Design and Analysis of a Hybrid Power System for Postville Labrador Canada

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Outline

Motivations

- Providing reliable and low-cost electricity to remote areas
- Reducing greenhouse gas emission
- Studying the behavior of HRPS components under different environmental conditions to ensure reliability and stability
- Designing and implantation a SCADA system for real-time monitoring and control of the hybrid HRPS

Renewable energy sources

- Renewable energy (RE) is sourced from naturally replenished resources, including wind, water waves
- Global investments in renewable energy climbed from 54 billion dollars to 260 billion dollars between 2004 and the year 2011, marking an increase of approximately 381% [1].
- According to the International Energy Agency Photovoltaic Power System report, over 99% of the worldwide PV capacity, amounting to 228 GW, was linked to grid connections [2].

Canada's Renewable Energy Landscap:

- Canada used 16.9% of its primary total energy from renewable energy sources in 2022 [3].
- Home to the world's largest hydroelectricity system.
- Canada has one of the highest installed capacities for wind power and PV
- installed capacity for solar PV has surged from 26 megawatts (MW) in 2007 to 6,452 MW by 2022 [3].
- installed capacity for Wind has risen from 1,846 MW in 2007 to 15,132 MW in 2022

Postville's power system

- Postville is a remote community situated in northern Labrador, Newfoundland and Labrador, Canada
- The community relies on three diesel generators, collectively generating 1072 kW, to supply its electricity

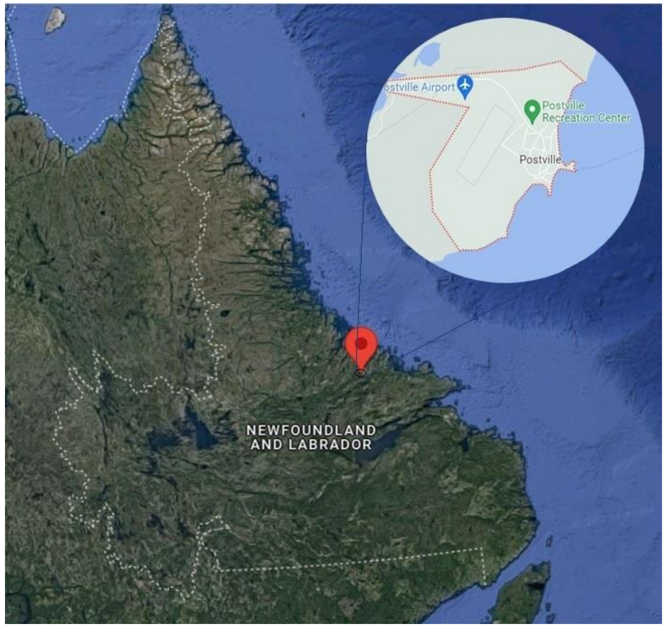

Figure 1: Postville Island

Table1. Specifics of the diesel generators in Postville

Unit	Make and Model	Power Output:	Year of Purchase
2096	Caterpillar C15	455 kW	2017
577	Detroit Diesel Series 60	252 kW	2001
2084	Caterpillar C15	365 kW	2009

Literature Reviews:

Table 2. An overview of various hybrid energy systems

Ref.	Hybrid structure	Software	Location	SA-GC-OG	Analyzed parameters
[4]	PV-Wind-Diesel-Battery	Homer	India	Off-grid	Net present cost & Cost of energy
[5]	PV-Diesel-Battery	Homer-Matlab	Iraq	Off-grid	Net present cost , Cost of energy & Excess Energy
[6]	PV-Diesel-Battery	Homer	Tamil Nadu	Off-grid	Net present cost , Cost of energy & Excess Energy
[7]	PV-Wind	Home	Philippine	Off-grid	Net present cost ,&Cost of energy
[8]	PV	-	Greece	Grid-connected	Net present cost & Cost of energy

Objectives of the Study

- To investigate Postville's annual power consumption
- Design and size an optimized HRPS using existing load information with Homer pro
- Build and simulate a dynamic model in MATLAB/Simulink based on the HOMER pro sizing result
- Design a low-cost Matlab-based SCADA System to monitor and measure relevant parameters

Site Selection and Optimal Sizing Dynamic

Postville community

- Located about 40 km (25 m) from Kaipokok Bay in northern Labrador, Canada
- No road connecting Postville to the rest of the world
- Current population 188 inhabitants
- The community is not linked to the grid

Figure 2: Image of Postville community

(Source: captured from Postville Inuit Community Government)

Site Selection and Optimal Sizing Dynamic

Postville community

- It relies on three diesel generators with a total power output of 1067 kW
- Annual consumption of over 500,000 liters of diesel fuel

Diesel generator disadvantages

- Not environmentally friendly
- It is difficult to provide fuel in the harsh climate
- Risking residents' lives and properties

Isolated hybrid renewable power system

- Decreasing in fuel consumption and pollution due to reduced in Diesel Generator size
- Lower electricity prices as a high proportion of renewable power system

Site Selection and Optimal Sizing Dynamic

Power consumption data

The load profile for the Postville has been provided by Newfoundland & Labrador Hydro (Electricity Generation Company) every 15 minutes

- The average daily electrical consumption is 4683.2 kW/day,
- random variation is 10.608%,
- peak demand is 401.71 kW.

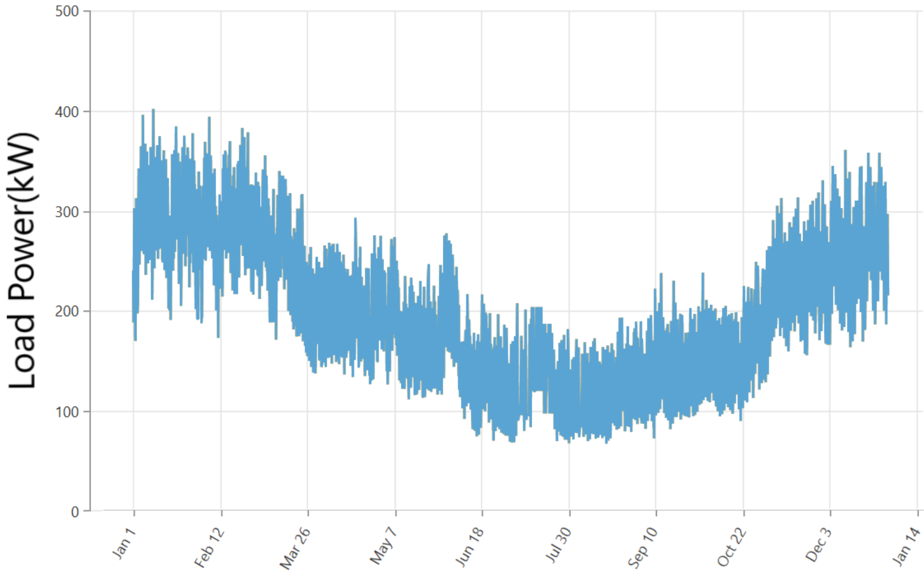

Figure 3: Average load demand for each month of the year

Site Selection and Optimal Sizing Dynamic

Weather conditions and Renewable Resources at the Site

Annual weather condition is achieved from Nasa Prediction of Worldwide Energy Resources.

The scaled annual average of solar irradiation is 2.87 kWh/m2/day

Figure 4: Monthly average solar irradiance and clearness index

The annual average wind speed is recorded as 7.81 m/s at 50m height

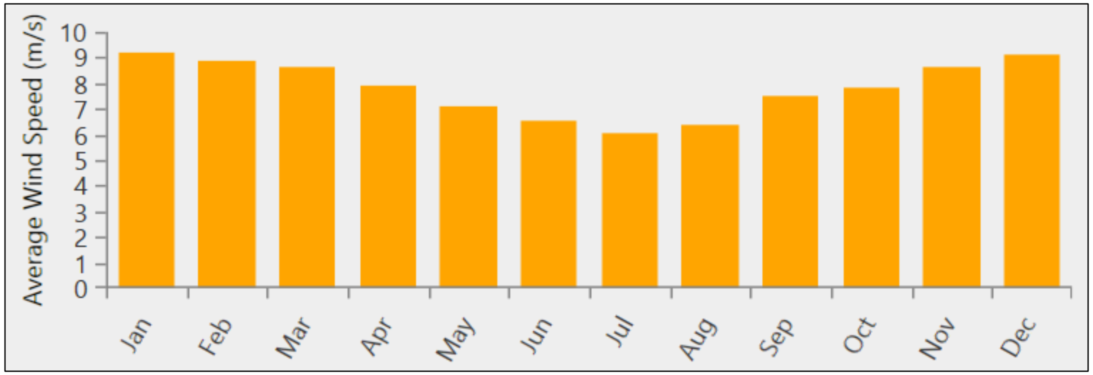

Figure 5: Monthly average wind speed

Sizing system using Homer pro

➢ Homer pro

- Optimization tool developed by the National Renewable Energy Laboratory (NREL)
- Aims to identify the most economical equipment configuration

➢ Sizing system

- Renewable energy and traditional energy sources are combined
- AC diesel generator as back-up power

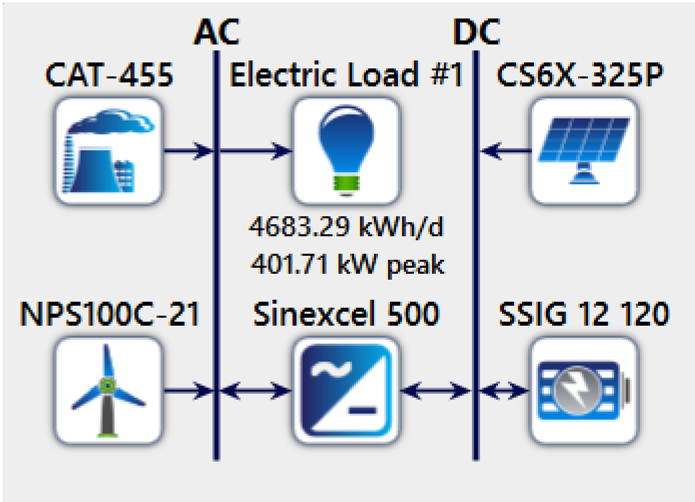

Figure 6: Schematic diagram of the hybrid power system

Specification of system components

Table 3. PV parameter

Technical data	Value
Maximum Rated Power	325 W
Cell per Module	72
Maximum Power Voltage	37 V
Maximum Power Current	8.78 A
Temp Coef of V_{oc}	-0.31 %/°C
Temp Coef of I_{sc}	0.053 %/°C
Lifetime	25 Years

Table 4. WT parameter

Technical data	Value
Rated power	100 kW
Rated voltage	400V
Rated wind speed	15 m/s

Table 5. Diesel generator parameter

Technical data	Value
Capacity	455 kW
Fuel type	Diesel
Rated voltage	208 to 600 V
Speed	1800 RPM

Table 6. Battery parameter

Technical data	Value
Type	Lead-acid
Nominal voltage	12V
Nominal capacity	1.42 kWh
Maximum capacity	118 Ah

Cost Summary of the Systems

- Case A: PV/Wind Turbine /Diesel Generator /Battery
- Case B: Wind Turbine/Diesel Generator/Battery
- Case C: PV/Wind Turbine /Battery
- Case D: Wind Turbine / Battery
- Case E: PV/Diesel Generator /Battery
- Case F: Diesel Generator /Battery

Table 7. Optimal results of hybrid power system for selected location

Configuration	NPC ($)	COE ($)	O&M($/year)	capital cost($)
Case A	5.357M	0.252	257.576	2.25M
Case B	5.92M	0.268	282.690	2.27M
Case C	6.85M	0.310	220.737	3.99M
Case D	7.82M	0.354	232.522	4.81M
Case E	9.97M	0.451	687.901	1.08M
Case F	13.3M	0.603	1.03M	7.765

Simulation Result of Homer pro

Based on the Homer Pro most optimization results consist of:

- 435 kW capacity PV array
- Five wind turbines (100 kW every)
- 720 number of battery with a string size of 30
- One diesel generator with a capacity of 455 kW
- power converter with a 306 kW rating
- The renewable fraction is 77.6%
- Excess electricity is 32.1%
- The net present cost is $5.57 million
- The Cost of Energy (COE) of $0.252 million
- The Annual operating and maintenance (O&M) costs of $257,546

Architecture											Cost			
					CS6X-325P (kW)	NPS100C-21	CAT-455 (kW)	SSIG 12 120	Sinexcel 500 (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
					435	5	455	720	306	LF	$5.57M	$0.252	$257,546	$2.25M

Figure 7: Optimization result

Dynamic Modeling & Simulation of Proposed System

Photovoltaic panel (PV)

PV array consists of:

- 15 PV modules connected in series
- 90 PV modules connected in parallel
- Each module is rated at 325 watts.
- The PV array generated power is 438 kW
- The PV system's output is linked to an 1100 µF and 0.001Ω DC link capacitor and resistor.

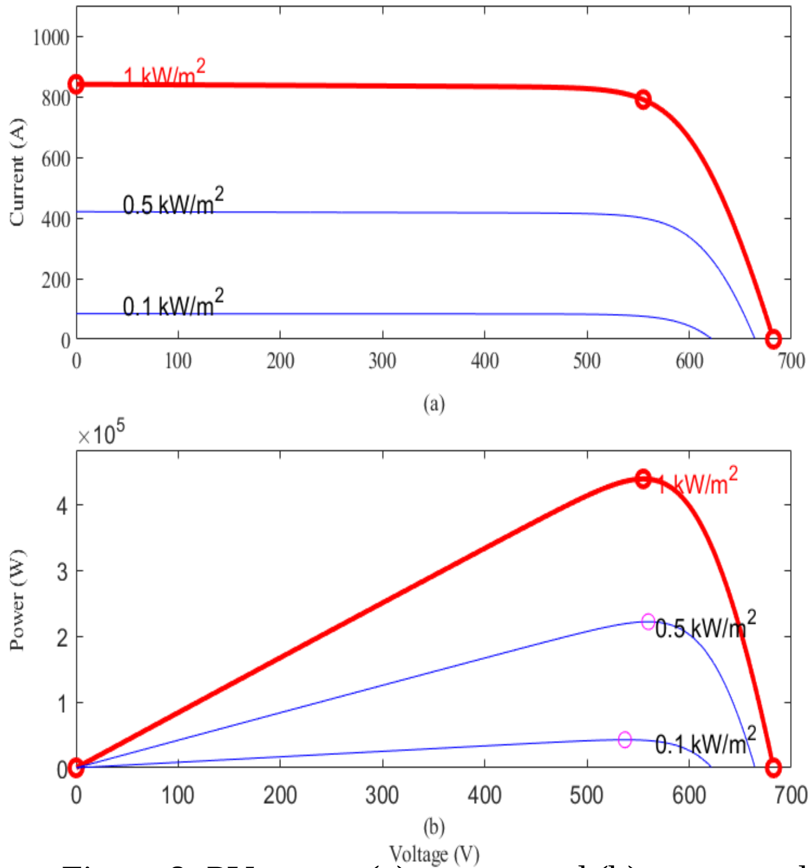

Figure 8: PV output (a) current and (b) power under different irradiances.

Wind Turbine

A wind energy setup consists of three parts:

1. Aerodynamic Phas
2. Mechanical Phase
3. Electrical Phase

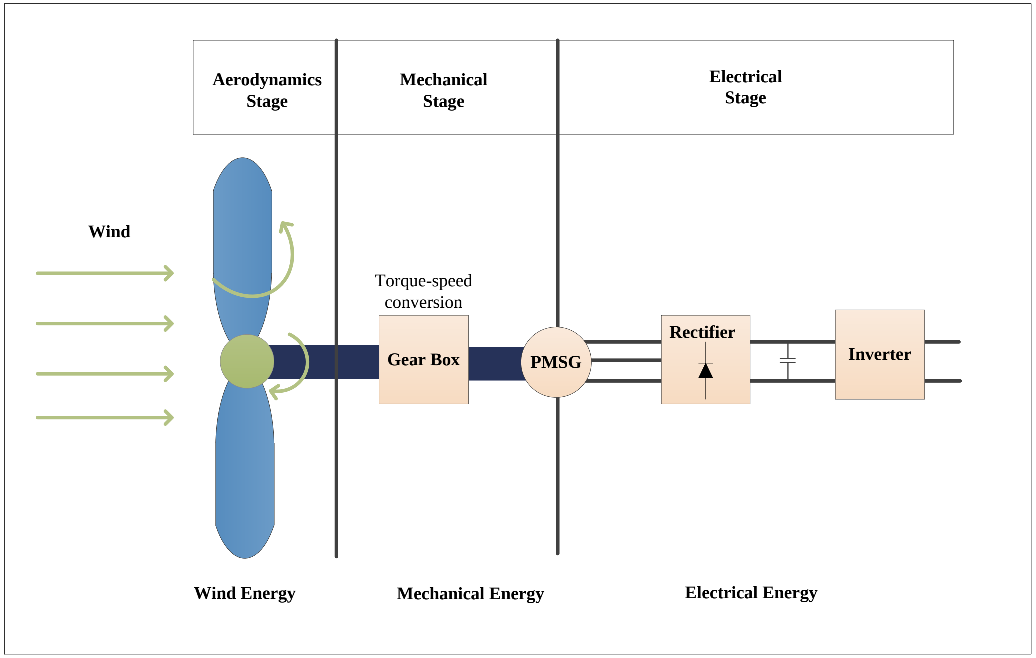

Figure 9: Wind turbine electrical system.

Diesel Generator

- A Diesel generator setup consists of three parts:
  1. Diesel engine
  2. Excitation system
  3. Synchronous generator
- It operates effectively within 208V to 600V
- The capacity of a diesel generator is 455 kW
- As a backup system, It Initially linked to a breaker before direct connection to the load

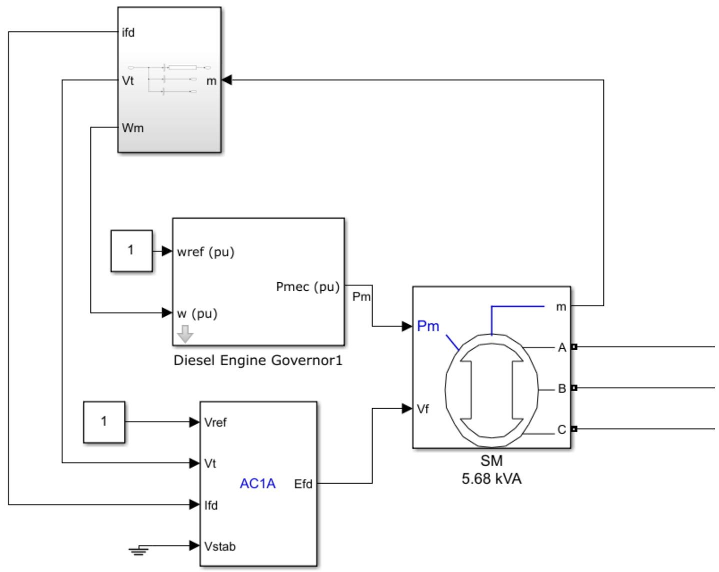

Figure 10: Diesel generator system

Control Strategy

- Maximum power point tracking (MPPT)

- DC-DC Buck Converter

The designed converter operates at a switching frequency of 10 kHz, featuring an inductance of $L_{Buck} = 0.247\ mH$ and a capacitance of $C_{Buck} = 0.423\ mF$.

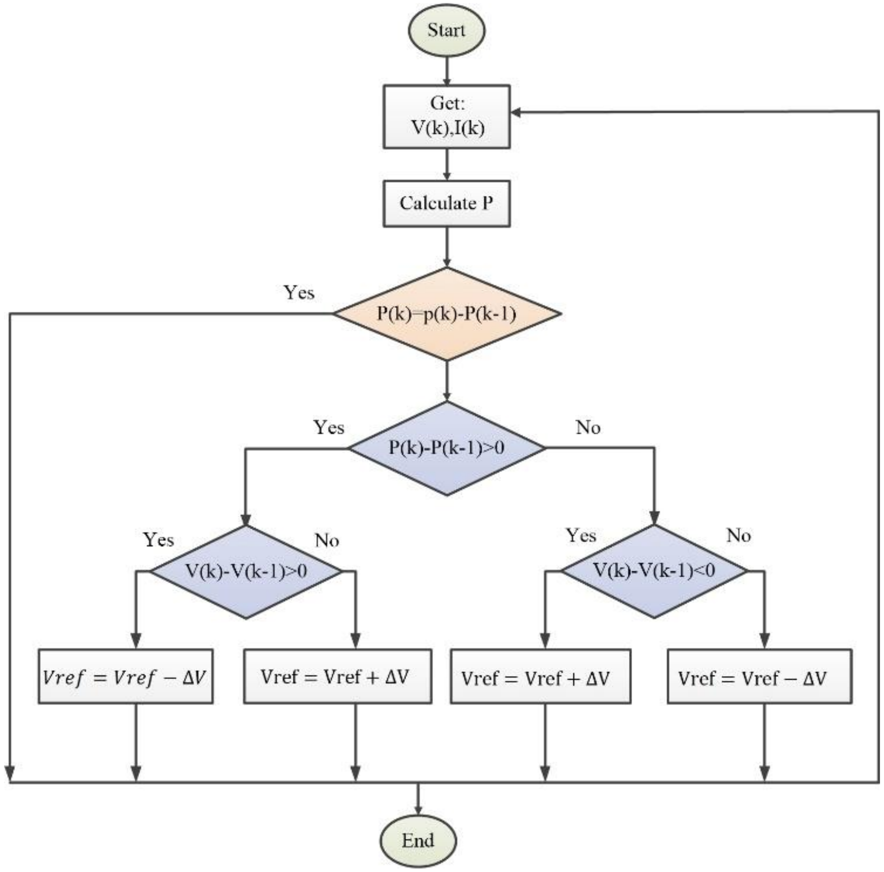

Figure 11: Flow chart of P&O technique for the MPPT

Dynamic Modeling & Simulation

Table 8: Weather and breakers situations.

Time (s)	Irradiance w/m2	Wind speed m/s	DG Breaker
0	1000	12	Open
2	600	10	Open
4	200	12	Close
6	400	10	Open
8	600	8	Open

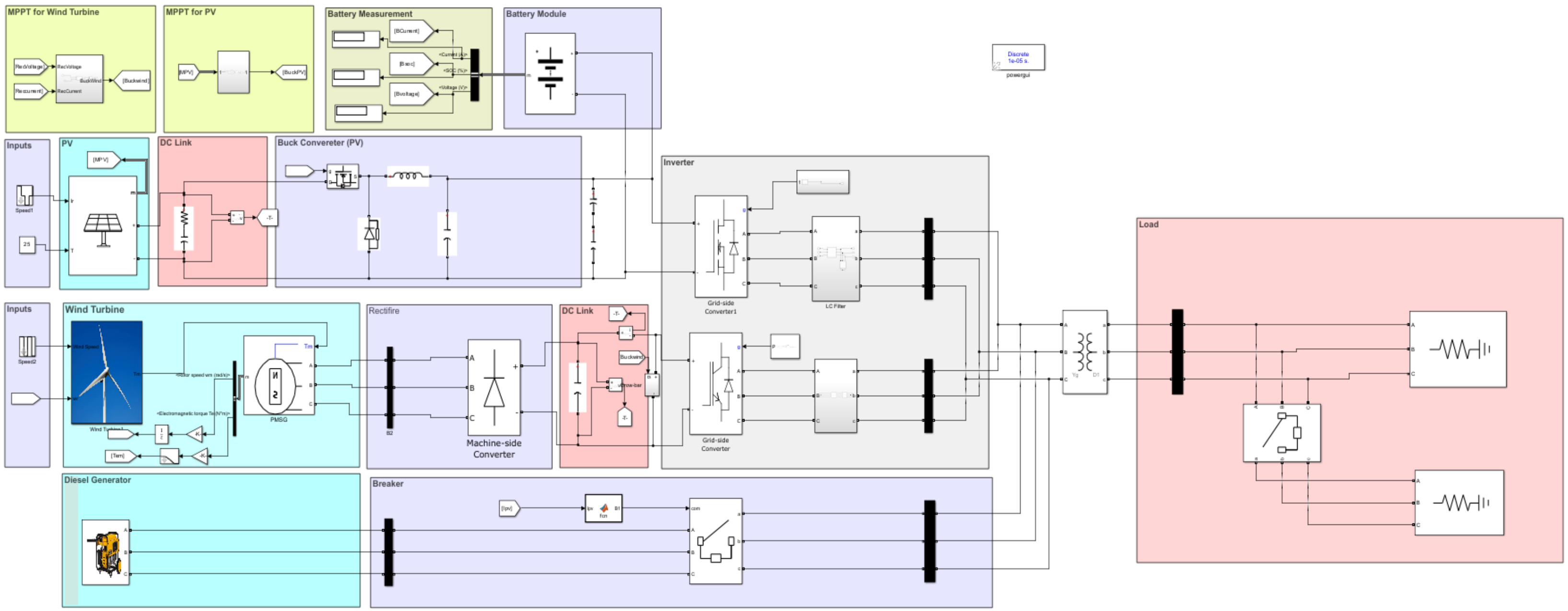

Figure14: MATLAB simulation model for proposed hybrid power systems

Dynamic Modeling & Simulation

Results

PV Power Dynamics:

- When PV power decreases, PV current output decreases.
- PV voltage remains relatively constant.

MPPT Controller:

- Manages voltage and current fluctuations.
- Ensures optimal PV output

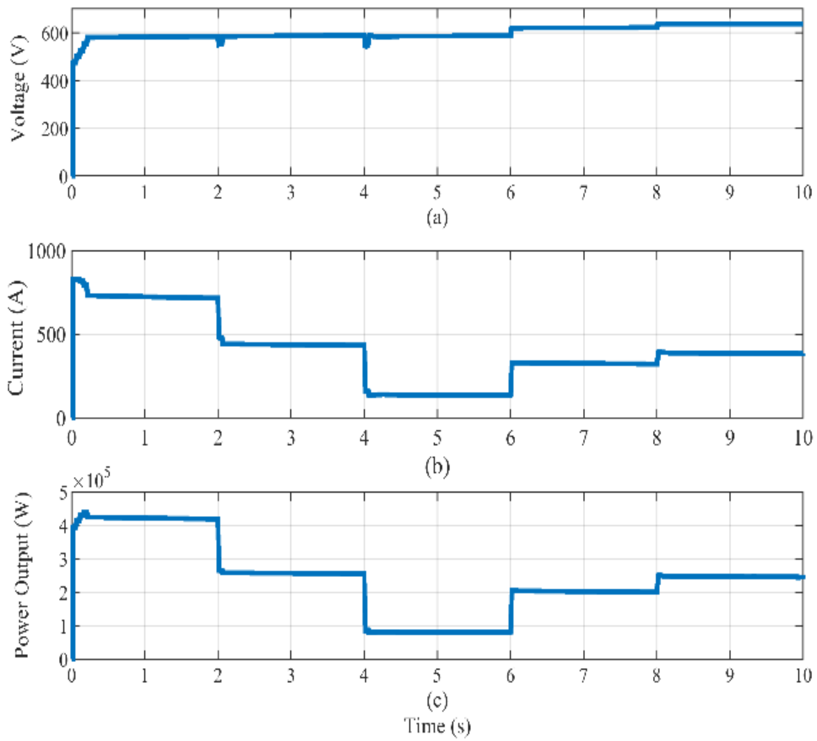

Figure 15: PV (a) Voltage, (b) Current, and (c) Power for varying solar radiation input.

Results

Surplus Power Condition:

- When Load power is lower than the combined output from WT, Photovoltaic PV panels, and DG)
- Battery Behavior: charging: Battery output power and current increase.

Insufficient Power Condition

- Scenario: Load power exceeds the combined output from WT, PV, and DG.
- Battery Behavior: discharging: Battery output power and current decrease.

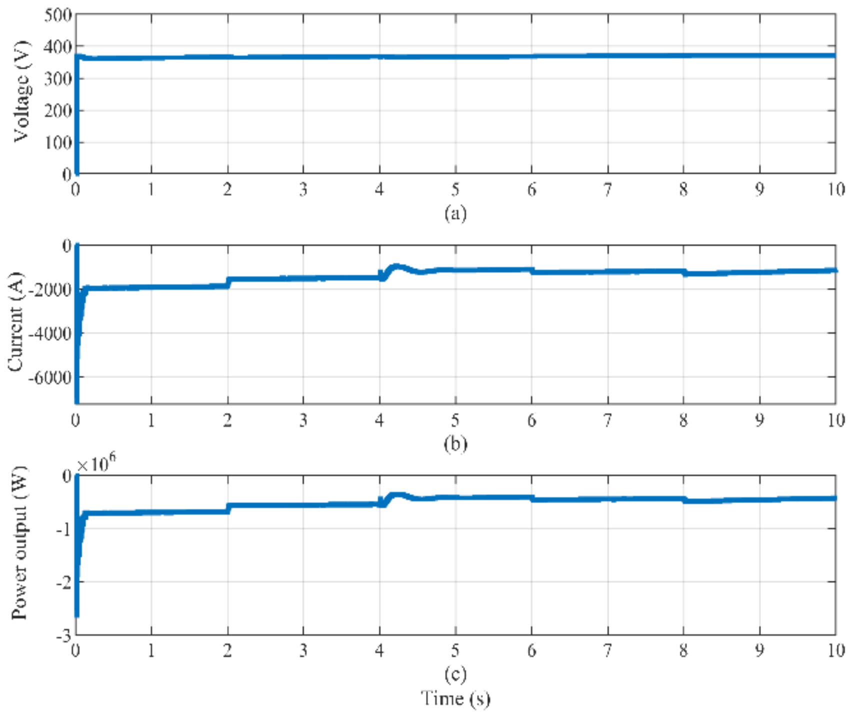

Figure 16: Battery (a) Voltage, (b) Current and (c) Power

Dynamic Modeling & Simulation

Results

- The peak load demand in Postville is approximately 400 Kw
- The average load demand is around 200 kW.
- The breaker is utilized to represent both the average and peak loads.
- Initially, the load is 200 kW.
- Between time 4 and 6, the load breaker is closed, adding approximately 200 kW
- The voltage peak level will remain constant regardless of the load power.

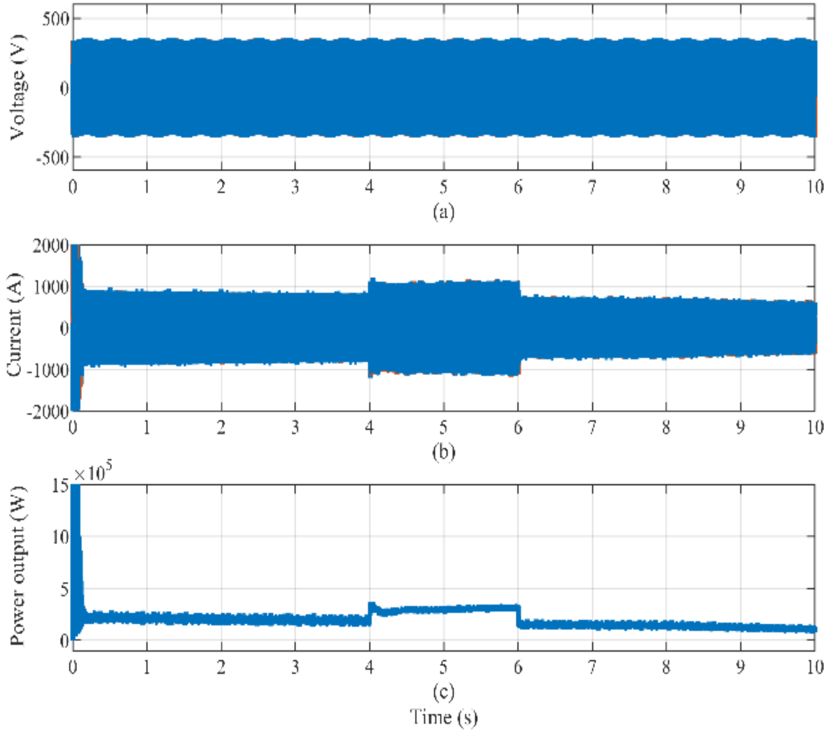

Figure 17: Load (a) Voltage, (b) Current and (c) Power

Dynamic Modeling & Simulation

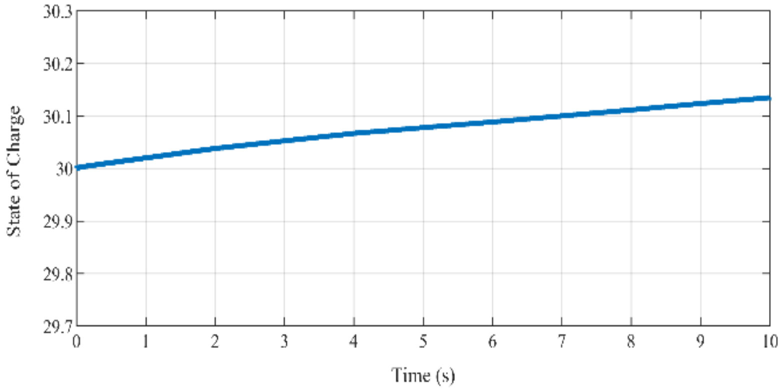

Figure 18: Battery state of charge

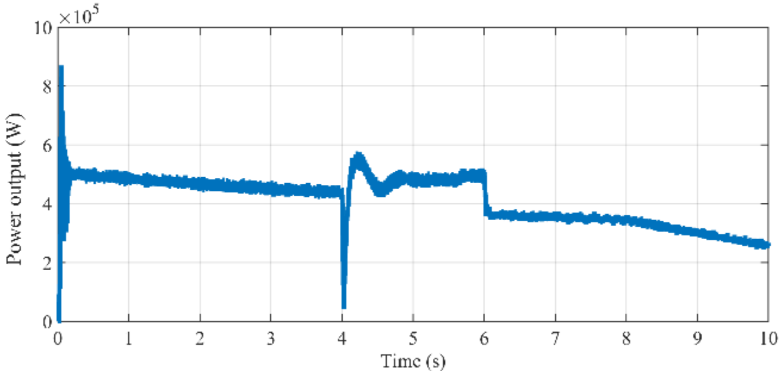

Figure 19: Wind Turbine output power

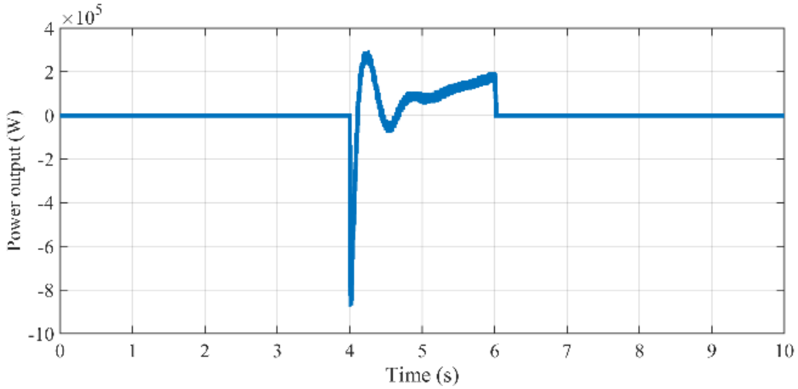

Figure 20: Diesel generator output power

SCADA System Design and Implementation

Proposed SCADA system

Main Objective:

- In-depth monitoring of the system's key parameters in real-time.
- Designing a relay mechanism to automatically activate and deactivate diesel generators
- Saving the received data for any future studies .
- Designing Low cost SCADA system for the cpmmunity

SCADA system design and implementation

SCADA system

Supervise Control & Data Acquisition

1- Field Instrument Devices (FIDs)
Sensors and Actuators connected to the system

2- Remote Terminal Devices (RTUs)
Microprocessor based device that monitors and controls field devices

3- Communication Network
Connect the remote terminal units (RTUs) with the SCADA Master (MTU)

4-Master Terminal Unit (MTU)
Issues the Control commands to the Remote Terminal Unit (RTUs), Gathers, store, process, and display Data

SCADA system design and implementation

System description

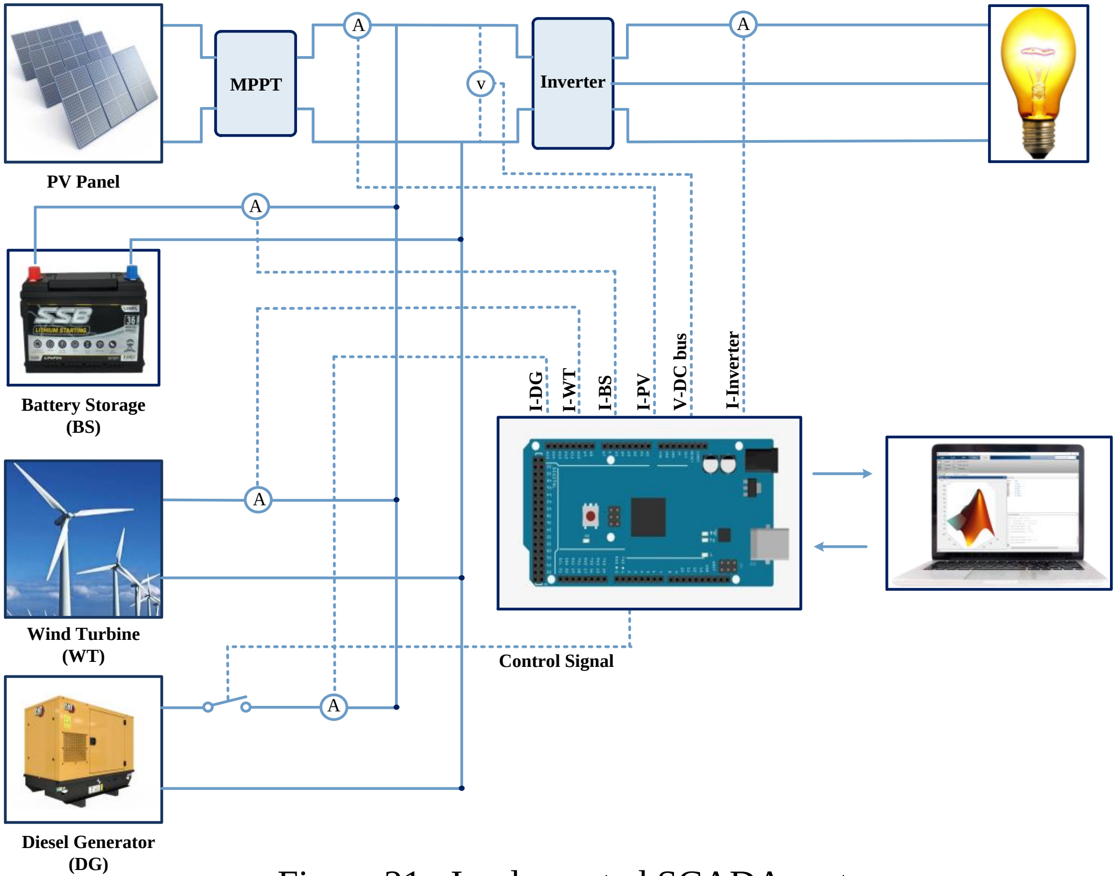

Figure 21: Implemented SCADA system

SCADA system design and implementation

System component

1- Remote Terminal Units

- The Arduino Mega 2560 is used as a remote terminal unit
- The board includes 4 UARTs for hardware serial communication
- 16 analog inputs and 54 digital I/O pins.
- This device runs at 16 MHz with a crystal oscillator
- Contains a USB port, power connector, ICSP header, and reset button.
- It supports serial (TTL), TWI (I2C), and SPI communication

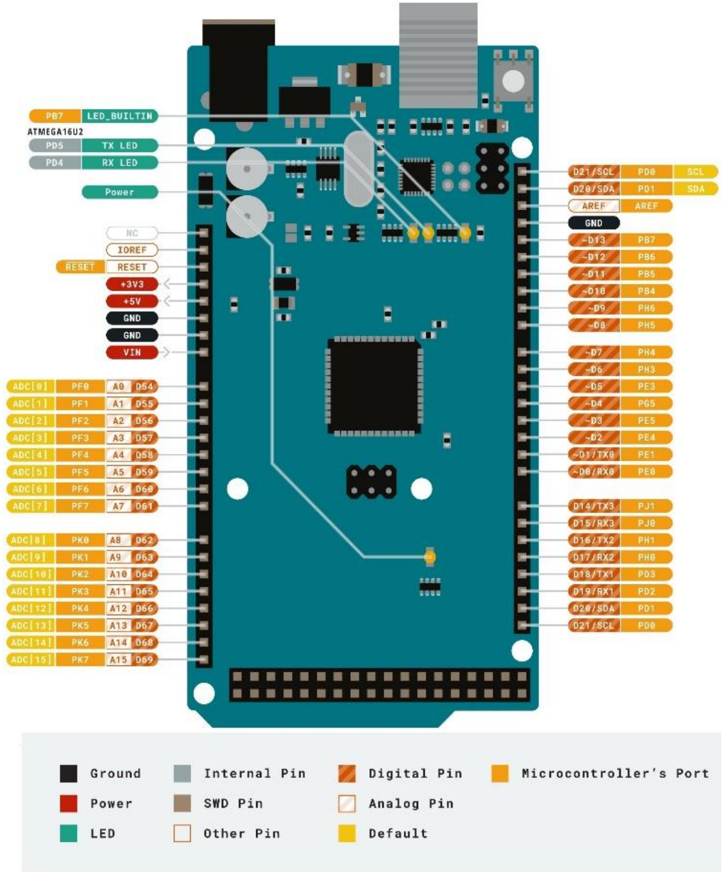

Figure 22: Pinout Diagram of Mega 2560 [9]

SCADA system design and implementation

System component

2-Sensors

❖ ACS712 Current Sensor

Figure 23: current sensor Module [10].

- ➢ both AC and DC currents
- ➢ Operating voltage 5.0 V
- ➢ Typically available in 5A, 20A, and 30A versions.
- ➢ This study uses the 5A and 185 (mV/A) of sensitivity
- ➢ Connected in series

❖ F031-06 Voltage Sensor

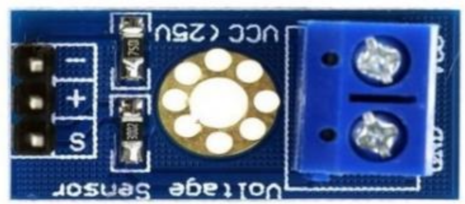

Figure 24: Voltage sensor Module [11].

- ➢ Voltage divider principle
- ➢ Operating voltage 3.3 – 5.0 V
- ➢ Range 0 – 25 V DC.
- ➢ Connected in parallel

System Components

3- Switching device

- The SRD-05VDC-SL-C one Channel Relay Module regulates the operation of a diesel generator.
- It is designed to switch high-voltage or high-current devices using a low-voltage control signal (typically 5V DC from Arduino GPIO pins).

Figure 25: relay module [12].

4- Core Terminal Device

- The main PC used for this research is an Asus Vivobook S13, Core(TM) i7

5- Software tool

- To build the SCADA system, MATLAB, including MATLAB App Designer, is used

Implementation Methodology

To implement the proposed SCADA system

- One voltage sensor connected in parallel with the DC bus.
- Five current sensors: connected in series with:
  1. PV panel
  2. Wind turbine
  3. Diesel generator
  4. Battery
  5. Inverter
- One Relay connected in series with the diesel generator.
- All sensors powered by Arduino Mega 2560's VCC pin
- Sensors grounded through the Arduino ground pin

Table 9:The Arduino interconnections with sensors

System	Specification	Analog / Digital	PIN #
1	Relay	Digital	24
2	DC bus voltage sensor	Analog	A0
3	Inverter current sensor	Analog	A1
4	PV panel current sensor	Analog	A2
5	Wind turbine current sensor	Analog	A3
6	Battery storage current sensor	Analog	A4
7	Diesel generator current sensor	Analog	A5

Data Acquisition and Control System Algorithm

```
Initialization;
1. Establish the connection between MATLAB and the Arduino board
2. read sensor values from analog and digital pins
3. Launch App Designer and loading the .mlapp file
  While data is being received from Arduino
        4. Collect measurements and update App Designer UI
          5. Calculate and calibrate the values of data
          6. Display all sensor values on the dashboard  and for data visualization;
          7. Write the current data in Excel file row by row
      if    PV and wind turbine current decrease by a certain value the
          8. Turn the generator on (the green LED);
       else
          9. Turn the generator off (the Red LED);
      end
   end
  if  Arduino does not send any data, then
     10. Print ' Data has not been received ', reconnect in 5s;
  else
     11. Go to step 3.
  end
```

System Setup

The setup consists of two primary components:

- A demo solar/wind energy training system (LabVolt Series) manufactured by Festo
- The hardware configuration assembled to implement the SCADA system.
- DC power supply was used as a diesel generator

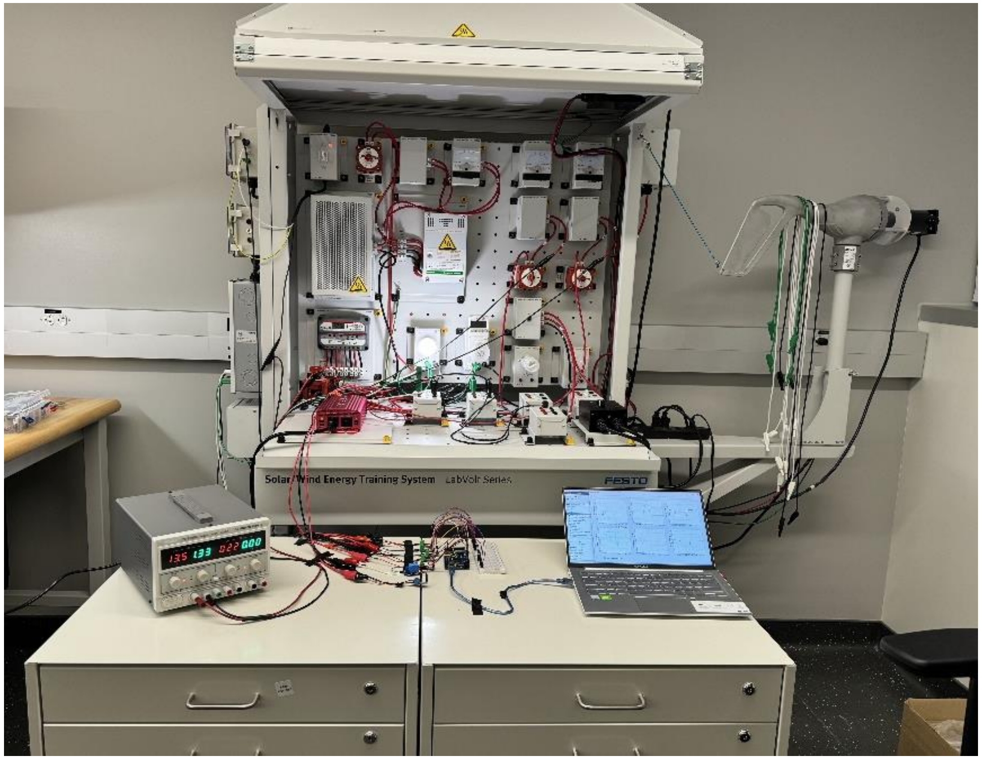

Figure 26:Experimental configuration.

System Setup

- The outputs from the solar panel, battery bank, power supply, and wind turbine are all connected to the DC bus
- The DC bus output is connected to a DC/AC inverter.
- The power inverter converts 12V DC power into 120V AC power using a 1 kW DC-to-AC converter.

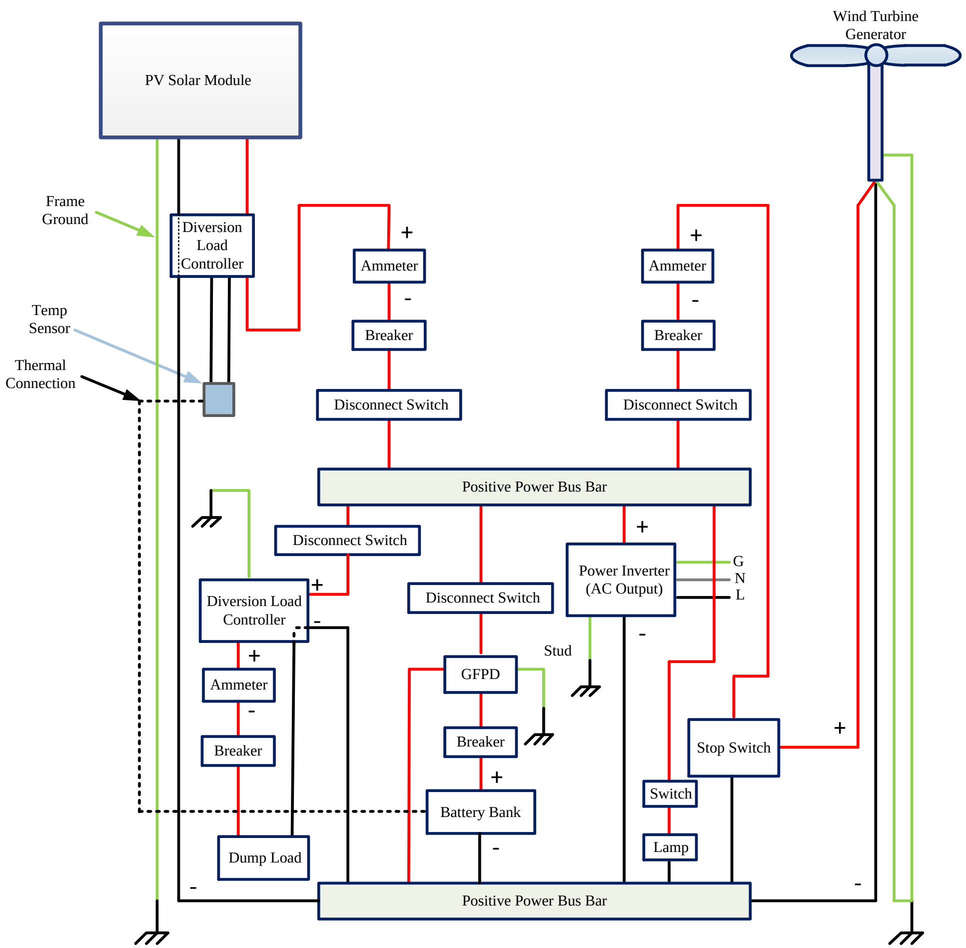

Figure 27: Wind turbine and PV system configuration

SCADA system design and implementation

System Setup

- The system's core processing unit is the Matlab App Designer dashboard.
- It handles all necessary processes including data monitoring, control, and fault detection mechanisms.

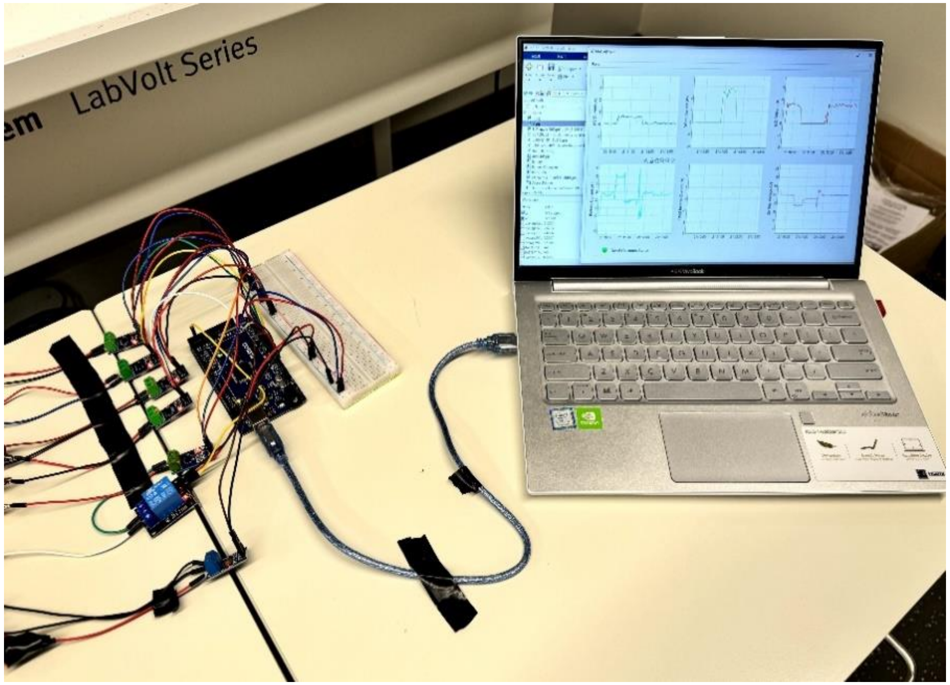

Figure 28: Assembled configuration of the proposed system

Results

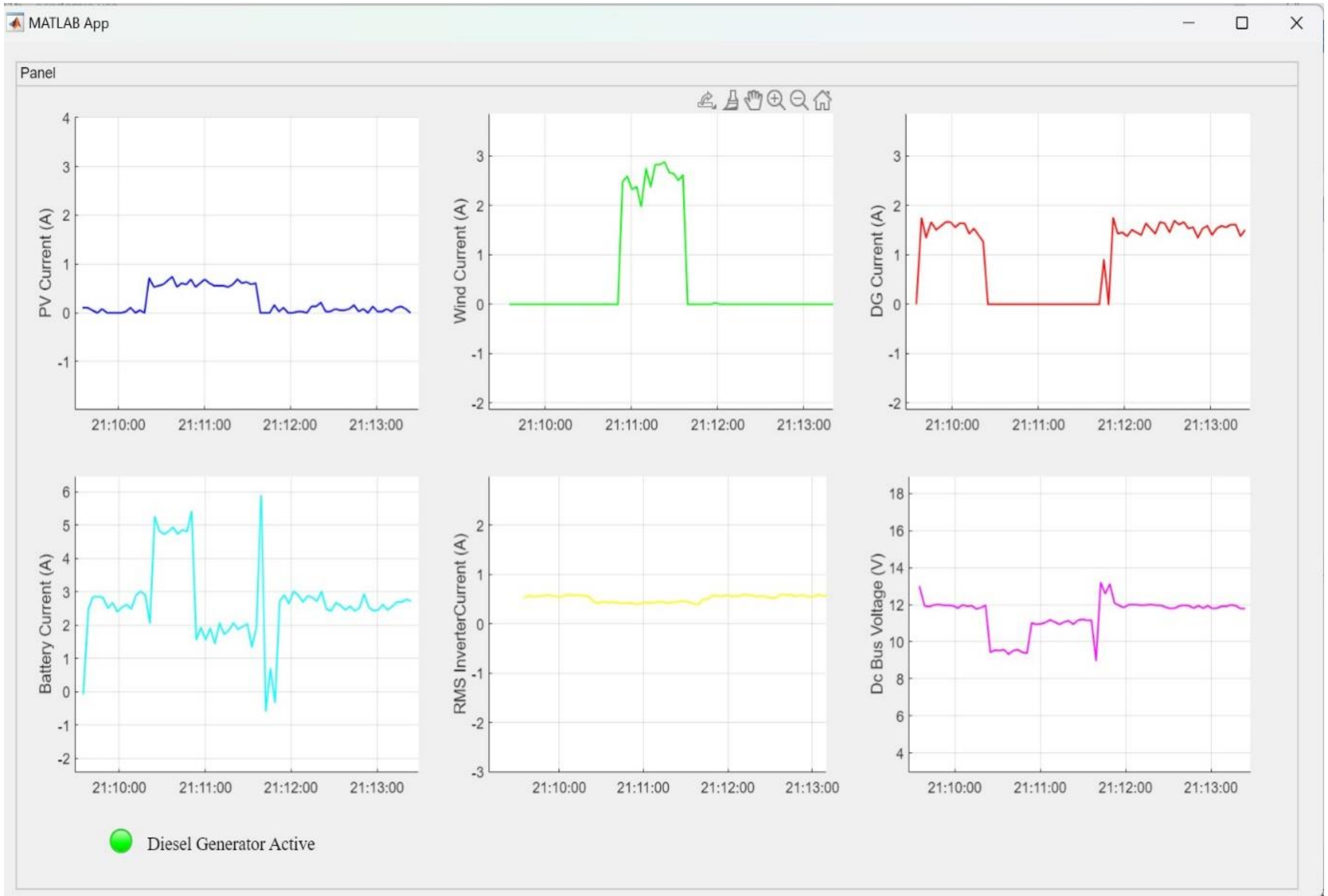

Figure 29: App designer dashboard for monitoring

Conclusion

Future Work

Acknowledgment

Conclusions

The research contributions of this study can be summarized as follows:

- Postville's climate and environment have been studied, and annual power consumption has been obtained
- An optimized low-cost HRPS has been designed and sized with Homer pro.
- Cost comparison between the existing system and the proposed hybrid system has been studied.
- The system dynamic behavior has been studied in MATLAB/Simulink.
- A Matlab-based SCADA system has been designed and implemented to monitor and control the HRPS.

Future works

- Investigating the integration of ocean wave energy and floating PV systems.
- Comparing the proposed renewable energy with other renewable sources.
- Enhancing Battery Charge Control by implementing advanced algorithms for real-time optimization of charge/discharge cycles.
- Designing open Source SCADA system & IoT-Based
- Implementing a wireless structure for remote monitoring and control
- Designing an email alert system for backup device activation/deactivation notifications.

List of Publications

- Farhadi, A., and M. T. Iqbal. “Optimal Sizing and Techno-Economic Analysis of a Hybrid Power System for Postville”. *European Journal of Engineering and Technology Research*, vol. 9, no. 2, Mar. 2024, pp. 5-12, doi:10.24018/ejeng.2024.9.2.3127.

- Farhadi, A., and M. T. Iqbal. “Simulation and Dynamic Analysis of a Hybrid Renewable Power System for Postville, Labrador”. *European Journal of Electrical Engineering and Computer Science*, vol. 8, no. 3, June 2024, pp. 38-45, doi:10.24018/ejece.2024.8.3.628

- Farhadi, A., and M. T. Iqbal. “Design and Implementation of Matlab-based SCADA Architecture for a Hybrid Power System”. *Journal of Electronics and Electrical Engineering*, under review

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- My husband, family, and friends

References

[1] Basaran, Kivanc, Numan Sabit Cetin, and Selim Borekci. "Energy management for on-grid and off-grid wind/PV and battery hybrid systems." *IET Renewable Power Generation* 11.5 (2017): 642-649.

[2] Negar Noroozi and Mohammad Reza Zolghadri, “Three-Phase Quasi-Z-Source Inverter With Constant Common-Mode Voltage for Photovoltaic Application,” *IEEE Transactions on Industrial Electronics*, vol. 65, no. 6, pp. 4790–4798, Jun. 2018, doi: https://doi.org/10.1109/tie.2017.2774722.

[3] Available from: https://natural-resources.canada.ca/our-natural-resources/energy-sources-distribution/renewable-energy/about-renewable-energy-canada/7295

[4] Khan, Mohammad Junaid, Amit Kumar Yadav, and Lini Mathew. "Techno economic feasibility analysis of different combinations of PV-Wind-Diesel-Battery hybrid system for telecommunication applications in different cities of Punjab, India." *Renewable and Sustainable Energy Reviews* 76 (2017): 577-607

[5]] Aziz, Ali Saleh, et al. "Techno-economic and environmental evaluation of PV/diesel/battery hybrid energy system using improved dispatch strategy." *Energy Reports* 8 (2022): 6794-6814.

[6] Vishnupriyan, J., and P. S. Manoharan. "Prospects of hybrid photovoltaic–diesel standalone system for six different climate locations in Indian state of Tamil Nadu." *Journal of cleaner production* 185 (2018): 309-321.

[7] Pascasio, Jethro Daniel A., et al. "Comparative assessment of solar photovoltaic-wind hybrid energy systems: A case for Philippine off-grid islands." *Renewable Energy* 179 (2021): 1589-1607.

[8] Sagani, Angeliki, John Mihelis, and Vassilis Dedoussis. "Techno-economic analysis and life-cycle environmental impacts of small-scale building-integrated PV systems in Greece." *Energy and Buildings* 139 (2017): 277-290.

[9] Arduino Mega Pinout. Available online: https://store.arduino.cc/products/arduino -mega-2560-rev3?queryID=undefined

[10] Current sensor.Available online: https://techiesms.com/product/acs712-5a-curren t -sensor-module/

[11] Voltage sensor. Available online: https://components101.com/sensors/voltage-sensor-module

[12] Relay module. Available online: https://digipurk.ee/en/product/keyes-5-v-relay-module-for-arduino/


Any
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