# Design and Simulation of a Hybrid Power System for St. Lewis in Labrador

Yuet Sing Li, Mohammad Bahrami, Mohammad Faraji Nejad, and Mohammad Tariq Iqbal

***Abstract* — St. Lewis is one of the isolated communities situated in Newfoundland and Labrador (NL). The easternmost province of Canada includes over seven thousand small islands with scattered populations. It brings various challenges to the electricity power supply companies, such as power outages and long resumption times due to the remote locations. Currently, three sets of diesel generators are supplying the electricity. The site is vulnerable to power outages if there is any malfunction of the generators or failure of the fuel supply through the trucks. Introducing an alternative energy source to the community can increase energy security and ensure livelihood for the residents. By utilization of the renewable energy, Greenhouse Gas Emission of rural communities can be largely reduced. This research aims to demonstrate St. Lewis as the epitome of hybrid renewable energy systems among those remote communities and the feasibility of alternative energy solutions for those communities.**

***Keywords* — HOMER Pro, Homer QuickStart, Hybrid Renewable Energy System, Reopt Web Tools, Simulink.**

## I. Introduction

Across the globe, numerous rural areas, suburbs, and countryside are located far away from the electric grid system, and for electricity, they rely on Diesel Generators (DGs). This method of electricity generation is costly, as the DGs require gasoline for operation and monthly maintenance [1]. Therefore, a new approach to energy production for such areas seems necessary. One such area is St. Lewis, a community on the coast of Labrador in Newfoundland and Labrador, Canada. The population was 185 in the 2021 Census [2]. Three diesel generators are used to produce electricity in St. Lewis, and the electricity consumption of this area is 1,461,675 kWh per year. To produce the required electricity, 408,568 litres of diesel is consumed annually. This electrification solution causes some problems, such as maintenance costs and emitting environmental contaminants [3].

In this research, we use renewable energies like solar and wind to address power needs. Homer Pro is used to design a hybrid power system. In this hybrid system design, we use batteries for power without solar and wind resources during days with bad weather. Then we will use MATLAB to analyze the control and protection of this hybrid system in the next stages. The system design is verified by software other than HOMERPRO, such as REOPT and Homer QuickStart.

## II. Literature Review

Several scholars have studied the use of renewable energy systems in different countries. Most of them focused on using PV, wind turbines, battery and designing, analyzing and evaluating the feasibility of different hybrid power systems in different combinations.

In 2019, Gebrehiwot evaluates the feasibility of a hybrid system to electrify an isolated rural Ethiopian community. The findings indicate that the most advantageous alternative from an economic standpoint is a hybrid system that combines a solar array, wind turbine, battery, and diesel generator [4]. In 2020, Jinze Li and his team attempted to use a case study of a village in West China to establish the techno-economic viability of an off-grid hybrid renewable energy system for remote rural electrification. According to the findings, a hybrid power system that combines solar, wind, and biomass energy is a dependable and affordable choice for environmentally beneficial remote rural electrification [5]. To reduce the amount paid to the grid, Khalil and his colleagues created a hybrid system for the Baluchistan Seashore in 2020. This system integrates wind, solar, and converter components into the system. The results demonstrated significant reductions in operation costs (66405 M$/Year) and pollutant gas emissions (64%) [6].

Adebanji and his team investigated the viability of adding a small hydropower system to an existing water supply dam in 2020 and created an ideal sizing optimization model for the Nigerian hamlet of Itapaji. The created hybrid power system (HPS) type includes a diesel generator, battery, modest hydropower, and solar photovoltaic system, and it will act as a guideline for power system engineers as they examine the viability of HPS and create the best design for rural electrification [7]. Fodhil in his research from 2018, provides a methodology for an autonomous hybrid PV-diesel-battery energy system's optimization and sensitivity analysis [9]. Hutasuhut plans to schedule the operation of a hybrid power plant diesel/photovoltaic/micro-hydro in Rumah Sumbul In order to find the most efficient system combination that can meet the needs of a continuous electrical load in 2022, and the diesel/micro-hydro combination is also more cost-effective [9]. In 2022, Jinze Li presented a case study of a village in West China to demonstrate the techno-economic feasibility and adaptability of hybrid renewable energy systems for rural electrification in both off-grid and on-grid modes.

Submitted on December 06, 2022.
Published on January 18, 2023.
Y. S. Li, Memorial University of Newfoundland, Canada.
(e-mail: ysli@mun.ca)
M. Bahrami, Memorial University of Newfoundland, Canada.
(e-mail: mbahrami@mun.ca)
M. F. Nejad, Memorial University of Newfoundland, Canada.
(e-mail: mfarajinejad@mun.ca)
M. T. Iqbal, Memorial University of Newfoundland, Canada.
(e-mail: tariq@mun.ca)

TABLE I: COMPARISON TABLE OF RESEARCH

| No | Author, Year | Method | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | PV | Wind | Battery | Generator | Hydropower | Software | Area |
| 1 | Gebrehiwot, 2019 | ✓ | ✓ | ✓ | Diesel | - | HOMER Pro | Ethiopian |
| 2 | Jinze Li, 2020 | ✓ | ✓ | - | Biogas | - | HOMER Pro | China |
| 3 | Khalil, 2020 | ✓ | ✓ | ✓ | Diesel | - | HOMER Pro | Pakistan |
| 4 | Adebanji, 2020 | ✓ | ✓ | ✓ | Diesel | ✓ | HOMER Pro | Nigerian |
| 5 | fodhil, 2018 | ✓ | - | ✓ | Diesel | - | HOMER Pro | Algeria |
| 6 | Hutasuhut, 2022 | ✓ | - | - | Diesel | ✓ | HOMER Pro | Indonesia |
| 7 | Jinze Li, 2022 | ✓ | ✓ | - | - | - | HOMER Pro | China |
| 8 | Balachander, 2020 | ✓ | ✓ | - | Diesel | - | HOMER Pro | India |
| 9 | fodhil, 2021 | ✓ | - | ✓ | - | ✓ | HOMER Pro | Iraq |
| 10 | Chaichan, 2022 | ✓ | ✓ | ✓ | - | - | HOMER Pro | Thailand |
| 11 | Kumar, 2021 | ✓ | - | ✓ | - | - | HOMER Pro | India |
| 12 | Hoque, 2021 | ✓ | ✓ | - | Diesel | - | HOMER Pro | Bangladesh |
| 13 | Abdul-Wahab, 2019 | ✓ | ✓ | - | Natural Gas | - | HOMER Pro | Oman |

The findings show that for sustainable rural electrification, a hybrid renewable energy system of solar, wind, and biomass is reliable and affordable [10]. Balachander and his team attempted to improve the hybrid electrical power network in 2020 to supply the electrical load of a residential unit in Coimbatore, Tamil Nadu. The pattern of energy consumption required and provided for various electrical uses by the PV/Wind/Diesel Generator (DG) combination is taken into consideration when determining the load shape of the home [11]. The viability of a compact hybrid electrical Micro-hydro/Photovoltaic/Battery supply system for road illumination is being investigated by Natiq Abbas Fadhil in 2021 [12]. In order to replace the external grid power system on the institute campus in Kurukshetra, Kumar will attempt to economically develop a hybrid power system in 2021. This research examines a hybrid solar photovoltaic, fuel cell and battery system [13]. For a rural location in Bangladesh, Hoque tried to build and optimize a hybrid energy system that is both affordable and sustainable in 2021. By using renewable energy sources to offset 88.7% of the load demand, the improved system lowers $CO_2$ emissions by 89.17% [14]. Abdul-Wahab examines the potential for a hybrid energy system made up of solar photovoltaics (PV), a wind turbine, and a natural gas generator to replace or enhance Masirah Island's present diesel generation system to fulfill the island's rising electrical demand. The simulation's findings revealed that a mix of wind turbines, natural gas, and diesel generators would be the best choice [15].

The researchers found that using renewable energies and designing hybrid power systems have lots of economic benefits and help to reduce air pollution. They also compensate for the initial expenditure in a long run. Fig. 1 can demonstrate several research, renewable energy combinations and the selected countries.

## III. METHODOLOGY

This research utilizes different engineering software to simulate and design the hybrid system. Based on location information on Google maps and using geographical studies on NL hydro website, it is determined that the most practical approaches to electricity generation are wind and solar systems. Well-known software such as Homer, Emex ESG & EHS Software, and Watch Wire is widely used in the commercial market for designing a hybrid energy system. In this paper, we use Homer pro as a main software and to confirm the design the Homer QuickStart and REopt software's are used. Homer pro software can accommodate the amalgamation of various renewable resources like Wind, Solar and hydro in the model, after Modeling the system and creating the structure of the whole system, MATLAB Simulink will be used to study the dynamic response of the whole system with the control section and the impact of different scenarios. The signal response will be studied in SIMULINK to see the effect on the control scheme. In addition, the transient state of the whole system can be simulated under SIMULINK. This way, the stability, reliability, and practicality of the system will be examined.

## IV. HOMERPRO DESIGN

### A. Electrical Loading Consumption

Since the electricity consumption in this community is not provided by Newfoundland Hydro, the electricity profile is projected by using the preset profile of a residential household and scaling to the total number of households at St. Lewis. In addition, the peak power and the annual power consumption are obtained from the provincial government. Hence, the projected electricity profile shown in Fig. 1 can be considered a reasonable assumption after entering all the above parameters of the system components and pinpointing the installation location at St. Lewis. HOMERPRO will search for the optimal solution in the space of the different constraints, such as wind speed and solar irradiance, during days with undesirable conditions. The following are the optimization results after considering all the feasible solutions in the space.

### B. System Details

System sizing is done by HOMERPRO, along with the financial analysis of the hybrid system. HOMERPRO is an excellent sizing tool for any energy system with a vast built-in database comprising various wind turbines, solar panels, and converters in the market.

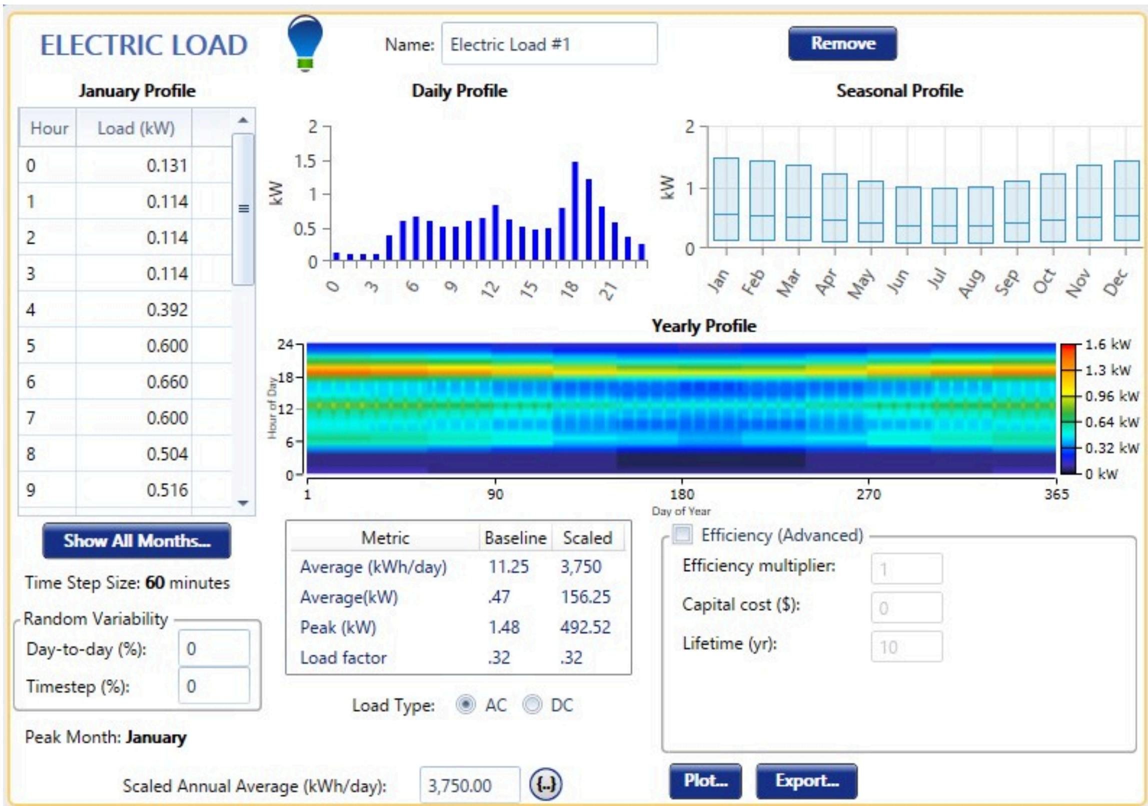


Fig. 1. Electrical loading profile in HOMERPRO.

TABLE II: COMPONENTS SIZING DETAILS IN HOMERPRO

| Components | Rating | Sizing Input | Capital | Replacement | O&M ($/year) |
|---|---|---|---|---|---|
| PV Panels (CS6U-330P) | 330W | 25 yrs lifetime | $300 | $170 | $10 |
| Wind Turbine (WES250) | 250kW | Lifetime: 20 yrs<br>Hub Height: 48m | $0.5M | $0.45M | $0.35M |
| Battery (SAGM 12 205) | 12V 263kWh | String Size: 66 | $555.4 | $450 | $50 |
| Converter (Sinexcel 500) | 500kW | 1 unit | $90k | $60k | $3k |
| Diesel Generators (Cat C Series) | 400kW | 1 unit | $0 | $25.5k | $40 (hourly) |
| | 350kW | 1 unit | $0 | $27k | $35 (hourly) |
| | 250kW | 1 unit | $0 | $29.2k | $25 (hourly) |

Fig. 2 is the HOMERPRO Schematic. It shows the connection between the different components. The PV system connects the DC busbar and charges up the battery. The existing diesel generator sets, and the wind turbine are connected to the AC busbar. The converter is used to convert the DC power to the AC busbar.

The Photovoltaic (PV) system adopts Canadian Solar MaxPower with the model CS6U-330P. This model is selected because it is one of the popular brands and is generally available in the retail market. In addition, the wind turbine used in the study is WES 30 (250kW). This rating is selected because the loading has 492.55kW. The capacity of the wind system is around half of the total wattage. Moreover, it is a well-known brand in the retail market with extensive household wind power project examples across North America. Both brands can provide adequate maintenance support, another important selection criterion for the hybrid system. The retail price on the internet, the Capital and replacement cost can be estimated.

The same approach is made for the other components of the hybrid system, such as power converter, wind turbines and other miscellaneous components. The calculation is made on the assumption that there are no government incentives provided.

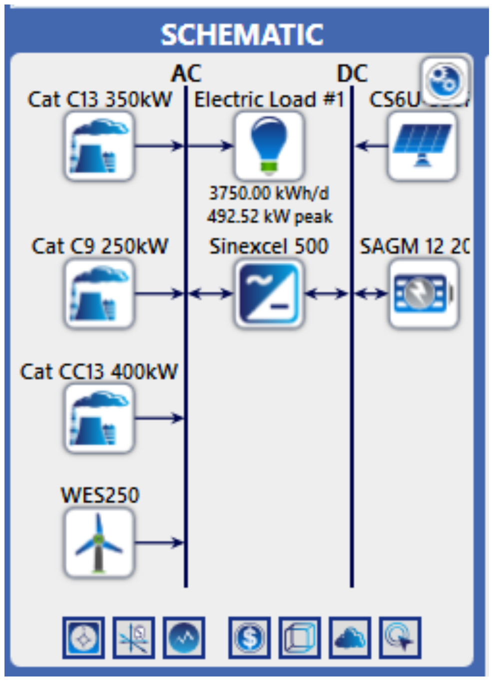


Fig. 2. Schematic of hybrid system in HOMERPRO.

The generator sets are assumed as three sets with a total capacity of 1000 kW. The sizing details of all components are demonstrated in Table II. Three sets of generators are deployed since the total capacity of the generator sets is 1020 kW, and an assumption is made that it is not solely a generator supplying the network. The power ratings of all the components are readily available in the market and are used for sizing.

### *C. Sizing Result*

Economically, the return period of the entire system is 25 years. the initial project cost is CAD$2.27M with a Net present cost of CAD$6.27M, which shows the above combination is the most economical solution. The overall system includes a PV system with 708 panels, two units of wind turbines with a rating of 250 kW, and a power converter with a 500kW rating.

Regarding electrical analysis, the total annual demand load in St. Lewis is 1,368,750 kWh/year. The wind turbine is the primary power contributor to the proposed system generating 1,028,407 kWh/year, which is 53.2% of total power production. The PV system contributes 783,170 kWh/year, 40.5% of the total generation, while the existing diesel power plants contribute 1,22,678 kWh/year, which only accounts for 6.3% of the total generation. It indicates the possibility of phasing out the diesel generators and employing them as the stand-by generation source for backing up the hybrid system. The renewable energy fraction of the hybrid system is 91.0% which indicates that a significant part of electricity is generated through renewable resources evenly throughout the year. This setup produces excess electricity of 478,589 kWh/year, 24.7% of total power generation. Surplus energy will be converted and stored in the battery storage system to avoid power interruption when the generation changes from renewable resources to fossil fuels. The battery storage system with an autonomy of 13.3hr shows that the system can supply the electric load for 13.3 hours during a power outage. If renewable resources are unavailable and the battery system is drained, the diesel generators will be utilized for supplying the electric load.

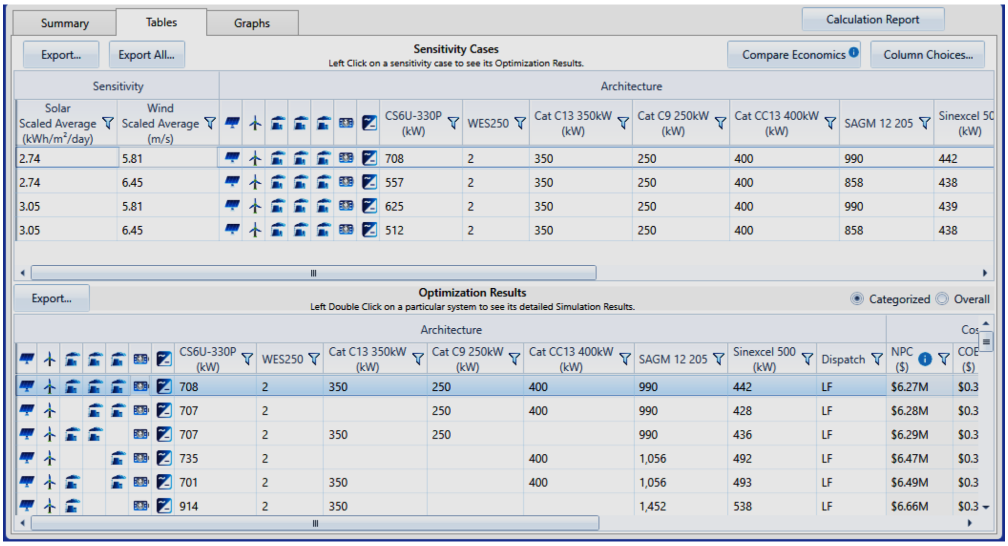



Fig. 3. Optimized hybrid system in HOMERPRO.

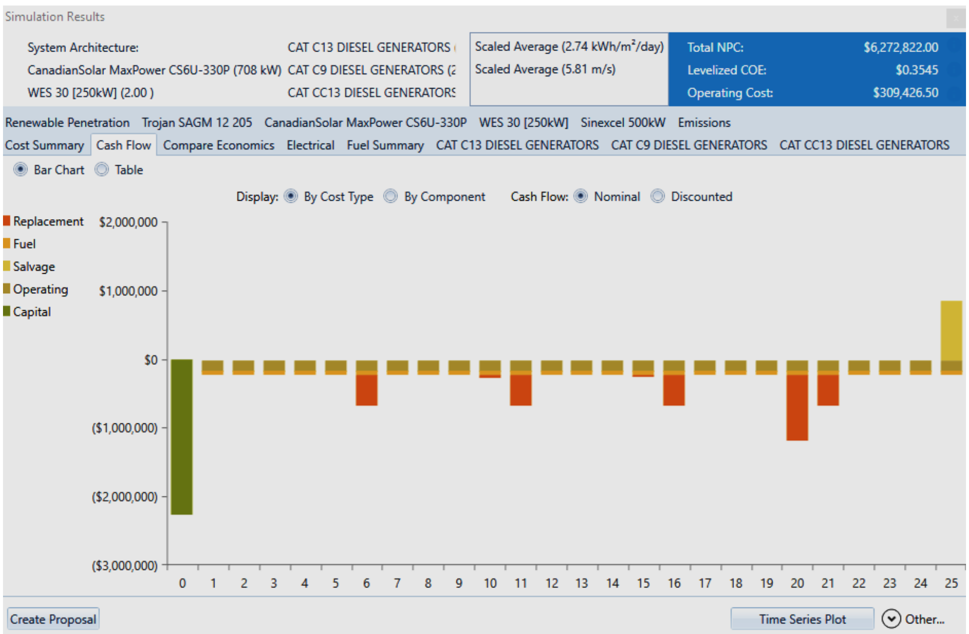



Fig. 4. Financial Analysis in HOMERPRO.

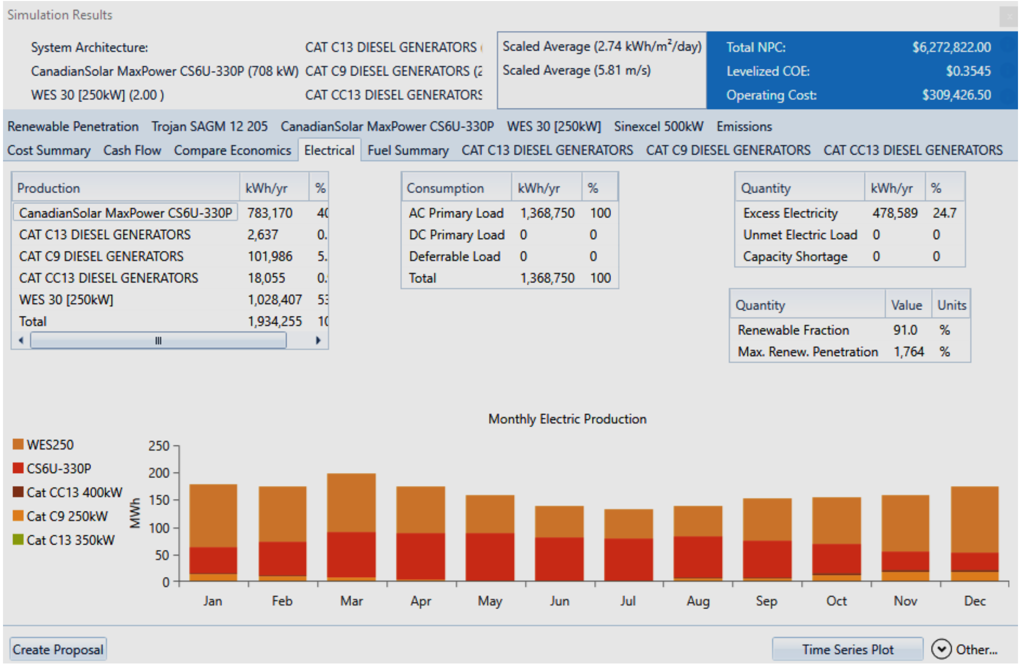
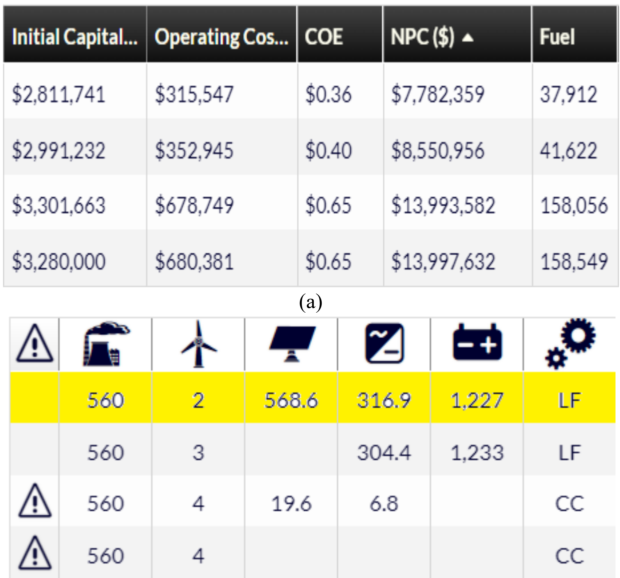



Fig. 5. Electrical analysis in HOMERPRO.



| Initial Capital... | Operating Cos... | COE | NPC ($) ▲ | Fuel |
|---|---|---|---|---|
| $2,811,741 | $315,547 | $0.36 | $7,782,359 | 37,912 |
| $2,991,232 | $352,945 | $0.40 | $8,550,956 | 41,622 |
| $3,301,663 | $678,749 | $0.65 | $13,993,582 | 158,056 |
| $3,280,000 | $680,381 | $0.65 | $13,997,632 | 158,549 |

(a)

| | | | | | | |
|---|---|---|---|---|---|---|
| | 560 | 2 | 568.6 | 316.9 | 1,227 | LF |
| | 560 | 3 | | 304.4 | 1,233 | LF |
| ⚠ | 560 | 4 | 19.6 | 6.8 | | CC |
| ⚠ | 560 | 4 | | | | CC |

(b)

Fig. 6. Homer QuickStart results: (a) Cost detail; (b) Hybrid system configuration.

## V. System Verification

### A. Homer QuickStart

The second tool to size the system parameters and analyze the financial aspects of the model is Homer QuickStart. Homer QuickStart is an online tool for designing a powerful hybrid system with multiple energy resources. It is somehow like HOMERPRO energy and has the same features. However, in terms of device variation and input availability, HOMERPRO is more powerful and resourceful software. However, this online tool is very handy to use. It does not complicate as HOMERPRO therefore, to get an idea or a budget in a short time for a particular project, this software proved to be very efficient.

In order to make our model in Homer QuickStart comparable to HOMERPRO, we tried to use the same component. In case there is not an identical device, the most similar one is considered. Moreover, for overall similarity, all components are placed in the same bus. For example, the P.V. panel is connected to the D.C. BUS, and the Wind turbine is connected to the A.C BUS. The same configuration allows us to compare results accurately. This way, by comparing the results of different software, we will be able to decide which component is eligible to exist in the model and which one is not. Also, in terms of the financial aspect, the best configuration is achieved more accurately. Due to some shortage in accessibility to location and resource profile, the load profile was imported from homer pro software. Thus, the resource inputs like irradiation and wind profile are identical to the setting in the HOMERPRO.

After entering all the above parameters of the system components and depicting the exact installation location, Homer QuickStart will search for the optimization solution within the space of the different constraints, such as wind speed, solar irradiance, and loading peak during extreme conditions. Fig. 6a shows the optimization results after considering all the feasible solutions in the space and Fig. 6 (b) illustrates the final configuration of hybrid system. In this configuration the power generators are diesel generator, PV, and wind turbine. As it is notable, this suggestion is also the more cost-effective solution. Software suggested more than 10 different configurations and in each of them, one mean of electricity generation is absent. However, in the first suggested configuration, all generators are present and interestingly, this model in terms of Net Percent Cost (NPC) is also the cheapest one. So, our choice is the first row which is highlighted as well.

TABLE III: Homer QuickStart System Architecture

| System architecture | | | |
|---|---|---|---|
| PV | Generic flat plate PV | 477 | kW |
| Wind Turbine | XANT L-33 | 2 | - |
| Generator | Auto size Genset | 560 | kW |
| Storage | Generic 1 kWh Lead Acid | 934 | Stings |
| Converter | Studer XTH 3000-12 | 228 | kW |
| Dispatch | Homer Load following | - | - |

As mentioned above, this software is limited component availability compared to Homer pro. Therefore, it is impossible to use the same component for each part. However, based on the datasheet of each element, it is tried to opt for the most similar aspect. The final architecture is shown in Table III shows the power of the total numbers of each component. The diesel generator in the software was limited to less than ten types; therefore, for the best result, the closest type to the HOMERPRO was chosen.

TABLE IV: ELECTRICAL PROFILE OF THE SYSTEM

| Electrical information | | |
|---|---|---|
| Quantity | Value | Units |
| Excess electricity | 1,833,799 | kWh/yr |
| Unmet load | 0 | kWh/yr |
| Capacity shortage | 0 | kWh/yr |
| Renewable percent | 86 | % |
| Component | Production (kWh/yr) | Percent |
| PV | 533,151 | 16 |
| Generator | 197,210 | 6 |
| Wind Turbine | 2,529,828 | 78 |
| Total | 3,260,189 | 100 |

As Table IV illustrates, the total excessive electricity produced in a year is almost 1,834 kWh, and 86% of this electricity comes from renewable energy, which is acceptable for our model. The breakdown of the system based on each component is illustrated in Table IV. It is considered that almost 78% of the total green energy comes from the wind, which is major electricity production means, followed by P.V. by the production of 16% of the whole electricity. The diesel generator is responsible for only 6% of total energy production, which is considerably low. Therefore, it is notable that the entire system is functioning based on renewable energies, and our model is a good fit for the area with lack of fuel accessibility.

Fig. 7 visualizes the information given in Table III. Wind energy is the major electricity producer in our system for all months for almost more than 70%. The second major producer is PV, and Genset is, by far, the lowest production burden.

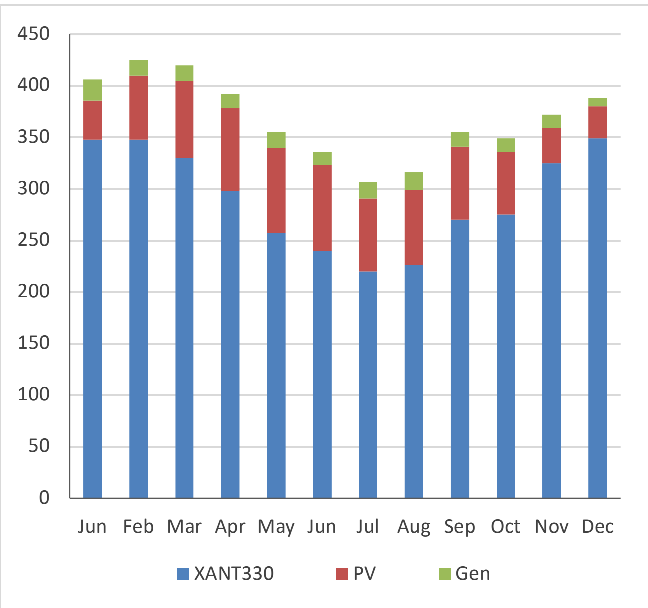



Fig. 7. Production burden graph based on each generator.

TABLE V: P.V. SYSTEM DETAILS

| Quantity | Value | Units |
|---|---|---|
| Rated capacity | 477 | kW |
| Mean output | 61 | kW |
| Mean output | 1460.69 | kWh/d |
| Capacity factor | 12.75 | % |
| Total production | 533,151 | kWh/yr |

The total rated capacity of the P.V. panels is 477 kW. The model of the panels, as mentioned in Table III is a generic flat P.V. panel. This is the only option for the panel in this software. This means that the total burden on P.V. panels for electricity generation is calculated, and it is up to the designer to choose the model and brand of units. As Table V illustrates, the total operation hour is 4394 h per year, and based on the location of St; Lewis, this is normal. Because the area is mostly cloudy and there is not enough solar irradiation to increase the P.V. production. That is why the software suggests using two wind turbines.

TABLE VI: WIND TURBINE SYSTEM DETAILS

| Quantity | Value | Units |
|---|---|---|
| Total rated capacity | 660 | kW |
| Mean output | 289 | kW |
| Capacity factor | 43.76 | % |
| Total production | 2,529,828 | kWh/yr. |
| Minimum output | 0.00 | kW |
| Maximum output | 670.00 | kW |
| Wind penetration | 184.83 | % |

The total rated capacity of each turbine is 330 kW, and together they produce a maximum of 660 kW as shown in Table VI. The model of the turbines is XANT L-33 330 kW. This type of turbine possesses the nearest features to the Homer pro setting. The system opts for two small-size wind turbines rather than one big turbine, which is reasonable in case of maintenance. The wind turbine is the best renewable energy means of production in the community. This site is wind-rich, and wind blowing is always the main climate feature. Therefore, the expectation of high energy production from the wind system is not unusual.

### 1) *Cost Analysis*

The software conducts the cost analysis. The results are shown in Fig. 8.

As Fig. 8 illustrates, the most capital consumer is the wind turbine, but in the long run, it has lower other costs like operation and maintenance. However, the P.V. panels seem to be the best option for electricity generation as it only needs capital cost and no other lateral expenses. Although the Genset has the lowest capital, the system's fuel price seems relatively high.

The initial cost of our model is almost 2.5 million, with is better than the model suggested with Homer pro. The other significant prices are replacement and fuel costs. The location is separate from the mainland, which can considerably increase the fuel rate. Therefore, the cost of fuel in the long run for 25 years is rather high. For 25 years, the price to provide secure electricity for the area is 7.3 million dollars.

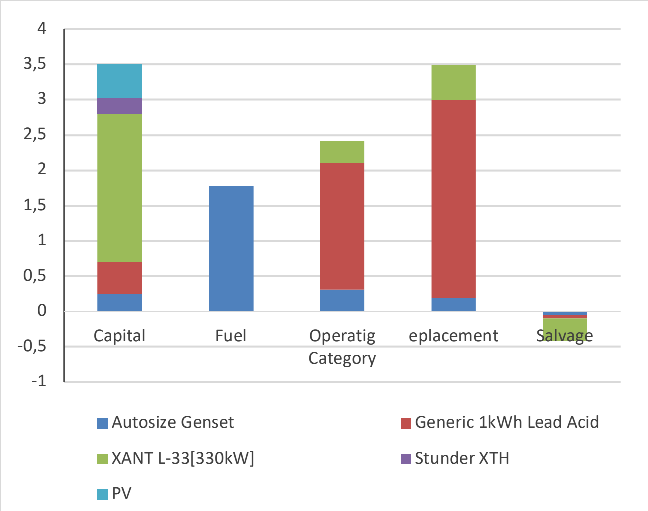



Fig. 8. Cost analysis.

## B. REopt

Users can assess the economic feasibility of distributed PV, wind, battery storage, combined heat and power (CHP), and thermal energy storage using the REpot online application. Estimating how long a system can support a critical load during a grid outage and determining system sizing and dispatch strategies to minimize energy expenditures are also helpful. Applications for this software include developing thorough operating plans for dispatchable energy assets and assessing the possibilities for renewable energy on-site portfolios. We also choose this software to design a hybrid power system and compare the result of these three software. By using REopt, we have a grid option to choose wind, and after applying wind, there is not possible to use diesel generators.

Considering the annual energy charge 0.16 $/kWh and the annual demand charge of 18 $/kW/month. The analyzing period is for 25 years. The system capital cost for PV is 1,592 $/kW-DC. The energy capacity cost for the battery is 388 $/kWh, and the power capacity cost is 775 $/kW. The chosen wind turbine is midsize (101-999kWh), and the system capital cost is 2,766 $/kW. The result shows that recommended solar installation size is 304 kW of direct current. The recommended wind installation size is 260 kW of alternating current. The recommended battery power and battery capacities are 269 kW and 779 kWh. The results show how doing business as usual compares to the optimal case. Table VII demonstrates the results of the REopt software.

TABLE VII: COMPARISON TABLE OF RESEARCH

| Items | Business as Usual | Financial | Difference |
|---|---|---|---|
| Pv Size | 0 kW | 304 kW | 304 kW |
| Wind Size (Midsize) | 0 kW | 260 kW | 260 kW |
| Battery Power | 0 kW | 269 kW | 269 kW |
| Battery Capacity | 0 kWh | 779 kWh | 779 kWh |
| Technology Capital Cost + Replacements, After Incentives | N/A | $1,158,112 | $1,158,112 |
| O&M Costs | $0 | $182,469 | $182,469 |
| Total Utility Electricity Cost | $3,683,839 | $955,834 | -$2,728,006 |

The net present value of the savings realized by the project based on the difference between the total life cycle costs of doing business as usual compared to the optimal case is $1,387,424. Table VIII shows the summary of financial metrics.

TABLE VIII: FINANCIAL MATRIX

| Items | Business as Usual | Financial | Difference |
|---|---|---|---|
| Total Upfront Capital Cost Before Incentives | N/A | $1,713,387 | $1,713,387 |
| Year 1 O&M Cost, before tax | $ 0 | $ 14,261 | $ 14,261 |
| Total Life Cycle Costs | $ 3,683,839 | $ 2,296,415 | -$ 1,387,424 |
| Net Present Value | N/A | $1,387,424 | $1,387,424 |
| Payback Period | N/A | 5.91 yrs | 5.91 yrs |
| Internal Rate of Return | N/A | 15.3% | 15.3% |
| PV Levelized Cost of Energy | N/A | $ 0.062/kWh | $ 0.062/kWh |
| Wind Levelized Cost of Energy | N/A | $ 0.038/kWh | $ 0.038/kWh |

By using the REopt software, we have some default input for 25 years analysis period which is showed in Table IX. The results are based on the following default data.

TABLE IX: DEFAULT INPUT FOR 25 YEARS ANALYSIS PERIOD

| Financial | |
|---|---|
| Analysis period (Year) | 25 |
| Host discount rate, nominal (%) | 5.64% |
| Host effective tax rate (%) | 26% |
| Electricity cost escalation rate, nominal (%) | 1.9% |
| O&M cost escalation rate (%) | 2.5% |
| Third party ownership | false |
| Third-party owner discount rate, nominal (%) | 5.64% |
| Third-party owner effective tax rate (%) | 26% |

Using renewable energies reduces air pollution, which causes health disorders. In Table X, the emissions reduction and climate emissions cost reduction which helps to protect the environment.

TABLE X: CLIMATE AND HEALTH EMISSION

| Items | Business as Usual | Financial | Difference |
|---|---|---|---|
| Total $CO_2$ Emissions in Year 1 | 1,190 Tons | 256 Tons | -934 Tons |
| Percent Reduction in $CO_2$ Emissions from BAU | N/A | 78.46% | 78.46% |
| Lifecycle Costs of Climate Emissions | $1,109,741 | $239,083 | -$870,658 |
| Lifecycle Costs of Health Emissions | $869,628 | $192,754 | -$676,874 |

## VI. SIMULINK ANALYSIS

Under the Simulink environment, the transient and dynamic response of the hybrid system can be tested with the control schemes to study the overall performance of the hybrid system. Apart from the control scheme, loading switching is also introduced in the Simulink model. It simulates that during severe weather conditions, electricity consumption is surging. It is a prevalent case, especially during the Wintertime. For the proposed system, the PV array transforms solar irradiance into electrical power. Also, the wind turbine system transforms the wind energy of the wind turbine into electrical power. To provide the steady-state output for various changes in input parameters, such as wind speed, solar irradiation, and load demand, suitable control measures should be implemented in the proposed system to maintain the system's stability against any potential changes in the previously mentioned parameters. Fig. 9 shows the Simulink model and detailed block diagram of each major component diesel generator, PV system and wind turbine system. The control block for the respective system and the theory behind it will be explained. In the proposed system, the PV array transforms solar irradiance into electrical power. Also, the wind turbine system transforms the wind energy of the wind turbine into electrical power. To provide the steady-state output for various changes in input parameters, such as wind speed, solar irradiation, and changes in the load demand, suitable control measures should be implemented in the proposed system to maintain the system stability against any potential changes in the previously mentioned parameters.

## A. PV System

PV array transforms the solar irradiance into electrical power, which is optimized by Maximum Power Point Tracker (MPPT) and the PV system block diagram detail is shown in Fig. 10. MPPT controls the PV array output using the incremental conductance method described in the flowchart in Fig. 11.

The MPPT algorithm utilizes the incremental conductance method with the battery charge control function of the battery storage. When the charge control signal is off, the output value of the duty cycle depends on the value of $VdI + IdV$. If the value is positive, the duty cycle will be increased; if the value is negative, the duty cycle will be decreased; if the value is zero, the duty cycle will remain unchanged. Equation (1) (2), and (3) translate the above logic algebraically.

When the charge control signal is off, the duty cycle will be switched to a value corresponding to the minimum PV output. Fig. 19 shows the PV array output power examined after changes in solar irradiance. It has been noted that output power is stable and steady when solar input changes refer to Fig. 12 with time. It implies that the control scheme is performing satisfactorily. Apart from MPPT, the inverter is controlled using PID controllers and closed-loop control.

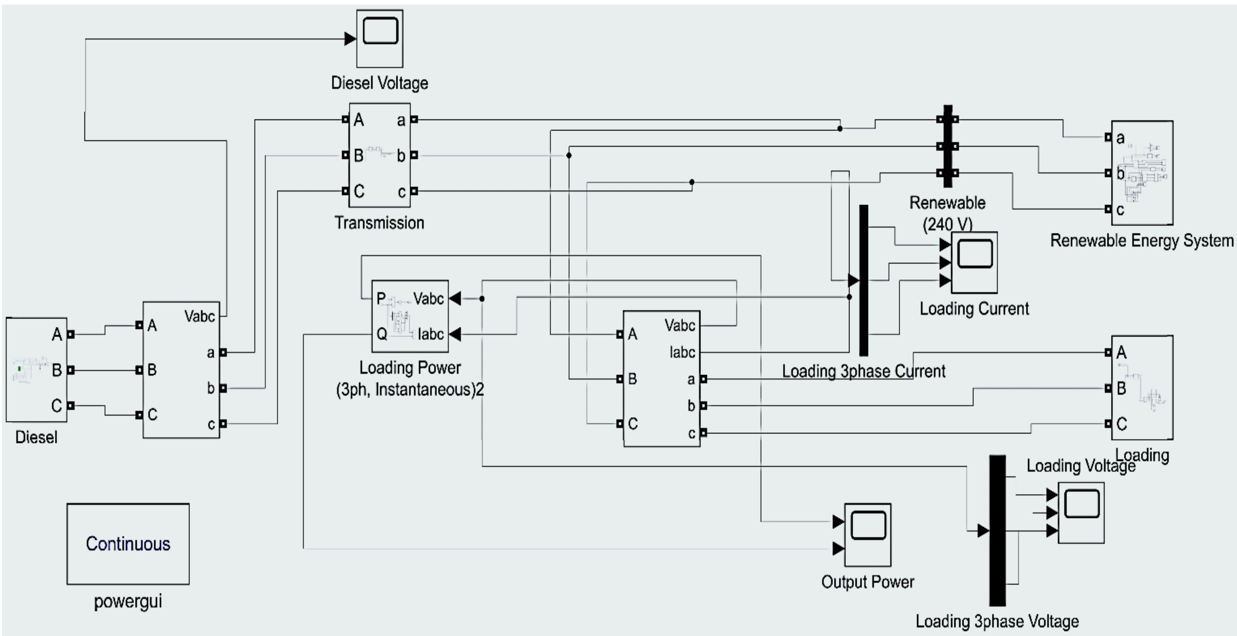



Fig. 9. Overall hybrid system.

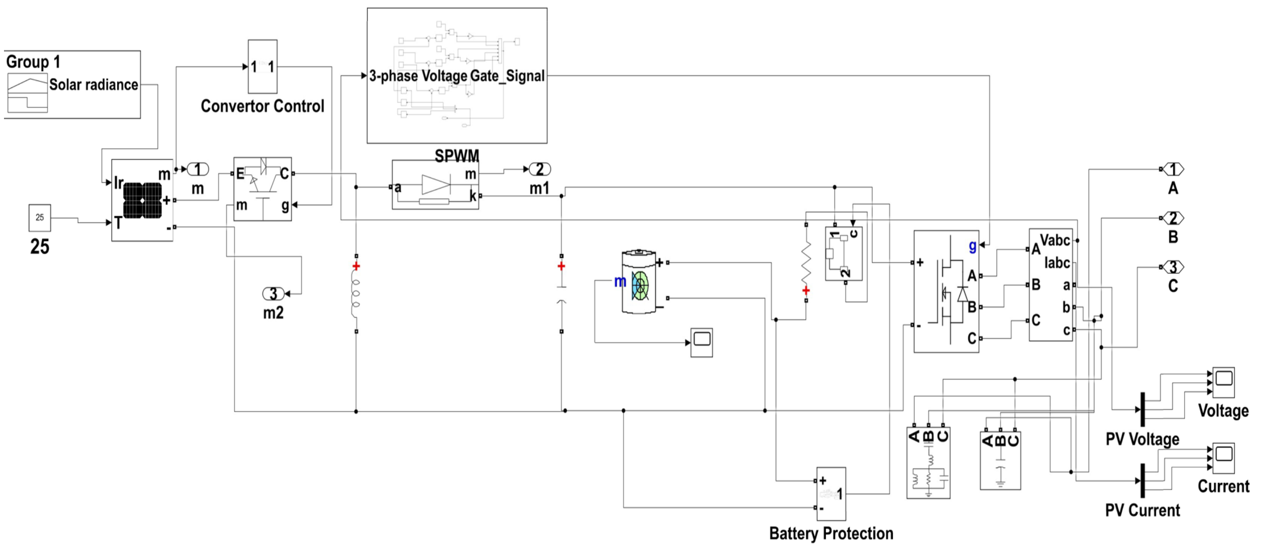



Fig. 10. PV system with battery.

The battery module is connected to the PV system, the same connection as the HOMERPRO. The PV system is connected to the DC bus. The battery protection system is implemented as shown in Fig. 13. The protection will prevent the battery system from overvoltage and Undervoltage.

$$\frac{d_i}{d_v} = -\frac{I}{v} \quad (1)$$

$$\frac{d_i}{d_v} > -\frac{I}{v} \quad (2)$$

$$\frac{d_i}{d_v} < -\frac{I}{v} \quad (3)$$

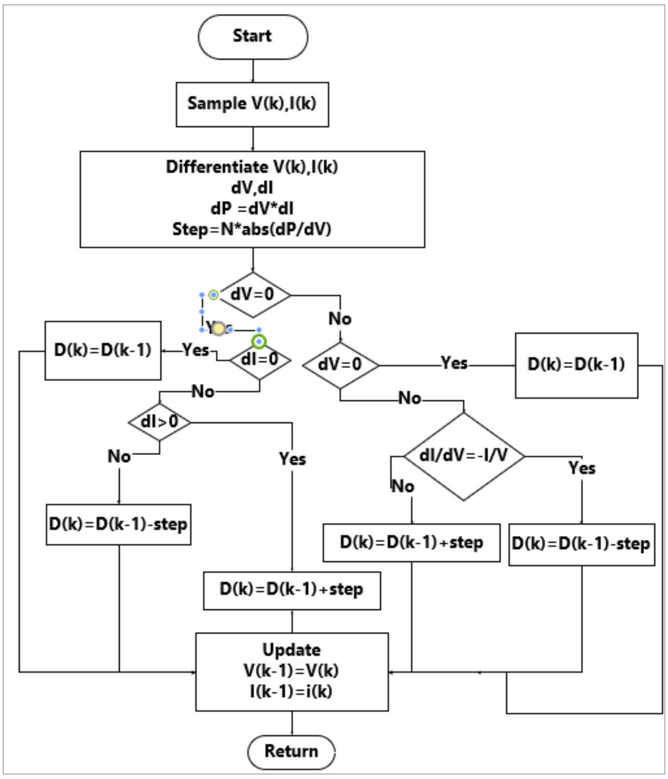


Fig. 11. MPPT Flowchart.

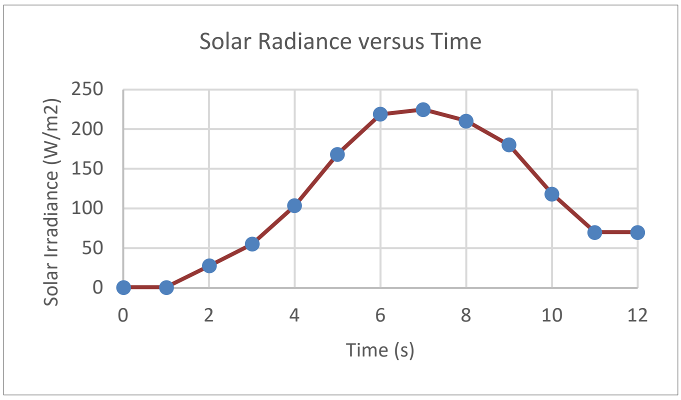


Fig. 12. Solar irradiance profile.

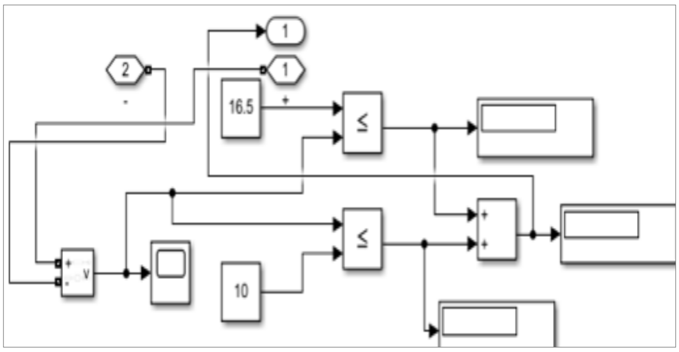


Fig. 13. Battery protection block.

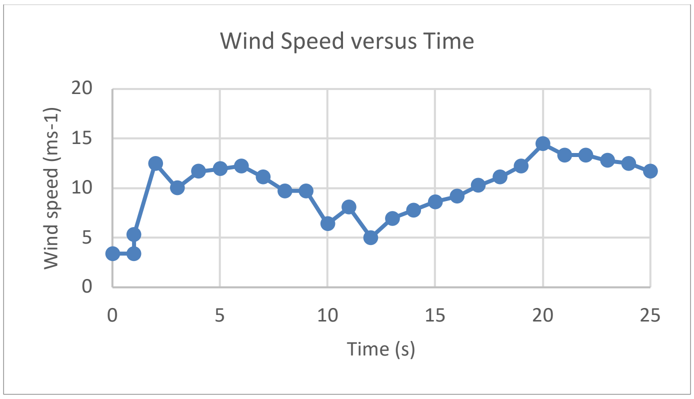


Fig.14. Wind speed profile.

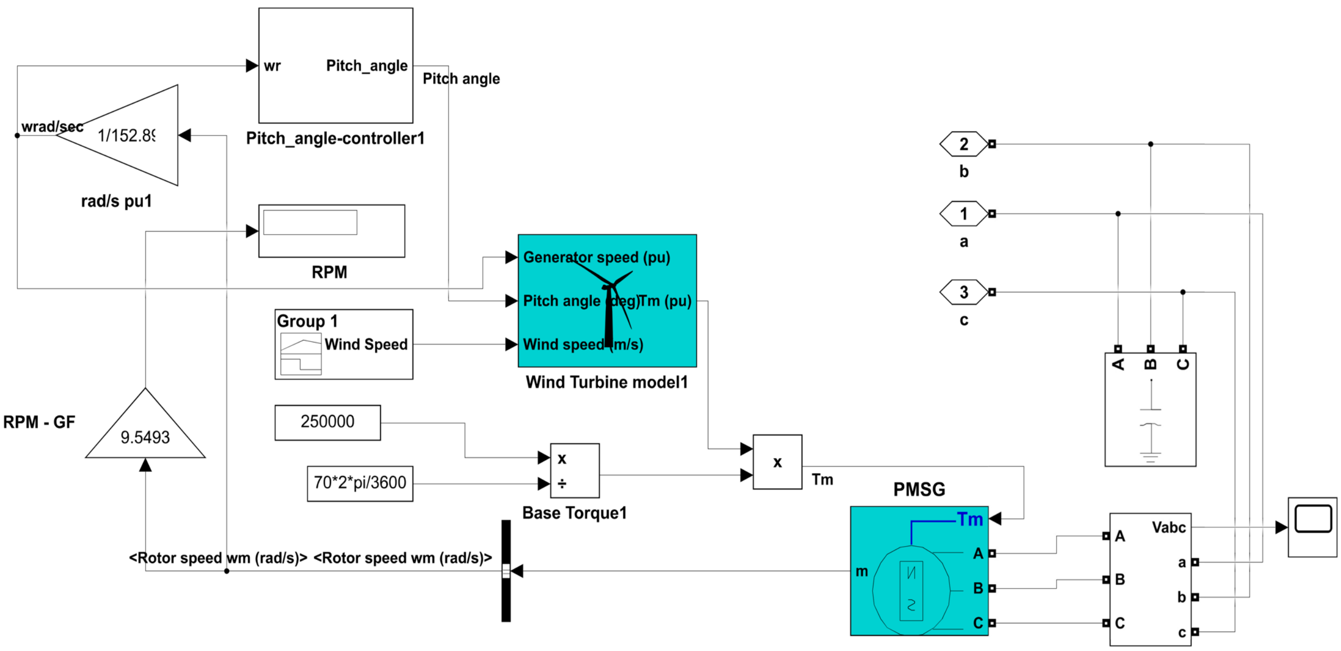


Fig. 15. Wind turbine conversion system.

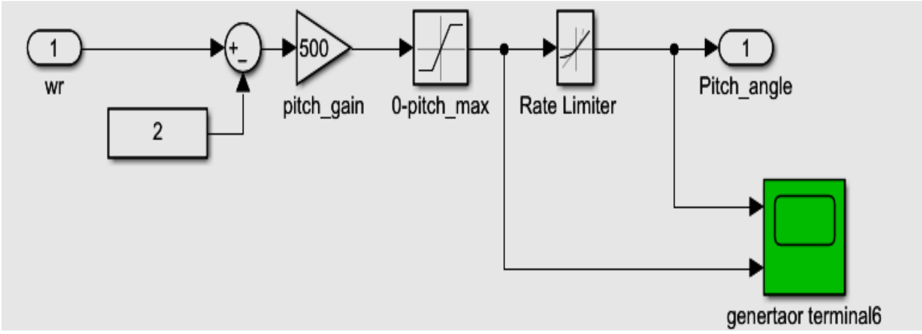


Fig. 16. Pitch control system.

Pitch control proportional gain is used to control wind turbine output voltage. The proportional gain controls the output voltage-based wind speed pitch angle; the wind speed increases, the pitch angle is increased, and the output power is reduced if the wind turbine speed in decreased pitch angle is decreased, the output power is increased, Fig. 16 shows pitch control proportional gain methodology for the proposed wind turbine.

As the wind speed keeps changing, as illustrated in Fig. 13, the pitch control will help deliver the optimized output of the system. Wind turbine power output was examined based on changes in the pitch angle control; it has been noted that power output was stable when the proportional gain value changed as Fig. 20. The overall wind turbine system connection is illustrated in Fig. 15.

### B. Diesel Generator

Since there are three generator sets in the homer pro design, in Simulink, only one diesel generator set and a voltage source representing the other two sets are connected to the system. It is because the electrical analysis part in HOMEPRO shows that those generator sets are not the main electricity contributor. Hence, assuming only one set of generators will generate electricity in an emergency case is reasonable. Nevertheless, it only operates when the renewable energy system is down. The breaker will switch on if the control block senses any power failure from either the PV system or the wind turbine system. After that, the diesel generator set operates as the emergency backup source of the hybrid energy system. The control block is shown in Fig. 18, and Fig. 17 is the detailed configuration of the diesel generator block.

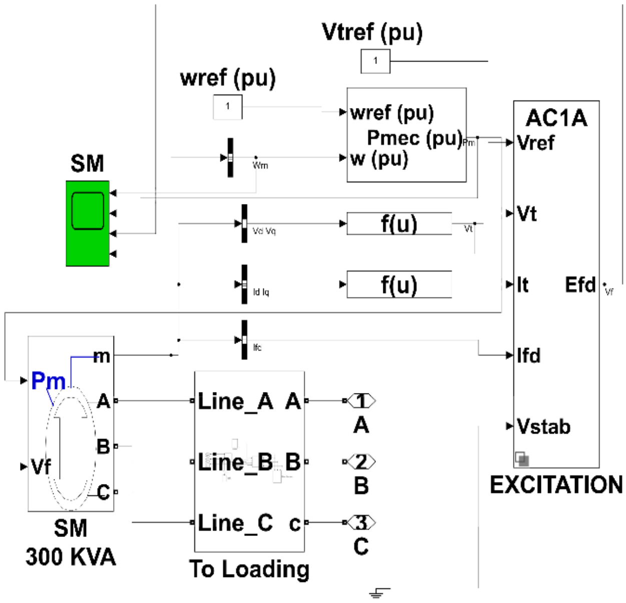


Fig. 17. Diesel generator system.

### C. Loading Output

The loading power output combines diesel generators, PV systems and WECS, and the result is shown in Fig. 23. The surge of the power and current of Fig. 23 and Fig. 21 is due to the additional loading switched into the system. After the additional loading disappears, the current quickly returns to the normal range. The voltage in Fig. 22 keeps steady during the simulation time of 0.2s. The hybrid energy system's control scheme successfully obtains a stable voltage output.

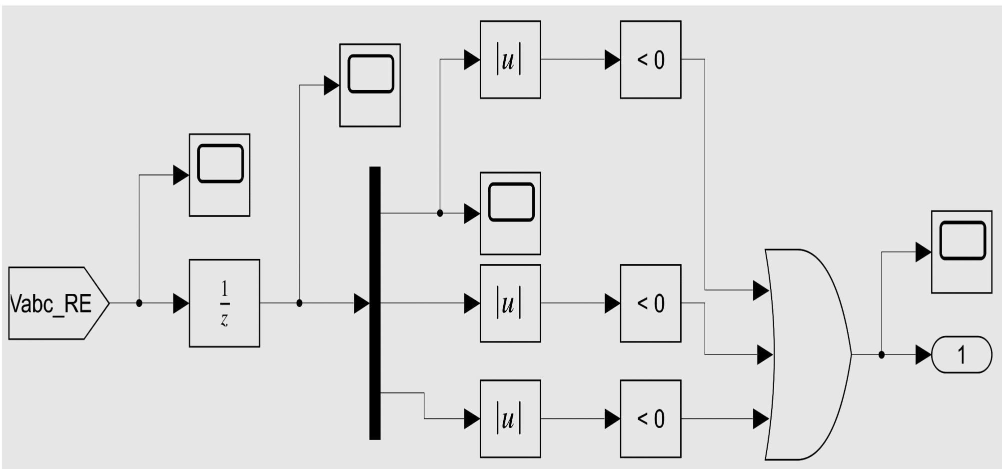


Fig. 18. Diesel generator control block.

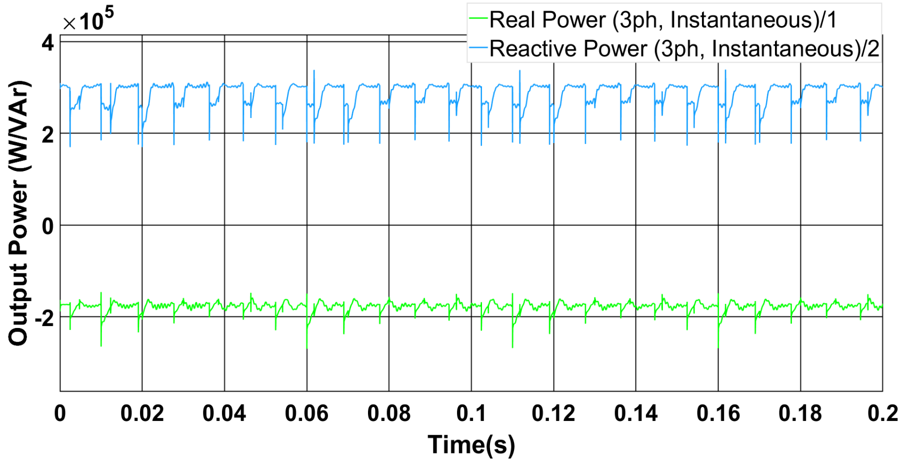


Fig. 19. PV system power output.

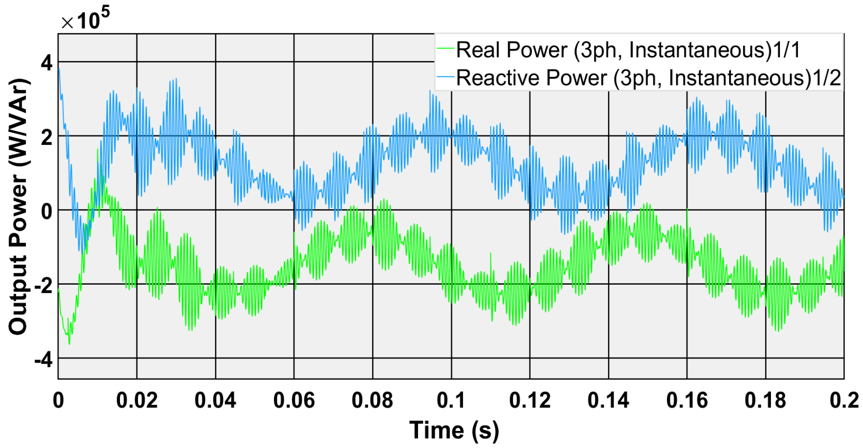


Fig. 20. WECS output power.

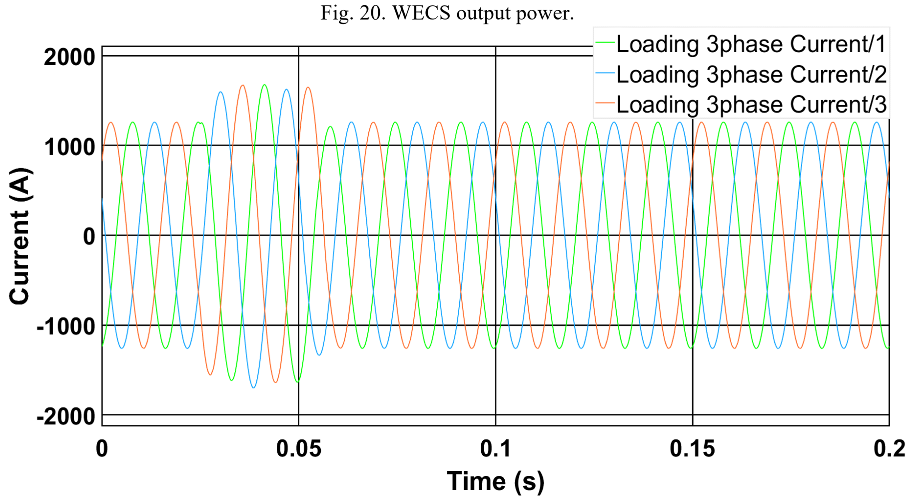


Fig. 21. Current of loading 1.

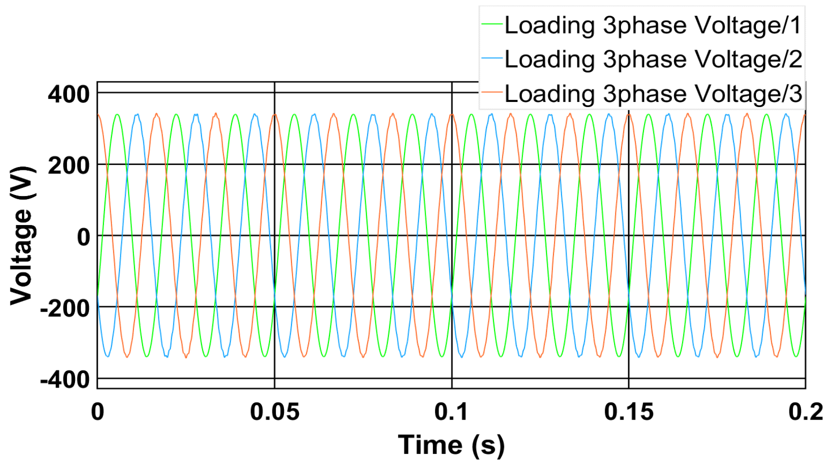


Fig. 22. Voltage of loading 1.

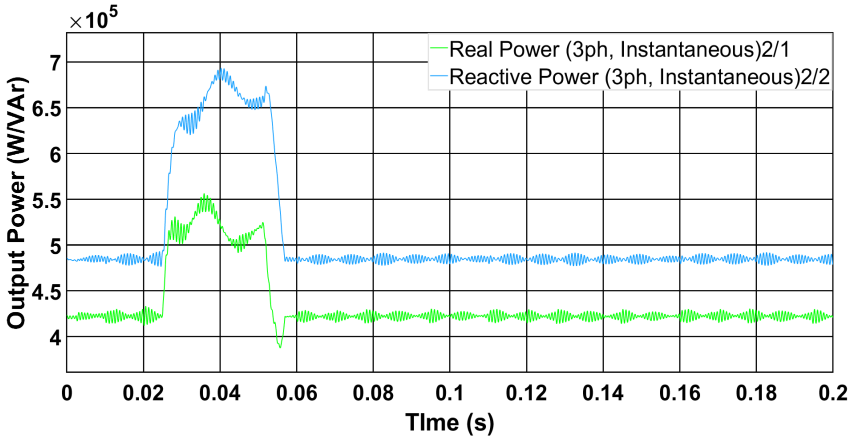


Fig. 23. Power output of loading 1.

## VII. Conclusion

The hybrid system is a successful and sustainable energy system. This paper demonstrates ways to implement the hybrid system in remote off-grid communities to replace existing diesel generator sets. There are several suggestions and anticipated challenges for further development of the system.

Three software are used to design a hybrid power system for St. Lewis. The results of three software and Simulink simulation are presented. HOMERPRO result is the most feasible solution with two 250kW wind turbines, 235kW PV system,500kW power converter and 990 batteries working along with the existing diesel generator sets at St. Lewis. Despite the challenges and issues, constructing a hybrid renewable energy system in St. Lewis can reduce energy costs and alleviate the environmental impact of human activities, which is a sustainable energy solution for the community.

## References

[1] Green N, Mueller-Stoffels M, Whitney E. An Alaska case study: Diesel generator technologies. *Journal of Renewable and Sustainable Energy*. 2017 Nov;9(6):061701.

[2] St. Lewis Profile-Community Accounts [Internet]. nl.communityaccounts.ca. Government of Newfoundland and Labrador; [cited 2022 Dec 5]. Available from: https://nl.communityaccounts.ca/profiles.asp?_=vb7En4WVgaauzXRrWw__.

[3] On Climate Change in Newfoundland and Labrador [Internet]. Government of Newfoundland and Labrador; Available from: https://www.gov.nl.ca/ecc/files/publications-the-way-forward-climate-change.pdf

[4] Gebrehiwot K, Mondal MdAH, Ringler C, Gebremeskel AG. Optimization and cost-benefit assessment of hybrid power systems for off-grid rural electrification in Ethiopia. *Energy*. 2019 Jun;177:234–46.

[5] Li J, Liu P, Li Z. Optimal design and techno-economic analysis of a solar-wind-biomass off-grid hybrid power system for remote rural electrification: A case study of west China. *Energy*. 2020 Oct;208:118387.

[6] Khalil L, Liaquat Bhatti K, Arslan Iqbal Awan M, Riaz M, Khalil K, Alwaz N. Optimization and designing of hybrid power system using HOMER pro. *Materials Today: Proceedings*. 2021;47:S110–5.

[7] Adebanji B, Adepoju GA, Olulope P, Fasina T, Adetan O. Feasibility and optimal design of a hybrid power system for rural electrification for a small village. *International Journal of Electrical and Computer Engineering (IJECE)*. 2020 Dec 1;10(6):6214.

[8] Fodhil F, Hamidat A, Nadjemi O. Potential, optimization and sensitivity analysis of photovoltaic-diesel-battery hybrid energy system for rural electrification in Algeria. *Energy*. 2019 Feb;169:613–24.

[9] Hutasuhut AA, Rimbawati, Riandra J, Irwanto M. Analysis of hybrid power plant scheduling system diesel/photovoltaic/microhydro in remote area. *Journal of Physics: Conference Series*. 2022 Feb 1;2193(1):012024.

[10] Li J, Liu P, Li Z. Optimal design and techno-economic analysis of a hybrid renewable energy system for off-grid power supply and hydrogen production: A case study of West China. *Chemical Engineering Research and Design*. 2022 Jan;177:604–14.

[11] Balachander K, Suresh Kumaar G, Mathankumar M, Manjunathan A, Chinnapparaj S. Optimization in design of hybrid electric power network using HOMER. *Materials Today: Proceedings*. 2021;45:1563–7.

[12] Abbas Fadhil N, Elmnifi M, Abdulrazig ODH, Jaafer Habeeb L. Design and modeling of hybrid photovoltaic micro-hydro power for Al-Bakur road lighting: A case study. *Materials Today: Proceedings*. 2022;49:2851–7.

[13] kumar A, Vadhera S. Design and Simulation of Hybrid Solar PV-Fuel-Cell-Battery System to supply in the Nit Kurukshetra Campus and its effect on the Environment using Homer Software. *Journal of Physics: Conference Series*. 2021 Nov 1;2062(1):012030.

[14] Hoque ME, Sakib N, Alam F, Ahmed MM, Rashid F, Rahman A, et al. Design and optimization of a hybrid energy system for sustainable development at rural areas in Bangladesh. In: 3RD INTERNATIONAL CONFERENCE ON ENERGY AND POWER, ICEP2021 [Internet]. *AIP Publishing*; 2022 [cited 2022 Dec 4]. Available from: http://dx.doi.org/10.1063/5.0116229

[15] Abdul-Wahab SA, Charabi Y, Al-Mahruqi AM, Osman I. Design and evaluation of a hybrid energy system for Masirah Island in Oman. *International Journal of Sustainable Engineering*. 2020 Jul 3;13(4):288–97.

**Yuet Sing Li** was born in Hong Kong, HK in 1994. He received a B.ENG. degree in Electrical Engineering from The Hong Kong Polytechnic University, Hong Kong, in 2017. He is currently a master's degree student at Memorial University of Newfoundland. His expertise is in power system control, renewable energy system and power system software simulation.

**Mohammad Faraji Nejad** was born in Iran, in 1988. He received a master's degree in Mechanical Engineering from the IAU University, Iran, in 2018. He is currently a master's degree student at Memorial University of Newfoundland. His research interest is in renewable energy system.

**Mohammad Bahrami** completed his BSc. In power electrical engineering in Iran at Azad university from 2008 to 2012, he worked as electrical power system in industry for 9 years from 2012 to 2021. Start completing his master's degree in Energy Systems Engineering at Memorial University of Newfoundland. His field of expertise is power system, transmission line, high voltage substation and protection system.

**Mohammad Tariq Iqbal** completed his B.Sc. (EE) at University of Engineering and Technology, Lahore in 1986, his M.Sc. Nuclear Engineering at CNS, Quaide-Azam University, Islamabad in 1988 and his Ph.D. in Electrical Engineering at Imperial College London in 1994. Since 2001, he is working at Faculty of Engineering and Applied Science, Memorial University of Newfoundland. he teaches many electrical engineering courses e.g. electrical engineering design, process control and instrumentation, renewable energy systems, filters synthesis. Currently, his research focuses on modeling and control of hybrid renewable energy systems.