Design a new and more Reliable Power Grid for Puerto Rico

Design Document

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Design of a More Reliable Power Grid for Puerto Rico

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1 Introduction

1.1 Acknowledgement

If a client, an organization, or an individual has contributed or will contribute significant assistance in the form of technical advice, equipment, financial aid, etc, an acknowledgement of this contribution shall be included in a separate section of the project plan.

1.2 Problem and Project 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.

1.3 Operational 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.

1.4 Intended Users and 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.

1.5 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.

1.6 Expected End Product and 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 written report encompassing the economic and physical redesign of the power system in Puerto Rico will be delivered by December of 2018.

2. Specifications and Analysis

2.1 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 [6]. 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.

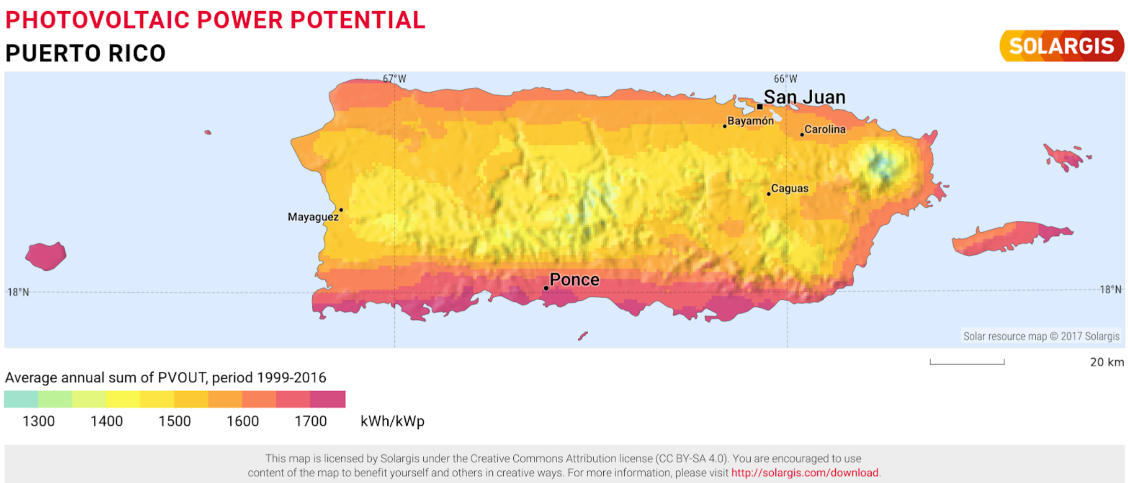

Figure 1: "Photovoltaic Power Potential - Puerto Rico." Solargis, 2017, solargis.com/maps-and-gis-data/download/puerto-rico.

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. [7]

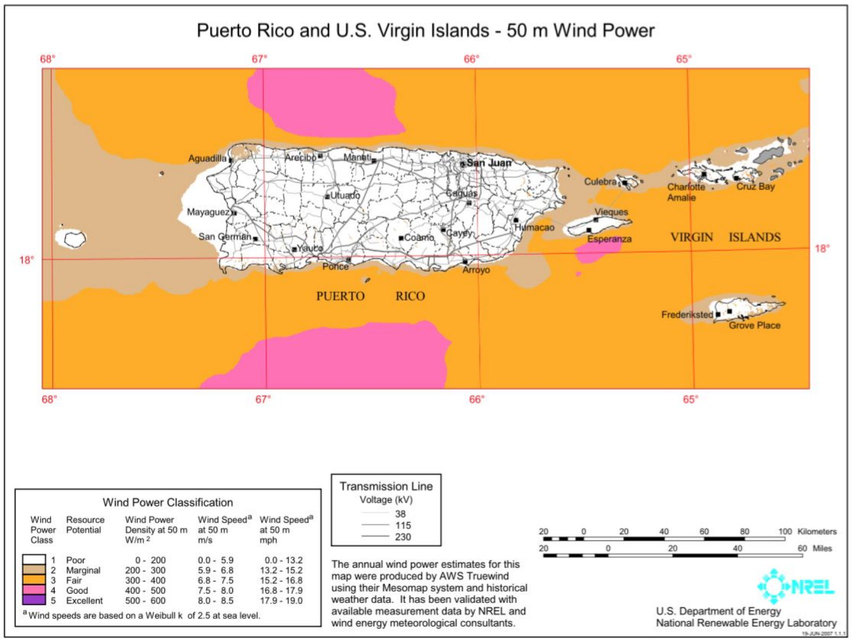

Figure 2: "Puerto Rico and U.S. Virgin Islands - 50m Wind Power." U.S. Department of Energy - National Renewable Energy Laboratory, 19 June 2007.

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 [2] .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"[7]. 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."[7] 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. [7]

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"[7]. 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.[8] Other statistics show Puerto Ricans suffer 4-5x more blackouts than the average American.[8] 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 [3]. However, a further cost reduction for the residential sector ($0.20/kWh) and industrial sector ($0.18/kWh)[7] 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"[9] . 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.[9]

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" [1], 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 [7], and calculate the money saved by PREPA by mitigating blackouts by introducing microgrids.

2.2 Design Analysis

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 2.1, 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.

Until we reach that place, no real "design" has been implemented, per say. Instead, we've designed all of the puzzle pieces that will eventually piece together to form one extensive redesign of the entire power grid and market in Puerto Rico. Even though we don't have a map of the redesign or have the financial proposal sorted out, we have had pieces of solutions that have either been reasonable or did not work. One example was implementing offshore hydro-electric generation plants. Although this option is reasonable for an island country, the costs associated with the installation and the climate and natural disaster history of Puerto Rico may mean this form of generation is not one that will pay off in the long run. We also discussed the installation of solar roads, but the costs associated with such new technology as well as the uneven distribution of solar irradiance throughout the mountainous section of Puerto Rico led us to move in other directions.

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 2.1 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. 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.

3 Testing and Implementation

When choosing to design a power grid on a large scale such as creating a power grid for Puerto Rico, there needs to be tests that needs to be done to ensure that the power grid that we are designing are functioning at optimum level and is reliable. However, since creating a power grid on a country to just test its functionality is not practical. Therefore, we have to focus on different methods of testing the power grid that we design.

2.3 Interface Specifications

The power grid that we are implementing is more of a designing project which will be focused more on the theory of creating the power grid. However, currently there might possibly have some algorithm that can be used to create the power grid for the team to work on.

2.4 Hardware and software

For this project, we will be working with many different devices and components to realize the whole project. The power grid that we are trying to create or design consists of:

a. Solar Panels

Solar panels will be one of the hardware that will be very crucial in assembly this power grid that we are designing. Solar energy is first and foremost a progressive step into a more innovative world. It is a renewable energy source that could help preserve the world that we live in for a bit longer.

Besides that, solar energy would be a very good source of energy for Puerto Rico due to how much sun intensity does the country get a year. With this constant intensity that is received by Puerto Rico per year, this is a very logical step in creating the power grid. The power grid that we are implementing will consist of these solar panels that will be placed around the island to supply not to only one area of the country but throughout the island. These solar panels which are connected to other devices will help make this power grid possible.

b. Wind Turbines

Wind turbines act similarly the solar panels in making the power grid into a reality. The wind turbines is another innovative step when creating the power grid because of the fact that Puerto Rico gets a lot of wind per year. The island gets a 22mph trade winds that flows through the island all year long and for every 5 years, the wind gets strong enough to create a cyclone.

The wind turbines is one of the components that we will be studying when looking at creating the power grid for Puerto Rico. We will have to understand how strong must the wind blow to create enough power to generate electricity to help supply to the country. The wind turbine will function as another generator to supply power for the power grid.

c. Gas Turbines of Natural Gases

Gas turbines are not something new but however will prove to be the most beneficial and cost effective generator for the power grid. These gas turbines will act as a backup for the solar and wind energy that will be supplying the island. The gas turbines will be very useful for cloudy days or days without wind and sun or even night time. These gas turbines can help assist in supplying power to the island to make sure that if the solar and wind energy goes down, the whole power grid will be demolished.

d. Microgrids

Microgrids are something that could be very helpful for countries that face situations where the rely on only one power source and if that goes down, the whole country will be living without any electricity. The microgrids functions as multiple small power grids that interconnect with each other to create a connection of power grids. This is useful for the fact that if one microgrid goes down, the other microgrids will help out in supplying energy for the island.

e. Energy Storage

Energy storages are always important when creating a power grid that uses renewable energy such as solar energy. The energy storage focuses on storing the energy that is generated to the energy storages. These energy storages are used to supply Puerto Rico with sufficient energy similarly to how a battery is used to supply energy. However, the price of implementing a numerous amount of energy storage is not practical due to its high price, therefore, we also focus on the use of gas turbines and natural gases.

2.5 Functional Testing

We must first put the design through a functionality test and also a reliability test. The functionality test is to test the design whether it would even work as expected or would it break down. This is a very important test and to conduct such a test, we have to use a software that some power companies are using to test the power grid. This software can take the intended design and simulate the design and can give us the output that we want. Besides that, if the software was too inaccurate, we will conduct a test for the power grid using a certain algorithm that is obtained from professionals in this field of study.

Moreover, we must also set a reliability test for the power grid. This is also another important test that must be conducted if we want to implement the power grid in Puerto Rico. Puerto Rico faces many natural disasters which could affect the result or the reliability of the power grid, for example, due to Hurricane Maria that hit Puerto Rico recently, the power grid went down and currently there are still natives of Puerto Rico that are living without electricity in their homes. Another situation for the importance of the reliability test is that Puerto Rico runs on only one main power grid, and if that power grid goes down, even temporarily, the country will live without electricity. Therefore, the power grid must not only be efficient, but it must also be reliable enough to supply constant supply of energy to the island.

Besides that, there are also tests that needs to be conducted to test individual units that we are preparing for the design.

1. Solar Panels

   The solar panels are used as the primary energy supply of the design to generate electricity from gathering solar energy. These solar panels need to be tested to ensure that they will supply the appropriate amount of electricity for the design. We have to test how much each individual panels can generate and then create a whole farm of the solar panels to ensure that enough electricity can be generated.

2. Gas Turbines of Natural Gas

   The gas turbines will be used as a cogenerator to the solar panels to help ensure the constant supply of electricity throughout the island. These gas turbines are used to generate electricity by using natural gases. These gas turbines must also be tested to ensure its optimal efficiency. Based on the numerous version of the gas turbines by Siemens, we must test the gas turbines to be able to choose the most appropriate one for the design. We will still look towards the datasheet for these values but we must also test the gas turbine to ensure that it follows correctly with the datasheet.

3. Energy Storage

   Whenever we are discussing about solar energies and solar farms, we can’t avoid the implementation of energy storages for these solar energies. Solar energy whenever they are implemented, there must be a method of storing the energy and that is what the energy storage is for. The AES energy storage that we have chosen needs to be tested to check if they can store the amount of energy supply that we are generating from the solar farms without resulting in any problems. Besides that, the energy storage must also be tested to check whether it is suitable with our design.

4. Microgrids

   The microgrids will function as a small connector to the design with other microgrids to ensure constant and reliable supply of electricity for the island. Therefore, it is very vital that we test how reliable these microgrids function. Since microgrids are smaller grids connected to each other, will they be reliable and powerful enough to supply the sufficient amount of energy to the island. For this, we can look towards the Berkeley Lab Microgrids to get a better idea of the data involved.

2.6 Non-Functional Testing

An important test that needs to be conducted with our power grid are test cases. The power grid needs to be tested under different conditions or circumstances. For example, based on the insulation data of Puerto Rico, the country is constantly supplied with sun throughout the year, however, we must test the power grid to check whether it will still function if there are days or a week without sun due to cloudy days. This is very important to check how optimal the design will be for Puerto Rico.

Another condition that we have to test the power grid is to test how robust or reliable the design would be under harsh conditions with the weather such as hurricanes and earthquakes. We are not expecting the design to withstand these natural disasters completely, however, the power grid should not be too fimble to that it will break down and won't be easily repaired.

Besides that, we must also conduct a compliance test for every value of the datasheet of components such as the gas turbines, energy storage and also microgrids. We have to test these components and their values to see how accurate the values are and from this, we can test how usable the design is to be implemented for Puerto Rico. When we have these results, we can choose the most suitable design that is most compatible with the desire of Puerto Rico.

2.7 Process

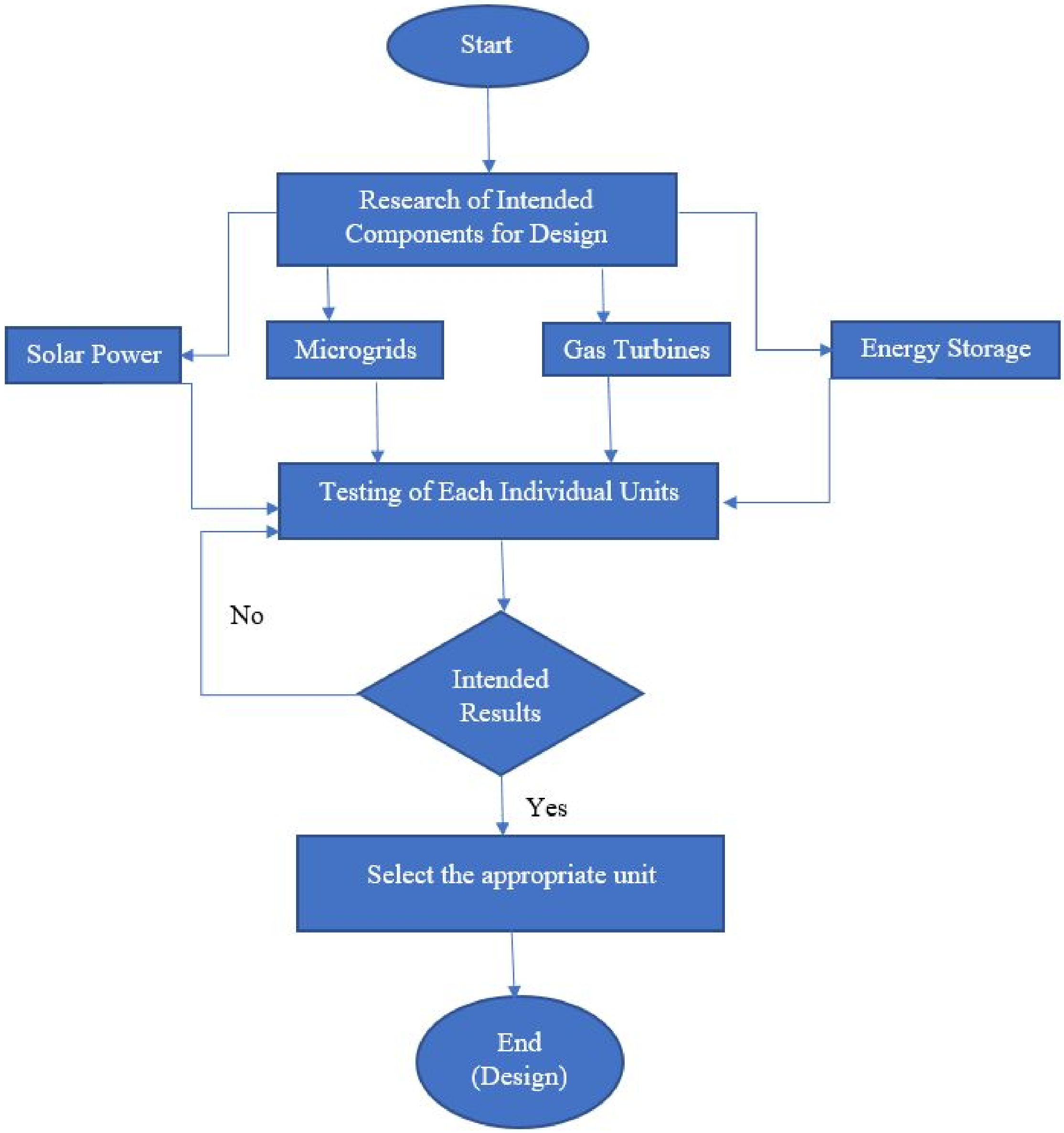

Figure 3: Flowchart of Designing of Power Grid

2.8 Results

The power grid that we are designing should pass all these tests to ensure that it would be reliable enough for Puerto Rico. The design should function optimally with corresponding to the supply of solar energy that is stored in the energy storage and also the generation of power from the gas turbines with the use of natural gas. With these two supplies, the microgrids should be supply sufficient energy to the whole island even through unsavory conditions such as natural disasters that do occur to the island.

The tests will test be conducted and each test result will be evaluated. If there are any unwanted results, we will fix any errors and edit the design to get the intended result. We will then keep retesting its functionality until we get the results that we want and all the results will be recorded and documented.

4 Closing Material

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.

4.2 References

1. Brown, Nick, et al. "Special Report: The Bankrupt Utility behind Puerto Rico's Power Crisis." *Reuters*, Thomson Reuters, 4 Oct. 2017, www.reuters.com/article/us-usa-puertorico-utility-specialreport/special-report-the-bankrupt-utility-behind-puerto-ricos-power-crisis-idUSKBN1C92B5.

2. Colthorpe, Andy. "Storage Industry Players Working to Repower Puerto Rico." *Energy Storage News*, 7 Dec. 2017, 13:16, www.energy-storage.news/news/storage-industry-players-working-to-repower-puerto-rico.

3. "Energy Snapshot: Puerto Rico." *Energy Transition Initiative: Islands*, www.nrel.gov/docs/fy15osti/62708.pdf.

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

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

6. “Puerto Rico Electric Power Authority.” *Wikipedia*, Wikimedia Foundation, 2 Mar. 2018, en.wikipedia.org/wiki/Puerto_Rico_Electric_Power_Authority.

7. “Puerto Rico Territory Energy Profile.” *EIA*, U.S. Energy Information Administratoin, 21 Sept. 2017, www.eia.gov/state/analysis.php?sid=RQ

8. Vives, Ruben, and Molly Hennessy-Fiske. “Puerto Rico's Debt-Plagued Power Grid Was on Life Support Long before Hurricanes Wiped It Out.” *Los Angeles Times*, Los Angeles Times, 28 Sept. 2017, www.latimes.com/nation/la-na-puerto-rico-power-20170925-story.html.

9. Williams Walsh, Mary. “How Free Electricity Helped Dig $9 Billion Hole in Puerto Rico.” *The New York Times*, The New York Times, 1 Feb. 2016, www.nytimes.com/2016/02/02/business/dealbook/puerto-rico-power-authorit ys-debt-is-rooted-in-free-electricity.html.

10. Microgrids at Berkeley Lab, Berkeley Lab. https://building-microgrid.lbl.gov/

11. “Gas Turbines Siemens” https://www.energy.siemens.com/ru/pool/hq/power-generation/gas-turbines/d ownloads/gas-turbines-siemens.pdf

12. “Puerto Rico Territory Energy Profile.” EIA, U.S. Energy Information Administration, 21 Sept. 2017, www.eia.gov/state/analysis.php?sid=RQ

13. “Puerto Rico Electric Power Authority.” *Wikipedia*, Wikimedia Foundation, 2 Mar. 2018, en.wikipedia.org/wiki/Puerto_Rico_Electric_Power_Authority.