Design of a More Reliable Power Grid for Puerto Rico

PROJECT PLAN

sddec18-03

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PREPA: Puerto Rico Electric Power Authority. Sole provider of electricity production, transmission, distribution, and sales to 1.5 million customers.

1 Introductory Material

1.1 Problem Statement

Over 80% of Puerto Rico's power grid was recently destroyed in hurricanes Irma and Maria. However, even before these storms ravaged the electric utilities on the island country, a lack of maintenance and upgrades under unstable and underfunded PREPA leadership led to a grid susceptible to collapse, with many natives citing downed power lines and power outages as a normal occurrence. As a design team, we aim to design a power grid for Puerto Rico that is more reliable and makes maintenance easy and possible should other natural disasters occur.

Our proposed solution encompasses every area of the country's current electrical utility system, including but not limited to upgraded generation stations, transmission lines, and utility poles. We will also assess the economic impact of redesigning the electric grid through costs, jobs created, and the asset of creating a safe, reliable power grid for the country.

1.2 Operating Environment

The proposed design will be exposed to rain, severe tropical storms and hurricanes, and temperatures averaging between 61˚F and 80˚F, with maximum and minimum temperatures of over 100˚F and below 40˚F, respectively. The main consideration for this project design is creating an energy system robust enough to handle tropical storms, hurricanes, and other natural disasters when paired with proper maintenance.

1.3 Intended Users and Intended Uses

The intended users of this plan include utility companies and legislators in Puerto Rico. This proposed solution will combine research, grid design, economic suggestions, and additional area improvements to revamp Puerto Rico's energy market.

Firstly, this plan will discuss the economic market surrounding electric utility in Puerto Rico. The suggested changes aim to change the way utilities are subsidized in turn generating revenue and cutting losses for the current bankrupt system.

Secondly, the proposed solution will discuss the redesign of the current power grid. This outline introduces solutions such as interconnected microgrids, the addition of solar and wind resources, added energy storage, and addition of other resources such as a natural gas deliquification plant.

1.4 Assumptions and Limitations

Assumptions:

Current political policies and procedures will not be taken into consideration within this proposal.

Population measurements will be approximated using the most recent census data.

Limitations:

This power grid redesign must fall under feasible budgetary limitations.

This power grid must withstand temperature swings and severe weather common in Puerto Rico.

This power grid will be tested by virtual means only.

1.5 Expected End Product and Other Deliverables

The end proposed power plan will provide a solution in two sections: an economic redesign and a physical redesign.

The physical redesign will encompass the entirety of the country and discuss the current grid and generation systems. From this basis, the proposal will suggest the addition of solutions such as wind and solar resources, increased energy storage, interconnecting microgrids, and the addition of other energy sources such as gas turbines or a natural gas deliquification plant. The grid shall be designed with natural disasters in mind with components that can withstand severe weather.

The economic redesign will propose solutions related to subsidization of utilities in the commercial, industrial, and residential sectors. The cost and price of energy will be discussed and a solution related to these findings will be presented. This economic report will also encompass the costs and profits associated with installation of new physical energy components such as solar and wind farms, gas turbines or a natural gas deliquification plant.

The combined report encompassing the economic and physical redesign of the power system in Puerto Rico will be delivered by December of 2018.

2 Proposed Approach and Statement of Work

2.1 Objective of the Task

Puerto Rico is in a horrible state after the recent hurricane that hit, Hurricane Maria and this left the population living without electricity in their homes. However, the power grid of the country was also in horrible conditions before the natural disaster. This is due to improper management of the already existing power grid.

Therefore, we are going to focus on the fact that the power grid, even before the natural disaster hit. We are going to focus on creating a better economic and physical design of the power grid to make sure that the entirety of the island will constantly be supplied by with electricity even during an occurrence of hurricanes, earthquakes and other natural disaster.

We will be performing this task by introducing wind and solar energy farms due to how much sun the country gets per year. We are also implementing energy storages located throughout the island in case of a shortage of power and also creating interconnecting microgrids at the corners of the island. Other energy sources such as natural gas and gas turbines deliquification plants will be introduced for this project.

2.2 Functional Requirements

2.2.1 Solar and Wind Energy Farms

The main requirement when talking about implementing this that a country needs to have a consistent supply of sun and wind throughout the whole year. However, Puerto Rico does have a persistent 22 mph trade winds move throughout the island all year round. The supply of wind is very strong to the point that every 5 or so years, a cyclone will bring in high intensive winds; Hurricane Maria.

The solar supply that Puerto Rico gets is also immense. Throughout the whole year the sun will rise around 5:30 am and set around 7:30 pm which will provide the whole country with a total of 14 hours of daylight throughout the year. The country averages around 2829 hours of daylight a year. About 65% of the day is filled with daylight and the other percentage of the day are filled with cloudy days or haziness.

2.2.2 Natural Gas or Gas Turbines Deliquification Plants

To do this, the main problem that Puerto Rico has is that since it is an island, it would be difficult to move these gases from the outside to the island. Therefore, the best solution that we could think of is to create a port on the island for moving these gases. After creating these ports, then it would be easier to have a constant supply of the gases.

2.2.3 Cost Issue

Currently in Puerto Rico, there are situations where some public infrastructure such as hospitals happen to receive free electricity. This is quite a problem because if they are getting the supply without pay, then the workers who have to supply the electricity will not be paid well enough which will cause a problem in continuously supplying the electricity to other places on the island.

Therefore, to implement these ideas such as the microgids, the energy storages, and the solar and wind farms, these places that receive free electricity needs to help pay for it to ensure that the rest of the island will be able to get electricity.

2.3 Constraints Considerations

The political aspects of the project will not be considered during this project and we will instead be supplying a concept of a better energy system for Puerto Rico.

There are also other constraints that are obvious such as the fact that most the work that we will be doing is mostly theoretical research. We are not able to go to Puerto Rico to witness what is happening there ourselves. However, we are able to contact a few power companies in Puerto Rico such as the Puerto Rico Electric Power Authority (PREPA) which is in charge of most of the islands electrical needs.

Another major constraint that can affect the outcome of the project is that when creating this power grid, we are mainly focusing on the theoretical side of the project. We can do our research and theoretically be able to create it as well as we can, but in the end, we won't be able to ensure that these projects will work physically.

The other constraint that might be a problematic issue when developing this power grid is that since we are using renewable energy such as solar energy and wind energy, the intensity of the sun that Puerto Rico is supplied with can really affect how the power grid will work. For example, research must be done to understand whether there are weeks where Puerto Rico does not get any sun and is facing cloudy days. This factor could really set us back because since the sun is something that we can't control, we can only look at the insulation data as reference.

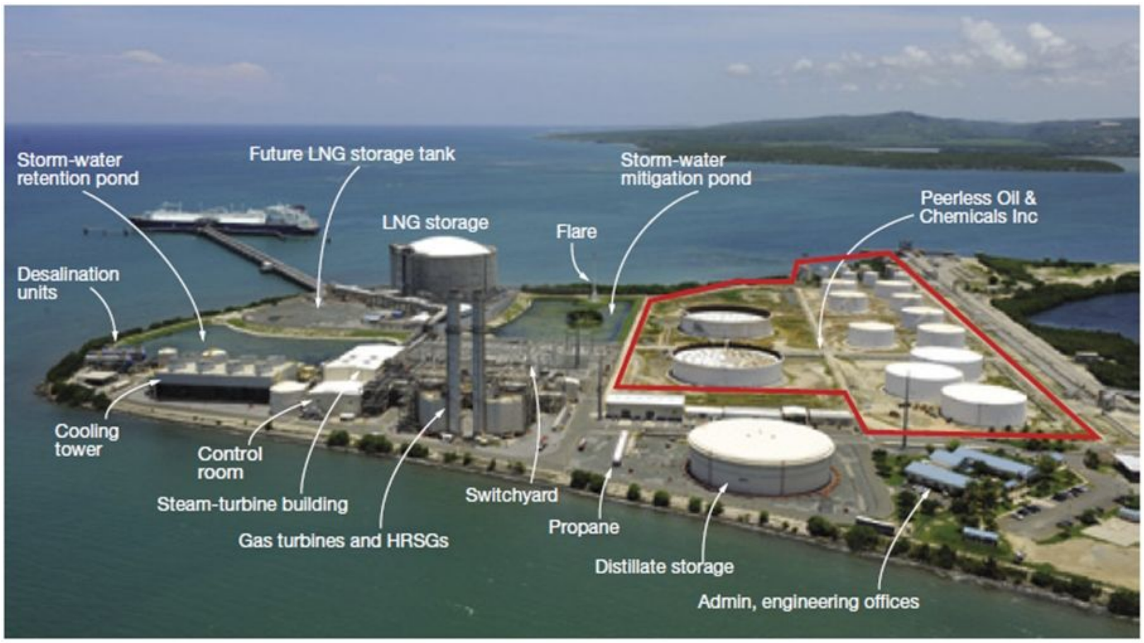
2.4 Previous Work And Literature

2.4.1 Natural Gas Deliquification Port

Natural gas deliquification plants have already been implemented in Puerto Rico as stated by the U.S. Energy Information Administration. On the website, it is stated that natural gases currently import liquified natural gas (LNG) each year mainly from Trinidad and Tobago to supply the 507 megawatt EcoEléctrica generating plant.

There is a proposed idea of creating a floating deliquification port off the coast of Peñulas where the natural gases are being imported through. This proposition has been approved by the U.S. Federal Energy Regulatory Commission (FERC) in 2015 and the project is currently in the works.

There are currently three natural gas-fired generation plants on the north coast that is being used to transport LNG by using trucks. PREPA has also run the feasibility reports to check if the northern deliquification port is possible.



1. EcoElectrica shares a small peninsula with Peerless Oil & Chemicals Inc that juts out into Guayanilla Bay and the Caribbean Sea beyond. Here an LNG tanker discharges its cargo to the 1-million-bbl storage tank via a pipeline mounted on the causeway connecting the plant site to the unloading dock

Figure 1: Natural Gas Deliquification Port

Figure 2: Location of the LNG Terminal

2.4.2 Solar and Wind Energy Farms

There are previous solar panels that are being implemented in Puerto Rico by Elon Musk and his company Tesla. The solar panels that are implemented are set as supply storages in case of another outage of electricity. This currently was implemented after the absence of electricity from Hurricane Maria, and Hurricane Irma.

The beginning of the usage or the plan of using solar energy happened when technicians from a company called Tesla Powerwall implemented a solar battery pack on the wall of a house in San Juan and it was able to supply enough power to the whole house. This is now being implemented to a few dozen houses already.

After the event of Hurricane Maria, there are a lot of other companies that are trying to implement a better power grid for the island and hopefully work itself towards solar and wind energy. It has first been implemented to a children's hospital in San Juan, Hospital del Nino.

Figure 3: Solar Panels implemented in Hospital del Nino, San Juan

2.4.3 Gas Turbines

Gas turbines are meant to be implemented into the power grid at the natural gas deliquification ports where they can generate energy through this. The natural gases will act as a backup or will co-supply power to the island. One of the major companies that are working on gas turbines is Siemens. Siemens is one of the leaders in gas turbines that has been implemented throughout the world.

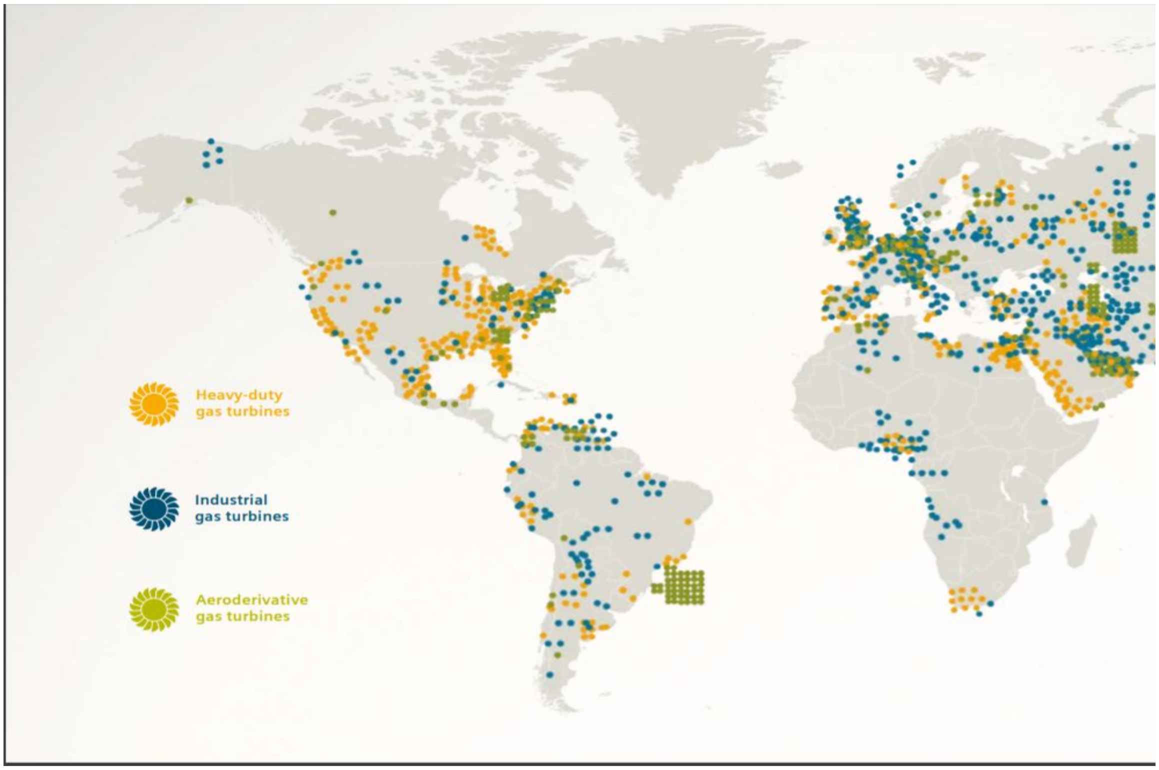


Figure 4: Location of Siemens Gas Turbines

The gas turbines that has been introduced to us by Siemens are Heavy-Duty, Industrial and Aeroderivative Turbines. Each turbines is used for unique purposes however, the one that we will focus on when implementing the power grid is the Heavy-Duty Turbines. These turbines act as cogenerators to other power generations which in our case would be the solar and wind energy.

The power that is supplied by these gas turbines range in various values and the cost of these gas turbines are up to 2 to 3 million. Siemens created a complete data overview of the different values of power output that their power grid can supply.

Mechanical drive applications (metric units)							
	Power output	Gross efficiency	Heat rate	Drive shaft speed*	Pressure ratio	Exhaust mass flow	Exhaust temperature
SGT-750	41.0 MW	41.6%	8,661 kJ/kWh	3,050 – 6,100 – 6,405 rpm	24.3 : 1	115.4 kg/s	468° C
SGT-700	33.7 MW	38.2%	9,424 kJ/kWh	3,250 – 6,500 – 6,825 rpm	18.7 : 1	95.0 kg/s	533° C
SGT-600	25.2 MW	34.6%	10,390 kJ/kWh	3,850 – 7,700 – 8,085 rpm	14.0 : 1	81.3 kg/s	543° C
SGT-400 (15 MW)	14.9 MW	36.8%	9,774 kJ/kWh	4,750 – 9,500 – 9,975 rpm	18.9 : 1	44.0 kg/s	540° C
SGT-400 (13 MW)	13.4 MW	36.2%	9,943 kJ/kWh	4,750 – 9,500 – 9,975 rpm	16.8 : 1	39.4 kg/s	555° C
SGT-300 (9 MW)	9.2 MW	35.6%	10,104 kJ/kWh	5,750 – 11,500 – 12,075 rpm	14.5 : 1	30.5 kg/s	512° C
SGT-300 (8 MW)	8.4 MW	35.1%	10,265 kJ/kWh	5,750 – 11,500 – 12,075 rpm	13.8 : 1	29.7 kg/s	491° C
SGT-100	5.7 MW	32.9%	10,948 kJ/kWh	6,500 – 13,000 – 13,650 rpm	14.9 : 1	19.7 kg/s	543° C
SGT-A65 TR DLE	54.2 MW	43.6%	8,256 kJ/kWh	2,380 – 3,430 – 3,570 rpm	34.3 : 1	154.4 kg/s	428° C
SGT-A65 TR WLE	61.8 MW	41.9%	8,590 kJ/kWh	2,380 – 3,430 – 3,570 rpm	36.1 : 1	164.2 kg/s	431° C
SGT-A30 RB (27 MW) DLE	27.9 MW	37.3%	9,648 kJ/kWh	3,120 – 4,800 – 5,040 rpm	20.6 : 1	91.0 kg/s	501° C
SGT-A30 RB (27 MW) Non-DLE	29.1 MW	37.7%	9,540 kJ/kWh	3,120 – 4,800 – 5,040 rpm	21.3 : 1	93.0 kg/s	501° C
SGT-A30 RB (30 MW) DLE	30.6 MW	38.5%	9,341 kJ/kWh	3,120 – 4,800 – 5,040 rpm	21.7 : 1	96.0 kg/s	503° C
SGT-A30 RB (30 MW) Non-DLE	30.9 MW	38.6%	9,336 kJ/kWh	3,120 – 4,800 – 5,040 rpm	22.0 : 1	96.0 kg/s	503° C
SGT-A30 RB (32 MW) DLE	33.0 MW	40.3%	8,922 kJ/kWh	3,153 – 4,850 – 5,093 rpm	21.6 : 1	94.0 kg/s	510° C
SGT-A30 RB (32 MW) Non-DLE	33.8 MW	40.4%	8,912 kJ/kWh	3,153 – 4,850 – 5,093 rpm	22.1 : 1	95.0 kg/s	510° C
SGT-A35 RB DLE (34 MW)	33.1 MW	38.9%	9,255 kJ/kWh	2,400 – 3,429 – 3,600 rpm	22.3 : 1	98.2 kg/s	500° C
SGT-A35 RB (34 MW)	33.7 MW	39.1%	9,219 kJ/kWh	2,400 – 3,429 – 3,600 rpm	22.8 : 1	99.3 kg/s	501° C
SGT-A35 RB (38 MW)	38.1 MW	40.3%	8,938 kJ/kWh	2,400 – 3,429 – 3,600 rpm	25.2 : 1	109.5 kg/s	488° C

Figure 5: Performance Data Overview of Siemens Gas Turbines

2.4.4 Interconnecting Microgrids

The microgrids are slowly being implemented by numerous groups of people due to how cost effective and improving the safety of power grids and improve grid performance.

They are low-voltage generated systems that connect with many other microgrids that can help provide a sustainable power grid. These grids will continuously help with providing the power that is needed to supply a whole country.

This can eliminate the fact of having to depend on one single power plant/source to supply enough energy. This works as many smaller power sources to help supply energy. The works of this microgrid is focused by the Berkeley Lab which is trying to spread the use of microgrids around the world.

Figure 6: High-Level Microgrid Schematic

2.5 Proposed Design

The proposed solution that could help with the power grid problem in Puerto Rico is by implementing the solar and wind energy farms to the country since it has been proven to be effective by how Tesla is currently implementing solar panels to the country. The wind energy has not yet been done but could also be a good alternative due to the wind supply from the country throughout the year.

We then can also implement these renewable energy sources to supply power storages and microgrids around the island to help supply the island. The energy storage is only there in case of another power outage or another possible natural disaster that can provide enough power to the island.

The power grids however are there to help supply energy more efficiently and in a safer way to make sure the island is constantly being supplied.

Puerto Rico could also implement the use of building a port on the island for the trading or transportation of natural gases and the use of gas turbines.

2.6 Technology Considerations

In case of another natural disaster, the solar panels or the wind turbines might be greatly affected by the incident which might cost more money to repair. This could be very costly because the island will constantly need to replace the broken equipment everytime that there are any natural disasters that could ruin them.

These equipments also need very good maintenance and therefore will require a set of qualified workers that are able to fix or maintain the functions of these equipments.

Even though, that if the solar panels or wind turbines happen to be broken after a natural disaster, the function of a energy storage will be very useful and helpful for the island. This storage can help supply enough energy until the fix has been done. Therefore, to ensure that this happens, maintenance of the equipment should be done regularly and quickly to make sure that the island is constantly being provided.

2.7 Safety Considerations

Since this project involves a power grid, if we were to come close to a power plant or have to work with one, we have to be very careful of the dangers of the plants such as high voltages.

2.8 Task Approach

To create this project, we will be including research for the most part of this semester of components that could possibly be used to create the power grid. That includes the research of the solar and wind energy generation and the power that it can generate and whether it is feasible. We also include the concepts of microgrids that can interconnect with other microgrids that can supply the whole island.

Moreover, we also include the research of energy storages and also the uses of natural gases. When including natural gases, there requires a gas turbine and a deliquification plant that has to be implemented on the island. The natural gas is very cheap and can work as a cogenerator to the renewable energy.

Therefore, the current plan is to implement the power grid using the renewable energy as the main source due to how much sun and wind the country gets per year. To use renewable energy, we will need energy storages to store these energies. The natural gases and the gas turbines will also function to co-generate power for the island for days or weeks where there is no presence of sun nor wind. The microgrids will be used to connect to each other to ensure that energy can be supplied to the whole island continuously and not depend on only one whole power grid generator.

2.9 Possible Risks And Risk Management

The possible risks that could come out from this is that of how accurate we can get to solving this problem. We are doing the research but in the end, we are merely doing a theoretical assumption of the work that we are doing based on the work that others has done online. Some works that others have done might not be as accurate and complete as we would like them to be therefore, we have to ensure that the sources that we use are officially correct.

We might also face some issues with communication between us and the companies that we are attempting to contact in Puerto Rico. This could be due to the fact of time zone difference or language barriers or even just difficulty communicating with each other.

2.10 Project Proposed Milestones and Evaluation Criteria

1. Appropriate and intensive deep research must be done on the background of the current power grid and the intended power grid that we want to do.
2. Using a certain algorithm from other power companies that can help recreate or design the work that we want to do.
3. Understanding the limitations or problems that may occur when designing the project and finding the solutions for each of them.
4. Test benching the project to check if it is actually working when implemented.

2.11 Project Tracking Procedures

We will set certain milestones that we will communicate about with our mentor to make sure that we are on track to be able to finish the project on time. We will also set smaller milestones for individual work that should be done week by week to make sure that we are properly prepared for the work that we are going to have to do.

After doing so, the group will meet once or twice a week with our mentor and we can check if everyone is currently up to date with the milestones that we have to accomplish. If the milestones are not met yet, we will have to help each other to accomplish them.

What will your group use to track progress throughout the course of this and next semester?

2.12 Expected Results and Validation

The expected results or the outcome from the project is to be able to give a conducive theoretical presentation of a better power grid that is hopefully able to be implemented or even help implement a better power system for Puerto Rico.

Even if the project is not 100% accurate or functional or able to be constructed, we want to be able to help any other companies out there that are trying to create a better power grid with another point of view or insight that other projects have not yet provided.

To check if the solution can work at a High level is by constantly checking in with our mentor or client to see if it could be implemented so. We could also check with other power companies by presenting such idea and see what their opinions are on our work that we have done.

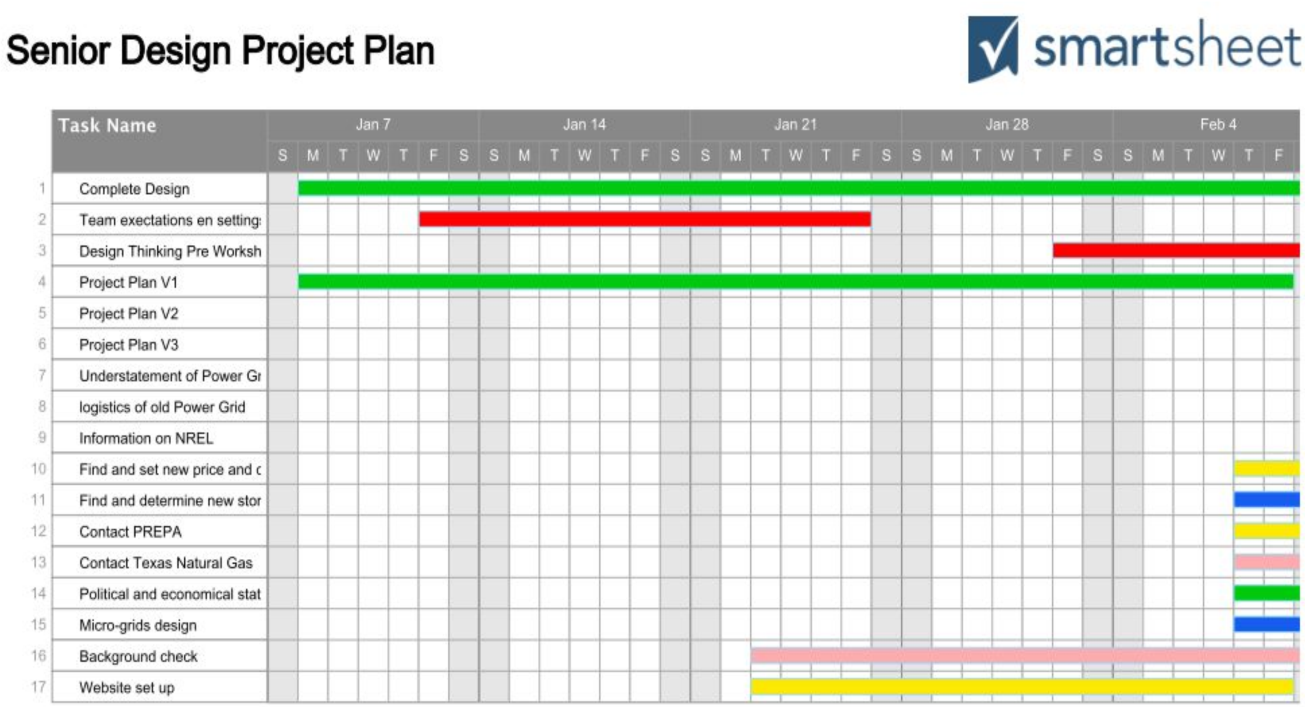
2.13 Test Plan

We have a few ideas on how to test the power grid that we are attempting to implement. The first idea was to use a program that an energy company has used in previous works to test power grids which will be researched more into.

The other idea was to meet with professionals that work in the energy companies that can give some kind of algorithm that can help us test the grid that we intend to create to see if it is functional or feasable.

3 Project Timeline, Estimated Resources, and Challenges

3.1 Project Timeline



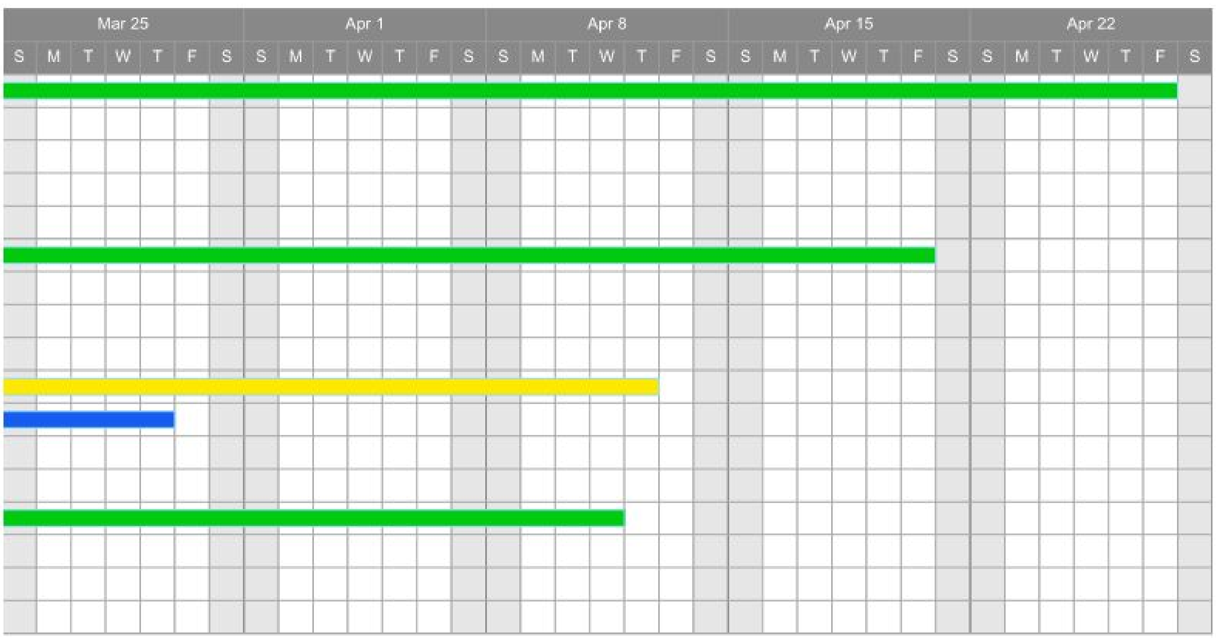


Table 1: Senior Design Project Timeline

For this Gantt chart we established the beginning of the course as the first date for our project in case that creates some confusion. Colors are setted so we can determine which task are assigned for each one of us. Team (green), Individual (red), Heiqal (blue), Logan (pink) and Ricardo (yellow). To use the diagram and work on it collectively we are using the smartsheet website, its very easy to set up and we believe it works better for us.

3.2 Feasibility Assessment

After researching the background of Puerto Rico and its electric utility history, we found ourselves with the problem of deciding whether to redesign the whole grid of the country of Puerto Rico or to take only the critical zones affected by the hurricane.

After meeting with our client, we set our goal as creating an economic and technical redesign of the Puerto Rican power grid. Currently, the main obstacle preventing us from reaching our goal is finding reliable and in-depth information on the power grid. Also, our knowledge in power and geographic position of Iowa don't fully prepare us for taking coastal zones nor elevated zones (Mountains). Its sure that we must also design a grid capable of facing upcoming natural disasters on the future, because it will be pointless to build any new power grid and let the country equally exposed and in deeper poverty.

It is imperative to understand about management of power grids in general, and the old system of Puerto Rico. Find how many power plants the country has and where are those located. What alternatives for energy consumption the country has. What are the logistics of this biorenewables resources. In the case of Solar and Wind energy we must find parts of the country with more solar incidence and more wind flow. Finally to find among all these tasks we must determine and arrange the cost and price of electricity for the island itself and how will these pricess accommodate to other sectors and institutions since previously the power in the island was totally free.

To further include in the project any alternative solution we must understand about Storage, Algorithms and Microgrids. We see Microgrids as a very feasible and profitable solution for the new power grid with the additions of Natural gas mini turbines and supplemental nets in case of blackouts. With Natural gas we envisioned Texas Natural Gas among the suppliers due to proximity and economic possibilities that this trade will open for the island.

3.3 Personnel Effort Requirements

We expect to share most of the task and no individually assign problems due to the magnitude of this project and the logistics of our group. As designated task we have Logan coordinating meetings, contacting clients and references. Also she organized the group and does research too. Ricardo plans and manages the project outline and makes cost estimates and feasibility deductions. Heiqal is responsible of the simulation and design of the structure for the new power grid. All of us presentate and discuss together once a week for our private meeting that usually last an hour on Mondays a day before the class. On thursdays we gather with our client for 1.5 to 2 hours and discuss with him our progress and outline new objectives. Then individually each one of us spend between 4-5 hours weekly on recommended tasks.

Our team follows closely the ethical rules of IEEE and it is projected through its demands. Since all components of this team are part of the organization and comfortable and inspired following the purpose of IEEE, then we adopt their rules as ours.

"We, the members of the IEEE, in recognition of the importance of our technologies in affecting the quality of life throughout the world, and in accepting a personal obligation to our profession, its members and the communities we serve, do hereby commit ourselves to the highest ethical and professional conduct and agree:

1. to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment;
2. to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;
3. to be honest and realistic in stating claims or estimates based on available data;
4. to reject bribery in all its forms;
5. to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems;
6. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;
7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;
8. to treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression;
9. to avoid injuring others, their property, reputation, or employment by false or malicious action;
10. to assist colleagues and co-workers in their professional development and to support them in following this code of ethics."

This are the rules that we as a team and part of the IEEE organization will follow and obey throughout the timeline of the project.

3.4 Other Resource Requirements

(Identify the other resources aside from financial, such as parts and materials that are required to conduct the project.)

So far we don't have to build anything but if it were to include within our budget we should include travel expenses to meet with scholars and power grid experts. Also the probable purchase of a power grid designing program or simulator differently from PSS/E and a unrealistic but most desire trip to Puerto Rico.

3.5 Financial Requirements

We believe that for the complexion of this project the total financial resources we might need are not enough relevant to be mentioned.

4 Closure Materials

4.1 Conclusion

In conclusion, this proposed plan will present a more reliable power solution for Puerto Rico in the form of economic and physical redesign of the current utility structure. By presenting data relating to the current grid and generation compared to data associated with the addition of physical grid and generation changes listed, we aim to prove a more reliable power grid for Puerto Rico is both feasible and a more sustainable financial option for the country.

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