Design and Analysis of a DC Microgrid for a remote community in Ghana

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Presentation Outline

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List of abbreviations

- BESS – Battery Energy Storage System
- COE – Cost of Energy
- DG – Diesel Generator
- NPC – Net Present Cost
- O &M – Operation and maintenance
- PV – Photovoltaic
- WT – Wind turbine

Background

- Reliable and affordable electricity is essential for socio-economic development, supporting healthcare, education, communication, and income-generating activities
- In Ghana, despite national efforts, nearly 5 million people remain unelectrified
- Many island communities around the Volta Lake, including Azizakpe, rely mostly on kerosene lamps and diesel generators, which are costly, inefficient, polluting, and unreliable
- In Azizakpe, there is no history of electricity
- Lack of electricity negatively impacts education, healthcare, water supply systems, business development, and overall socio-economic growth in such communities
- These challenges have prompted increasing interest in renewable-energy-based microgrids as sustainable alternatives for rural electrification
- Microgrids (MGs) offer localized electricity generation and distribution using renewable resources
- The study designs and analyzes a DC microgrid (MG) for the Azizakpe community
- Key factors considered include the community demographics, as well as load consumption and seasonal variations

Literature Review

Table 1: Related works

[Ref]/Author/Year	Site location	System architecture(s)	Objective(s)	Simulation Software
[1]/ M. Nurunnabi et al/ 2019	Magnama, Dinajpur, Kuakata, Sitakunka, all in Bangladesh	Grid/Wind, PV/Grid, Wind/PV/Grid, Wind/PV/Grid	To optimally design an MG system for different regions in Bangladesh and minimize system costs.	HOMER
[2]/ S. Palanisamy et al/ 2024	India	PV/Wind/Battery/Biogas	To optimally design a hybrid system for hydrogen and EV charging	HOMER
[3] Y. Lin et al/ 2022	China	PV/Wind/Battery	Design off-grid medium voltage DC MG	PSCAD/EMTDC
[4]/ N. Alluraiah et al/ 2023	India	PV/Wind/Grid	Minimize LCOE and GHG emissions, raise renewable energy fraction	HOMER
[5]/ S. Iqbal et al/ 2022	University campus in Pakistan	PV/Battery/Grid	To design a resilient hybrid MG to reduce campus blackouts	HOMER
[6] O. Khaled et al/ 2024	University campus in Pakistan	Grid/PV/BESS	Minimize cost, maximize renewable energy fraction	HOMER

Aims & Objectives of the study

Aim

To design a sustainable and cost-effective microgrid system tailored to the specific energy needs and resource conditions of an island community in Ghana.

Objectives

- To size & design an optimal DC Microgrid in Homer Pro
- Design & simulate a dynamic model of the proposed system in MATLAB/Simulink
- Develop a low-cost data logging system for the system

System sizing, economic, and sensitivity analyses

Site Location

❖ Latitude: 5°46'39.6"N Longitude: 0°39'48.9"E

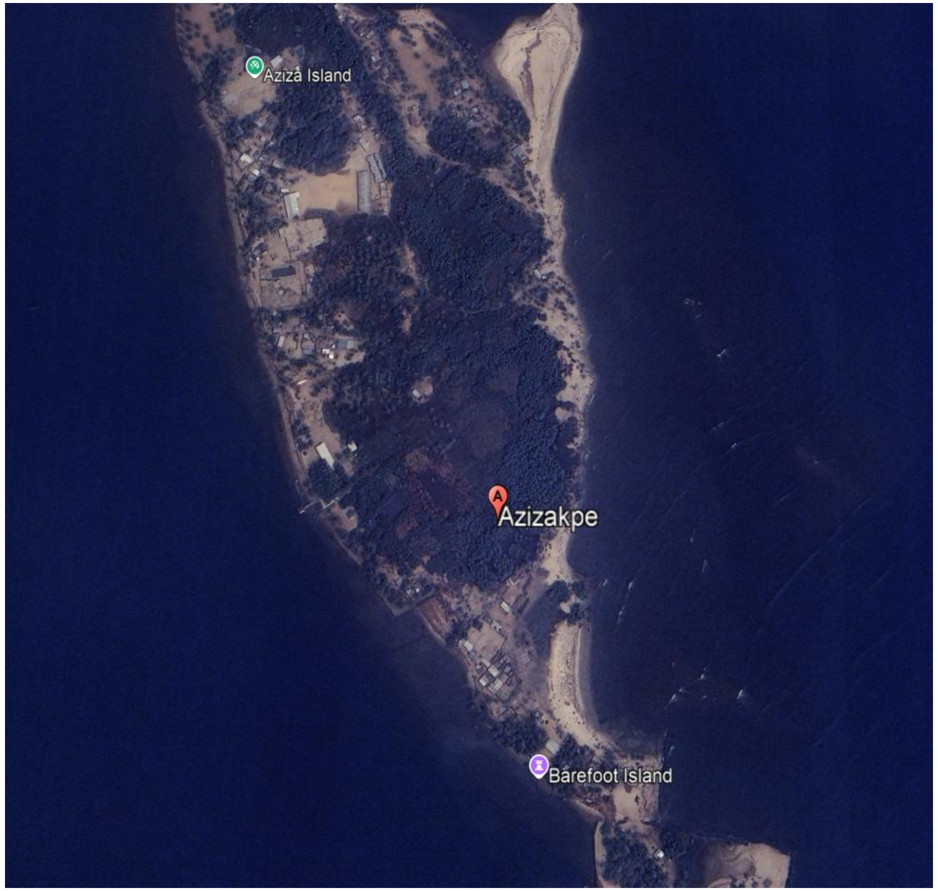


Figure 1: Map of Azizakpe

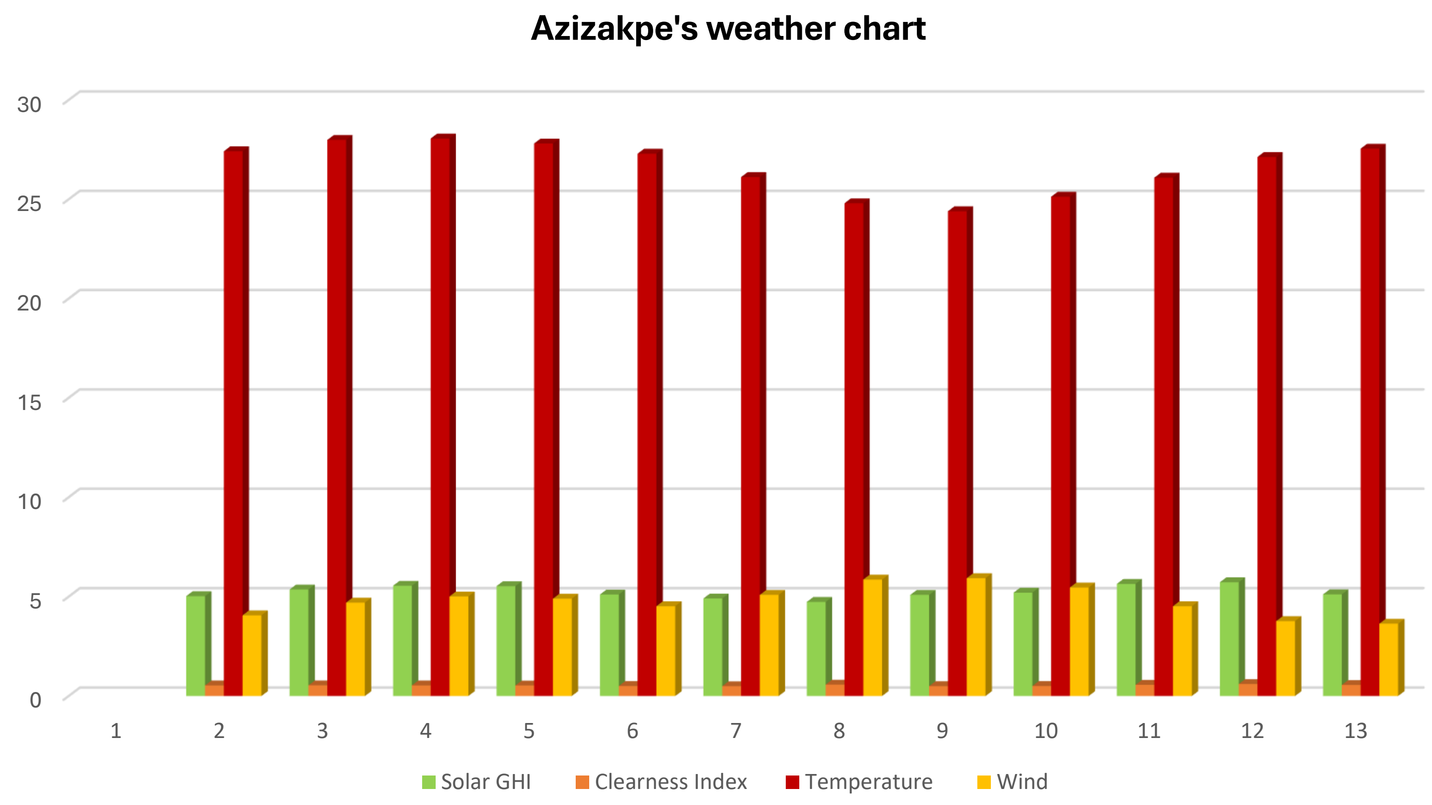


Figure 2: Annual weather chart of Azizakpe

Load Estimation

Table 2: Appliance energy estimation

Equipment	Average rating (kW)	Average number per household	Hours of use per day	Average energy demand (kWh/day)
Light bulb	0.01	5	6	0.3
Television set	0.05	1	8	0.4
Fan	0.017	2	8	0.3
Refrigerator	0.1	1	12	1.2
Electric iron	1.2	1	0.25	0.3

- Average energy demand per household: 2.5kWh/day
- Number of houses:
- Public energy consumption: 10kWh/day

System Sizing in Homer Pro

❖ Homer pro

- A tool developed by the National Renewable Energy Laboratory (NREL)
- For system sizing, optimization, economics, etc

❖ System

- Solar: 350W Jinko Solar Panels
- Wind: 4.85kW Zhejiang Huaying
- Diesel Generator: 30kW
- Battery: 12V BAE Secura
- Inverter: 50kW Satcon PVS

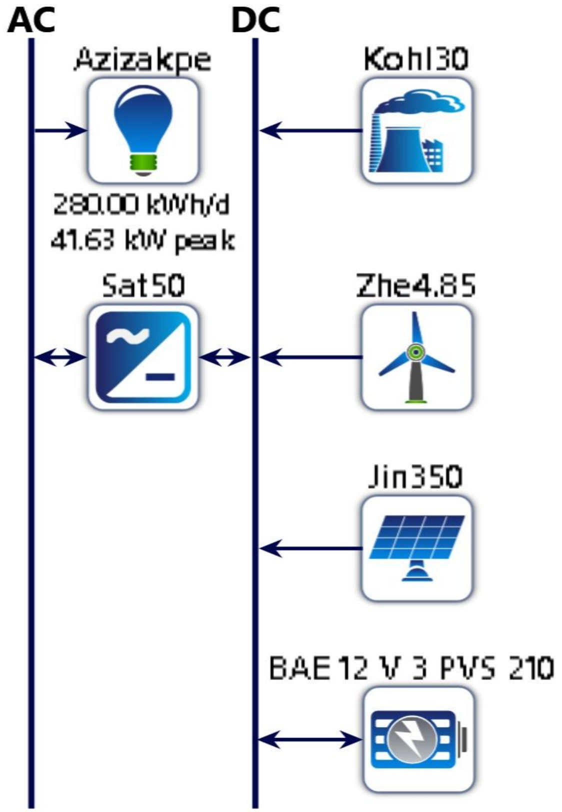


Figure 3: System architecture

System Sizing Performance

Table 3: Summary of yearly energy metrics

Production				
Component	Capacity	Energy production (kWh/yr)	Percent production (%)	Number of components
PV	102kW	153,373	73.80	292
Wind turbine	24.3kW	52,978	25.50	5
DG	30kW	1,475	0.71	1
Consumption				
Load type	Capacity (kWh/yr)	Percent Consumption		
AC Primary Load	102,198	100%		
DC Primary Load	0	0%		
Deferrable Load	0	0%		
Power supply gaps				
Quantity	Capacity (kWh/yr)	Percentage		
Excess electricity	94,707	45.6%		
Unmet electrical load	1.72	0.0017		
Capacity shortage	10.5	0.0103		
Renewable metrics				
Quantity	Value			
Renewable Fraction	98.6%			
Maximum renewable penetration	1,689%			

System Sizing Performance

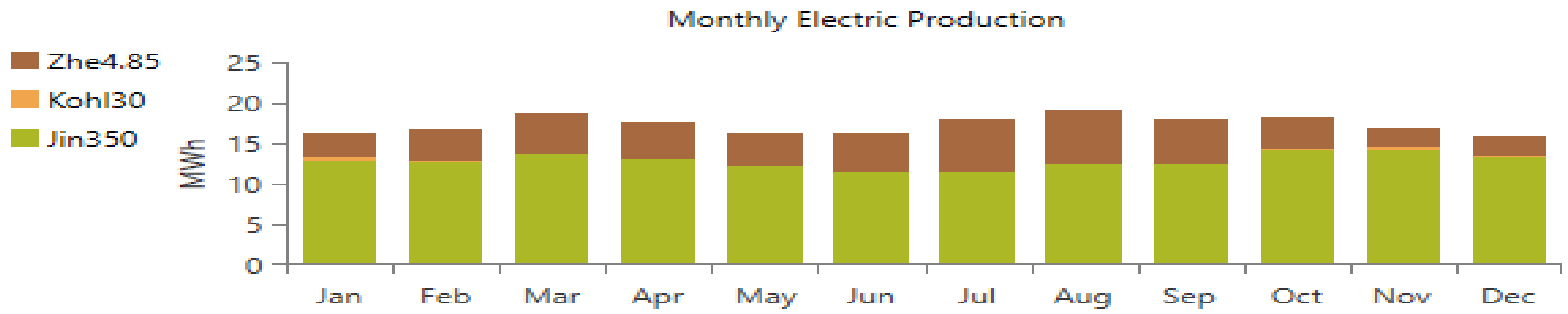


Figure 4: Monthly electricity production

Table 4: System emissions

Gas	Quantity Emitted (kg/year)
Carbon Dioxide	1,488
Carbon Monoxide	8.11
Nitrogen oxide	7.62
Sulfur Dioxide	3.64
Particulate Matter	0.486
Unburned Hydrocarbons	0.409

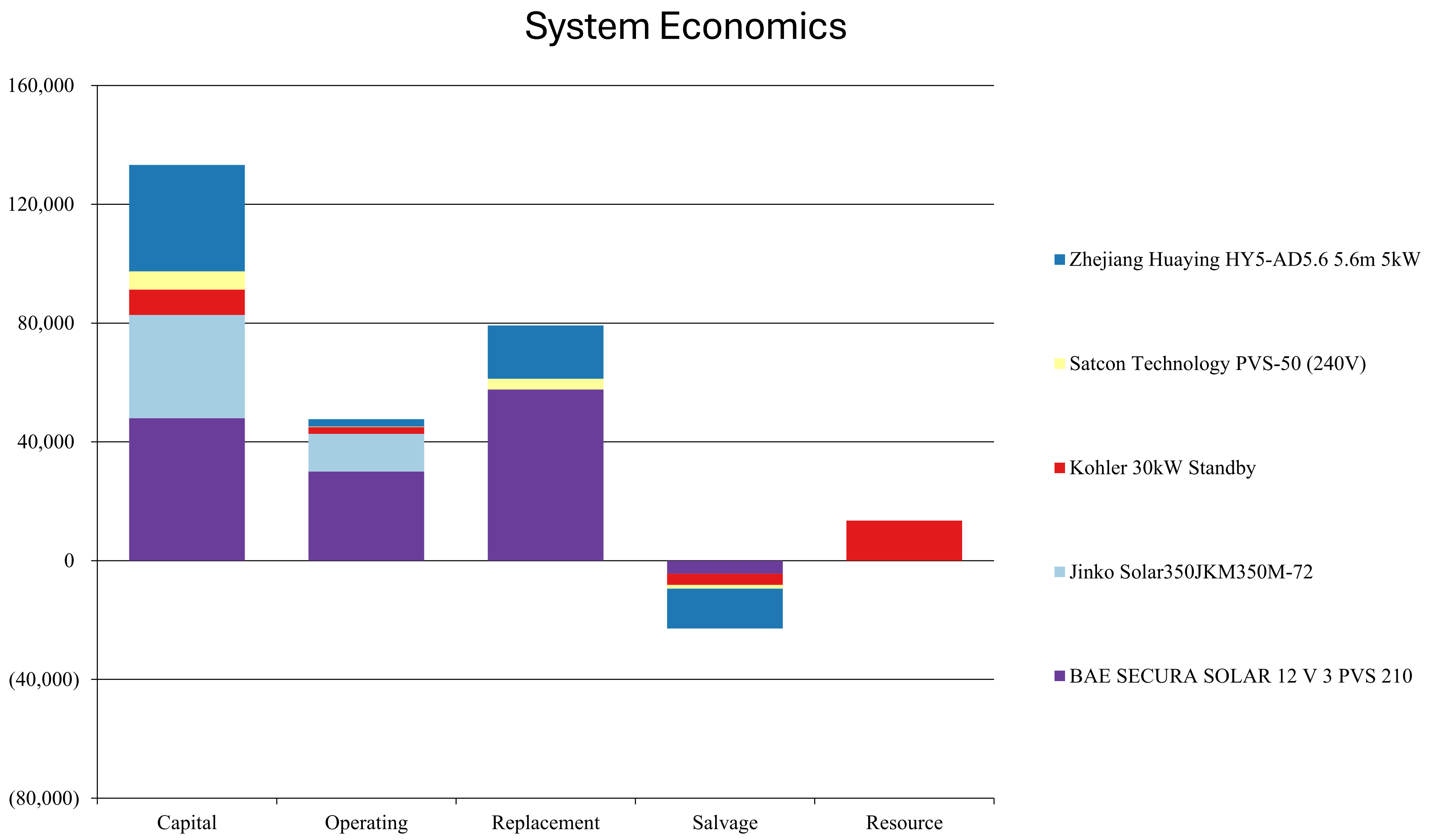
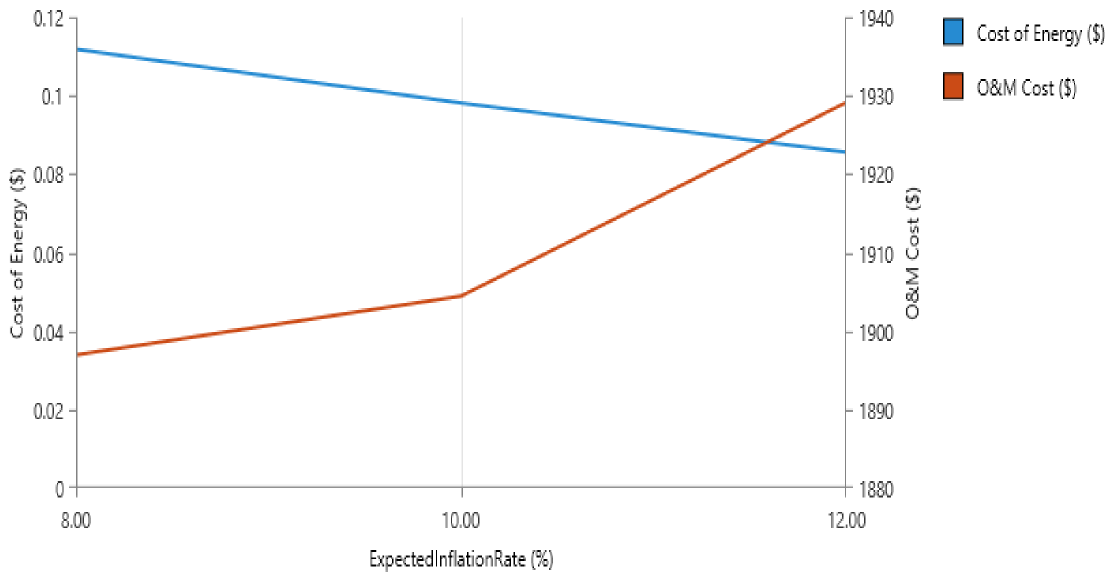


Figure 5: Cash summary of proposed system

Sensitivity Analysis

- Inflation versus O&M and COE at 8%, 10%, and 12%
- BESS state of charge versus NPC and BESS capacity at 0%, 20%, and 50%



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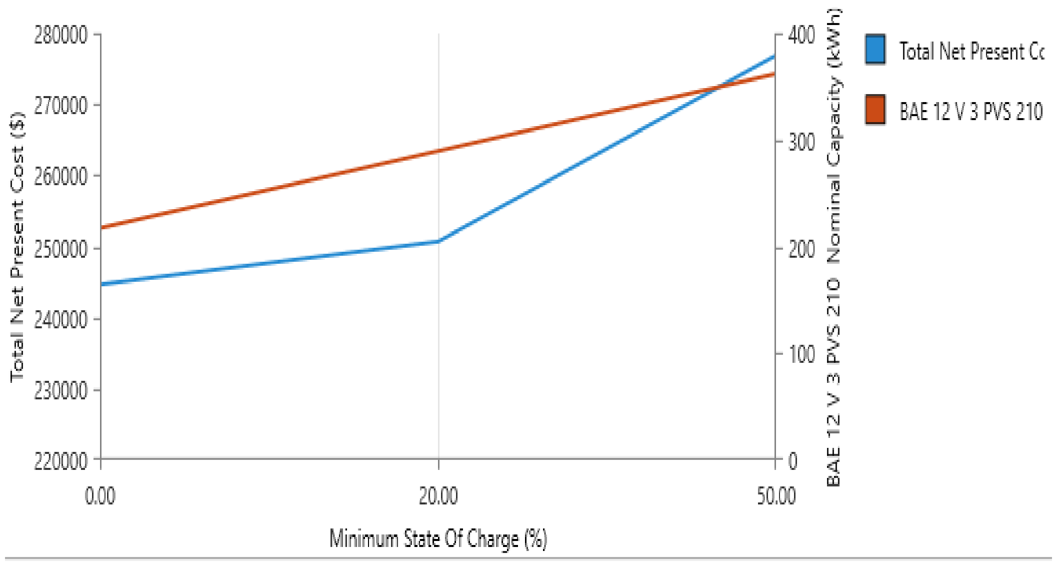


(b)

Figure 6: Effect of (a) inflation on the Cost of energy and O&M cost, (b) BESS state of charge on NPC and BESS capacity

Sensitivity Analysis

Table 5: Impact of load efficiency programs on the proposed system

% increase in load efficiency	Capital ($)	Consumption (kWh/year)	Operating Cost ($/year)	LCOE ($/kWh)	Renewable Fraction (%)
10	10,000.00	91,980.00	3,906.05	0.105	99.3
20	20,000.00	81,760.00	3,276.78	0.115	99.8
30	30,000.00	71,538	2,787.94	0.130	100

Table 6: Impact of load increment on the proposed system

% increase in load demand	Consumption (kWh/year)	Operating cost ($/year)	LCOE ($/kWh)	Renewable fraction (%)
10	112,412	5,654	0.098	97.5
20	122,637	8,978	0.117	91.0
30	132,842	11,712	0.128	86.8

System Modelling in Simulink

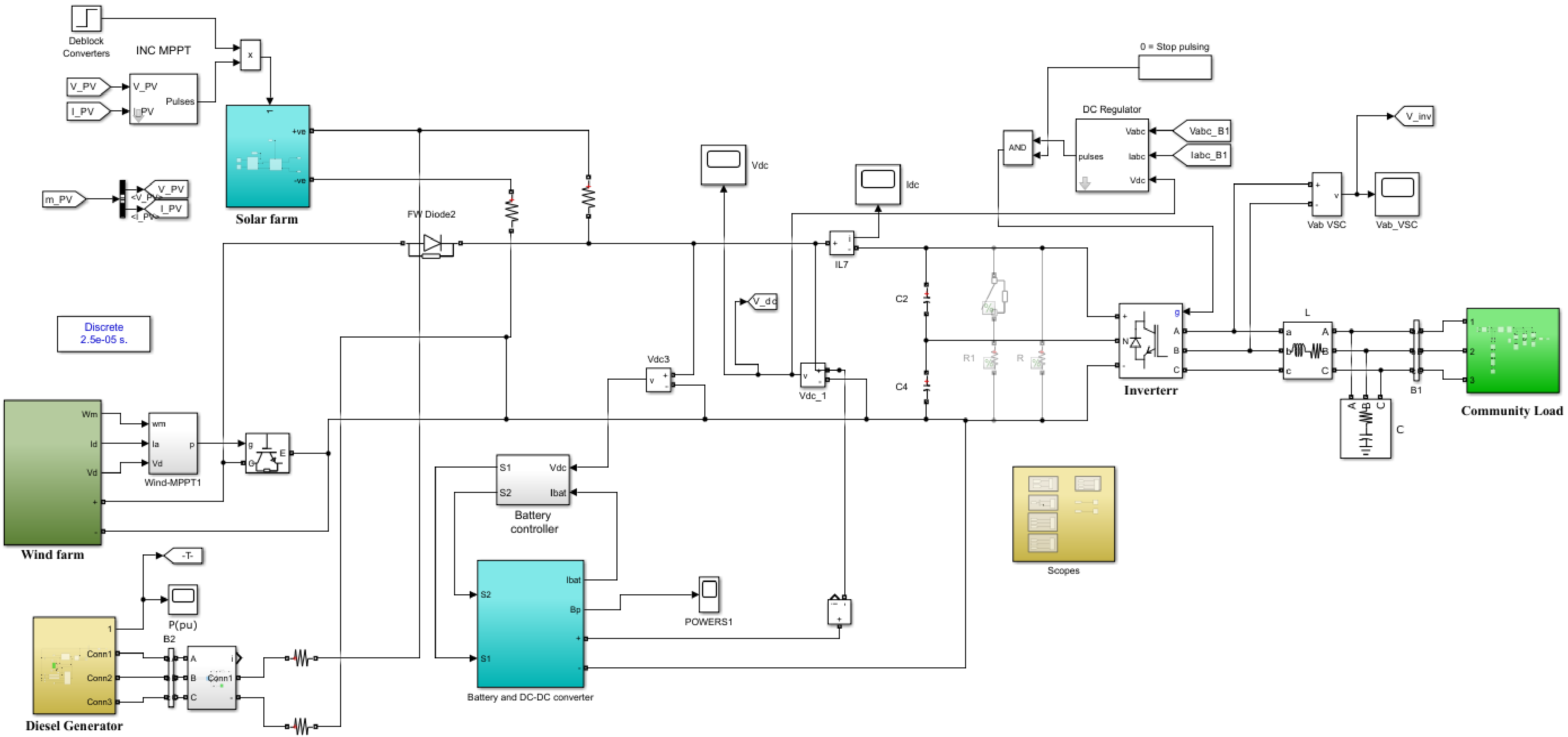
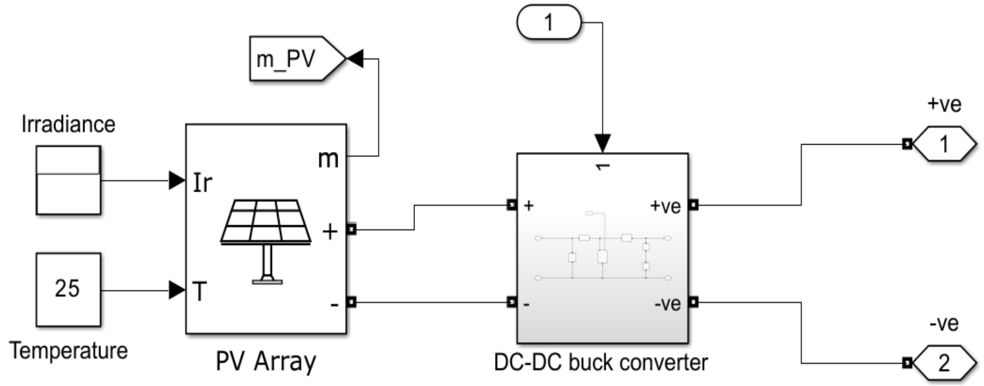


Figure 7: Modelled system in Simulink

PV system modelling

Table 7: PV Module parameters

Parameter	Value
Model	Jinko Solar
Maximum power rating	349.554W
Open circuit voltage	47.5V
Short-circuit current	9.38A
Voltage at maximum power	39.1
Current at maximum power	8.94
Temperature coefficient	-0.329
Parallel strings	21
Series-connected module per string	14



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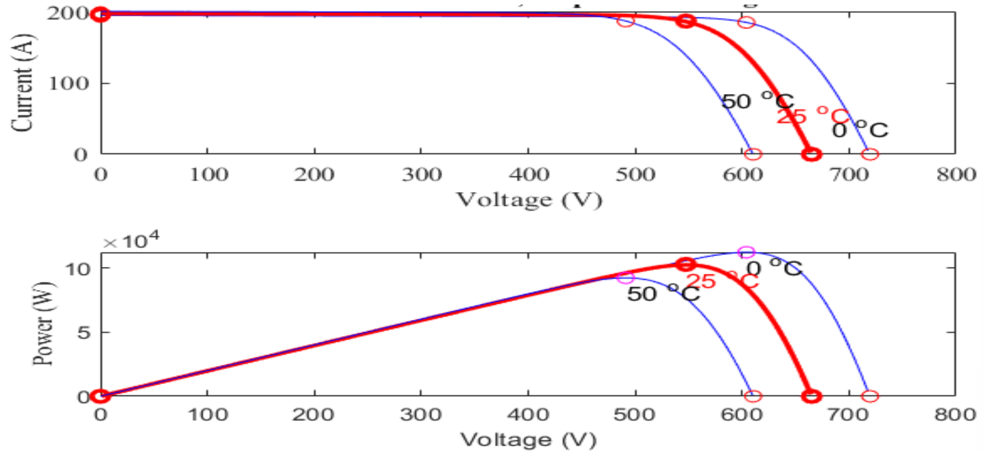

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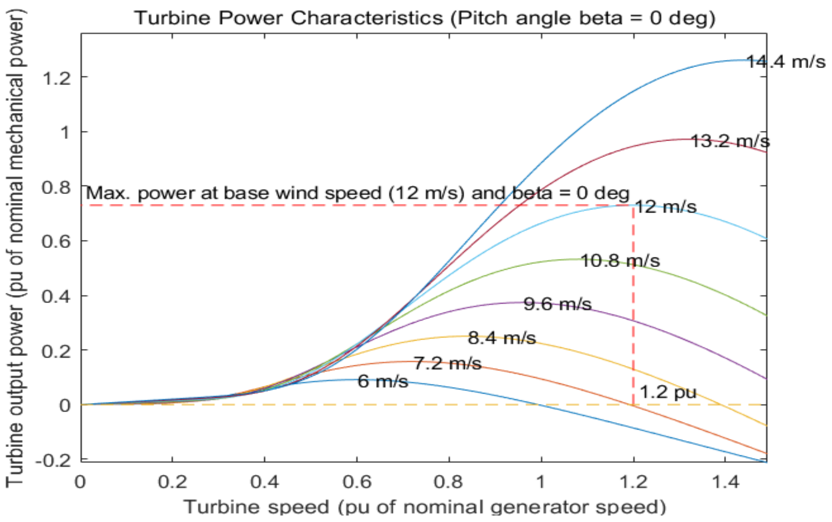
Figure 8: (a) Modelled PV system in Simulink, (b) PV I-V & P-V curves

Wind turbine modelling

Table 8: Turbine parameters

Parameter	Value
Rated Power	5kW
Base wind speed	12m/s
PMSG phase resistance	0.425Ω
Flux linkage	0.433



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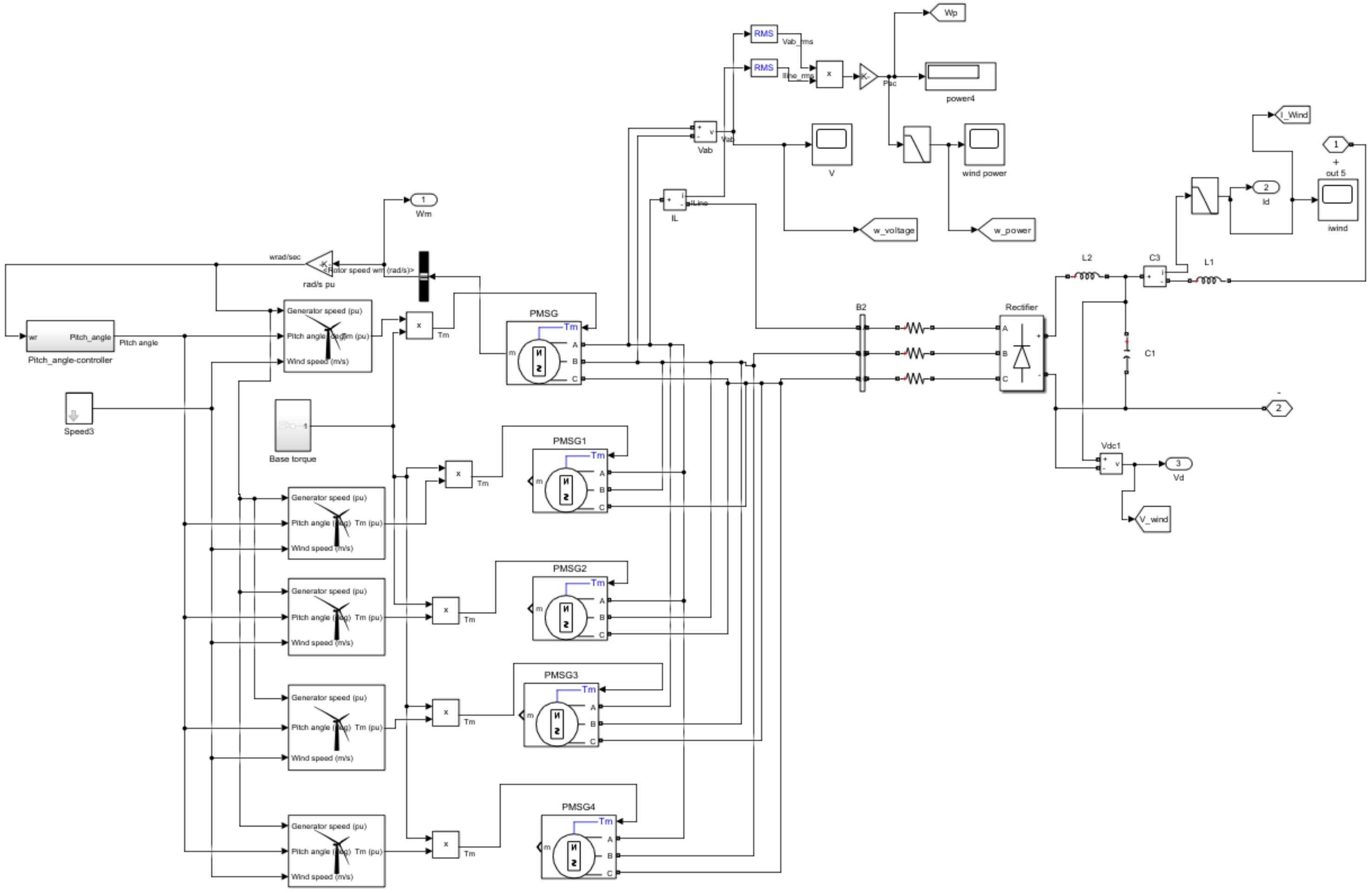


(b)

Figure 9: (a) Turbine power characteristics, (b) Modelled wind turbine in Simulink

BESS modelling

Battery Storage System

- Type: Lead-acid
- Nominal Voltage: 360V
- Rated capacity: 802Ah
- Initial state of charge: 80%
- Battery response time: 30s

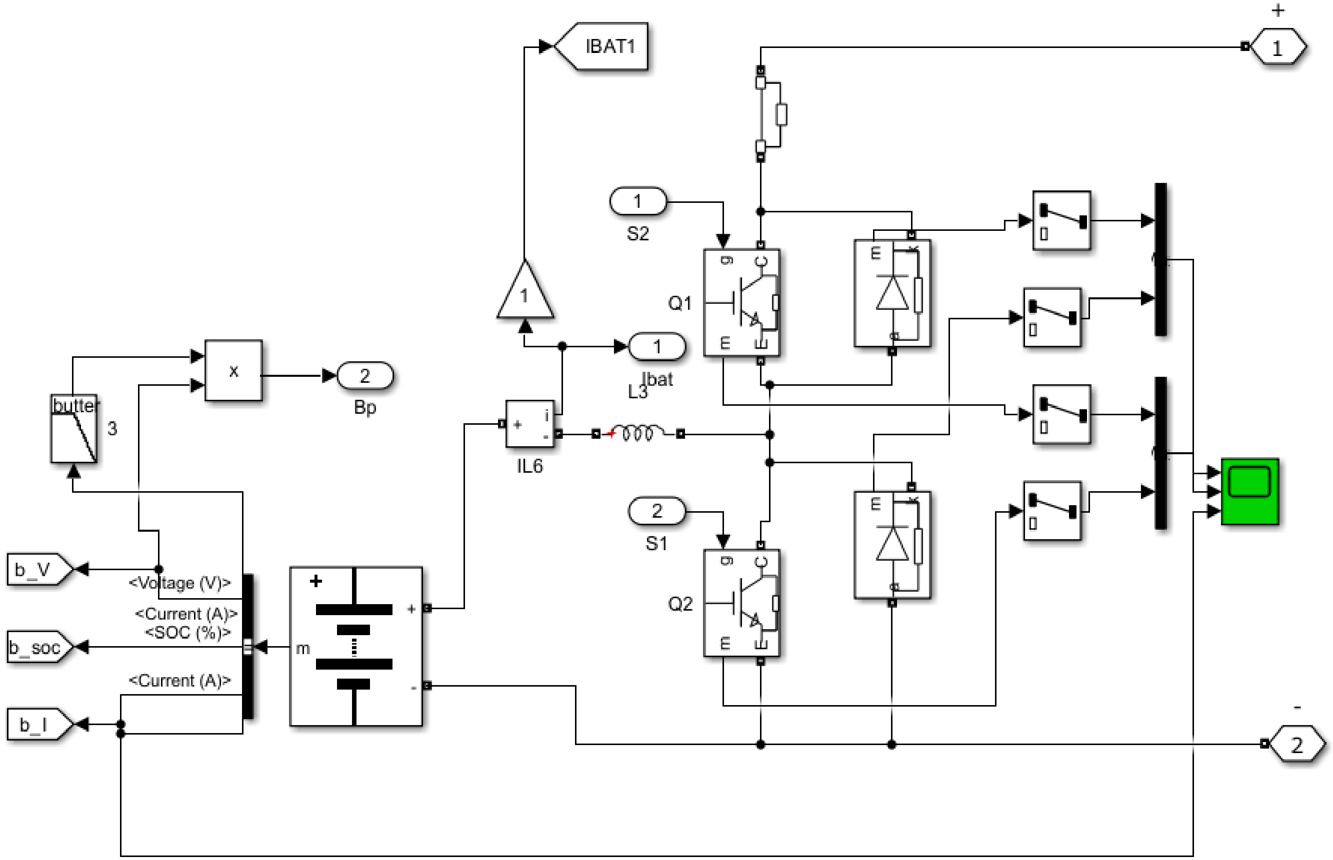


Figure 10: Modelled BESS in Simulink

DG Modelling

Table 9: DG Parameters

Parameter	Value
Nominal Power	30kW
Line voltage	380V
Frequency	50Hz
Flux linkage	0.433

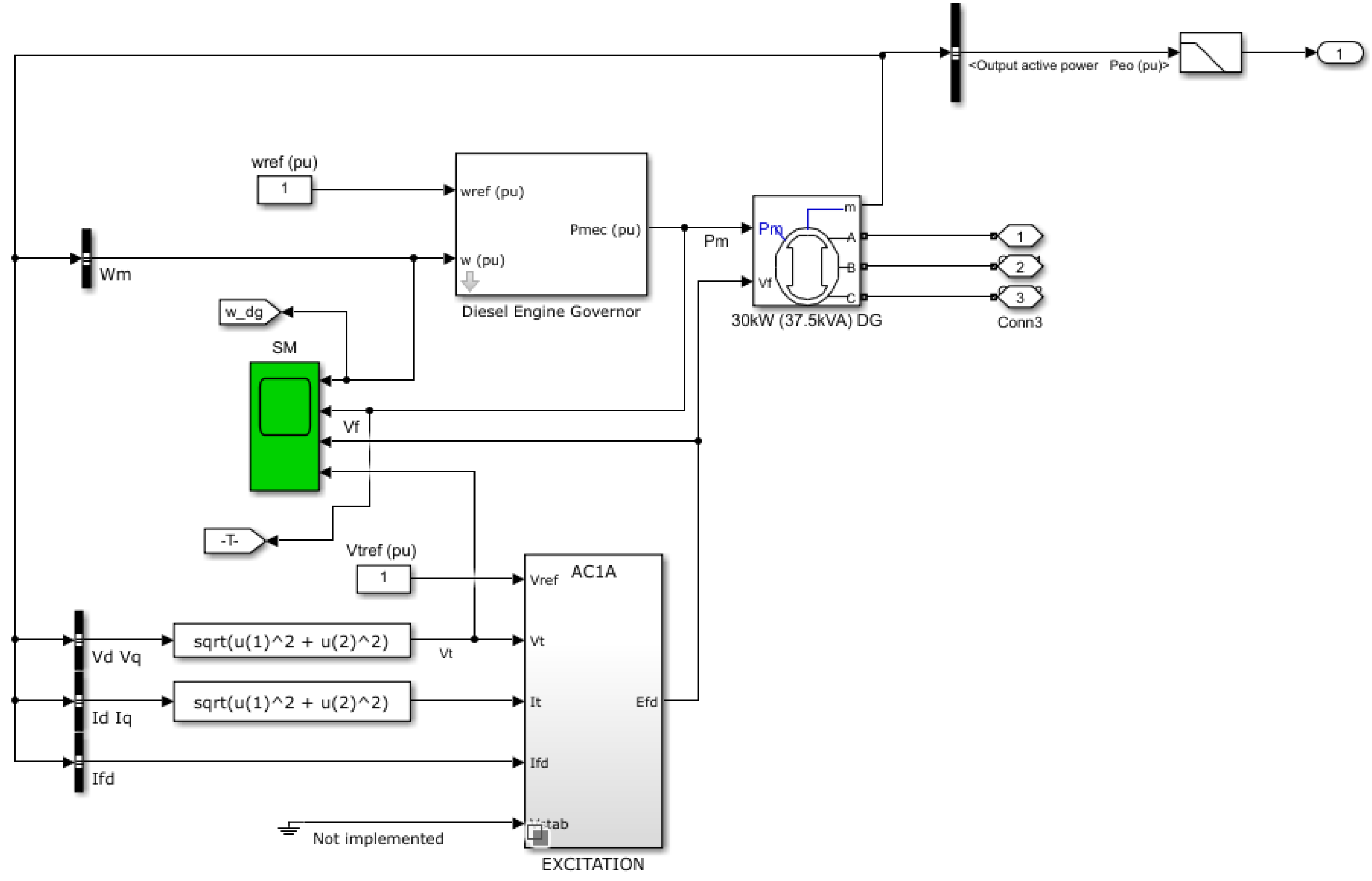


Figure 10: Modelled DG in Simulink

Community load modelling

Community Load

- Distribution lines: 300m & 500m
- Transformers (2): 100kW, 11kV/400V, 50Hz
- Three-phase breakers
- Nominal 11.63kW
- Peak load: 41.6kW
- 70.5% load: 8.2kW
- 170% load: 20kW

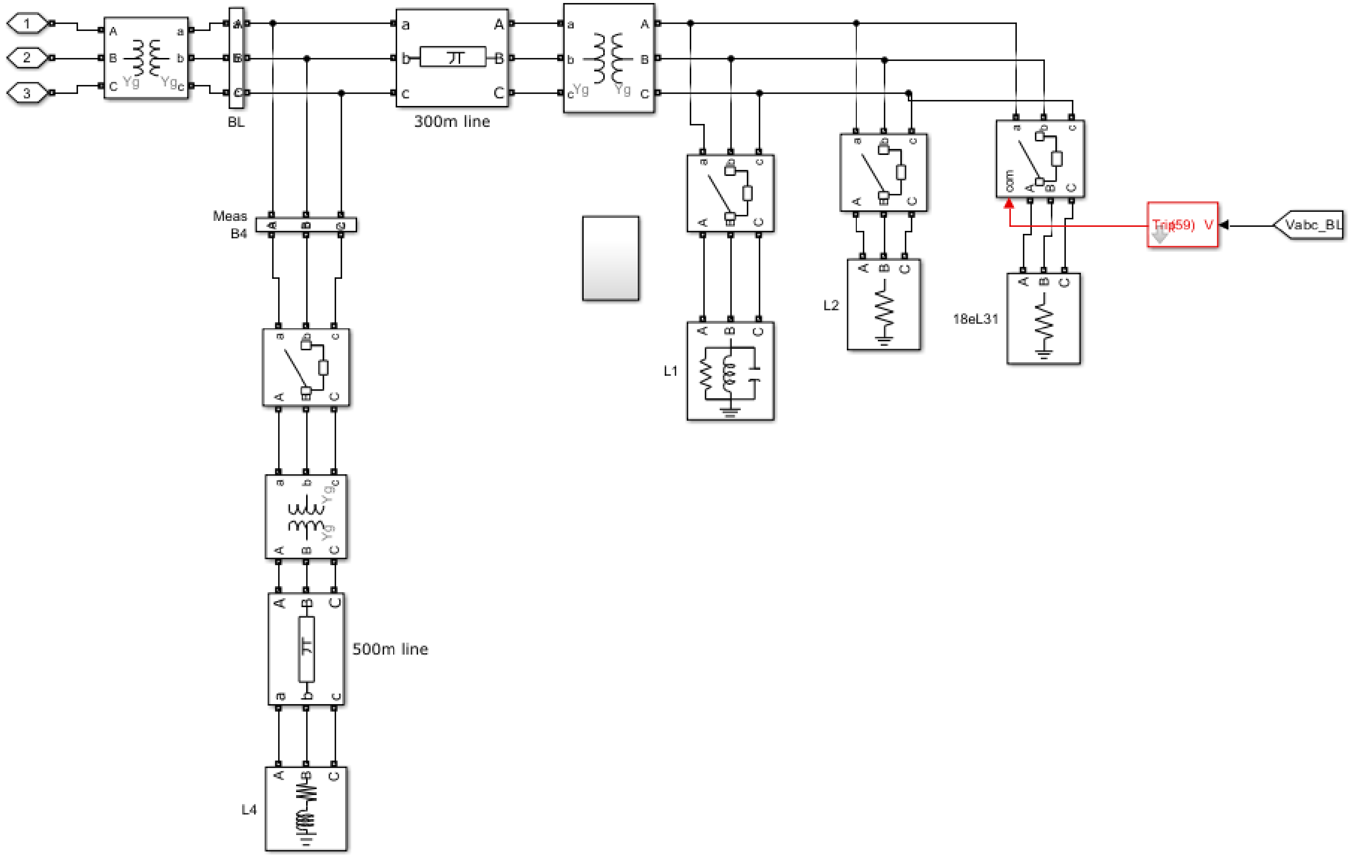


Figure 11: Modelled load in Simulink

Simulation results (1)

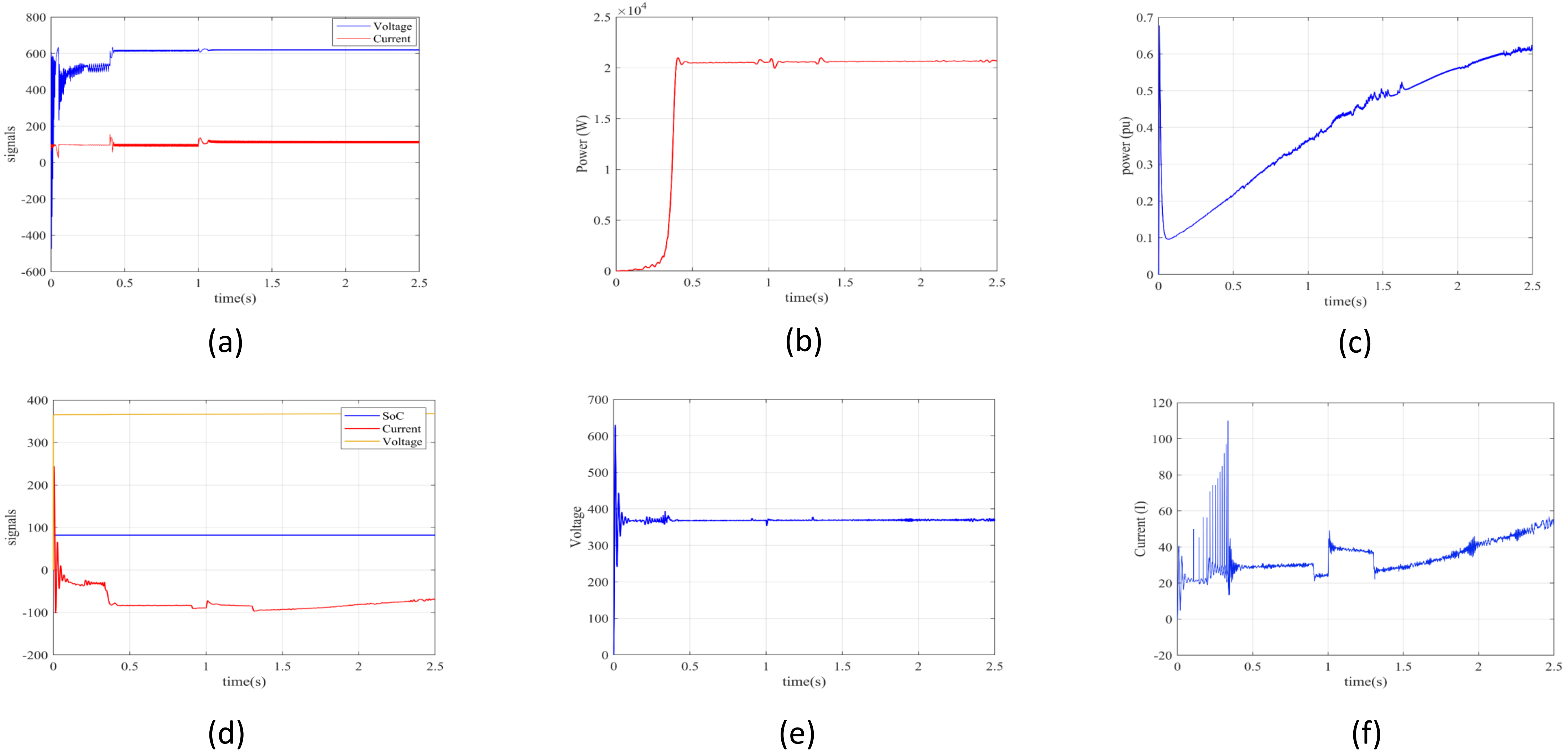
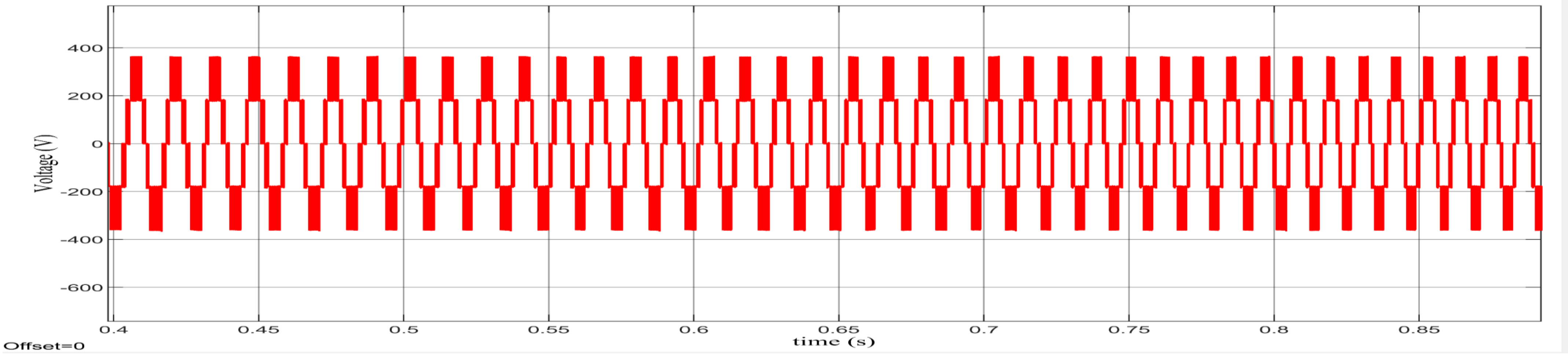


Figure 12: Simulation graphs (a) PV, (b) WT, (c) DG Power, (d) BESS, (e) DC Voltage, (f) DC current

Dynamic modelling and simulation

Simulation results (2)



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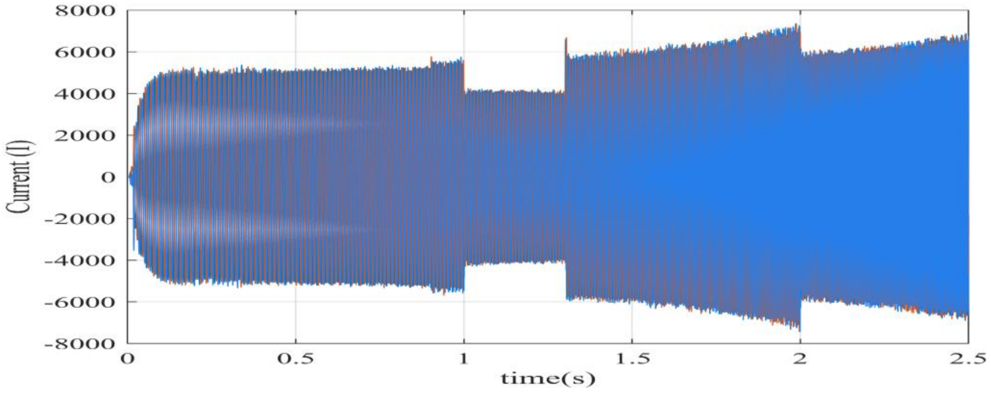

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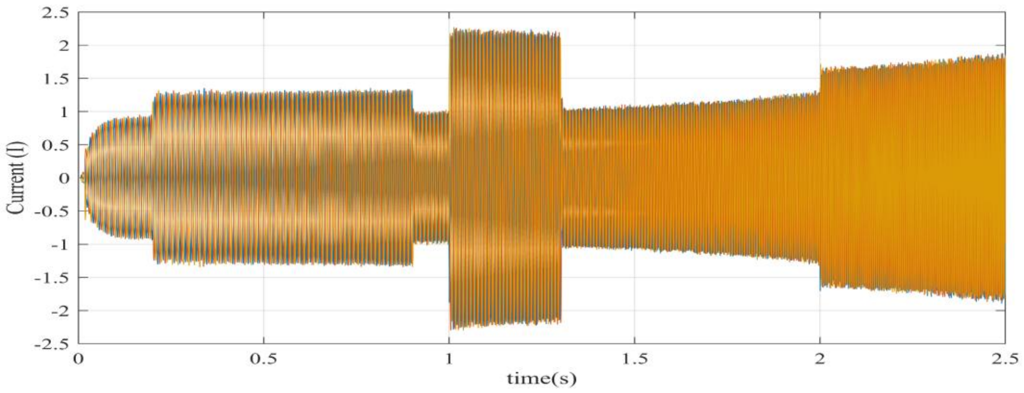


(c)

Figure 13: Simulation graphs (a) inverter voltage, (b) Load current, (d) load voltage

System Architecture

- Collect real-time current and voltage data
- Accurately monitor microgrid parameters
- Store data for future analysis

Table 10: Components' parameters

Component	Specification
PV Module	85W
Wind turbine	400W
Inverter	500W
DC power supply	30V, 5A
Battery	12V, 110Ah

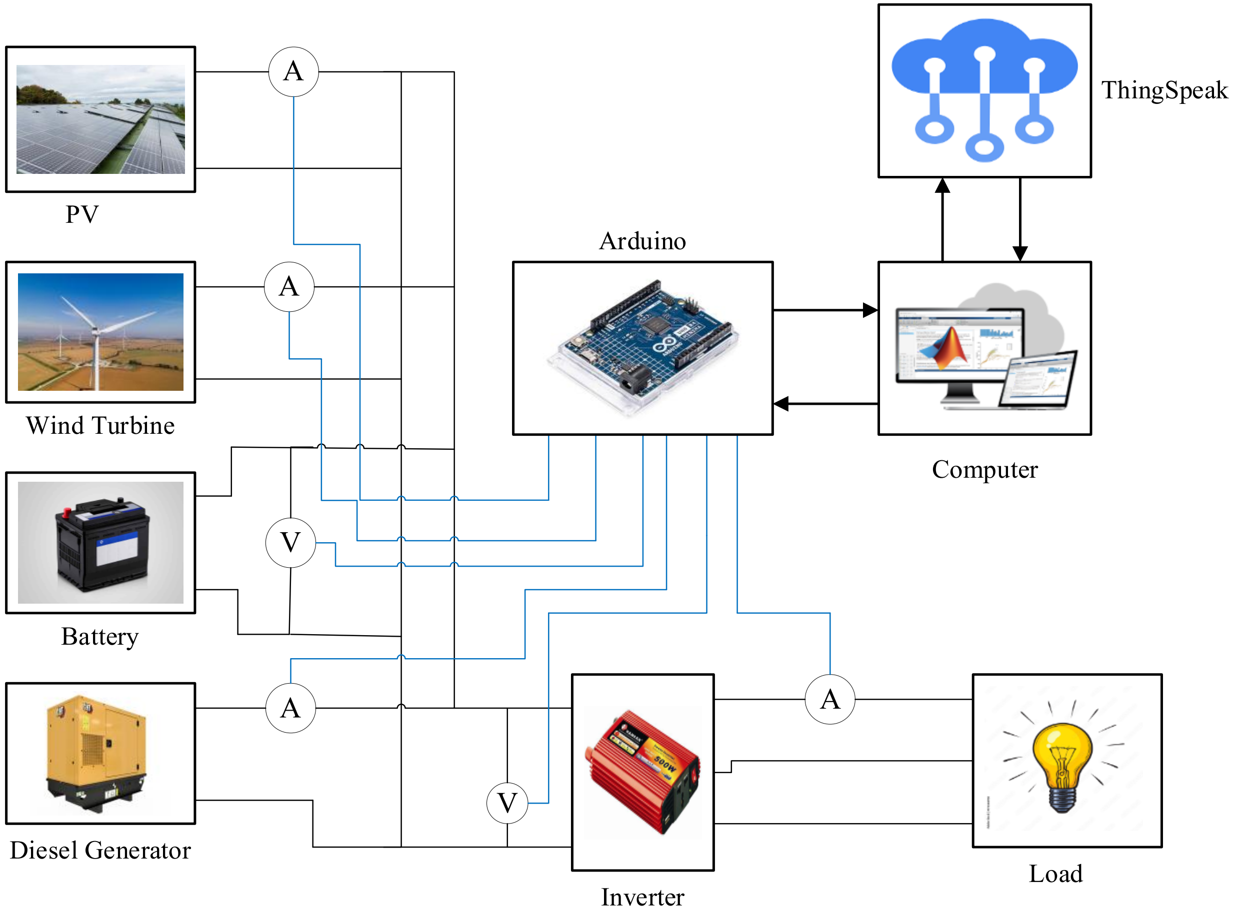
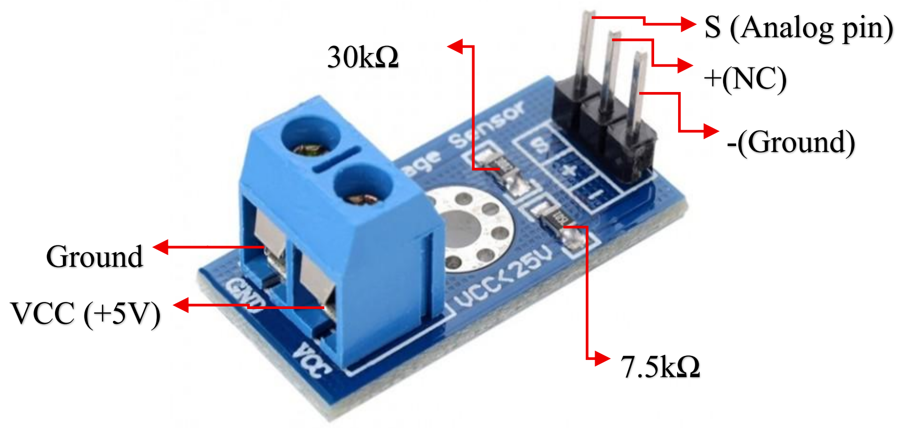


Figure 14: Data Logger System setup

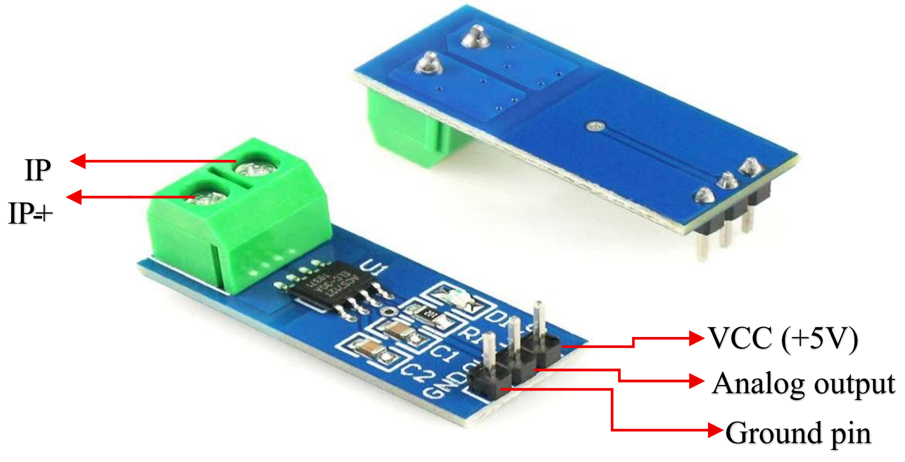
Field measurement devices

1. Voltage measurement

Parameter	Description
Sensor type	ACS 712 Hall-effect current sensor
Current	±5
Sensitivity	185mV
Sensor output	Ratiometric analog voltage



2. Current measurement



Parameter	Description
Sensor type	B25 voltage sensor
Input voltage range	0-25V
Output voltage range	0-5V
Configuration	Voltage divider

Data logging system

Remote terminal device

- Data collection from sensors
- Data pre-processing and signal conditioning
- Data transmission via its Wi-Fi capability

<u>UNO R4 Specifications</u>

- Device name: Arduino UNO R4
- Microcontroller: 32-bit, 48MHz
- Wi-Fi: ESP32-S3 running up to240MHz
- Storage: 256KB flash
- Voltage: 5V operating, 6-24V input
- Pins: 6 analog, 6PWM, 14 digital

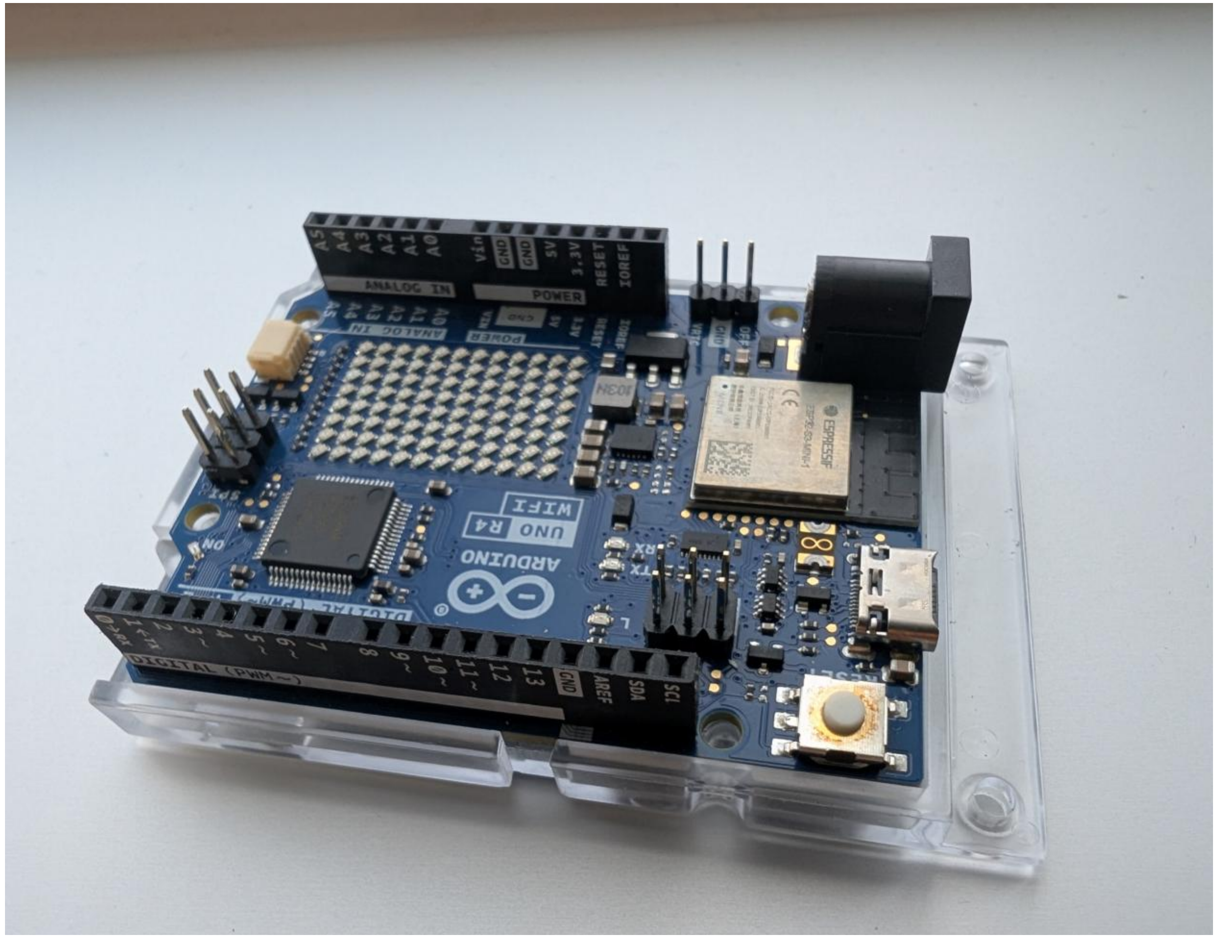


Figure 14: Arduino UNO R4 microcontroller

Experimental setup

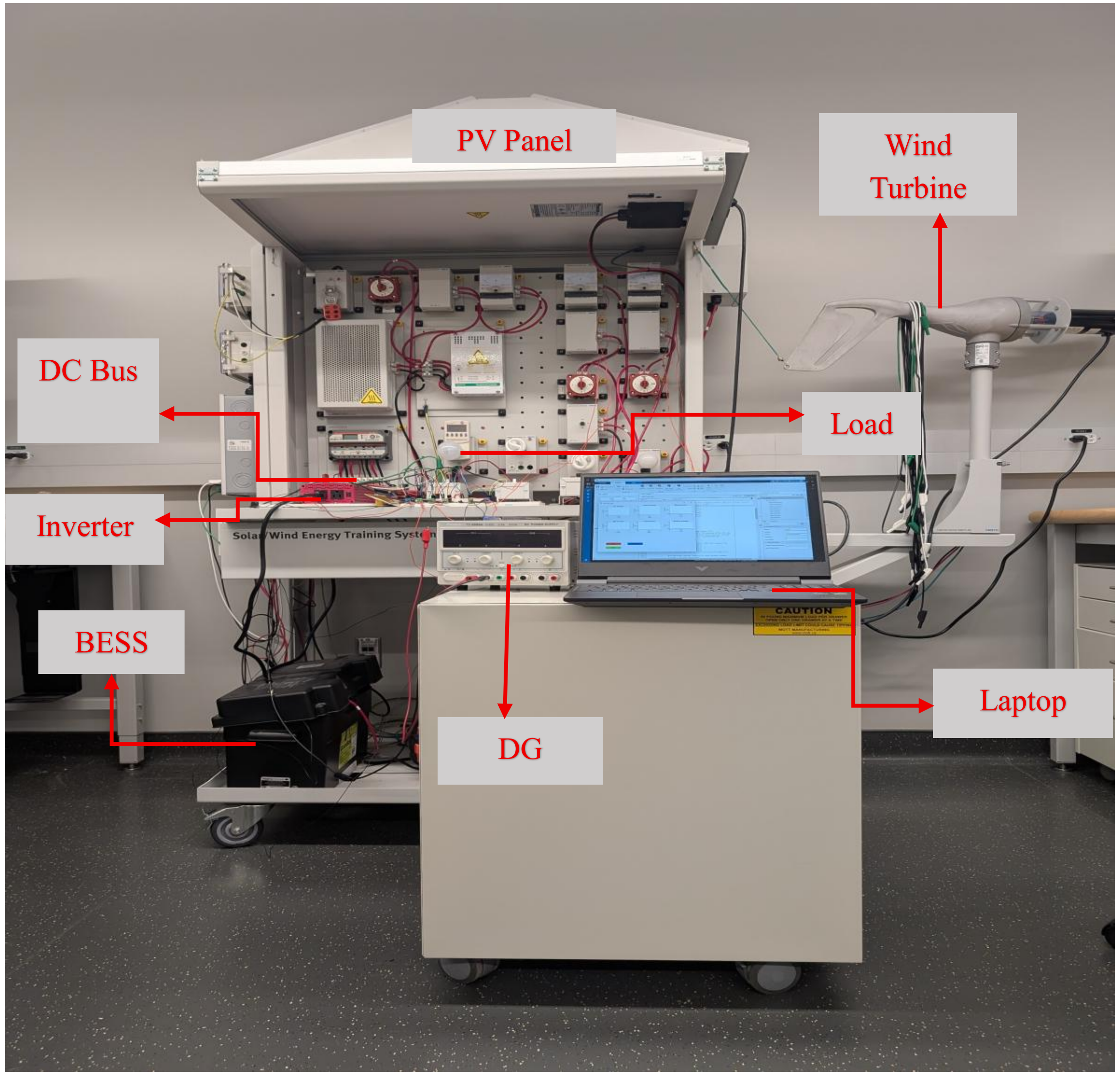


Figure 15: Complete system setup

Experimental results (local)

- Solar & wind are powered at time 4s
- Solar was completely turned off at 36s, 76, and 96s while wind speed was reduced, and DG turned on at approximately the same times, respectively
- Load is switched on and off at different times

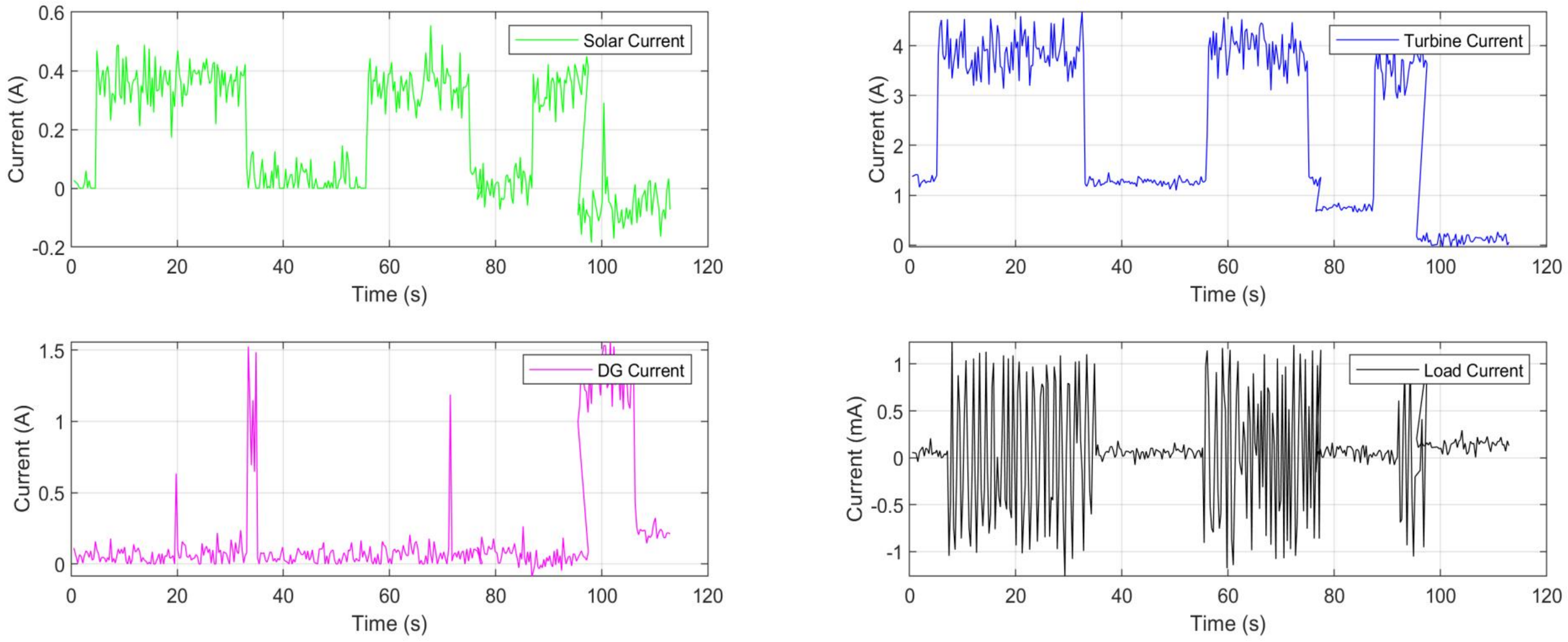


Figure 15: Local data logging simulation graphs for selected components

Data logging system

Experimental results (remote)

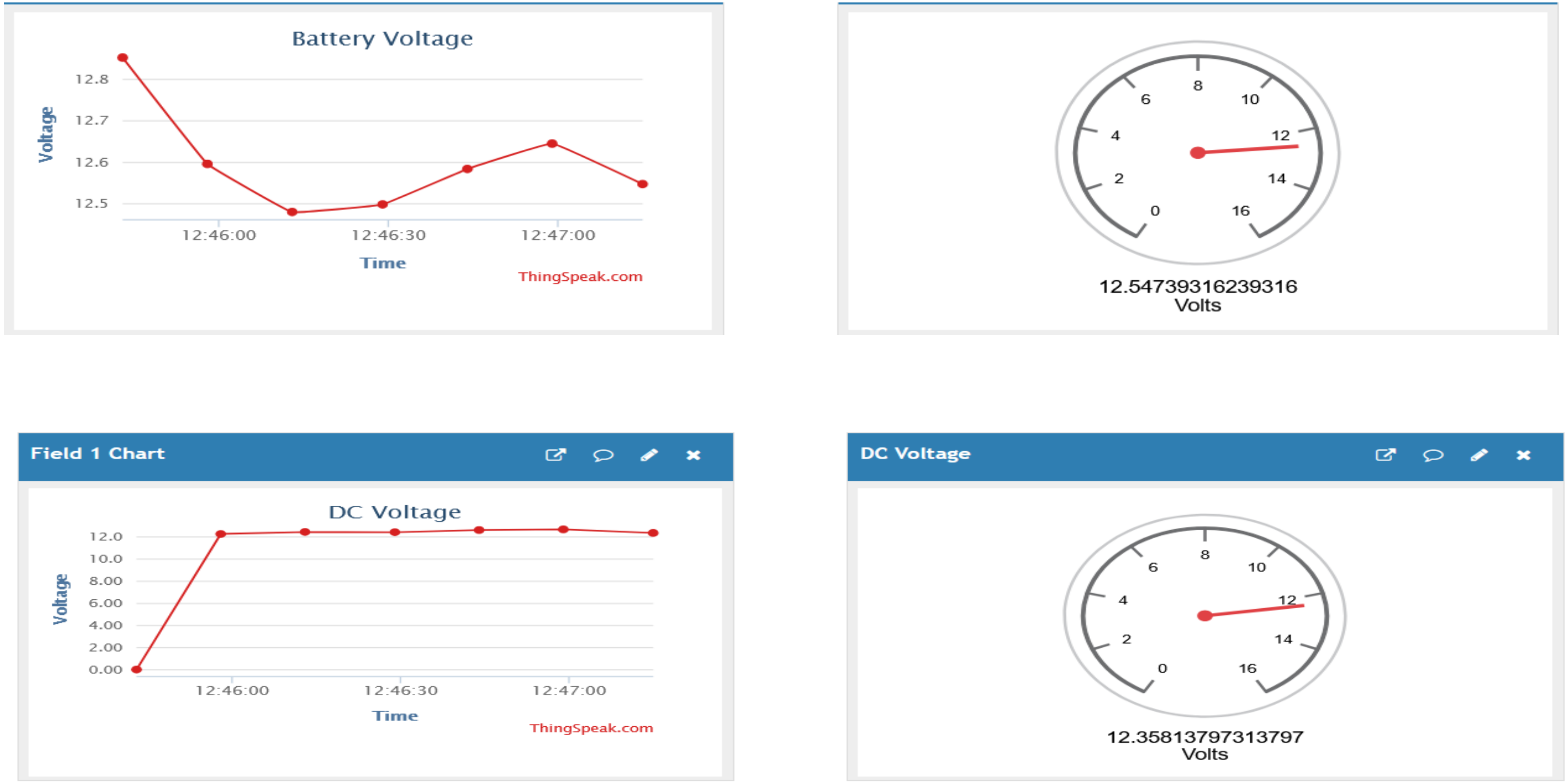


Figure 15: Remote data logging simulation graphs for selected components

Conclusion and Future work

Conclusion

- Developed an optimal DC microgrid for Azizakpe, a remote community in Ghana
- Key considerations included load growth, seasonal variations, and economic changes
- Modeled and simulated system dynamics in MATLAB/Simulink to ascertain system performance under transient conditions
- Several control algorithms were used to optimize the system performance
- Designed an IoT-based data logging system to monitor system parameters in real-time

Future Works

Future studies of this research would involve:

- Developing a machine learning-based fault detection system to improve protection and reduce downtime
- Developing a comprehensive AI-based forecasting tool for the microgrid
- Developing a smart energy management system to enhance system efficiency

List of Publications

- G. Atinkum, M. T. Iqbal, and J. E. Quaicoe, "Design of a low-cost IoT-based Data Logger for a remote DC Microgrid in Ghana." Currently under review with the *Journal of Electronics and Electrical Engineering*
- G. Atinkum, M. T. Iqbal, and J. E. Quaicoe, "Dynamic Simulation of a DC Microgrid for a Remote Community in Ghana," *Journal of Electronics and Electrical Engineering*, pp. 195–212, Oct. 2025, doi: 10.37256/jeee.4220257851.
- G. Atinkum, M. T. Iqbal, and J. E. Quaicoe, "Techno-Economic Design and Sensitivity Analysis of a DC Microgrid for a Remote Community: A Case Study in Ghana," *Journal of Electronics and Electrical Engineering*, pp. 357–378, May 2025, doi: 10.37256/jeee.4120256509.

Thank You!

Any Questions?