Microgrids to support Communication Infrastructure

DESIGN DOCUMENT

Team 46, May 2021
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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 303: Energy Systems and Power Electronics
- EE 388: Sustainable Engineering and International Development
- EE 456: Power System Analysis I
- EE 457: Power System Analysis II
- EE 459: Electromechanical Wind Energy Conversion and Grid Integration.
- 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

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 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 shipping 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 Iowa weather including but not limited to wind, snow, ice, and heat.

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.

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 at most 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.

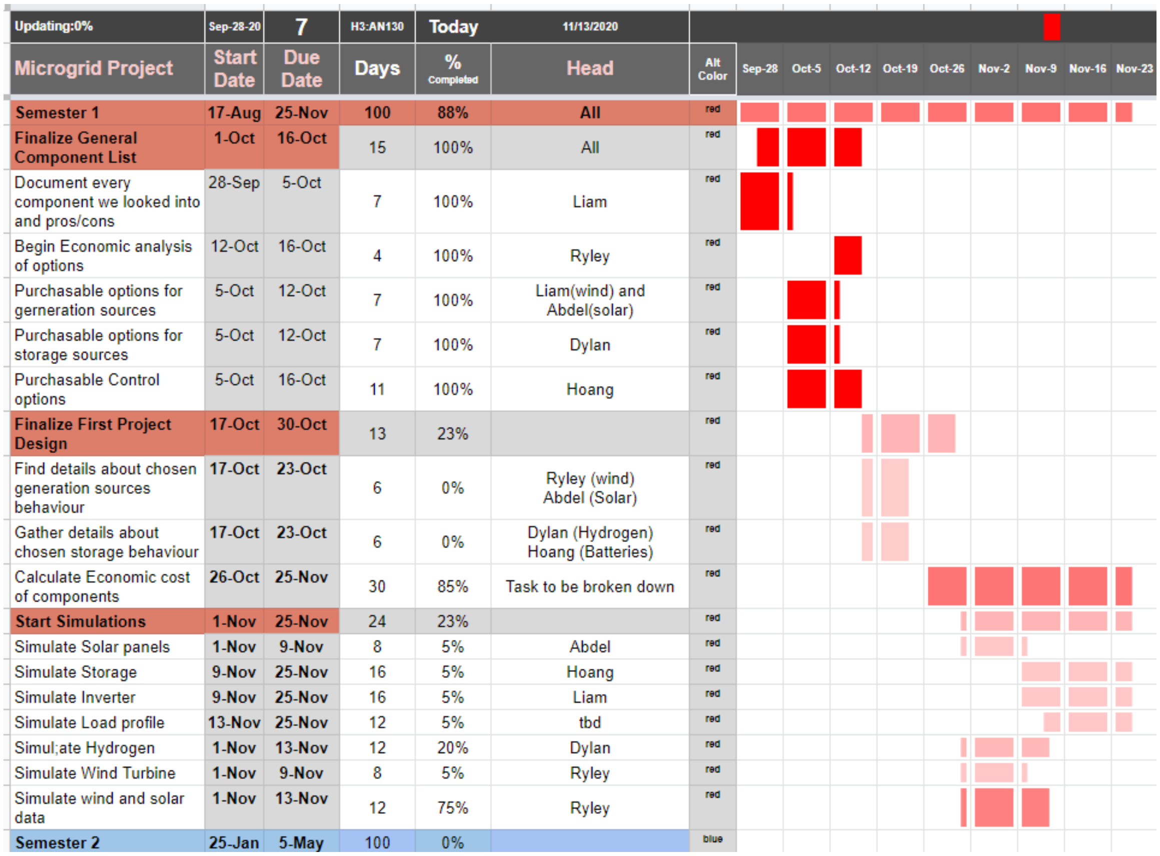
Milestone 3: Document showing cost justification of each component will be complete.

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	11/13/2020	
Microgrid Project	**Start Date**	**Due Date**	**Days**	**% Completed**	**Head**	**Alt Color**
Semester 1	**17-Aug**	**25-Nov**	**100**	**88%**	**All**	red
Finalize General Component List	**1-Oct**	**16-Oct**	15	100%	All	red
Document every component we looked into and pros/cons	28-Sep	5-Oct	7	100%	Liam	red
Begin Economic analysis of options	12-Oct	16-Oct	4	100%	Ryley	red
Purchasable options for gerneration sources	5-Oct	12-Oct	7	100%	Liam(wind) and Abdel(solar)	red
Purchasable options for storage sources	5-Oct	12-Oct	7	100%	Dylan	red
Purchasable Control options	5-Oct	16-Oct	11	100%	Hoang	red
Finalize First Project Design	**17-Oct**	**30-Oct**	13	23%		red
Find details about chosen generation sources behaviour	**17-Oct**	**23-Oct**	6	0%	Ryley (wind) Abdel (Solar)	red
Gather details about chosen storage behaviour	**17-Oct**	**23-Oct**	6	0%	Dylan (Hydrogen) Hoang (Batteries)	red
Calculate Economic cost of components	**26-Oct**	**25-Nov**	30	85%	Task to be broken down	red
Start Simulations	**1-Nov**	**25-Nov**	24	23%		red
Simulate Solar panels	**1-Nov**	**9-Nov**	8	5%	Abdel	red
Simulate Storage	**9-Nov**	**25-Nov**	16	5%	Hoang	red
Simulate Inverter	**9-Nov**	**25-Nov**	16	5%	Liam	red
Simulate Load profile	**13-Nov**	**25-Nov**	12	5%	tbd	red
Simul;ate Hydrogen	**1-Nov**	**13-Nov**	12	20%	Dylan	red
Simulate Wind Turbine	**1-Nov**	**9-Nov**	8	5%	Ryley	red
Simulate wind and solar data	**1-Nov**	**13-Nov**	12	75%	Ryley	red
Semester 2	**25-Jan**	**5-May**	100	0%		blue

Fig 1: 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

The tasks are broken down into five major sections. Each section is further broken down into specific tasks that would be assigned to one or more team members.

Task	Person-hours
Initial Documentation and Evaluation	
Review Literature	50
Write Grant Application	60
Begin Economic Analysis of Options	20
Evaluate Purchasable Options for Generations Sources	25
Evaluate Purchasable Options for Storage Sources	25
Evaluate Purchasable Options for Control	30
Component Documentation	10
Calculate Generation Amount	10
Find Details about Generation Source Behavior	30
Calculate Storage Amount	15
Find Details about Storage Component Behavior	30
Calculate Cost of Components	15
Calculate Cost of Control	15
Find Details about Control Behavior	30
Initial Microgrid Simulation	
Simulate Solar Subsystem	40
Simulate Wind Subsystem	30
Simulate Storage Subsystem	30
Simulate Inverter Subsystem	30
Simulate Hydrogen Subsystem	30
Simulate Diesel Generation Subsystem	30
Simulate Load Profile Subsystem	30
Simulation Integrations	60
Construct Nanogrid (analog benchtop microgrid)	

Set up solar and battery	20
Set up wind turbine	40
Test Hydrogen Fuel Cell and Electrolyser	60
Integrate components	60
Testing	
Collect measurements from crate	60
Data log from nanogrid wind turbine	20
Collect measurements from Hydrogen system	20
Collect measurements from nanogrid solar	20
Final Simulations	
Update simulation models with measured data	100
Simulate Renewable grid (hydrogen, solar, wind, storage)	170
Simulate Economic grid (diesel, solar, wind, storage)	170
Economic analysis for final designs	60
Accumulate findings into reports	60
Total	1505

Table 1: Task List

2.7 Other Resource Requirements

Simulation Software

- MatLab Simulink/Simscape
- SAM (System Advisor Model)

Sustainability Analysis Tools

- TEA (Techno-Economic Analysis)
- EIO-LCA (Economic Input Output Life Cycle Assessment)

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 systems: Dranetz meter, Enphase Envoy

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

While microgrids are a more recent technology, a substantial amount of groundwork has been laid. In the paper “MICROGRID: A Review”, the authors defined microgrid as a single controlled unit that often consisted of generators, energy storage and load controllers as well as interfaces like inverters [1]. The paper also lays out the importance of MGs in today’s power grid, such as the ability to maintain power supply during natural disasters and improved reliability and quality of power received by the customers. The textbook, “Distributed Energy Resources in Microgrids: Integration, Challenges and Optimization” offers the history of microgrid (MG) research and development, common configurations of microgrids, and advantages and disadvantages of various components and configurations.[3]

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.[1][3][4] The lack of appearance of mobile microgrids in research papers and textbooks indicates that this is a novel adaptation of the newly established microgrids.

AC based microgrids have the advantage of being able to connect to most pre-existing grids. Additionally, many of the components within an AC system are well established and therefore generally less expensive and more reliable. Drawbacks of AC systems are lower efficiency due to conversion losses, integration with renewable technologies, and lower overall stability due to the larger number of necessary devices, conversion levels, and frequency matching requirements when synchronizing.[1] DC microgrids require less conversion steps and components. Lack of need for costly conversion mechanisms leads the DC microgrids to be cheaper than AC microgrids when using entirely new components, but can be more costly if AC microgrids use existing distributed energy resources. DC microgrids also pose the advantage of increased efficiency. The DC microgrid disadvantages include need for bidirectional converters to connect to the main grid, and lack of standards for systems.[1]

A common trend in microgrid design is to have systems that are separated by AC and DC buses. These microgrids offer the ability to interface with the main grid or existing AC systems. This allows for increased stability of the microgrid, enabling the system to use the main grid as a battery and charge storage devices at times when the microgrid is not needed to supply power. The AC and DC buses can connect directly to AC and DC loads. Microgrids that use both AC and DC buses will often use a bi-directional interlinking converter (BIC) to allow power flow between the two buses. It is especially important to use a synchronous switching control strategy, so that when interconnecting the two buses there is no instantaneous current due to a voltage and phase difference between the two sides of the connection point.[1][5]

IEEE Standards for Microgrid Controllers[6] defines a set of guidelines for building microgrid control systems. This standard allows for different controllers and components to operate cohesively and platform-independent. One of the most important management systems of microgrids is the microgrid energy management system (MEMS). According to the standard, the control functions enable the microgrid to operate autonomously or grid connected, as well as connect and disconnect to the grid smoothly. Control systems play an important role in microgrids, and are often technically challenging.

Microgrids have been implemented across the globe to play various roles in connected distributed energy resources. Some provide fail safes for grid power loss and increase stability in power supply. Other microgrids act purely in island mode to allow for power connected off-grid living. Some microgrid systems supply communities with energy distribution for locally generated renewable energy. A commonality between various roles of microgrids are the types of energy generation sources typically used. The most common generation sources currently implemented in microgrids are PV panels, diesel generators, and wind turbines. Some less common generation methods include hydro-electricity and hydrogen fuel cells. Lithium batteries are the most common energy storage method whereas methods like flywheel storage, hydrogen synthesis and pumped hydro are less common storage methods.[1][3][4][8]

Some of the most successful case studies of microgrids include a hybrid combination of solar/wind and diesel generation. The system referenced by "Hybrid PV - Wind Driven Generator Supplying AC/DC Microgrid for Rural Electrification" utilizes both solar and wind generation with storage capabilities in addition to a standby backup diesel generator. Both solar and wind have intermittency problems where enough power is not generated when it's desired. The battery storage capabilities allow energy to be stored when generation is at its maximum, then power can be delivered from the batteries. The diesel generator acts as a backup source to provide power when the batteries are charging; this allows for constant power flow at any given time. The hybrid system configuration is the most common due to its increased reliability and affordability.[6]

Pertinent sustainability and economic analyses methods are detailed in “Sustainable Energy: Choosing Among Options”. This textbook offers a wealth of information regarding the different aspects of sustainability analyses methods as well as the inherent sustainability of different energy systems, such as wind energy, solar energy, and fossil fuel energy. Pages 249-292 detail the interrelation between economics and sustainability as well as analysis methods for the energy project economics. One of the major tools used for economic analysis of energy systems is

Techno-Economic Analysis (TEA).[2] Since TEA is widely used, a plethora of existing analyses are available for reference to base calculations for distributed energy systems. There exists two open access softwares designed for sustainability analysis that are relevant to microgrids. These are Life Cycle Analysis (LCA) and Economic Input Output Life Cycle Assessment (EIOLCA).

3.2 Design Thinking

To better understand the problem we are trying to solve, we first had to understand the client. We were provided some specifications directly from the client that are seen below:

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.
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.

Through additional conversations we also concluded that the following points are also extremely important to the client:

- Cost of installation
- Payback time
- Maintenance
- Reliability

With this in mind, our team conducted extensive research into the world of microgrids in order to obtain an understanding of the current state and inner workings of the technology. 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.

The first aspect we need to decide is which type of generation we want in our design. To solve this problem, we consult previous use cases as well as Dr. Kimber and Dr. David to narrow down our sources. During our discussion, we found that hydrogen fuel cells are a promising technology for storage but haven't been implemented into microgrids. Dylan volunteered to look more into hydrogen technology and how to implement it into our projects. After further discussion, we came to a conclusion with 3 generations type: solar panels, wind turbines for their popularity in microgrids and hydrogen fuel cells to test out their capability.

The second problem came when we had to decide whether to design a DC microgrid or an AC microgrid. A DC microgrid has the advantages of being simple, often a one line diagram, and certainly easier to control because we don’t have to worry about things like frequency and reactive power. However, an AC microgrid is chosen in our project simply because the majority of electrical appliances in our daily life nowadays run on AC current, so it makes sense to assume that the targeted communication hub runs on AC power. Finally, after the discussion, we came to a conclusion that the designs should always output 240V/60 Hz AC voltage and satisfy a 12 kW as mentioned earlier.

These three defined needs combined with the generation sources mentioned in section 3.1 led to the proposed design of the green mobile microgrid design. Some of the other design ideas, along with the reasons why they were not chosen, are listed below.

- Using a thermoelectric (seebeck) generator. This option, while intriguing, is simply not as efficient as using PVC. [9]
- Using flow batteries rather than regular batteries. Flow batteries have a low energy density, are heavy, and expensive

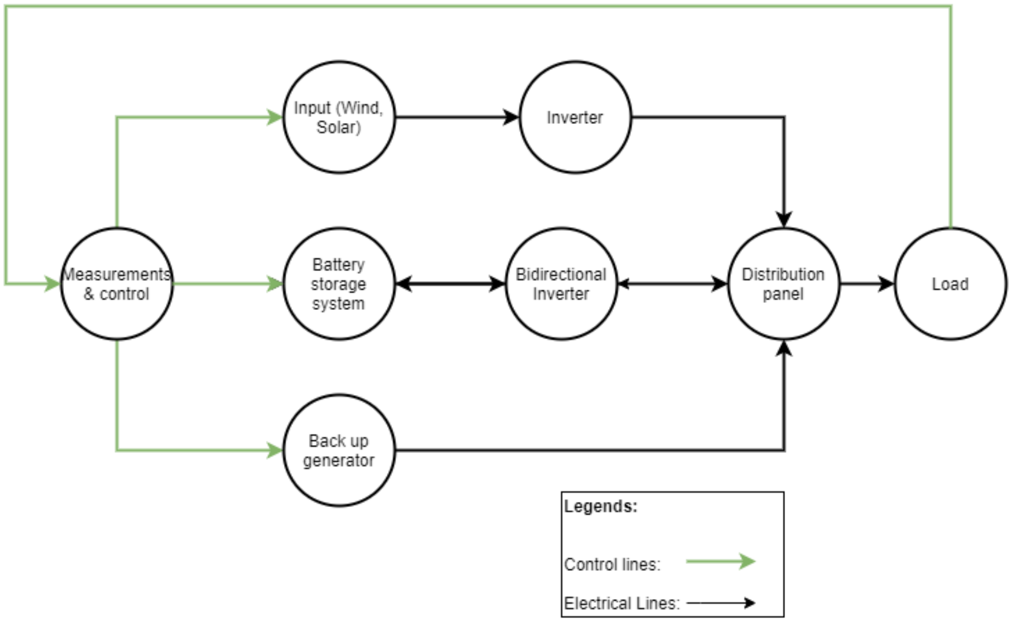


Fig. 2: Design sketches for Microgrid.

3.3 Proposed Design

The first microgrid to be designed and simulated is the environmentally sustainable microgrid. The generation subsystem of this microgrid will include a wind turbine, hydrogen fuel cells, and PVC panels. The storage subsystem will consist of lithium ion batteries, and a hydrogen electrolyzer. Inverters will connect the storage and generation systems to a distribution panel, which will then feed to the load. Current and voltage sensors will be used to provide information to the controller. The controller will regulate through the system through the use of relays.

The wind turbine will be a horizontal axis wind turbine with a ten foot mast. The output of the wind turbine will be an AC voltage. The electrical output will be routed to a controller that will achieve a constant VAC which will be routed to the distribution panel.

The PVC subsystem will output a DC voltage. It will feed an inverter which contains a maximum power point tracking (MPPT) embedded into it. The MPPT decides which voltage the PV output to achieve maximum power, and from there feeds the power distribution panel.

The lithium-ion batteries will be connected to the distribution panel via a bi-directional inverter. The batteries will operate at 48 VDC.

The hydrogen electrolyzer will take water as an input, and output hydrogen and oxygen. It will be powered through the distribution panel. The hydrogen will be directed to and stored in hydrogen tanks. A check valve will be used to prevent backflow from the hydrogen tanks to the electrolyzer. The tanks will, through a valve, direct hydrogen to the hydrogen fuel cells. The hydrogen fuel cells, when needed, will produce electricity and output water as a bi-product. The water will be directed back to the hydrogen electrolyzer.

The control system will consist of voltage and current sensors, a controller, and relays. Voltage sensors at each generation and storage device will ensure that all systems are operating at their functional voltage. Current sensors at the load and at the output of each storage and generation component will determine the current being drawn. All sensors will be fed back to the controller. The controller will regulate all storage and generation devices through the use of normally open relays at the load and at all generation and storage components. The following table outlines various situation responses.

Situation	Response
No load, storage full	All relays open
Small load, storage full	Generation relays closed, storage relays open
Small load, low storage	All relays closed
Large load, storage full	All relays closed
Large load, low storage	Generation relays closed, storage relays open
Load larger than available power	Load relay open, all other relays closed

Table 2: Microgrid Situational Response

The components mentioned above will be implemented in Simulink using building blocks from Simscape library under the Specialized Power System tab. From these blocks, one can use topology of the components and its parameters to simulate the behaviours of these components and interconnect them into a microgrid system.

The second microgrid design, focused on economic priorities, will be similar to the first. The primary difference will be that the hydrogen energy storage system will not be used, while a fuel generator will be added.

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 systegreems 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-esque 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

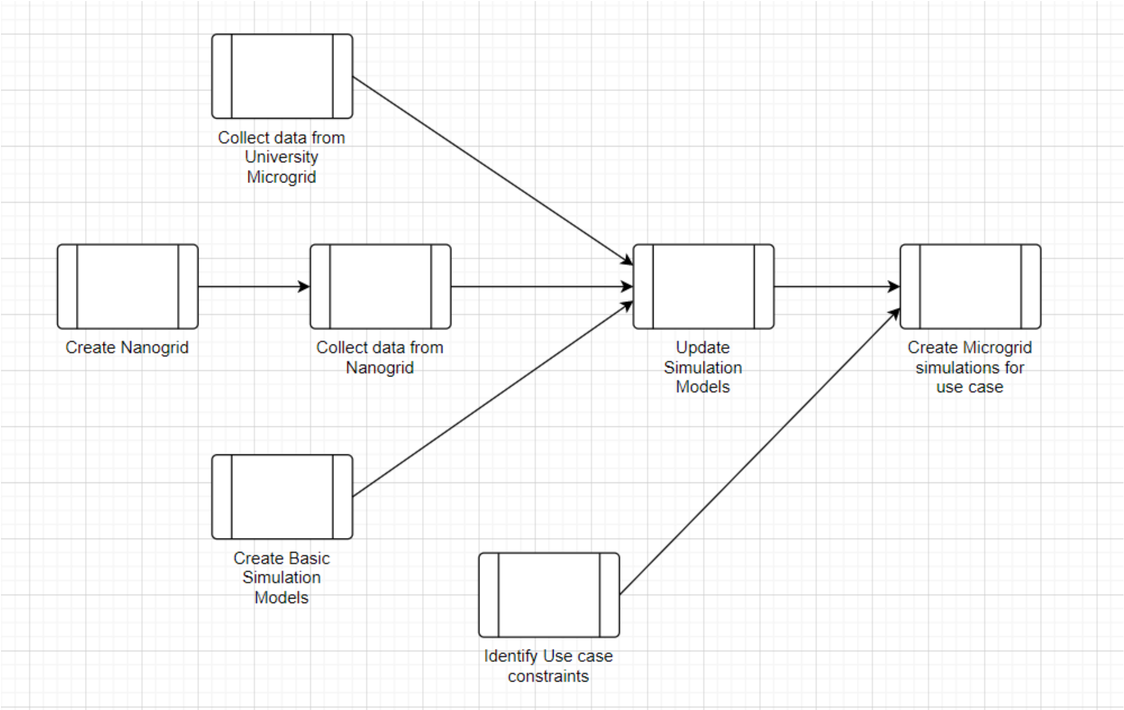


Fig 3: Design Plan Flow Chart

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.

Then, we will take measurements taken from the Sun Crate, a microgrid built by Dr. Kimber and her team here at ISU. The measurements will then be compared to the expected outputs from the microgrid simulations model that we have built. Errors will be regulated by fine tuning parameters of the microgrid simulation. These measurements will be taken from the Enphase Envoy already built inside of the Sun Crate.

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. These tests will be conducted using the Dranetz meter, a smart meter purchased by Dr. Kimber. This meter will give us access to fast and reliable data from the nanogrid to compare with its simulation model.

After these measurements are taken, our simulation model will be in a good spot.

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

At this time we have not conducted testing, and thus do not have any results to report. Our testing will be occurring in February and March of 2021.

5 Implementation

The simulation parameters from the initial simulation in Simulink discussed in 3.3 will be adjusted to simulate a nanogrid. With a grant funded by GridEd, we will build an actual nanogrid to both test our simulation parameters and fine tune the simulation as needed. The focus of the prototype nanogrid is to show the integration of hydrogen electrolyzers and fuel cells with known generation sources of microgrids like wind turbines and solar panels. The plan is to control this nanogrid with sensors and Arduino to manage and respond to the changes of the load.

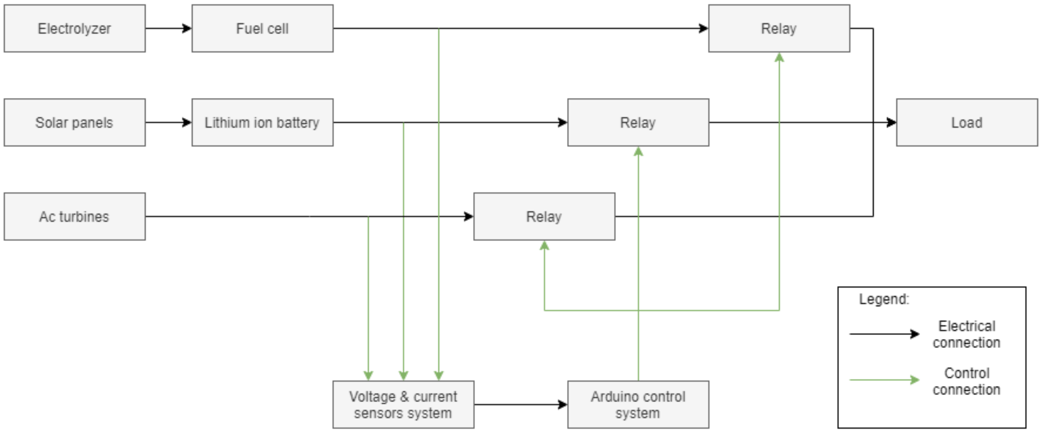


Fig 4: High Level Diagram of Nano-Grid Design

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 3: Nano-Grid Component List

In our nanogrid, the main source of generation will be solar panels and the wind turbine. The solar panels will be connected directly to the battery as there will be a MPPT device embedded in it. The battery output AC voltage that will be connected to the load via relay. The wind turbine is also connected to the load through this protection device.

The hydrogen electrolyser will receive power from the battery in conditions when the power generated by wind and solar exceeds the power that the load requires. Compressed hydrogen will be outputted from this device into cylinders that are compatible with the hydrogen fuel cell. The hydrogen produced by excess energy will supply the hydrogen fuel cell when the load requires more energy than can be produced by the wind turbine and battery.

Voltage and current sensor will determine the power output of each device and in combination with the load demand to decide whether the battery is in charge or discharge mode.

6 Closing Material

6.1 CONCLUSION:

The goal of our project is to design microgrids that can sustain a communication hub 12 kW constant load during disastrous scenarios. To tackle this problem, our team decided to first design a microgrid simulation using the general knowledge accumulated by reading papers and parameters provided by Dr. Kimber on her crate. The first simulation aims to create a general knowledge on simulation of microgrid.

After the first simulation is completed, we will use that knowledge to create a simulation for the nanogrid that is going to be built using the GridEd grant. This simulation also shows the integration of hydrogen fuel cells into a typical microgrid system. Testing that was discussed in part 4 will be implemented after this step.

Finally, after the simulation is fine tuned, we will use the simulation to decide the components of two microgrid designs: Economical microgrid and Sustainable microgrid discussed in Section 3.3. An economic report will be performed for each microgrid design to ensure the design meets the requirements of the loads.

6.2 REFERENCES

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