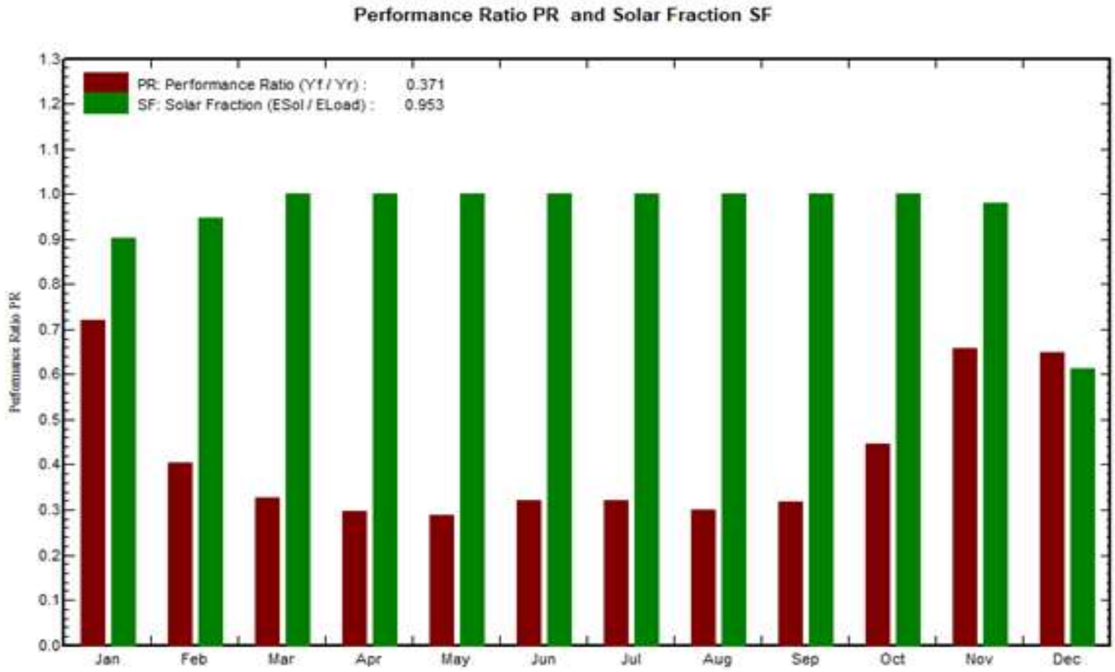


Figure 11.Performance ratio and solar fraction for the proposed system

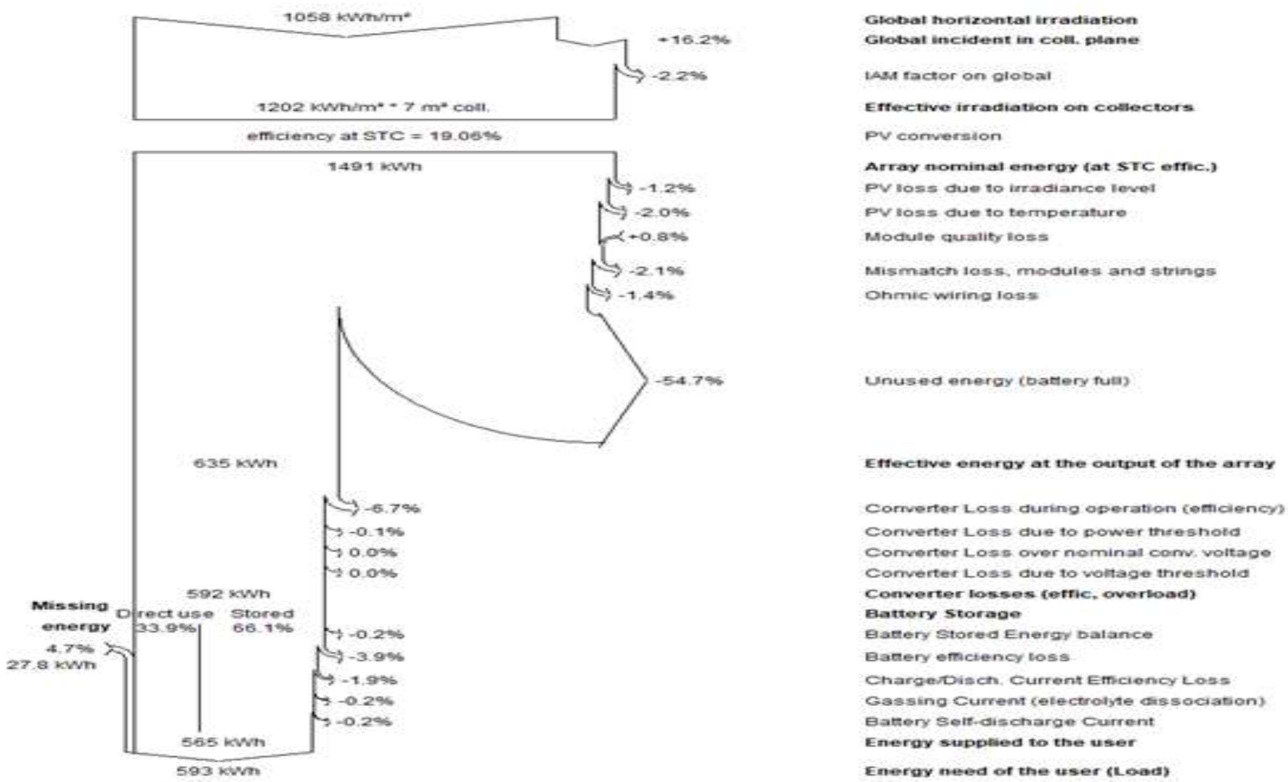
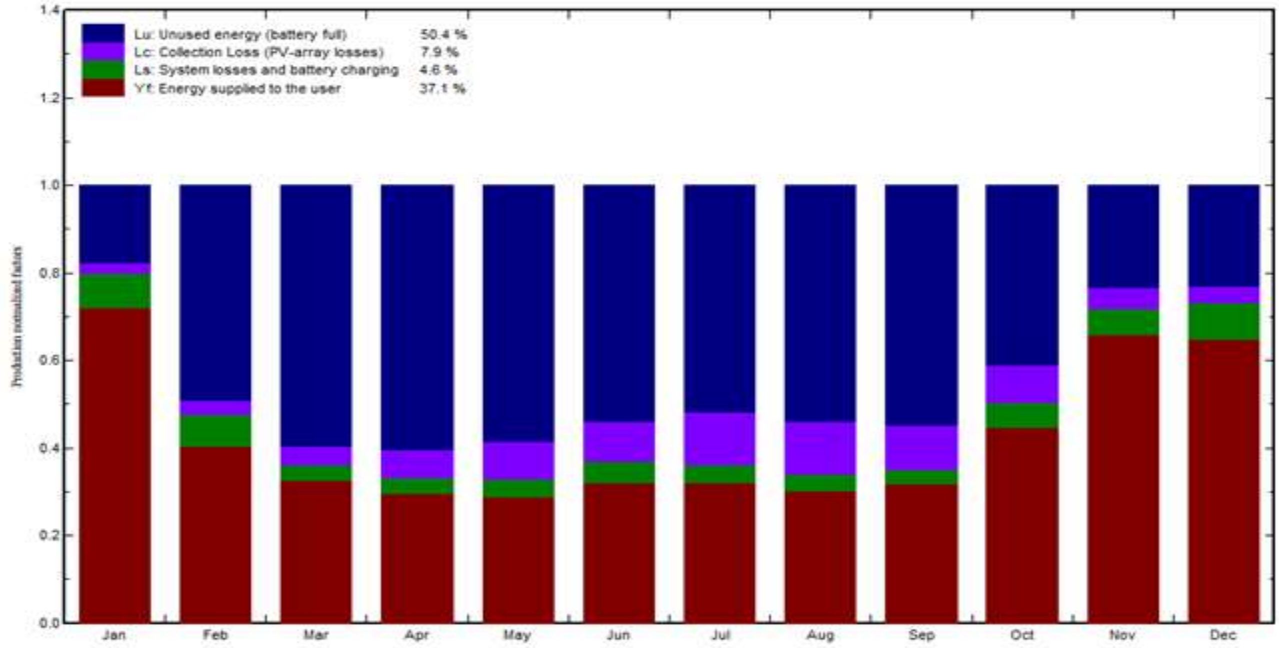
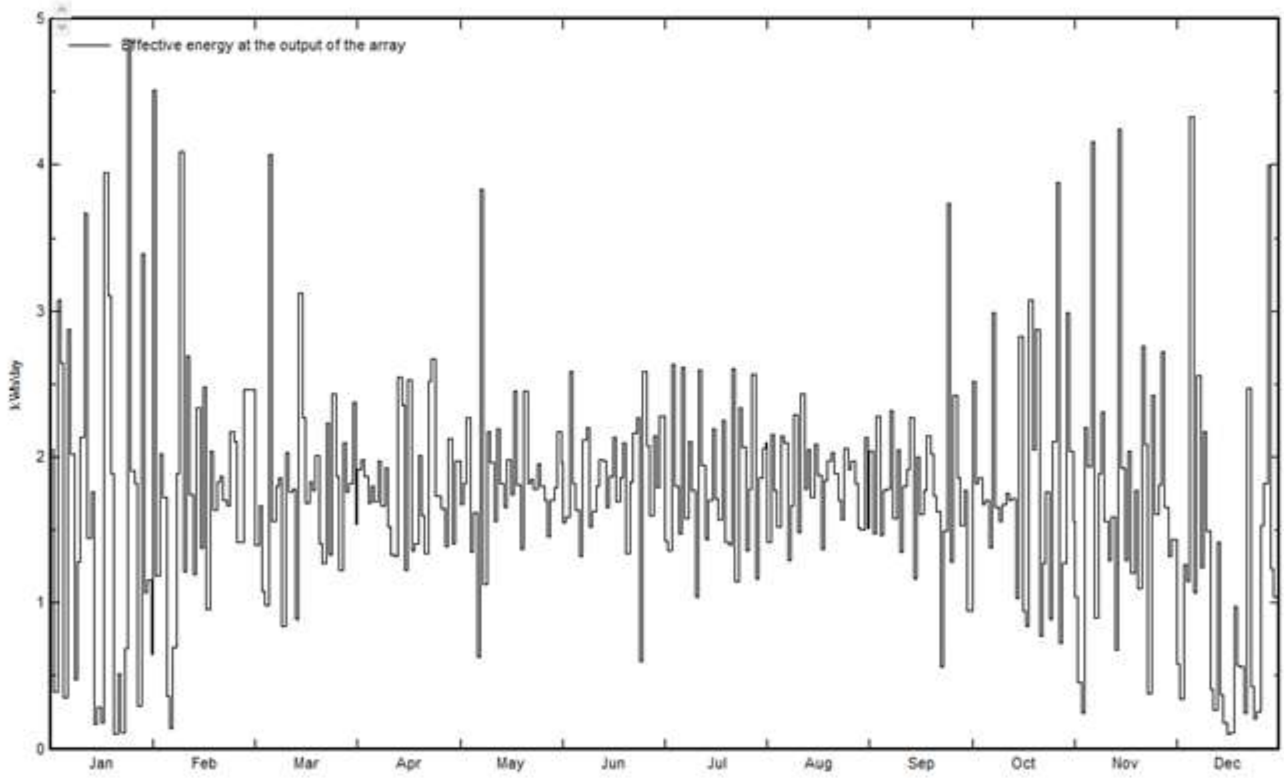


Figure 12.Loss diagram of the proposed system

Normalized Production and Loss Factors: Nominal power 1240 Wp



Daily Array Output Energy



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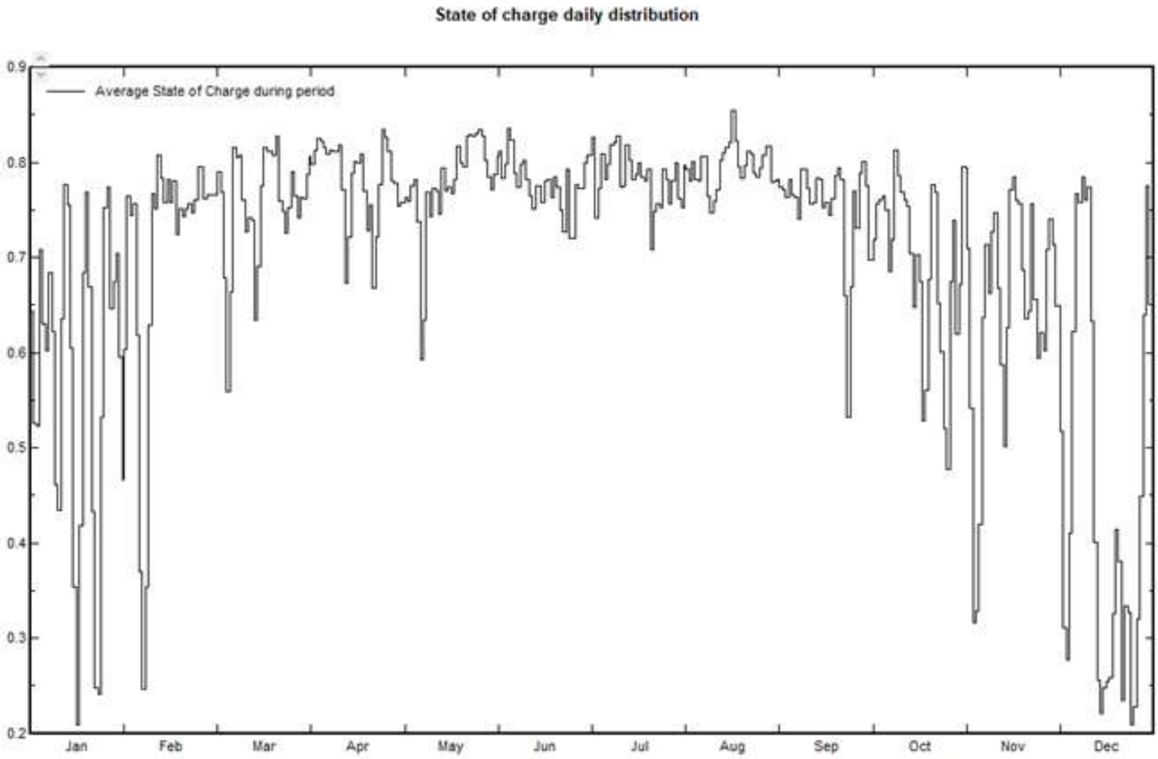

Figure 13.Normalised production and loss factors for the proposed system

The simulation process used to create the figures and tables in this research was limited to the Newfoundland site. Because computational modelling is the focus of this research, we solely offer the simulation results in place of a description.
The steps in PVSyst simulation are as follows –

1. Choose geographical site
2. Import load data needs
3. Set PV module's optimal orientation (tilt and azimuth)
4. Selection of PV module and battery
5. Choose system controller
6. Simulation and results

The Figure 8, Figure 9 and Figure 10 shows the sun path in the proposed location; in winter, the sun height is low at solar point 7 (22 December) and higher in summer at solar point 1 (22 June). Figure 11 presents the available energy produced by the solar system and system efficiency from solar is 37.1%. System efficiency is an important term to know for solar systems [9]. Figure 11 also indicates the solar fraction of the system, which is the energy supplied by the PV array divided by the energy used. Figure 12 shows the system's losses concerning components and weather changes. The losses due to PV modules, battery efficiency, and inverter efficiency are present in Figure 12.The loss diagram displays each loss that arises in the system sequentially. The system produces 592 kWh of energy at the output. The PV plant's performance is assessed using the performance ratio (PR). The system's performance ratio measures the relationship between energy output and radiation incidence in a specific area, as displayed in Figure 11. It is acceptable for a system this size because it hovers around 0.4 for most months in a year [10-15]. Following several software loss corrections, as shown in Figure 12, the output energy to the load is obtained. Figure 13 depicts the system's daily energy output. The system's daily energy output fluctuates because of ongoing changes in solar radiation, the surrounding temperature, and wind speed. Figure 14 describes the battery state of charge variation annually.

V. CONCLUSION

The results shown are for specified parameters, which can vary for individual customers and from area to area. The economically feasible system was identified, which will meet the load demand constantly. Given the load curve, the proposed micro-hybrid system will at least 70% of the customer's total need. The proposed system is not dependent on a single renewable energy source so that due to any foreseen weather scenario, it does not affect the overall renewable energy production. Adding a micro-hydro system was an attractive solution, but the customer's location was not feasible to incorporate a micro-hydro system. The proposed system was simulated in Homer and PVSyst to see the performance of the recommended plan, and the results were verified to make sure that it would meet the demands. Integrated techno-economic development of a typical grid integrated hybrid energy system is presented. In this context, the configuration and model details of the proposed hybrid energy system are described first, including the battery storage system and the electronic devices. Considering the extensive results, a hybrid energy system may be a cost-effective electrification solution for numerous consumers. The techno-economic feasibility study of hybrid energy systems demonstrates that these systems can theoretically reduce generation costs and increase the reliability of energy supply. The operation and upkeep of the electricity system, as well as managing the collection of fees from each family, will be handled by locals, which may be used for maintaining the system's sustainability. On top of this, subsidy possibilities –granted by the ministry of power – should significantly increase the economic attractiveness of similar electricity production applications.

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