Power System Reliability in the Midwest for High Wind/Solar Levels

DESIGN DOCUMENT

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Midcontinent Independent System Operator

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List of Definitions

Balancing Authority (BA): Regional authority that ensures real time supply and demand balance of whole sale electricity.

Capacity Credit: Ratio of average energy production during peak net load conditions over the installed capacity. Reported as a percentage or a number between 0 and 1.

Capacity Factor: Ratio of actual energy production in a year divided over the total energy production in a year. Reported as a percentage or a number between 0 and 1.

DG: Distributed generation

DPV: Distributed photovoltaic

Eastern Interconnect: One of the 3 major grid interconnections in the United States. It borders the Western Interconnection on the border of Nebraska and Colorado and stretches North-South from Mexico to Upper Canada.

Expected Load Carrying Capability (ELCC): The largest amount of load that the grid could carry if all generators were turned up to highest performance.

Federal Energy Regulatory Commission (FERC): United States Federal Agency that regulates the interstate transmission of natural gas, oil, and electricity.

Independent System Operator (ISO): Regional power balancing authority that monitors and operates the process of wholesale electricity sales and transmission.

Kaleidoscope: Software that allows for visualization of PLEXOS models via geographic diagrams, chord diagrams, and dispatch charts.

Loss of Load Expectation (LOLE): A NERC requirement that states that any location cannot expect to have a loss of load (under-generation) that is greater than one event in 10 years.

Midcontinent Independent System Operator (MISO): Sponsor of this research project. MISO is the system operator that operates within 14 states.

North American Electric Reliability Corporation (NERC): A nonprofit corporation with the goal of reliability throughout the North American power grid.

Net Load: The difference between the gross load and renewable generation

PLEXOS: Modeling software that is used by system operators to predict how the grid will be affected by proposed changes.

Python: A computer programming language that will be used to automate part of this project.

Renewable Energy: Energy produced by renewables sources such as wind and solar.

Renewable Integration Impact Assessment (RIIA): Study performed by MISO to look into how renewable energy, based on several projections, will impact the power grid in different ways [2].

Renewable Energy Penetration: Amount of renewable energy that is on the grid or the area. This is given in a percentage form.

UPV: Utility scale solar photovoltaic.

1 Introduction

1.1 Acknowledgement

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MISO Team: *James O., Armando F. and Brandon H.*

Iowa State Faculty: *Dr. McCalley and Dr. Zambreno*

1.2 Problem and Project Statement

Renewable energy generation is currently the fastest growing source of energy in the United States, with some predictions calling for a 28 percent increase in renewables by the year 2033 as seen in figure one below [3]. Coupled with the retirement of older generation plants and the reliability of renewable energy to meet the constantly changing demand, there are many unanswered questions relating to the impact of the increase of renewable generation on the U.S. power grid.

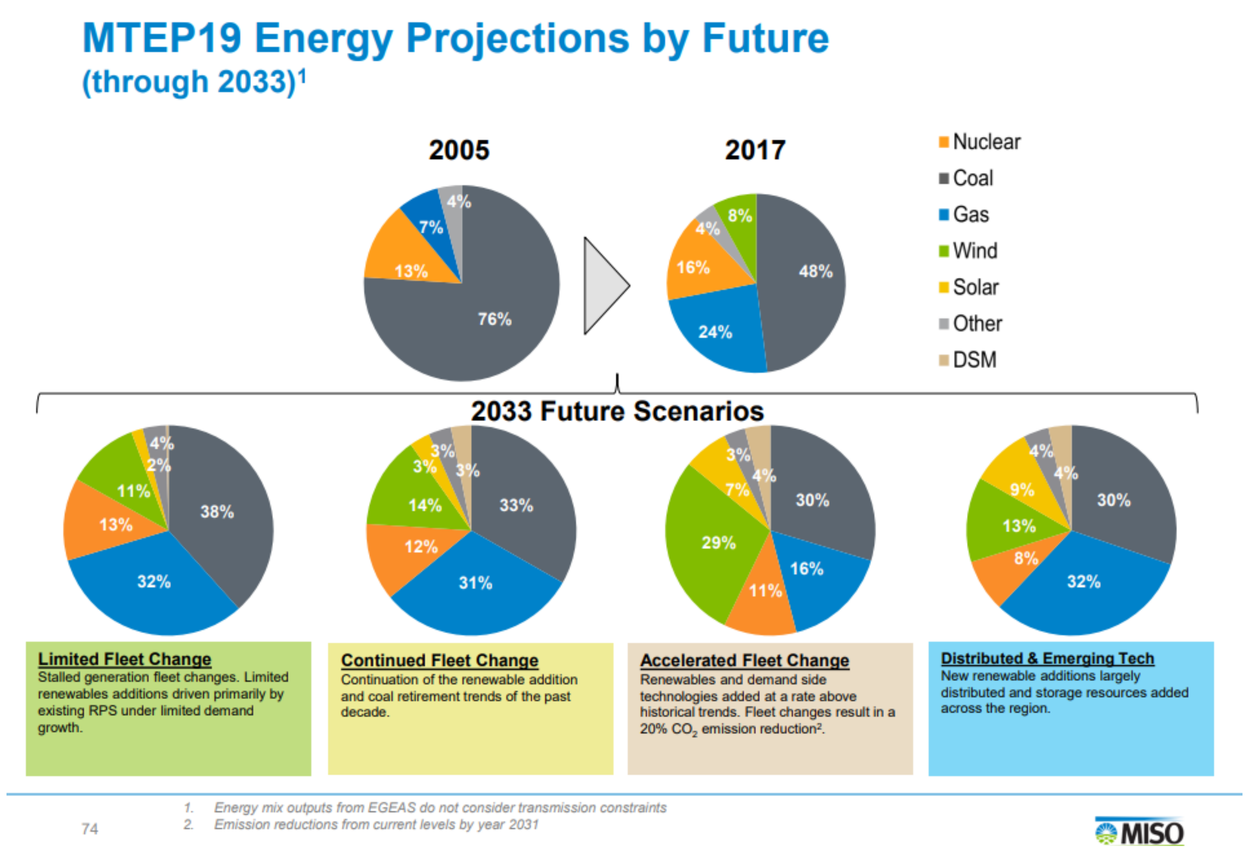

Figure 1: MISO MTEP Futures Summary [3]

The North American Electric Reliability Corporation (NERC) requires ISOs such as MISO, to do analysis on resource adequacy, otherwise known as the balance in energy generation and demand. The goal of this project is to do this analysis for increasing renewable levels in the energy grid to further the understanding of the impact it will have on the future of the grid. The design team will primarily be using software for mathematical analysis and developing models to accurately reflect the increase in renewable generation on the grid in order to determine its effect on the loss of load expectation (LOLE). At the end of this project the design team will have a clear picture of what the grid will look like with increased renewable penetration at the appropriate expected load carrying capability (ELCC) and LOLE. This includes what generators will be retired and where the new energy sources will be placed. The team will be able to present findings of what happens to the grid at these penetration levels so that MISO and their shareholders can better prepare for the future.

1.3 Operational Environment

At the conclusion of the project, the team will present a report which will explain their findings of the impact(s) renewable generation has on the MISO grid, and how the grid might look in the future. Most of the findings will root from calculations and models that the team creates through PLEXOS and other programs such as excel and kaleidoscope.

MISO will give the report to their shareholders, who will use the information in the study as an aid when making future decisions about the grid. Because of this, the study results will need to be extremely thorough and clear. Additionally, the team will develop a simple software to automate the ELCC calculation and save MISO the hours it would take to do the calculations manually.

1.4 Intended Users and Uses

The data gathered and models created by the design team will be reported directly to MISO. The results will be encompassed into the already extensive analysis done within MISO's Renewable Integration Impact Assessment (RIIA) [2]. The data finalized by MISO within RIIA is made public, and accessible by anyone seeking the information. This includes the general public as well as the MISO shareholders, who will use the information in the study to make future decisions regarding the grid and penetration of renewable energy.

1.5 Assumptions and Limitations

This project will be done with several different assumptions for the future of renewable energy production. The first is an assumption of a future with half wind and half solar renewable energy. Once the team has a good idea of what the 50/50 mix looks like on the grid, they will assume a 75 percent solar and 25 percent wind mix. MISO has completed a study for 25 percent solar and 75 percent wind, so no time will be spent evaluating this case. Additionally, for each assumed mixture of wind and solar, the team will need to consider 10, 30, 50, and 100 percent penetration of renewables into the MISO grid. Therefore, the team will need to consider both cases for each penetration level.

The design team's largest limitation is time. Because of the nature of the project, an unlimited amount of time could be used to study the effects of an infinite number of futures that could potentially happen. Because the team does not have unlimited time, clear thought and careful planning about what scenarios will give the best image of what could happen in the future is highly stressed. If high, low, and medium levels of renewables are studied, then the result should be an adequate picture of what is going on with the grid as more renewables are introduced. Other limitations include where and how much wind and solar generation can be sited, and what generators can be retired and what order to retire them in.

1.6 Expected End Product and Deliverables

The team's main goal for the conclusion of this project is to have a clearly planned out model that provides an accurate prediction of what the MISO grid could potentially look like in the future with ever-changing generation mixes. Deliverables to MISO will be in the format of a study which will include charts and maps showing the locations of where new generation is expected to be built and written arguments and data showing why, and how, the locations for siting were determined. For each penetration level studied (as described in section 1.5), an ELCC of wind and solar will be produced, along with documentation of used assumptions and descriptions of how the new renewables were sited.

In addition to the written study, the design team will be delivering the updated PLEXOS model(s) used for calculating the LOLE, along with the team's reasons for changing the model, and any code or scripts written to automate the ELCC calculations to the client. The team will be using Python for the automation process.

2. Specifications and Analysis

2.1 Proposed Design

This project must answer questions that will highlight where and what problems might arise in the future due to added renewables, and what the future of the grid will look like. The design team must plan the design of the study around the LOLE which sets the criteria of having "one event in ten years", or in other words, only not matching the load one day in ten years due to lack of generation. There is no way of knowing for sure what the future of the grid will look like, but using current grid data along with analysis in PLEXOS, an adequate prediction can be made. To do this, the team will have to run through a series of steps to try and design a reasonable prediction for the future.

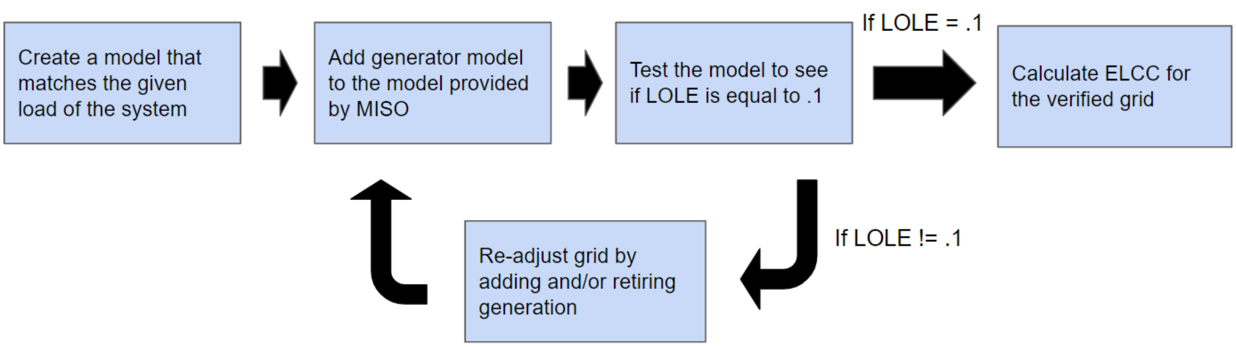

Figure 2: Generalized Design Process

Step 1) Creating a Model to Match the Load.

The design team was given data about the load that needs to be met within the MISO footprint, along with the capacity factors of already existing sites. The team used the load data to determine how many megawatts (MW) of generation each type of technology (wind, utility solar tracking, utility solar fixed, and distributed solar) would need to produce for each assumed level of penetration on the grid.

The team then ranked each existing generation site according to capacity factor, nearby population, generation at peak, if the site is currently in the MISO queue,and current political and company incentives. With this step, the team was essentially looking at the potential each site has for new renewable generation, ranking them from highest potential to lowest for each type of generation. Once the sites were ranked, max generation was added to each site until the load was met, in this case the amount of generation per site was capped at 200 MW. (Note: 200 MW would be the capacity of the site, meaning how much it can produce, not how much it actually produces.) Next, the MW generation at each site was multiplied by the average capacity factor of the respective site, and the results were summed.

Step 2) Adding Generator Model to Existing Model and Testing

For each level of renewables, a slightly different model will be generated. At each level, the team will want to add the generators to the model provided by MISO, enter this data into PLEXOS and then run a simulation of the model. PLEXOS will produce an LOLE value, and if the value is not reasonably close to 0.1, then the team will need to adjust the model and repeat the process until it is near the 0.1 value. The team wants to hit the 0.1 value because NERC has set a standard of only allowing one loss of load event every 10 years [4].

Step 3) Re-Working Model

If the LOLE does not match the desired 0.1 value as previously stated, the team will need to adjust the model. In order to do this, the team will do the following: add more generation as needed and or retire old plants as needed. After this step, steps two and three will be repeated to see if the LOLE is closer to the desired 0.1 value.

2.2 Design Analysis

Step 1) The first part of step one in the design process was simple and straightforward, as it was just performing a simple calculation on the data given. This gave the team concrete data to work with and was not up for critique by anyone within the group. The second step of the process, however, proved to be slightly more troublesome.

The client, MISO, set the task for the team to create a ranking system, commenting that this system would be a mix of quantitative and qualitative analysis. This caused quite a bit of confusion amongst the group as to how the ranking system should be implemented. The team agreed that capacity factor had to be weighed heavily in the ranking, but couldn't all agree on what else should be taken into account, and how much weight each factor should contain.

In order to solve this problem, our team came up with a ranking system, the process went back to being straightforward and simple, as the team now had concrete numbers and criteria to begin work with and allowed a focus on proceeding with the design and analysis phase of the project.

Step 2) The model used in this project is an aggregation of multiple buses within the MISO footprint, and thus contains far fewer variables to work with. While this makes the results of the analysis not perfectly accurate, it allows for a simulation to be run on home computers in about ten minutes. More complex models can take upwards of a few days to run, and require much more computing power. In the interest of time and efficiency, the simplified model was deemed suitable and accurate enough for this project.

Step 3) While some mathematics will have to be utilized to assess the given situation, this step should be fairly straightforward. The team will look to retire generators with a high heat rate if the LOLE is low, and add additional generation if it is too high.

3 Testing and Implementation

3.1 Interface Specifications

This project is dependent on different software to organize and analyze the data gathered during testing of the renewable models. These include Microsoft Excel, PLEXOS, and eventually Python and Kaleidoscope. Excel is used for data aggregation and mapping. Excel is a well-known and common platform, making it very valuable for data sharing and calculation. PLEXOS will be used for analyzing the created models and calculating the LOLE. This is very important to validate the siting assumptions. Finally, Python and Kaleidoscope will be utilized towards the end of the project. Python will be used to automate the data processing for PLEXOS' input and output, and Kaleidoscope will be used to generate maps showing what is going on in the system.

3.2 Hardware and software

The model will be created by entering generation site data into an excel file that is formatted in such a way that the data can be easily imported into PLEXOS. The team will enter information regarding the type of generation the generator site is producing, and how many MWs the generator is producing for every hour of the year. All other required information about the current grid exists in the model that MISO provided. As such, the team will just have to enter the new generator data found by the ranking system.

Once the updated model is complete, the team will run PLEXOS and track only key output variables so the simulation does not take an unreasonable amount of time to run. Since this study is not concerned with cost, the team will mostly be looking at what PLEXOS determines to be the LOLE, and the heat rate of non-renewable generators.

Additionally, the team will be utilizing Kaleidoscope to run quick sanity checks on the model. This software maps out generation across the MISO footprint and can be used to quickly check that the data seems reasonable. Any obvious errors in data, like a large amount of wind generation in the south, could be caught using this software a lot more easily than it could be found by combing through an excel file.

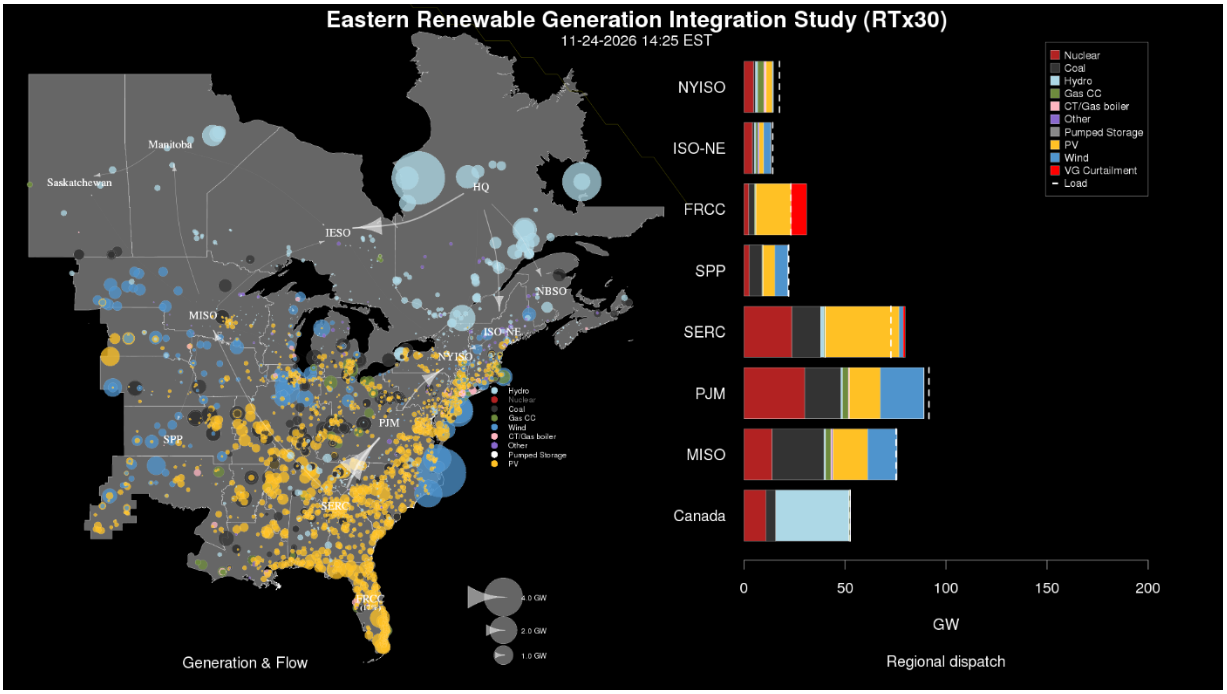

Figure 3: Sample of Kaleidoscope [5]

3.3 Functional Testing

The software PLEXOS will be used to test the functionality of the model. PLEXOS can take in models and run simulations on them that can predict how the system will respond due to various physical and economic driving forces. Through these simulations, the team will try to find the LOLE of the system and the heat rate (correlative with efficiency) of non-renewable generators.

For each level of renewable penetration, the team will run the model in PLEXOS and look at the LOLE and heat-rate for non-renewable generators. The LOLE will be used to calculate the ELCC (see non-functional testing section 3.4) to ensure it matches the load of the system. The team will then proceed depending on how well the desired LOLE and ELCC are matched.

Every time a change is made to the model due to results from non-functional testing, the model will be tested again. The team will look at the new outputs and will continue to repeat the process again until the desired target values are obtained.

3.4 Non-Functional Testing

Once the target LOLE is derived, the team will calculate the ELCC and make sure it matches the load requirements. At first, the team will determine the ELCC via traditional mathematical methods using the data generated by PLEXOS. Later on, the team plans to develop a script in Python that will automate this process. If the requirement is not met, the team will know that the model generation needs to be adjusted.

However, if the LOLE falls short of the target, the team will want to start looking into generating facilities that could be retired. This will be done by looking at the heat rate (efficiency) of non-renewable generators. Facilities with a high heat rate that are running, but not actually supplying energy into the grid due to the presence of cheaper renewable sources are costly. Because of this, the team can assume that in a future with high renewables, these facilities will retire. In the event of this case: the team will retire the chosen generators, update the model, and then run through the functional testing phase again.

3.5 PROCESS

As shown in the figure four, testing will begin with the process of performing various calculations, such as capacity factor and capacity credit per site, using excel. Additionally, the team will be using excel to create heat maps to help better visualize what is going on with the given wind and solar data. In terms of siting, there is no real way to test the sites chosen. There are certain criteria, such as generation requirements, the team will have to consider when siting renewables. The next round of testing will come when the team utilizes the PLEXOS software. The team will begin putting in different sets of data and calculating the LOLE, trying to get it as close to a one day in ten-year event as possible. After this, the team will have to write some program in python to automate the calculation of the ELCC.

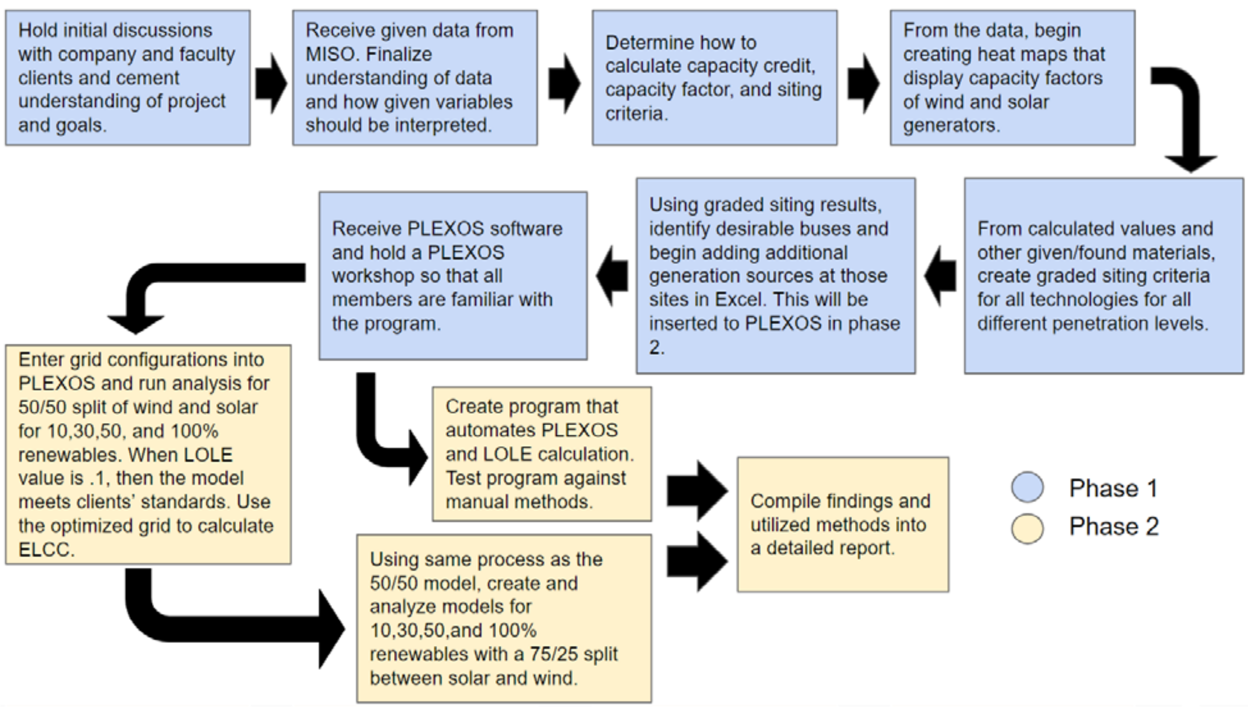

Figure 4: Flow diagram of process

3.6 RESULTS

Results Thus Far:

- Capacity factor and capacity credit calculations have been completed.
- Capacity factor heat maps have been created and were approved by MISO for all technologies.
- Final siting rankings of the different buses (locations) have been posted and used an agreed upon equation by the team and MISO.

Failures:

- First round of capacity credit calculations failed, as the team took the wrong time frame into account. The first round of siting was OK but the client wanted the team to change a few things and be more defined in why and how the ranking criteria were chosen.
- Getting PLEXOS onto personal computers and the VM took many more weeks and significantly more hours than originally expected. This alone put the team behind schedule about a week.

Successes:

- Yearly average capacity factors were correct and well received by MISO and the team has learned how to better utilize Excel.
- Developed a mathematical system to properly rank generation sites according to a set of criteria that the whole group agreed upon.
- Got PLEXOS running on team computers and learned how to use it to find the LOLE of the model.
- Installed and set up PLEXOS on the Virtual Machine and all team members are able to access it.
- Ranking of the best locations to place future renewable energy is completed but will continue to be updated as new information is discovered.

Implementation Issues and Challenges:

- After the team created the heat maps for all years and technologies, MISO realized that they had given the team improper data. The team had to redo all the heat maps the next week, setting them behind schedule.
- Many challenges arose while deciding on how to perform siting. The entire team had a solid understanding of how to create a ranking system, but disagreements arose within the group on how exactly the criteria should be formed. In addition to making sure the siting criteria was approved by every team member, it was also important that the client at MISO agreed with the proposed ranking system for the buses.
- After agreeing on siting specs, the team encountered a bit of trouble while trying to get PLEXOS up and running on the team's computers. After some cooperation with Energy Exemplar, the team managed to have the program set up and running properly. This will allow the team to enter model data and find the LOLE.
- Due to the nature of siting, with there being several different influencing factors with several different data sheets, the team found it difficult to combine all the information into one set of data.
- The team presented siting results to the client, MISO, which resulted in some feedback from the client. This required the team to rework how siting was being done and ranked.

4 Closing Material

4.1 Conclusion

With renewable resources being the fastest growing energy resource in the U.S., and many older generation units retiring, there is an uncertainty on what the grid of the future will look and behave like. In recent years the conversation on understanding these changes has been rapidly changing and the desire to expand upon these topics has become increasingly prevalent in industry.

This project aims to be a part of that conversation by expanding the knowledge on resource adequacy of the energy grid for varying levels of renewable energy integration.

This will be done by closely working with MISO and advisors at Iowa state. The team will be developing and carrying out a model building process. These models will be the estimated future grid of the Midwest, including new levels of renewable mixes. With these the team will be able to directly study the impact the changes have by utilizing PLEXOS to understand the LOLE and ELCC of the additional renewables. This design document lays out the steps intended to be followed in order to assist the understanding of future changes on the energy grid.

4.2 References

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