Microgrids to support Communication Infrastructure

DESIGN DOCUMENT

Team 46, May 2021
Client
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Executive Summary

Development Standards & Practices Used

- Matlab/Simulink simulation
- IEEE 1547: IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

Summary of Requirements

- Design and simulate 2 microgrid systems:
    - 1st system that is unrestrained in renewable vs nonrenewable generation and storage
    - 2nd system that solely utilizes renewable generation and storage components.
- Perform economic analyses for each system and provide a report of findings.
- Perform sustainability analyses for each system and provide a report of findings.
- Each member of the team should develop familiarity with testing and evaluating microgrids.

Applicable Courses from Iowa State University Curriculum

- EE 388: Sustainable Engineering and International Development
- EE 459: Electromechanical Wind Energy Conversion and Grid Integration.
- EE 456: Power System Analysis I
- EE 457: Power System Analysis II
- EE 475: Control System Simulation

New Skills/Knowledge acquired that was not taught in courses

- Wind/solar data gathering.
- Microgrid simulation
- Microgrid economic analysis
- Project Planning/Management

Table of Contents

List of figures/tables/symbols/definitions (This should be the similar to the project plan)

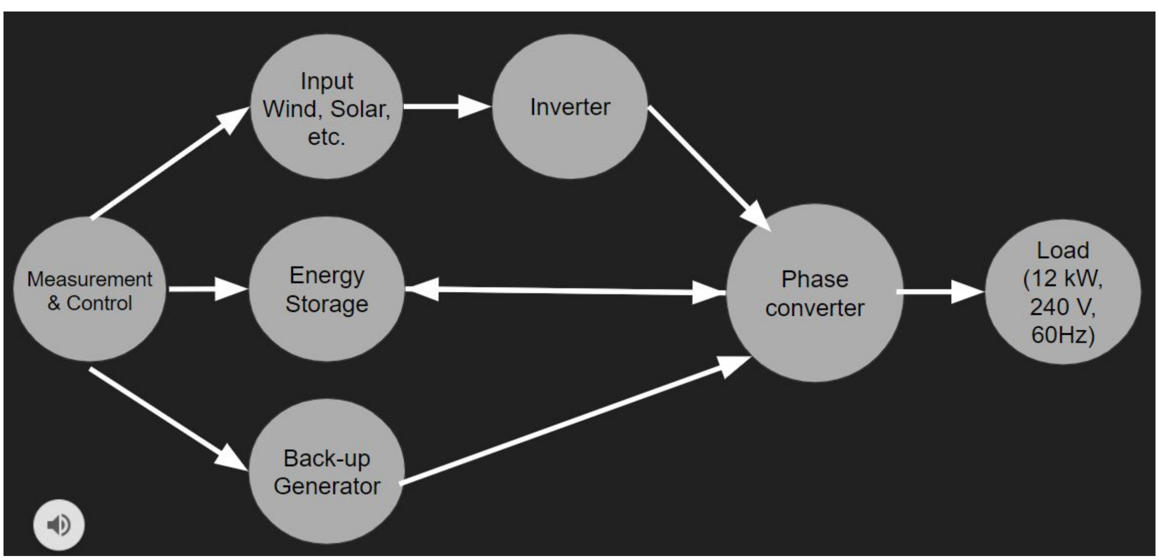

Fig. 1: Design sketches for Microgrid.

1 Introduction

1.1 Acknowledgement

Special thanks to Dr. Anne Kimber and Nick David, for their mentoring and assistance.

1.2 Problem and Project Statement

Problem Statement

An electrical outage, caused by an event such as a thunderstorm or blizzard, can have devastating effects on our ability to communicate. When communications equipment loses the ability to function due to power loss, critical communication between emergency crews and the ability to inform those within the impacted area is severely inhibited, potentially exposing people to dangerous situations.

Project Statement

In response to the above problem, we will design two mobile microgrids, capable of powering communications hubs for an extended period of time. The first microgrid will be powered entirely by renewable resources, including photovoltaic cells (PVC), wind turbines, and hydrogen fuel cells. The second microgrid will have a more standard design and will use both renewable and non-renewable resources with an emphasis on affordability.

1.3 Operational Environment

Both microgrids will operate in Kossuth County, IA. The components will be stored inside of a crate capable of being easily transported between locations. Most components will be protected from outside whether conditions, but some, such as wind turbines and PVC, may be exposed. Those components will need to be capable of withstanding wind, snow, ice, heat, etc.

1.4 Requirements

- The microgrid designs will be able to supply a 12kW constant load
- The microgrid should output AC 240V/60Hz.
- The microgrid should be economically feasible
- The microgrid should be built entirely from components available on the market
- The microgrid should be designed with the addition of data-logging equipment in mind
- The microgrid must be transportable within a 20' shipping container

1.5 Intended Users and Uses

The microgrid will be operated by utility companies providing communication infrastructure. The intended target for our designs will be to power a communications hub in northern Iowa that provides internet access to the area. The facility requires a 12kW constant load output at 240V/60Hz.

1.6 Assumptions and Limitations

Assumptions:

- The product will be used in North Central Iowa (Kossuth county).
- The crate will be stationary on a reasonably level surface while it is being used.
- The load required will be a 12 kW constant value

Limitations:

- Produce 240V/60Hz AC voltage, 12kW power output.
- The design should not exceed the volume of a 20' shipping container in it's transportation configuration
- Costs limited to market standard for new microgrid technology

1.7 Expected End Product and Deliverables

This project will deliver 2 simulations of potential microgrid designs. Each simulation will be complemented by an economic and sustainability analysis of the design as well as a bill of materials. Documentation and reasonings for design choices will be provided in a final report.

2 Project Plan

2.1 Task Decomposition

1. Finalize General components list: Researching generations and storage options as well as their economic benefits.
2. Finalize first project design: Sketch first prototype of a microgrid. Detailed description of each component (datasheet, economic cost, behaviours under different conditions).
3. Economic Analysis: perform economic analysis of the microgrid.
4. Start Simulation: Divide microgrid into several parts for easier simulation.
5. Simulation (continue): gather all parts to integrate into 1 simulation.
6. Measurement: measuring parameters and evaluating the performance of simulation.
7. Work on 2 different microgrids.

2.2 Risks And Risk Management/Mitigation

1. Economic analysis may run into pitfalls due to a lack of clear data regarding costs of loss of communication (Probability = 0.2). If this is a problem, research will be done into areas affected by communication loss (for example, the cost to businesses who lose the ability to communicate effectively) and the costs associated with each area will be summed.
2. Lack of data for specific wind patterns at desired altitudes for desired locations may possibly lead to miscalibration of simulations (Probability = 0.15). To account for this issue, we will design our systems that use wind generation to function optimally within a wider range of wind speeds.
3. Through dividing simulation into parts and integrating each part into one simulation, it is possible to miss an integration issue in early simulations (Probability = 0.1). This risk will be mitigated by proactively designing interfaces for simulation components.

2.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

Milestone 1: Document showing proposed generation components, storage components, inverters, and controls, with pros and cons detailed, will be complete.

Milestone 2: One line diagrams of the microgrid power system and control system will be complete.

Milestone 3: Document showing cost justification of each component will be complete.

Milestone 4: Document detailing sustainability analysis of each system will be complete.

Milestone 5: Integrated simulation will show expected results.

Milestone 6: Final report will be complete.

2.4 Project Timeline/Schedule

Updating:0%	Sep-28-20	7	H3:AN130	Today	10/4/2020										
Microgrid Project	**Start Date**	**Due Date**	**Days**	**% Completed**	**Head**	**Alt Color**	Sep-28	Oct-5	Oct-12	Oct-19	Oct-26	Nov-2	Nov-9	Nov-16	Nov-23
Finalize General Component List	1-Oct	16-Oct	15	18%	All	red									
Document every component we looked into and pros/cons	28-Sep	5-Oct	7	90%	Liam	red									
Begin Economic analysis of options	12-Oct	16-Oct	4	0%	Ryley	red									
Purchasable options for gerneration sources	5-Oct	12-Oct	7	0%	Liam(wind) and Abdel(solar)	red									
Purchasable options for storage sources	5-Oct	12-Oct	7	0%	Dylan?	red									
Purchasable Control options	5-Oct	16-Oct	11	0%	Hoang	red									
Finalize First Project Design	17-Oct	30-Oct	13	0%		red									
Calculate amount of each generation	17-Oct	23-Oct	6	0%		red									
Find details about chosen generation sources behaviour	17-Oct	23-Oct	6	0%		red									
Calculate amount of storage	17-Oct	23-Oct	6	0%		red									
Gather details about chosen storage behaviour	17-Oct	23-Oct	6	0%		red									
Calculate Economic cost of components	26-Oct	25-Nov	30	0%	Task to be broken down	red									
Calculate Cost of Control	17-Oct	23-Oct	6	0%	Task to be broken down	red									
Find details about control behaviour	17-Oct	30-Oct	13	0%		red									
Start Simulations	1-Nov	25-Nov	24	0%		red									
Simulate Solar panels	1-Nov	9-Nov	8	0%		red									
Simulate Wind turbine	1-Nov	9 Nov	8	0%		red									
Simulate Storage	9-Nov	25-Nov	16	0%		red									

Updating:0%	Sep-28-20	7	H3:AN130	Today	10/4/2020											
Microgrid Project	**Start Date**	**Due Date**	**Days**	**% Completed**	**Head**	**Alt Color**	Sep-28	Oct-5	Oct-12	Oct-19	Oct-26	Nov-2	Nov-9	Nov-16	Nov-23	No
Calculate amount of storage	17-Oct	23-Oct	6	0%		red										
Gather details about chosen storage behaviour	17-Oct	23-Oct	6	0%		red										
Calculate Economic cost of components	26-Oct	25-Nov	30	0%	Task to be broken down	red										
Calculate Cost of Control	17-Oct	23-Oct	6	0%	Task to be broken down	red										
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Simulate Wind turbine	1-Nov	9 Nov	8	0%		red										
Simulate Storage	9-Nov	25-Nov	16	0%		red										
Simulate Inverter	9-Nov	25-Nov	16	0%		red										
Simulate Load profile	13-Nov	25-Nov	12	0%		red										
Simulate wind and solar data	1-Nov	13-Nov	12	0%		red										

Fig 2: Gantt chart

2.5 Project Tracking Procedures

This Senior Design Group will track progress by creating and storing documents in Google Drive, and by regularly updating progress completed on the Gantt chart shown in section 2.4.

2.6 Personnel Effort Requirements

Task	Person-hours
Component Documentation	5
Begin Economic Analysis of Options	4
Evaluate Purchasable Options for Generations Sources	12
Evaluate Purchasable Options for Storage Sources	12
Evaluate Purchasable Options for Control	15
Calculate Generation Amount	3
Find Details about Generation Source Behavior	4
Calculate Storage Amount	3
Find Details about Storage Component Behavior	4

Calculate Cost of Components	6
Calculate Cost of Control	3
Find Details about Control Behavior	4
Simulate Solar	20
Simulate Wind	20
Simulate Storage	20
Simulate Inverter	20
Simulate Load Profile	20
Total	175

Table 1: Task List

2.7 Other Resource Requirements

Simulation Software

- Most Likely MatLab Simulink
- SAM
- PVMapper
- HYDROGEMS
- Compose

Sustainability Analysis Tools

- TEA
- EIO-LCA

Testing Equipment

For testing and measurement we will be using

- Multimeters and probes to measure and test the preexisting microgrid under different scenarios. In addition,we will be using this equipment to gather data to help our simulations.
- Data acquisition system

Additional equipment we may use:

- Power recorder
- High potential testing equipment.

2.8 Financial Requirements

At this time, the project does not have any financial requirements as we will only be using materials and software that have already been acquired for use by the university.

3 Design

3.1 Previous Work And Literature

[1] Chauhan, Rajeev Kumar, and Kalpana Chauhan. Distributed Energy Resources in Microgrids: Integration, Challenges and Optimization. 1st ed., Academic Press, 2019.

[2] Tester, Jefferson, et al. Sustainable Energy: Choosing Among Options (The MIT Press). Second edition, The MIT Press, 2012.

[3] A. Banerji et al., "Microgrid: A review," 2013 IEEE Global Humanitarian Technology Conference: South Asia Satellite (GHTC-SAS), Trivandrum, 2013, pp. 27-35

[4] A. Hirsch et al, "Microgrids: A review of technologies, key drivers, and outstanding issues", Elsevier Renewable and Sustainable Energy Reviews, Elsevier, July 2018, Vol 90, pp 402-411

[5] J. Jiao, R. Meng, Z. Guan, C. Ren, L. Wang and B. Zhang, "Grid-connected Control Strategy for Bidirectional AC-DC Interlinking Converter in AC-DC Hybrid Microgrid," 2019 IEEE 10th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Xi'an, 2019, pp. 341-345, doi: 10.1109/PEDG.2019.8807601.

[6] D. Singh, A. Agrawal and R. Gupta, "Power Management In Solar PV Fed Microgrid System With Battery Support," 2017 14th IEEE India Council International Conference (INDICON), Roorkee, 2017, pp. 1-6, doi: 10.1109/INDICON.2017.8487837.

[7] G. B. Arjun Kumar, Shivashankar and B. Shree Ram, "Hybrid PV - Wind Driven Generator Supplying AC/DC Microgrid for Rural Electrification," 2018 3rd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT), Bangalore, India, 2018, pp. 2283-2287, doi: 10.1109/RTEICT42901.2018.9012328.

[8] IEEE Standard for the Specification of Microgrid Controllers," in IEEE Std 2030.7-2017 , vol., no., pp.1-43, 23 April 2018, doi: 10.1109/IEEESTD.2018.8295083.

While microgrids are a more recent technology, a substantial amount of groundwork has been laid. Microgrids of various sizes across the globe range from acting as fail safes to increase stability in power supply. Other microgrids act purely in island mode to allow off-grid living. Some microgrid systems supply communities with energy distribution for locally generated renewable energy. The most common energy generation sources utilized with existing microgrids are PV panels, diesel generators, and wind turbines. Some less common generation methods utilized are hydro-electricity and hydrogen fuel cells. Lithium batteries are the most common energy storage method whereas methods like hydrogen synthesis and pumped hydro are less common storage methods.

Some advantages of previous microgrids include well established combinations of the various energy generation and storage systems, existing technology designed to connect and manage energy generation and storage systems, and thoroughly developed simulations for individual components. The main shortcomings are that microgrids and more generally distributed energy resources are not as widely accepted. They typically have high upfront costs, and the large scale infrastructure has not been as fully developed as more traditional centralized forms of energy delivery. An additional shortcoming that we plan to improve upon is the lack of mobility of most microgrid systems.

3.2 Design Thinking

1. Communication companies need a way to power their data hubs during power outages, so the ability to communicate remains intact. Output power ought to be at least 12 kW, provided at 240 VAC with a frequency of 60 Hz.
2. They need the power generation to be mobile, in order to minimize the number of generation modules required.
3. They need to use primarily green energy, to prevent carbon emissions.

These three defined needs led to the proposed design of the green mobile microgrid. Some of the other design ideas, along with the reasons why they were not chosen, are listed below.

- Using a thermal (seebeck) generator. This option, while intriguing, is simply not as efficient as using PVC.
- Using flow batteries rather than regular batteries. Flow batteries have a low energy density, are heavy, and expensive.

3.3 Proposed Design

Our team has conducted extensive research into the world of microgrids in order to obtain an understanding of the current state and inner workings of the technology system. The aspects that we have given the most attention to are as follows: microgrid review literature, energy generation devices, energy storage devices, inverters, microgrid control systems, use cases, communications infrastructure electrical load data, and simulation tools.

We used the findings of our research to design a nano-grid as a testbench to try out different configurations of storage and generation sources. This design will have a special focus on hydrogen storage and power, due to the relative lack of relevant information we could find during our research. The design will be controlled by a number of relay switches in tandem with an arduino. The generation sources we will be able to test will include solar, a hydrogen fuel cell and a wind turbine. The options we will be investigating will include a battery and stored hydrogen. This microgrid will supply a standard 120VAC output using the components in the Component List below.

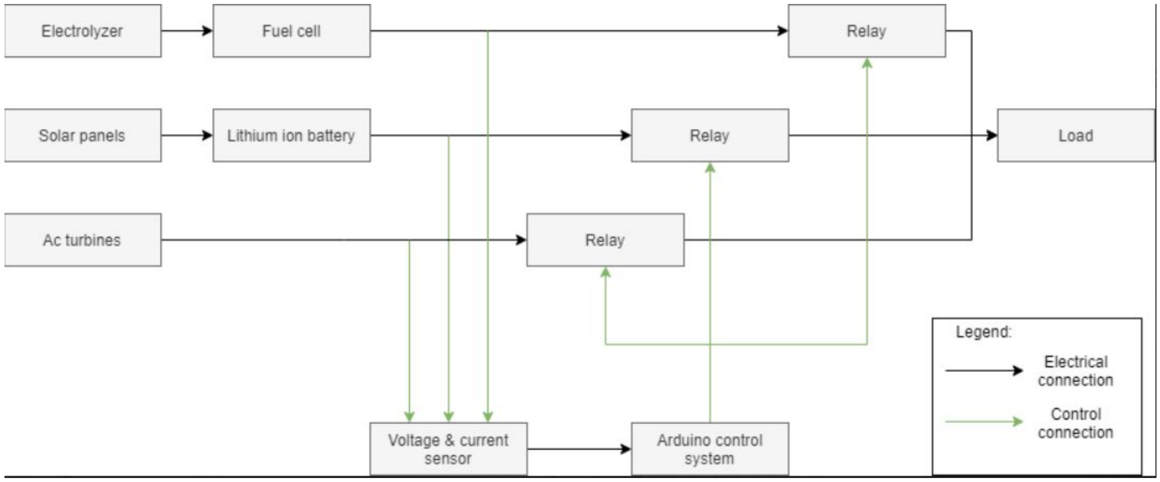


Fig 3: High Level Diagram of Nano-Grid Design

Component	Price ($)
100W Hydrogen Fuel Cell	1,499
Hydrofill Pro Electrolyser	999
600W Wind Turbine	740
500W Lithium Battery	499
100W Solar Panel	299
Frequency Converter	200
Miscellaneous Circuit Components	150
Hydrostik Pro Cylinders	98
Total	**4,484**

Table 2: Nano-Grid Component List

3.4 Technology Considerations

The extent of existing power and electrical systems and components in MatLab is quite high. This allows for easy entry into the simulation of each individual device for our microgrid designs. However, there is a fairly steep learning curve in the control systems aspect of simulations. The control systems must be created specifically for each individual system and is one of the most important aspects of the simulation. Prebuilt systems offer lower learning curves, but can be quite costly and would not operate beyond outside of the niche software. The ubiquity of MatLab's implementation allows for our systems to be run by any person that has MatLab and no additional licenses are required. Additionally, MatLab is a lower level software that allows for greater customization. We can tailor our simulations to our needs to a much greater degree than with other preexisting microgrid or energy system simulation softwares. Overall, using MatLab will allow for greater simulation control and accessibility, at the cost of the need to overcome a steeper learning curve.

System Advisor Model (SAM) is a technical modelling tool with an emphasis on the economic analysis of the system. It allows the user to design their solar/wind design environment, and generates a holistic economic overview of the system. The platform offers a simplistic way to integrate the design aspects with economic considerations which are quintessential to our overall system. Most of the limitations of this system are in the technical aspect; SAM does not allow much room for technical experimentation. As such we're limited to the options the software provides.In addition, the simulations are typically designed for residential or utility scale, which may be limiting to the purposes of our design. That being said, SAM will be used mainly as a reference for the economic simulation.

3.5 Design Analysis

Currently, there is no reason to assume our proposed design from 3.3 will not work. However, there are some modifications that could be made if changes are warranted.

- Adding a back up fuel powered (most likely diesel) generator if simulations and/or tests indicate that we may not always be able to meet load requirements with our current design.
- If further economic analysis warns that our current design is economically untenable, some design parts that are desirable for other reasons, but expensive, may be replaced with a less costly option (For example, Lithium Ion batteries could be replaced with Sulfuric Acid batteries).

3.6 Development Process

Right now we are following a waterfall development process. This is due to the type of work that we have done up to this point. A lot of research, documenting and grant writing does not lend itself very well to more iterative development processes. Once we begin designing simulations and putting our prototype together, we intend to rely on an agile-esc design process, where we implement small components and test that they function as intended. We then build up from those basic components and put things together into more complex systems.

3.7 Design Plan

The use case from section 1.5 gives us parameters in which to design our microgrid. Those parameters are as follows:

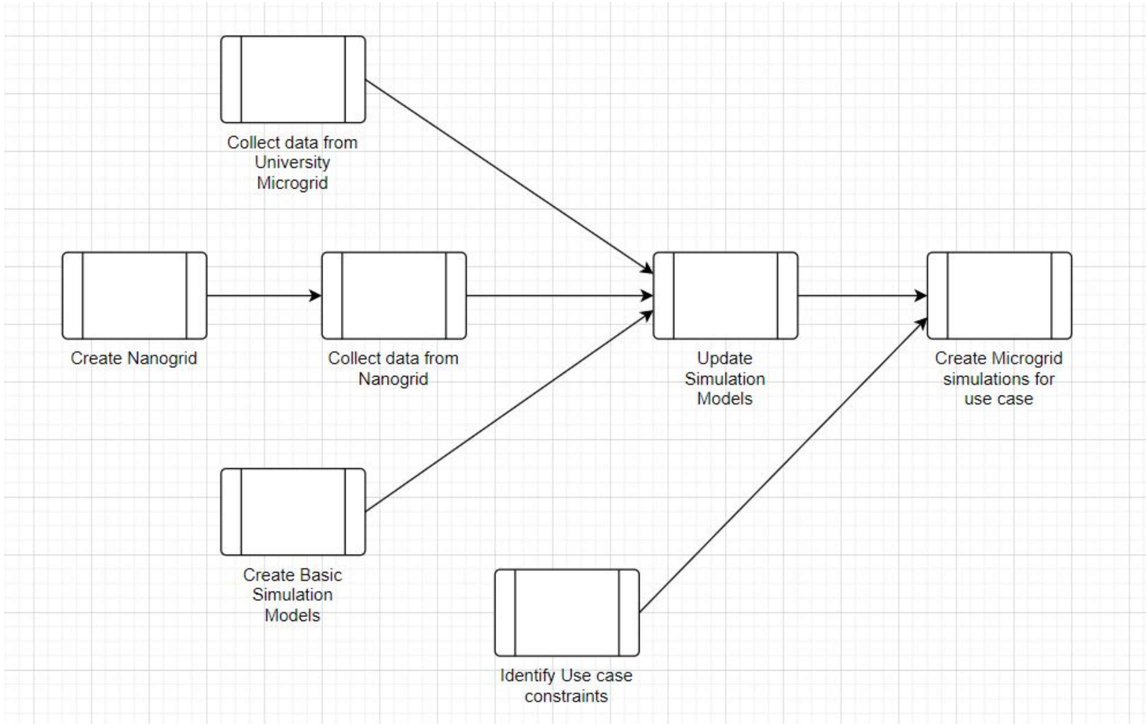
1) A binding constraint of 12kW constant load
    a) need to have this much power provided at all times
    b) ideally always from a combination of stored energy and energy generation (not some consumable fuel)
2) A location, Kossuth county, used to obtain environmental data to be used as inputs for simulation models

Our design plan contains six major steps:

1. Collect data from University microgrid
2. Create nanogrid
3. Collect data from nanogrid components
4. Create basic simulation components
5. Adjust simulation models to match data collected from micro and nanogrids
6. Using updated models, create microgrid simulations to power our target communications hub

Requirements from table 1.4 will be met by our design plan as detailed below:

- The microgrid design will be able to provide a 12kW constant load
- The microgrid should supply AC 240V/60Hz
    - Data collected in steps 1 and 3 of our plan will allow for better understanding of actual performance of various components. This will be taken into account when selecting the components and amounts of each component to be certain the target load is reached
- The microgrid should be economically feasible
    - The nanogrid will be testing out components that we do not have access to currently on the University microgrid. The economics of the components of both grids will be
- The microgrid should be built entirely from components available on the market
- The microgrid must be transportable within a 20' shipping container
    - All models will be built based on component datasheets that are compatible with our design
- The microgrid should be designed with the addition of data-logging equipment in mind
    - Components will be chosen that either contain data-logging capabilities, or are compatible with data-logging devices



4 Testing

Simulations will be broken into 6 sections.

1. PVC
2. Wind Turbine
3. Hydrogen
4. Inverters
5. Battery Storage
6. Controls

Each simulation will input data respective to our project (i.e. wind and solar data from Kossuth County, IA, PVC characteristics, etc.) and output expected performance of the devices under each condition. These simulations will then be combined and the final output will be analyzed to ensure requirements are met.

Testing of the nano-grid will follow the same pattern as the simulations. Each individual component will be tested to ensure its requirements are met. Components will then be combined into systems, and each system will be tested. Finally, all systems will be tied together, and a series of final tests will be conducted.

4.1 Unit Testing

Matlab/Simulink simulation is divided into 5 units:

- Solar panels & MPPT control: Ensure maximum power output under various irradiances.
- Wind turbines: Output 240V/60Hz AC power according to wind speed.
- Battery Energy storage system (BESS): Test charge and discharge mode. Modeling batteries' conditions (life cycle, working temperature, etc...)
- Inverters: Outputting 240V/60Hz AC voltage with various DC input.
- Hydrogen fuel cells

Each simulation unit is subjected to testing.

4.2 Interface Testing

1. Connect solar panels & MPPT control with Inverter.
2. Connect BESS with Inverter.
3. Connect Hydrogen Fuel Cells with Inverter.
4. Connect all of the individual components together.
5. Test the simulation model with parts acquired (funding to be considered).

4.3 Acceptance Testing

- The simulation is considered functional if it correctly predicts the behaviours of a test microgrid. Test microgrid can be the nanogrid or the microgrid that our client Dr. Anne Kimber has already built with her team.
- Our nano grid, when functional, will be able to balance between energy storage and deliverance to a load depending upon changes in generation and load requirement.

4.4 Results

– List and explain any and all results obtained so far during the testing phase

- Include failures and successes
- Explain what you learned and how you are planning to change the design iteratively as you progress with your project
- If you are including figures, please include captions and cite it in the text

5 Implementation

Describe any (preliminary) implementation plan for the next semester for your proposed design in 3.3.

6 Closing Material

6.1 Conclusion

Summarize the work you have done so far. Briefly reiterate your goals. Then, reiterate the best plan of action (or solution) to achieving your goals and indicate why this surpasses all other possible solutions tested.

6.2 References

List technical references and related work / market survey references. Do professional citation style (ex. IEEE).

6.3 Appendices

Any additional information that would be helpful to the evaluation of your design document.

If you have any large graphs, tables, or similar data that does not directly pertain to the problem but helps support it, include it here. This would also be a good area to include hardware/software manuals used. May include CAD files, circuit schematics, layout etc,. PCB testing issues etc., Software bugs etc.