# Microgrids to support Communication Infrastructure

DESIGN DOCUMENT

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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)

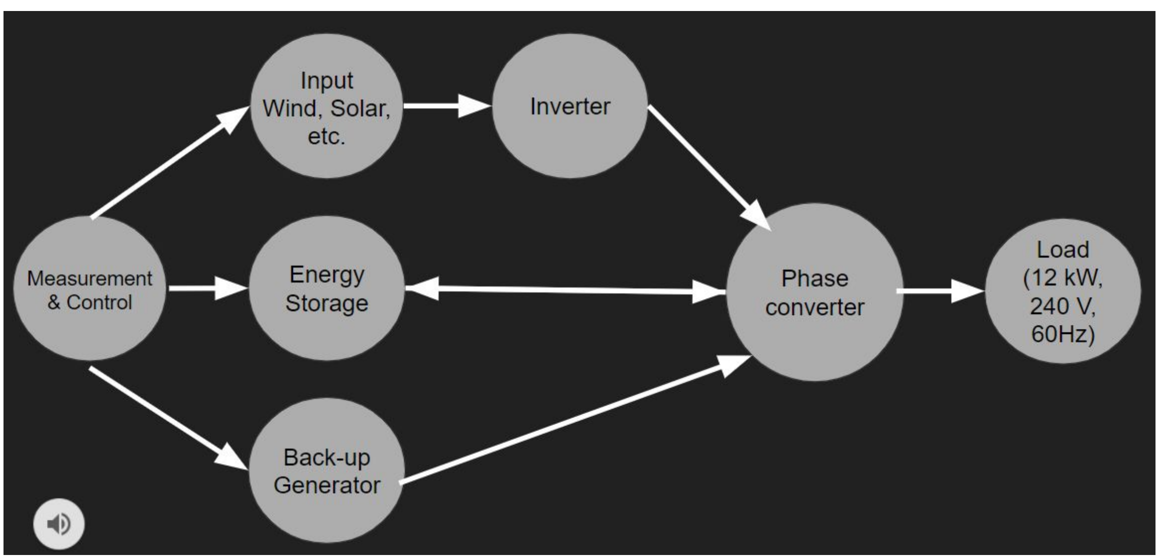


Fig. 1: Design sketches for Microgrid.

# 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 | | | | | | | | | | |
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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 | | | | | | | | | |

## 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 |

## 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.

Detail any similar products or research done on this topic previously. Please cite your sources and include them in your references. All figures must be captioned and referenced in your text.

### 3.2 Design Thinking

Detail any design thinking driven design “define” aspects that shape your design. Enumerate some of the other design choices that came up in your design thinking “ideate” phase.

### 3.3 Proposed Design

Include any/all possible methods of approach to solving the problem:

- Discuss what you have done so far – what have you tried/implemented/tested?
- Some discussion of how this design satisfies the **functional and non-functional requirements** of the project.
- If any **standards** are relevant to your project (e.g. IEEE standards, NIST standards) discuss the applicability of those standards here
- This design description should be in **sufficient detail** that another team of engineers can look through it and implement it.

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 tower data,

### 3.4 Technology Considerations

Highlight the strengths, weakness, and trade-offs made in technology available.

Discuss possible solutions and design alternatives

### 3.5 Design Analysis

- Did your proposed design from 3.3 work? Why or why not?
- What are your observations, thoughts, and ideas to modify or iterate over the design?

### 3.6 Development Process

Discuss what development process you are following with a rationale for it – Waterfall, TDD, Agile. Note that this is not necessarily only for software projects. Development processes are applicable for all design projects.

### 3.7 Design Plan

Describe a design plan with respect to use-cases within the context of requirements, modules in your design (dependency/concurrency of modules through a module diagram, interfaces, architectural overview), module constraints tied to requirements.

# 4 Testing

Testing is an **extremely** important component of most projects, whether it involves a circuit, a process, or software.

1. Define the needed types of tests (unit testing for modules, integrity testing for interfaces, user-study or acceptance testing for functional and non-functional requirements).
2. Define/identify the individual items/units and interfaces to be tested.

3. Define, design, and develop the actual test cases.
4. Determine the anticipated test results for each test case
5. Perform the actual tests.
6. Evaluate the actual test results.
7. Make the necessary changes to the product being tested
8. Perform any necessary retesting
9. Document the entire testing process and its results

Include Functional and Non-Functional Testing, Modeling and Simulations, challenges you have determined.

### 4.1 Unit Testing

– Discuss any hardware/software units being tested in isolation

### 4.2 Interface Testing

– Discuss how the composition of two or more units (interfaces) are to be tested. Enumerate all the relevant interfaces in your design.

### 4.3 Acceptance Testing

How will you demonstrate that the design requirements, both functional and non-functional are being met? How would you involve your client in the acceptance testing?

### 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 re-iterate your goals. Then, re-iterate 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.