# Design of a More Reliable Power Grid for Puerto Rico

PROJECT PLAN

sddec18-03


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## List of Definitions

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

At the end of our project, we aim to have a written proposal encompassing both the technical and economic factors associated with Puerto Rico's power grid.

The components of the physical, technological redesign will encompass the entirety of the country and discuss the current grid, technologies, and generation systems. From this basis, the proposal will suggest the addition of solutions such as solar resources, increased energy storage, interconnecting microgrids, and the addition of other energy technologies 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, as well as present information as to lost money due to lack of maintenance and blackouts.

Overall, this written proposal will describe the proposed technologies along with their locations, specifications, and costs, as well as outline the proposed economic model to be adopted to best profit the country. The plan will also have short and long-term cost outlines for implementing this plan.

The combined report will be delivered by December of 2018.

# 2 Proposed Approach and Statement of Work

## 2.1 Objective of the Task

After recent natural disasters, a majority of Puerto Rico's power lines, substations, and generation plants were left broken and unusable, leaving the population living without electricity in their homes for months. However, the power grid of the country was also in a horrible state before the natural disaster hit due to improper management of the current power grid.

Therefore, this task focuses on the current power grid of Puerto Rico with the goal of making it more reliable and more effective. The focus of this project is creating a better economic and physical design of the power grid and electric utility market to ensure the entirety of the island will constantly be supplied by with electricity, including during hurricanes, earthquakes and other natural disasters. Our team plans to design a power grid that not only provides constant electricity to the island, but also can be repaired quickly and cheaply to minimize the impact of a natural disaster on the power grid. We also will be calculating money lost due to blackouts both pre and post- Maria and Irma, calculating current and future cost analysis of implementing the suggested technological and economic changes, and encourage cognizant and responsible energy use.

We will carry out this task in two main sections: one focusing on the physical and technical component of the grid, and the other focusing on the economic section of the grid.

On the technological side, we have four main areas of focus: natural gas, renewable energy, energy storage, and microgrids. The basis of our proposal revolves around the construction of a natural gas deliquification port and subsequent updating of Puerto Rico's oil-run generating facilities. This also ties into the economic portion - by allowing Puerto Rico to convert their own natural gas, they could reduce their import costs from the current rate of imports - 55 thousand cubic feet of liquified natural gas per year (U.S. Energy Information Administration, 2017). From there, we will also be implementing natural gas turbines. The primary renewable resource we will be pursuing will revolve around solar energy. This decision was partially based on solar irradiance data and partially on the proven effectiveness for Tesla after they had implemented them at San Juan's Hospital Del Nino (BBC, 2017), and with AES, whom we have been in contact with throughout this project. . Whenever there are any renewable energy involved in a design, we must also implement energy storages for storing this energy. Current technologies are expensive to implement (considerably more so than natural gas, which ranges from $5 - $15 per thousand cubic feet (U.S. Energy Information Administration, 2018)), leading us to emphasize that natural gas is the most reasonable source of energy to start with as the 'base' of our project.

Lastly, we will be encouraging increasing the interconnectivity of the current grid. By connecting provinces and generation stations to various surrounding areas, the risk of blackouts, which currently happen at a rate of 4-5 times more than in the average American Household (Vives, Ruben, and Molly Hennessy-Fiske, 2017), and the length of these blackouts, will be reduced.

## 2.2 Functional Requirements

### 2.2.1 Natural Gas

The implementation of Natural Gas shows itself in two ways: through the introduction natural gas deliquification port and the introduction of natural gas turbines. The natural gas deliquification port must follow the guidelines of the proposal agreed to by the Federal Energy Regulatory Commission (FERC). The ports also must be able to withstand the historic temperatures and natural disasters the area sees.

### 2.2.2 Renewable Energy

Renewable Energy in Puerto Rico has been implemented and proven successful. This proposal focuses on the introduction of additional solar farms on the country's southern coasts. These solar panels must be compliant with IEEE and safety codes and abide by contractual agreements as set forth by PREPA. Generally, Puerto Rico receives around 14 hours of daylight each day, or around 2829 hours per year. After contacting AES, it was deemed even on the days with the lowest solar irradiance readings in all of their plant's life, they still receive enough solar energy to produce electricity. Therefore, these panels need to be at a place that allows them to collect sunlight as well as be maintained and be in a location that benefits the surrounding public.

### 2.2.3 Cost Issue

Puerto Rico currently provides free power to all 78 of its municipalities, as well as many government-owned enterprises and even some for-profit businesses.(Williams Walsh, Mary , 2002) Along with that, the current electric utility rates are nearly $0.10/kilowatt-hour below the Caribbean regional average.(Energy Snapshot: Puerto Rico) These facts combined lead to the one main requirement of our plan: generate profit. This plan must propose a plan that in the long-term cost outlines generates a positive monetary amount for the currently bankrupt PREPA. This plan is also required to provide a cost breakdown of previously lost profits due to lack of maintenance, blackouts, and other happenings to provide background information on the money saved along with the money generated.

## 2.3 Constraints Considerations

The political and contractual 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 and AES, a private company with power technology on the island.

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

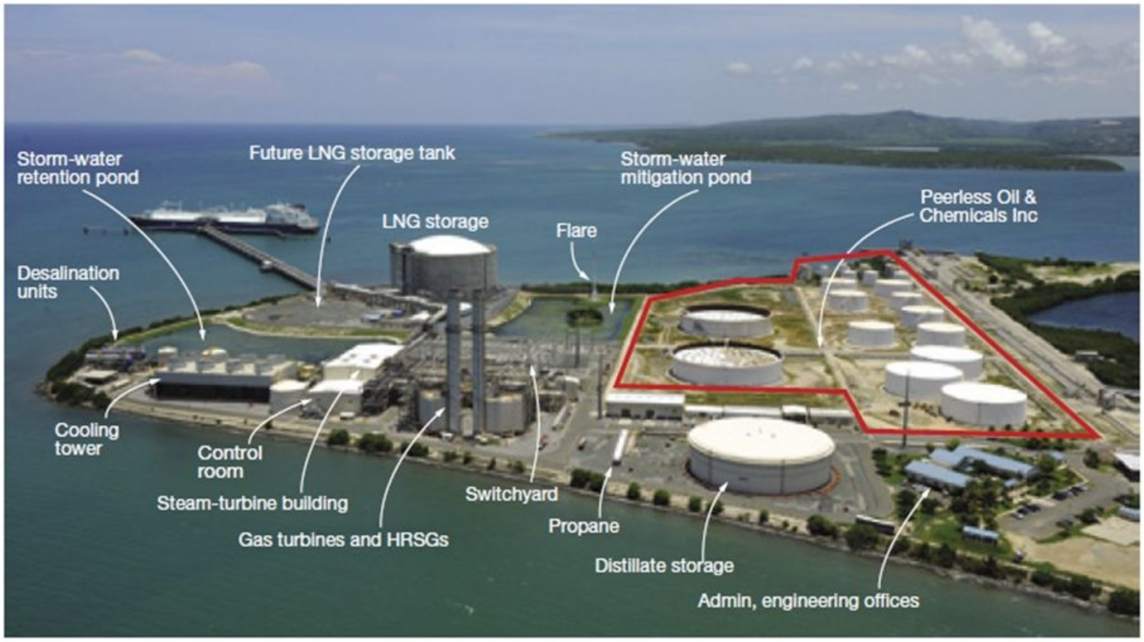
#### 2.4.1 Natural Gas Deliquification Port

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 (U.S. Energy Information Administration, 2017).

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.

Besides that, we also must meet all the multi-criteria optimization standard to determine where is the best location for installation for these deliquification ports. This is to help increase the security and the autonomy of supply security and the autonomy of the region for the installation of the deliquification ports (Moskalenko, Lombardi, Komarnicki, 2014).




**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 - EcoElectrica." CCJ Online - Plant Report - EcoElectrica LP, 2014. http://www.ccj-online.com/4q-2012/plant-reports-ecoelectrica-lp/*


*Figure 2: Location of the LNG Terminal on Google Maps*

2.4.2 Solar 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 (BBC, 2017). 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.

The solar panel and battery storage will provide power to a children's hospital

*Figure 3: "Solar Panels and Energy Storages implemented in Hospital del Nino, San Juan by Tesla." BBC, 12 October 2017. http://www.bbc.com/news/technology-41747065*

### 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.

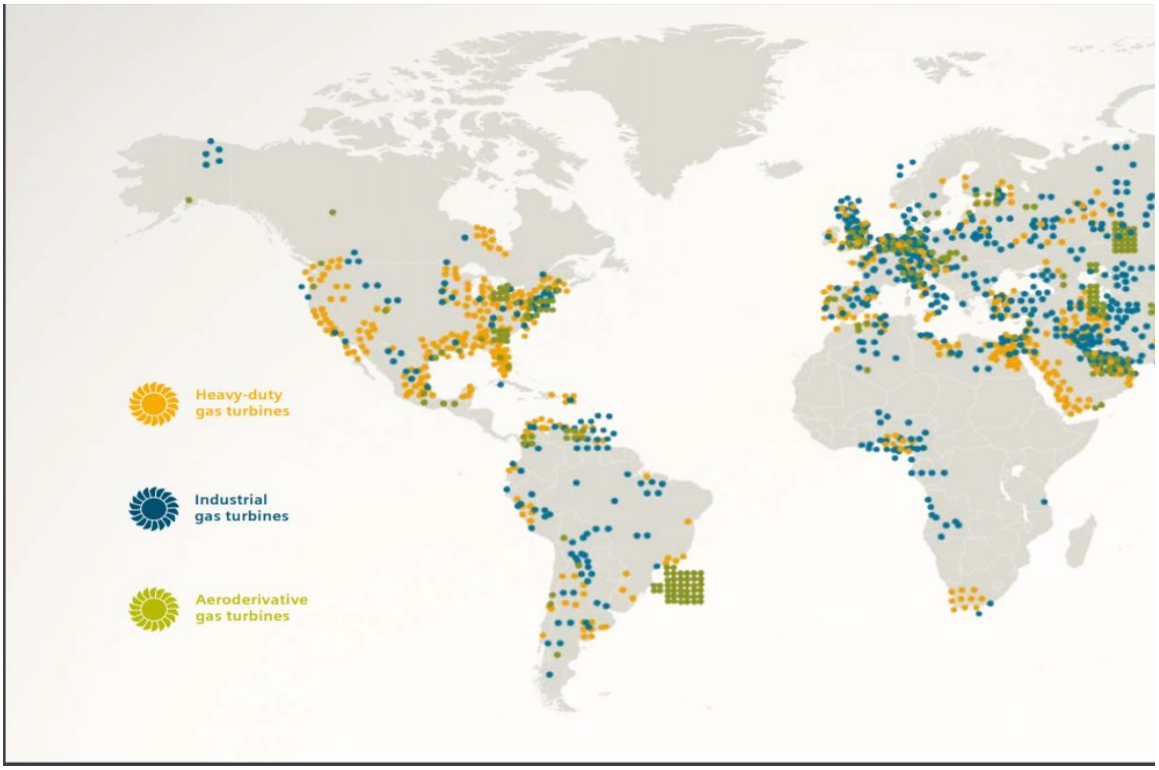



*Figure 4: "Locations of Siemens Gas Turbines." Siemens, https://www.energy.siemens.com/ru/pool/hq/power-generation/gas-turbines/downloads/gas-turbines-siemens.pdf*

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 Heavy-Duty Gas Turbines." Siemens, https://www.energy.siemens.com/ru/pool/hq/power-generation/gas-turbines/downloads/gas-turbines-siemens.pdf*

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 micrograms around the world.


*Figure 6: "High-Level Microgrid Schematic" Berkeley Lab - Microgrids at Berkeley Lab https://building-microgrid.lbl.gov/.*

### 2.5 Proposed Design

This proposed design encompasses two main areas: a technical proposal and an economic proposal. Throughout our design process, we've discussed many possible solutions and strategies that could be used.

One big decision we had to make was the focus of our project - would we be proposing a realistic solution that could be implemented immediately, or propose a 'best case' scenario with up and coming technologies like solar roads and removable turbines. Upon discussion with our advisor, we decided to take the approach of a realistic and economically feasible option that would best benefit the current financial and physical turmoil in the country's power sector

After this was decided, we began to plan the main areas to focus our sights on in terms of the redesign. On the technical side, the main areas we focussed on were renewable energy and energy storage, power generation and distribution, interconnectivity and microgrid implementation, and the introduction of gas turbines and a natural gas deliquification plant.

Renewable energy has already begun to be implemented in the country, with over 7 wind or solar fields already in place.(Puerto Rico Electric Power Authority, 2016) Upon researching the solar irradiance throughout Puerto Rico, it has been decided that the southernmost coast and possible locations on the northern coast are the most viable for solar installations.

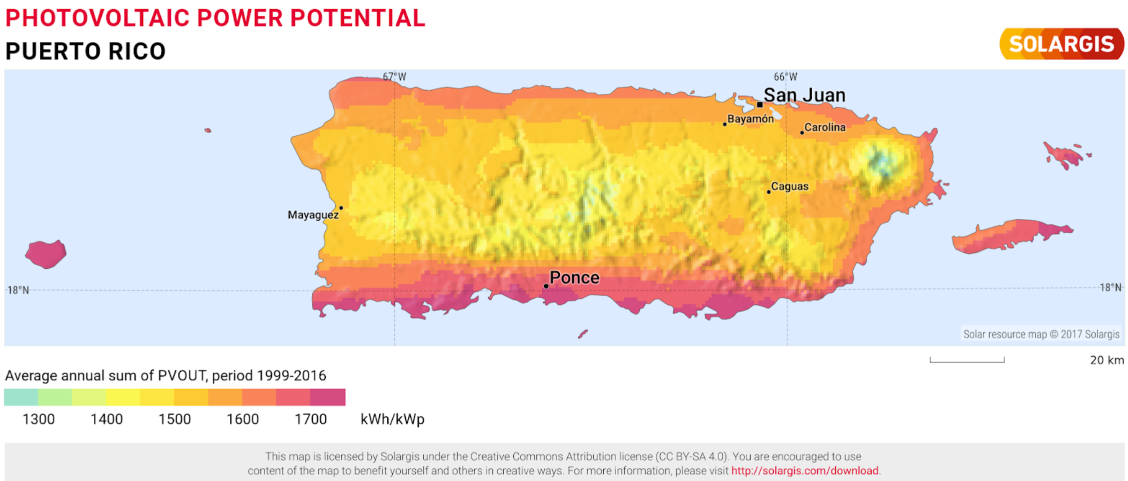



*Figure 7: "Photovoltaic Power Potential - Puerto Rico." Solargis, 2017, solargis.com/maps-and-gis-data/download/puerto-rico.*

As far as wind power goes, there is some conflicting information. For example, many wind power sources show the only economically viable options for installing wind farms to be offshore. However, other research has shown that the high, mountainous region in the center of the country may provide a constant enough supply of wind to provide a reliable source for power. For example, in 2016, two wind farms, including a facility at Santa Isabel which is the largest wind farm in the Caribbean, generated half of Puerto Rico's renewable energy.(Puerto Rico Territory Energy Profile, 2017) Due to the data discrepancies, our technical proposal will focus on the upkeep of the current wind farms but will not be recommending any additional wind farms.

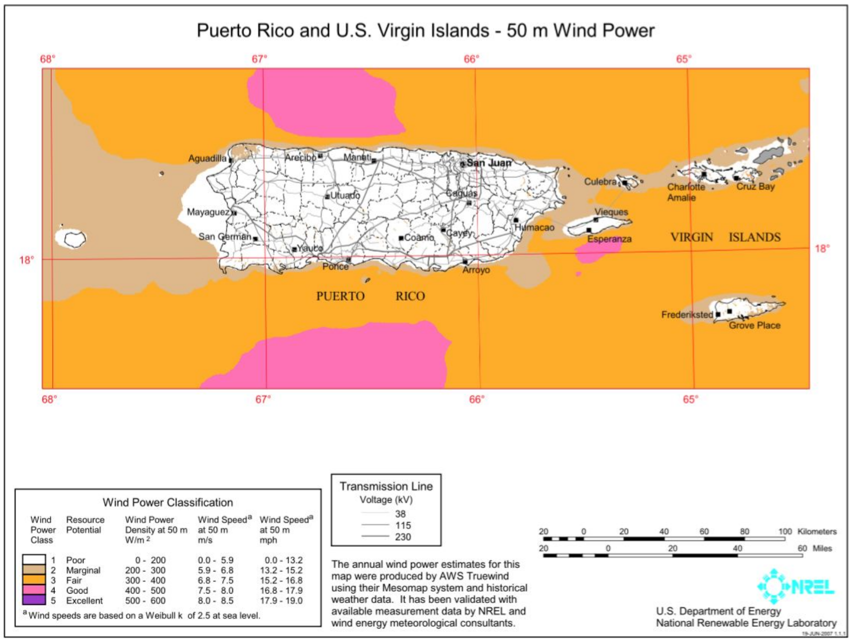



*Figure 8: "Puerto Rico and U.S. Virgin Islands - 50m Wind Power." U.S. Department of Energy - National Renewable Energy Laboratory, 19 June 2007.*

Energy storage, specifically for the renewable energy plants, will be a big factor in determining how much renewable energy is the 'right' amount to implement in terms of financial investment and reliability of power. For example, AES, who also runs some privately owned power generation facilities in Puerto Rico, has donated 6MW batteries to supplement the large-scale solar fields already installed. (Colthorpe, Andy , 2017) Other companies from around the world who are leaders in the energy storage company such as Tesla, Sonnen, and Tabuchi America have also donated time and money to the rebuild surrounding the grid. These donations help weigh down the cost of purchasing energy storage on its own, but purchasing enough energy storage to manage the installed renewable energy output is a large investment to make. AES has calculated that introducing 2.5GW of 10-hour battery storage could be sufficient, but other sources have argued the renewable power generation is too unreliable to ensure this amount would be sufficient.

A main focus of this plan to reiterate - this plan is NOT proposing a solely renewable energy-based design. While renewables are a great option, the lack of technology in the energy storage area combined with non-constant solar and wind resources and high initial and upkeep costs associated with renewable plants leaves traditional natural gas and other fossil fuels still a very stable and economically viable solution while the country works to rebuild its shattered power industry.

Puerto Rico has no natural gas reserves, so the country relies solely on imports to utilize this effective resource. On average, Puerto Rico imports 55 billion cubic feet of natural gas each year, mainly from Trinidad and Tobago. Furthermore, the only sector that uses natural gas is electric generation, and PREPA has plans in place to "add more natural-gas fired generating capability". (Puerto Rico Territory Energy Profile , 2017) Currently, of the 5.37GW of generation plants in Puerto Rico, only one 510 MW plant owned by Gas Natural Fenosa located in Peñuelas is fueled by natural gas. "Nearly all natural gas is imported as liquified natural gas (LNG) through the Peñuelas terminal and regasification facility at Guayanilla Bay on the southwestern coast." (Puerto Rico Territory Energy Profile , 2017) There has been a discussion of creating a pipeline to distribute this oil from the south coast to the north coast, but due to the mountainous region dividing the nation, the plan was discontinued, so currently a truck-loading facility allows the natural gas to be transported.(Puerto Rico Territory Energy Profile , 2017)

There has also been discussion of constructing a floating natural gas deliquification plant. Approved by the U.S. Federal Energy Regulatory Commission (FERC) in 2015, the plant would be "four miles offshore from the Aguirre generating station on the southern coast". (Puerto Rico Territory Energy Profile , 2017) Discussions are also beginning about the construction of a second plant and storage terminal on the north shore of an island, but no proposals have been submitted.

This proposal will continue with the current progress in constructing a natural gas deliquification plant, considering construction costs, transportation to the north coast, import costs, and various other variables.

As far as interconnectivity goes, the majority of research has shown very few stable connections between both towns and generation facilities. Our proposal includes adding transmission lines from town to town as well from multiple towns to each generation statement. Even before Maria, which made landfall in late September 2018, Puerto Rico's citizens often experienced blackouts, some widespread. For example, in 2016, the entire island experienced a 3-day total blackout after a fire in one of the plants. (Vives, Ruben, and Molly Hennessy-Fiske , 2017) Other statistics show Puerto Ricans suffer 4-5x more blackouts than the average American. (Vives, Ruben, and Molly Hennessy-Fiske , 2017)This can partially be attributed to the lack of interconnectivity and microgrids throughout the island. By connecting various plants and locations, should a line or substation malfunction, the remaining lines can still provide energy to power the city or to supply the generation plants with the power needed to restart.

One point we are considering thoroughly is the fate of this redesigned grid if and when a hurricane or tropical storm strikes the country. This requirement of cost-effective and replaceable technology ties in the physical and economical goals of this redesign. Our goal is to create a grid robust enough to withstand severe weather, but when damaged, is simple and economically viable to replace.

Economically, there are a few ideas being considered to better suit growth in the electric utility industry. Currently, Puerto Rico's utility rates are around $0.24/kilowatt-hour, nearly $0.10/kilowatt-hour below the Caribbean regional average.(Energy Snapshot:

Puerto Rico) However, a further cost reduction for the residential sector ($0.20/kWh) and industrial sector ($0.18/kWh)(Puerto Rico Territory Energy Profile , 2017) falls further below the average, pushing PREPA's already enormous deficit even higher.

Another factor in this ever-growing $9 billion debt is PREPA's gift if free power to "all 78 of Puerto Rico's municipalities, many government-owned enterprises, and even to some for-profit businesses".(Williams Walsh, Mary , 2002) This economic model has not been assessed since 1958, and many residents fear the repeal of this free power plan even though the plan does not directly benefit them. One main concern is that to pay for the energy, the citizens will have to increase property taxes or other spendings, an already touchy topic following an increased sales tax increase from 7 percent to 11 percent.(Williams Walsh, Mary,  2002)

One solution we've considered is creating a subsidy plan for the current municipalities and companies receiving free power. The idea behind this proposal is the government would provide a monthly stipend to cover the electricity for the month. This stipend would be calculated based on current power usage and factor in wastefulness, so the stipend would be a fair and reasonable amount if electricity is used responsibly. Not only does this solution ease our the free power plan versus implementing a full payment plan right away, it also cultivates room to emphasize conscious energy use.

Another economic factor to take into consideration is focused solely on PREPA. Due to "Frequent turnover in management and  leadership, which has long failed to prioritize grid maintenance"(Brown Nick , 2017) , there were many problems such as downed power lines and blackouts for months before Maria demolished nearly 80% of the current transmission and distribution system. Other factors play into this, including a tropical climate, but the root cause still remains at the lack of focus on maintenance from past PREPA leadership. By proposing that maintenance be treated with a higher regard, the threat of seeing such a large percentage of the island's lines wiped out could be much smaller.

After we determine the extent of physical changes to the current power grid, we plan to propose an economic report relating to these values at the time of installation through years in the future. We will calculate the yearly profits of renewables based on average sun and wind power readings compared to costs of installation in the country, provide information on the installation of a natural gas deliquification port and if the initial cost will save the country money by decreasing the spending on the 55 billion cubic feet of natural gas imported each year (Puerto Rico Territory Energy Profile, 2017), and calculate the money saved by PREPA by mitigating blackouts by introducing microgrids.

### 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.

We will however still follow the safety standards of IEEE ANSI/IEEE C95.1-2005 - IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields which requires the implementation of the design to create no harm towards the users which in this case are the people of Puerto Rico and to ensure there will be no suffering from the design that we are creating.

### 2.8 Task Approach

As Puerto Rico's power grid is not something we physically have the option to recreate, we have focused on mainly on research and background information on the current grid, renewable energy, and comparing the area to similar sizes and climates to get ideas of what will and will not work for the country's power market.

So far, as discussed in section 2.5, we have gathered extensive information on the renewable energy viability in the country as well as the current generation plants in the country. We've researched the current energy storage options as well as up and coming engineering projects focusing on renewable energy efficiency and storage. We've studied transmission diagrams to look at interconnectivity between different municipalities and generation plants. We've researched the costs and technical challenges associated with construction a natural gas reliquefaction plant. We've also delved into the economic side of Puerto Rico, studying electricity prices, historic events, and begun researching prices associated with implementing the technical improvements we've focused on. We will continue researching these topics until we know enough to definitively say that this solution is one worth proposing to the country to solve their power crisis.

As we move forward, we plan on meeting with transmission professionals from MidAmerican Energy and generation professionals from the Ames Power Plant to discuss realistic expectations in each of these two areas. We also plan on determining which areas are viable for solar and wind energy by combining the irradiance and wind potential maps from section 2.5 with the cost of land area and population of area in question. We will also do more research on Puerto Rico's natural gas market, looking deeper into what goes into a natural gas deliquification plant and how much money on imports the country could save.

The strengths of our current plan are the feasibility of all of the subjects are researching. Many of the technologies introduced are well-priced and have been very successful in regions with similar climates or similar populations. Another strength of this plan is our focus on the introduction of natural gas. Many proposals focus on a goal of %100 renewable energy, which isn't cost effective or realistic with current energy storage options. Our focus on updating the current generation to natural gas will be more efficient than the current fossil fuel burned while also being more cost-effective and environmentally friendly. One main weaknesses is the inability to see firsthand the power crisis in Puerto Rico. Many problems relating to poor maintenance and outdated equipment exist with the current grid, and the full extent will be hard to comprehend without actually experiencing it. Another weakness is the lack of totality associated with this proposal. Although we have a considerable amount of data for all components and sections, there are components, political and contractual obligations, and land-use restrictions that will not be incorporated, meaning this proposal would need to be edited with various laws and regulations in mind before being 100% feasible.

### 2.9 Possible Risks And Risk Management

One risk of this proposal deals with how accurately we can solve this problem without physically implementing or seeing the country and its current technology. We are doing the research but in the end, we are merely doing a theoretical assumption of the work that we are doing using research past engineers have shared online. Some work that others have published may be incomplete or inaccurate. Therefore, we have to ensure that the sources that we use are from reliable studies and publications. To mitigate this risk, our proposal will make clear this proposal is theoretical in nature and further research, specifically in contractual and case-specific standards, should be further studied.

### 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. Testing the project both on a computerized software and through a specified compliance test.

### 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.

### 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

For the project and the design to be viable in Puerto Rico, there are many conditions that need to be met. The design must be economically friendly due to the low budget and financial issues that Puerto Rico has. To conduct a viable design, we have to ensure that the design is cost effective for the country. We have to choose the right design that is effective and efficient but at the same time will not be too impactful to the country's finances.

To create the most viable and effective design, another condition that needs to be attended to is the fact that the country will require constant and reliable power supply throughout the year compared to how it currently is with constant power outages. This we can overcome will placing microgrids to not only rely on one power grid to supply energy to the country. This is a major part of the design to make sure that if a microgrid goes down, another will take its place to help supply energy.

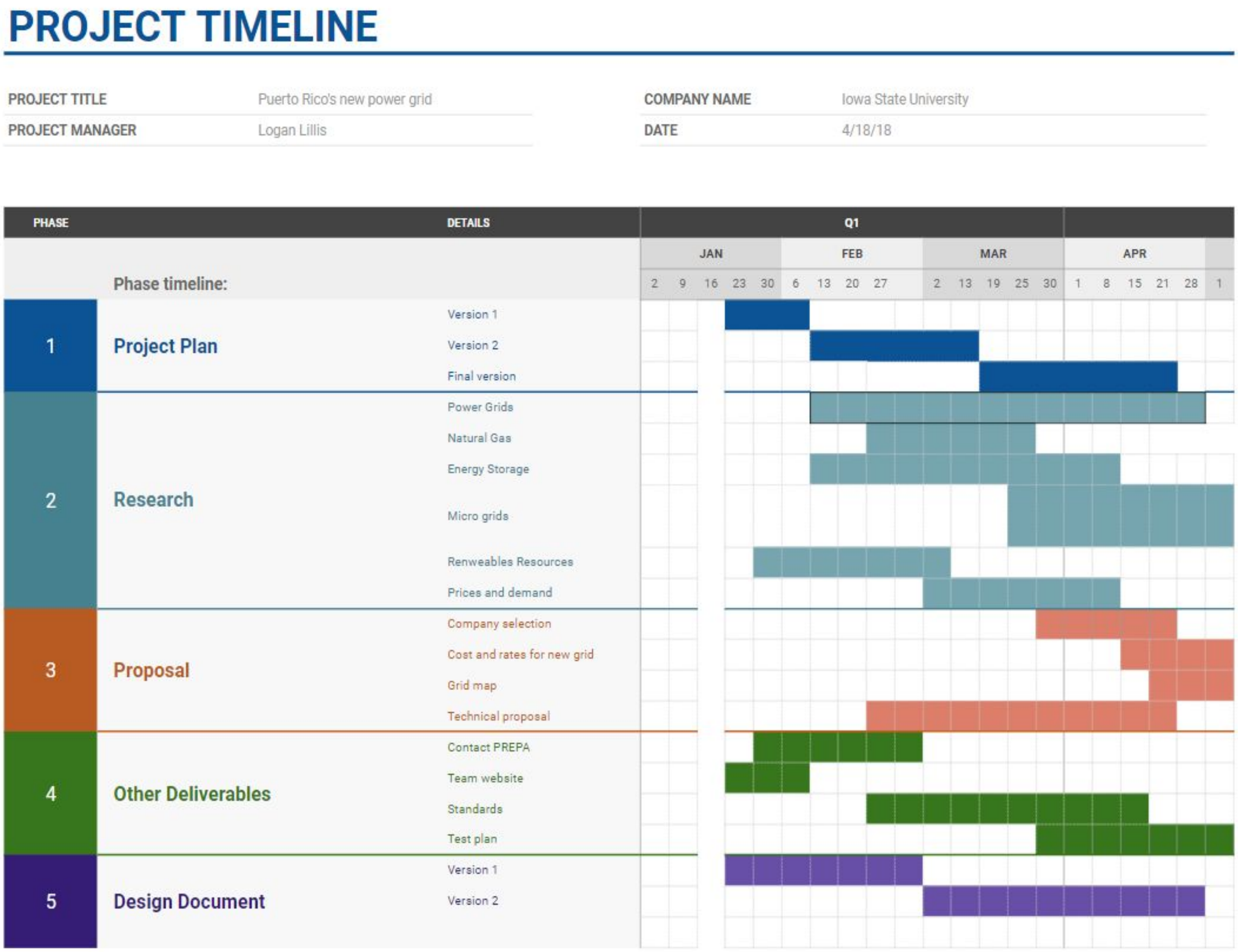
There is also the environmental factor that needs to be taken into consideration. There are constant natural disasters that occur in Puerto Rico due to high winds and other causes, therefore, a power grid design must be either robust or easily fixed incase of these occurrences. That is why we have to design a power grid that could resist and overcome these problematic situations.

Besides that, we will conduct a compliance test. This is very important because since we are designing a power grid based off the research we did from different companies and organizations, we have to make sure that the data that we have is accurate and correct to ensure that we do not create a power grid that is not effective or suitable for Puerto Rico.

We will also conduct a test to which involves simulation of the design by using a certain kind of software that some companies are using to test the power grid to see if it works or not. Besides the software, we will also simulate and test the design that we will create by using a certain algorithm given by professionals in the power industry.

# 3 Project Timeline, Estimated Resources, and Challenges

## 3.1 Project Timeline



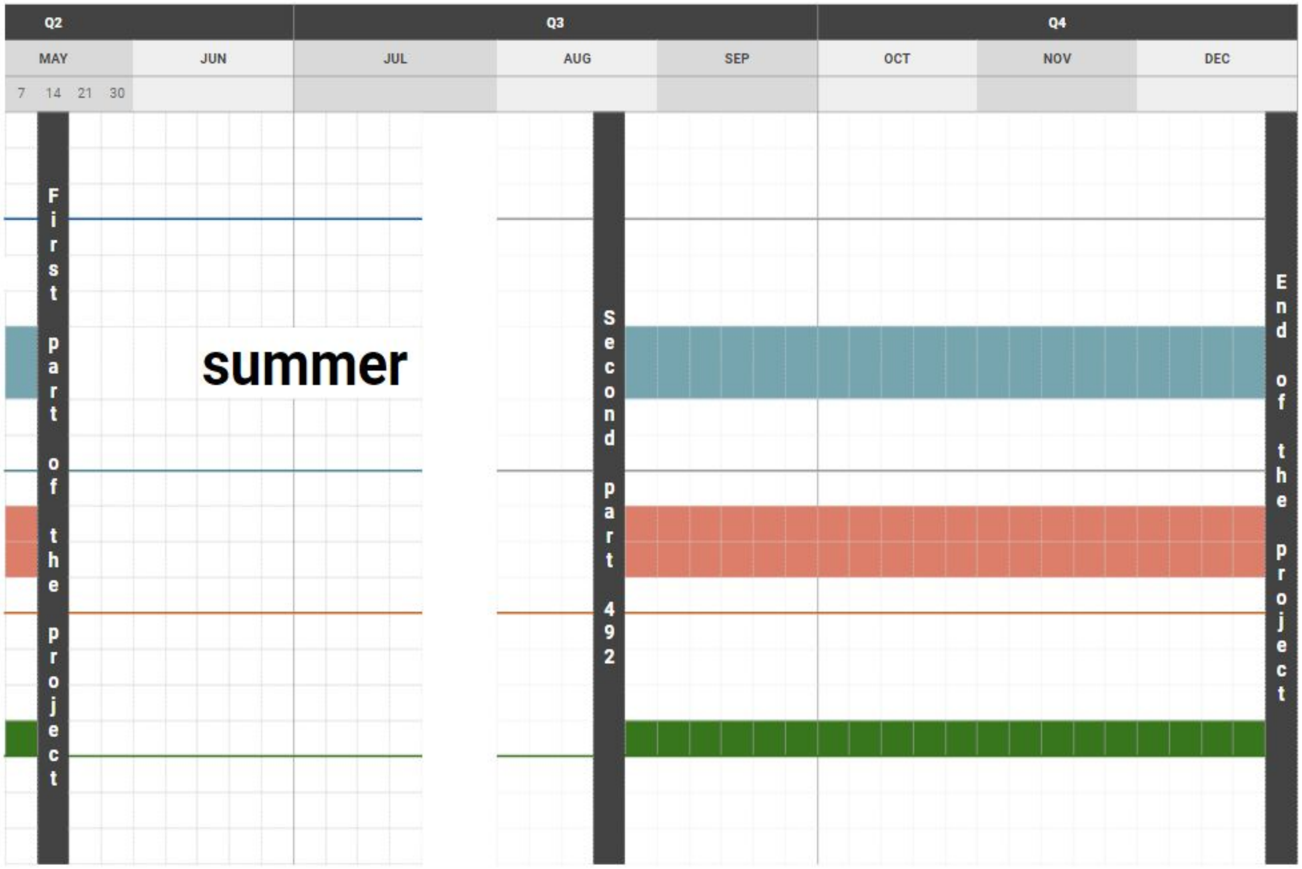



Table 1: Senior Design Project Timeline

Our project timeline consists on five primary phases to complete in our project. To be more precise this are the main components of our project for this semester. In our first timeline we delimited each task with different colors pointing the responsible of each one. In this timeline we will face each task as a team regardless of the amount of time or dedication that any teammate puts into the project with respect to others. We took this decision since it will help us to balance and coordinate the information, plus will help us more as a team. Each different phase of this project is correlated and we might be working in more than one at a time.

Documentation is a really big past of this first semester for our project, due to its importance, among the phases we pointed the duration and deadlines for the project plan and the design documentation versions. Research is our main activity in this first semester, on it we included each task petitioned by professor Dalal or those we felt relevant to our timeline. Then, proposal and other deliverables are the extra details extra to our documentation but no less important.

Those task that pass the final date of the semester finals or that "touch the black line" are going to be taken over again during the fall semester.

### 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. Logan Lillis, Communications and Reports Lead, keeps meeting minutes, writes weekly reports, communicates with outside parties, and has lead research on renewable energy, natural gas deliquification ports, generation, and the economic proposal. Ricardo Rodriguez-Menas, Webmaster and Project Plan Lead, created and updates the project timeline and heads research on standards, compliance, and energy storage. Heiqal Zamri, Test Engineer Lead, is responsible for the structure and implementation of the test plan as well as research on natural gas turbines and natural gas imports, as well as research on renewable energy and microgrids. The group discusses findings 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 and discuss with him our progress and outline new objectives. Then individually each one of us spend between 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:"

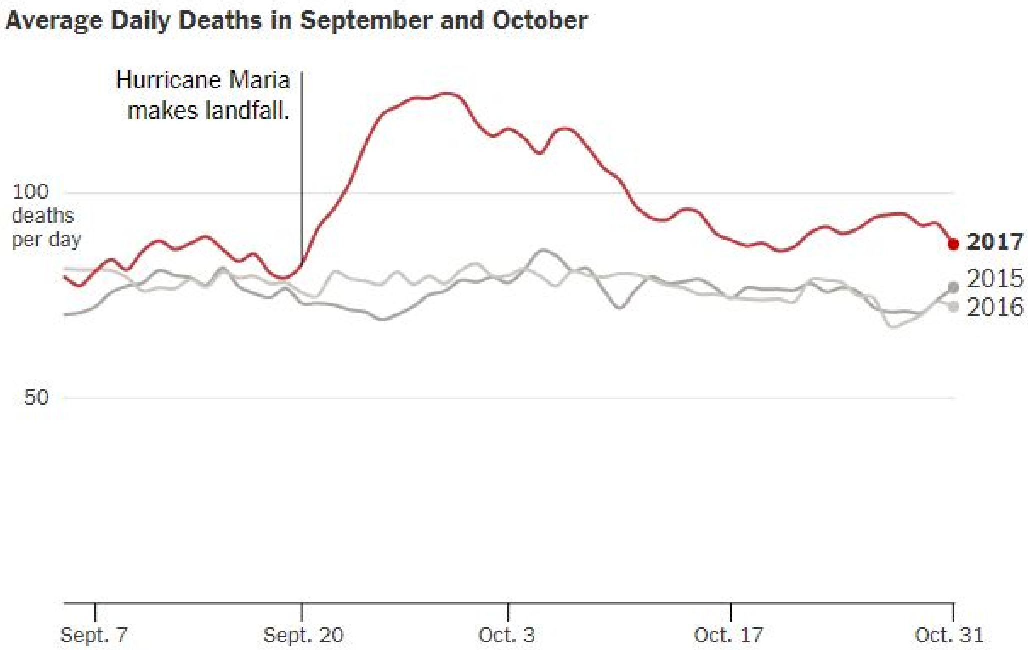
- Code of ethics

- https://www.ieee.org/about/corporate/governance/p7-8.html

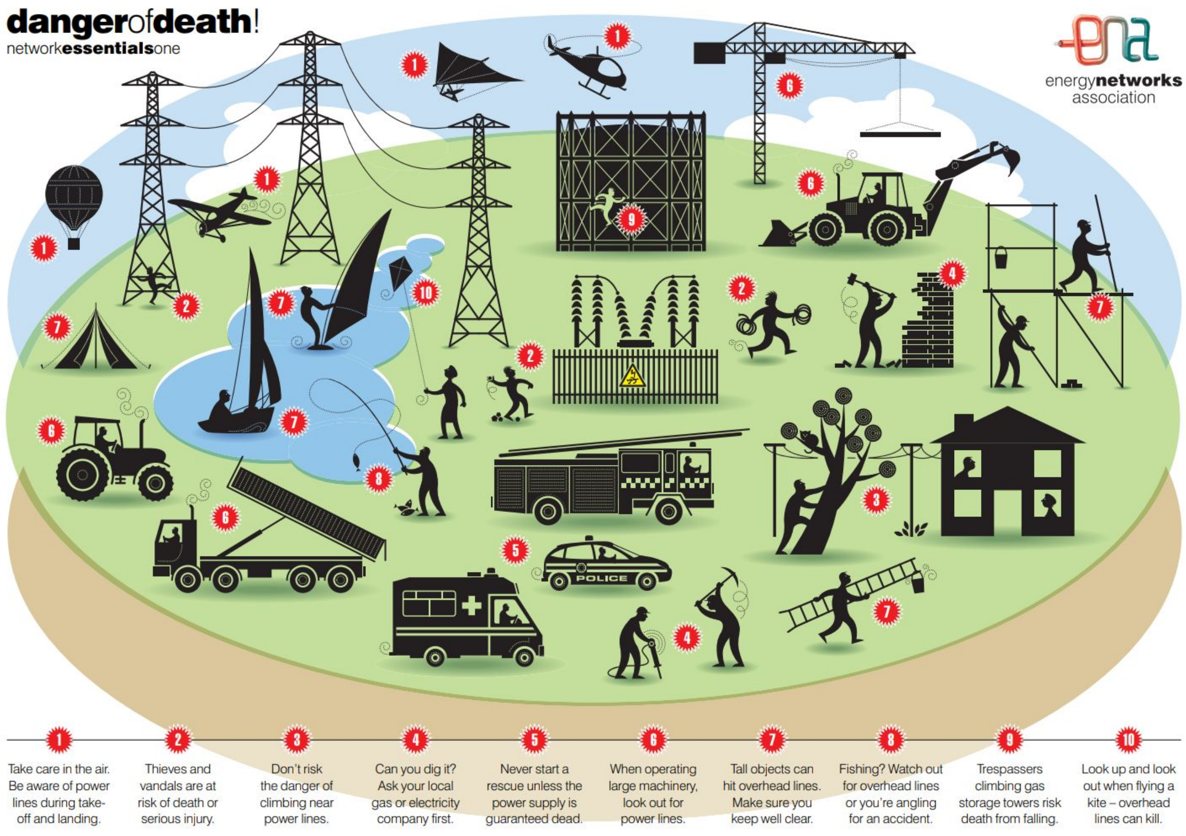
This are the rules that we as a team and part of the IEEE organization will follow and obey throughout the timeline of the project. We also added standards to our project based on those from IEEE organization. We divide them into Safety and Technology, these are a notable few among them.

- Safety

- ANSI/IEEE C95.1-2005 - IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz . Due to all the manipulation and necessary use of electricity is quite important to submit standards based on the ratios of which humans beings are allowed to be exposed without suffering injuries at any level. In this kind of process of reconstruction and maintenance of high voltage transmission lines and the required manipulation of power circuit components is vital to prevent the exposition of the body to high voltages. Normally after every disasters there are lines on the ground and all over the place. As a result of this there are always many accidents and deaths due to the manipulation of this. This standard works as a guide as it helps workers prevent those injuries and educate the population of the norms and danger in which they might be exposed. ENA states that there is an average of 13 fatalities per year due to contact with high voltage elements. After the storm in Puerto Rico the death toll increased sustainably, this is one of the statistics we want to change in favor of the population.

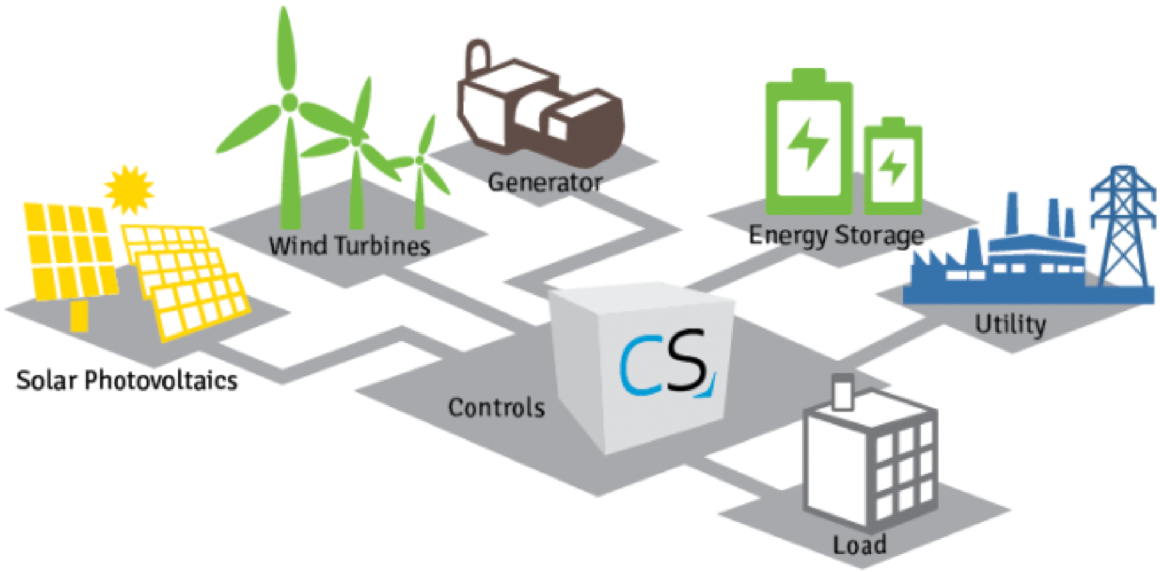



- 2017 National Electrical Safety Code(R) (NESC(R)) These standards are the general and basic recommendations for safety regarding equipment, substances and levels for required personal, also training. More related to the personal and equipment required this standard also help us to understand what kind of specialist will be needed for this task in order to avoid negligence. There has been countless reports in the island of these negligence due to political and economical reasons. Electrical engineers often leave the island or avoid energy and power jobs, due to this, the entities in the island tend to hire non-qualified personal for these kind of tasks. If we want to change and restructure the electrical system of the island we must do it thoroughly and efficiently. the equipment needed will further avoid injuries and accidents.

- 


- Technology

- IEEE Std 2030.7-2017 - IEEE Standard for the Specification of Microgrid Controllers. These standards were proposed with the intention of address the testing procedures to ensure the microgrids is a self sufficient component of any system regardless of topography or place. One of our main plans were to begin the integration of microgrid to the project since it will be important on the response to any black out and immediate lost of power. Among all the power courses we have taken in the program there hasn't been much information about microgrids and for this project we have had to research and learn about it on ourselves. These standards have helped to understand more about the topic and somehow helped us to clarify our limits with respect to what we really want to achieve.




- IEEE Std 2030.3-2016 - IEEE Standard Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications. This standard includes the proper order of procedures and tests required for Energy Storage applications and installations. These energy storage standards have a similar situation to the microgrid ones in the fact that it helped to increase our knowledge about a topic that we don't get much information in class. For Energy storage is slightly more complicated the situation since is complicated to choose the proper company for the installation. There are a lot of companies with promising solutions and applications for the project but since there is not much data available we must rely on these standards to make the best choice.

- IEEE Multi-criteria optimization for determining installation locations for the power-to-gas technologies. This might be one of the most important standards or criteria among those cited since one of our main goals for the project is to make possible a transit on Oil based Power system to a Natural Gas power based system. Professor Dalal has the idea that one of the main economical solutions for Puerto Rico is to turn their power system to Natural Gas in the majority. To accomplish this, also the majority of the system must be restructured to be compatible with Natural Gas power standards. The detail and requirement for the installation of the different components are specified on these standards.

These are among  the standards that we considered relevant to our project since it provides optimal constraint rules to follow. We used IEEE catalog of standards, other forums and information available on their website as guide to include these into our project. Standards are a really important part of every organization or project since it helps in our case a group of students from Iowa to be synchronized with the guidelines of majority of companies in the world, specially those  working in the island.

### 3.4 Other Resource Requirements

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

Specifically for our team, there are no costs associated with the designing or proposal of this redesign. However, we require the proposal's budget to be reasonable and beneficial to Puerto Rico and their economy.

## 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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