Abstract

Power from electrical substations is essential for a comfortable lifestyle, especially in urban areas. However, placing a substation in or near an urban area causes problems due to its size and poor aesthetics, coupled with the lack of space and the possibility of flooding. To solve these problems, extensive research regarding substations was conducted to formulate possible solutions. As a result, a parking garage with an underground substation that serves Newark, New Jersey was determined as the most cost effective and feasible option.

The blueprints of the parking garage and the substation were created using a Computer Aided Design (CAD) program, Autodesk Inventor. Gas-insulated transformers and switchgear were used to conserve space, and the most vulnerable equipment was elevated to prevent water damage during floods. Additionally, solar panels and electric vehicle charging stations were implemented to benefit the environment. Although it is designed for a specific situation, the parking garage design is extremely versatile and will remain a great option for urban areas in the future.

1. Introduction to Substation Redesign

A substation is a vital component of the electrical grid that is responsible for the transmission and distribution of electricity throughout any given community. Despite the substation’s crucial role in distributing electricity throughout the grid, its unpleasant aesthetics, poor resistance to severe weather, and excessive spatial requirements provoke a general discontent for the system and create suspicion towards its reliability and guard.

Multinational corporations such as ABB, Toshiba, and Siemens Energy acknowledge these limitations in the traditional substation design through the development of alternatives to the conventional layout. New innovations such as concealing the system in a house, elevating it above flood levels, and hiding it underground have addressed certain limitations of the traditional layout. However, there is yet to exist a design that addresses every weakness simultaneously.

Urban design in substation engineering is necessary to create a layout that provides a solution to weaknesses in the traditional design. The innovation brought by this perspective is essential in developing a compact layout for the infrastructural
components, while the incorporation of advanced technology within urban design contributes to the enhancement of resistance against severe weather. Contemporary solutions to conventional substation designs enhance the aesthetic appeal, improve the reliability, and decrease the spatial requirements of these systems.

The congested area near Newark Liberty International Airport in Newark, NJ was targeted due to the demand for a substation in that location.

2. Background

2.1. Types of Electrical Stations

There are three main types of stations that transmit electricity from a power plant to a community: switchyards, substations, and switching stations. Switchyards simply redirect or distribute power to different locations without changing the voltage or current. Substations, the main focus of this project, lower the voltage of electricity from long-distance transmission lines that carry electricity at a high voltage, usually 138 Kilovolts, to a voltage useable by a community’s local grid. This lower voltage is for residential use and is usually 13.8 Kilovolts (kV). 26kV is used for certain commercial use, such as in airports. The process of lowering the voltage is called “stepping down”. A switching station is a combination of a switchyard and a substation, redirecting power and changing voltage.¹

2.2 Three Phase Power

To provide electricity to their customers, utilities employ a system called “three phase power”, which involves using three wires to carry alternating current (AC). The three currents reach their peaks at one-third of a cycle away from each other. When the currents are superimposed, a uniform flow of current is produced by a phenomenon known as destructive interference (Figure 1). A constant current is necessary for running certain equipment such as heavy-duty motors, due to the need for a constant magnetic field. With standard AC power, a magnetic field cannot be sustained, but three phase power produces a constant magnetic field. Additionally, electric utilities use three phase power because it uses less conductor material than single-phase power, and is therefore less costly.¹

Figure 1: Three Phase Power²

2.3 Substation Technology

Power enters a substation through transmission lines carrying electricity at high voltage levels, usually 138kV. The incoming electric flow travels through the substation beginning with a bus system. A bus system is a network of wires, circuit breakers, and disconnects. Circuit breakers are electrical switches that automatically stop the flow of current when a fault is detected that could damage the electrical system. Disconnects allow one transmission line to be shut off. Bus systems give the substation redundancy, allowing the station to still function despite the failure of a number of transmission lines. The electricity then flows to the transformers, devices that either increase or decrease the voltage from 138kV depending on whether they are step-up or step-down substations. A step-down
transformer consists of two wires, one incoming and one outgoing, wrapped around an iron loop. One wire has more coils than the other, and the incoming current transfers to the outgoing wire (Figure 2). This incoming wire is known as the primary coil. The current in this wire creates a magnetic flux that magnetizes the iron core, which in turn creates a current in the outgoing wire. The ratio of the number of coils in the primary coil to the number in the secondary coil determines the ratio of the incoming voltage to the outgoing voltage.\(^1\)

Figure 2: Inside a Transformer\(^3\)

After being stepped down to lower voltage levels, the electricity moves to feeder rows that are designated for their particular voltage levels. Feeder rows contain bus systems that serve the same function as the main bus; they distribute power and provide redundancy. Electricity exits the station from the feeder rows and then moves into neighborhoods either underground or via utility poles.\(^1\)

2.3.1 Levels of Redundancy

In order to prevent frequent and devastating power losses, redundancy is incorporated into substations. Redundancy allows sections of the system to fail without impacting the station, preventing many power outages. This is achieved by providing multiple paths for the electricity to travel so that if one path goes down, the electricity can still flow correctly. Substations can be designed to different levels of redundancy, allowing for a larger safety cushion in the design depending on the customer they are servicing. For example, airports and hospitals require great redundancy, whereas homes require less. The nomenclature for these levels is determined by how many lines in the station can fail before the station ceases to function. The N-1 configuration, which is most common for homes and standard businesses, allows for the failure of only one line. The N-2 design, used for airports, hospitals, and other important facilities, allows for the failure of two lines.\(^1\)

2.3.2 Types of Bus Systems

Bus systems provide a method of transportation for electricity and alter the direction of electric flow through the power grid. These systems can be designed in various configurations to enhance the reliability of the unit during failures. The designs connect the bus system in unique manners in order to provide alternative routes for electric flow. Each system possesses its own advantages and disadvantages and can be implemented depending on the circumstances. In systems that place the greatest importance on the reliability of the configuration for a complex system, N-2 designs are preferred over less redundant systems. The additional equipment required for higher redundancy increases costs, causing lower redundancy to be used to minimize expenses.

Figure 3: Circuit Diagram Notation

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\(^1\) Figure 2: Inside a Transformer

\(^3\) Figure 3: Circuit Diagram Notation
2.3.2.1 Straight Bus

The straight bus system, shown in Figure 4, is the most basic substation configuration; however, it is the least reliable in the event of system failure. Failure of a single circuit-breaker can lead to the outage of an entire substation if utilized alone. Therefore, these systems are commonly known as N-0 configurations. Due to their structure, multiple straight buses can be used. Switching between the systems allows each to be de-energized for maintenance. The straight bus system is advantageous in situations where the infrastructure is required to be compacted into a small plot of land. This simple design is also inexpensive and can be easily implemented and operated. In such circumstances, the straight bus is efficient and ideal for smaller substations.

Figure 4: Straight Bus

2.3.2.2 Sectionalized Bus

The sectionalized bus system is an effective extension of the straight bus system (Figure 5). This improvement primarily targets the main weakness of reliability present in the straight bus system. The sectionalized bus adds a connection through an additional circuit breaker in the center that can be normally opened or closed. This addition prevents the breakdown of the entire system in the event of a breaker failure, because an alternative path is available for the electricity to travel through. A bypass system similar to the one in the straight bus system can be implemented with the sectionalized bus configuration as well.

Figure 5: Sectionalized Bus

2.3.2.3 Breaker-and-a-Half

The breaker-and-a-half bus is a development that enhances the reliability of the system to that of the N-2 design, which allows the system to function despite the failure of any two components (Figure 6). There are three breakers for every two circuits present in the system, allowing the circuits to be independent of specific breakers. Thus, the components are easily removable for maintenance. The breaker-and-a-half configuration, however, is very expensive because of the additional components in the system. This further complicates the power grid with the addition of components beyond simple straight chain designs. Still, this design proves to be necessary in substations supplying crucial facilities, such as neighboring airports. The key advantage of maintaining an N-2 design is reducing the risk of consequences from breaker failures.

Figure 6: Breaker-and-a-Half

2.3.2.4 Ring Bus

The ring bus system is an advancement of the straight bus design (Figure 7). It provides a solution to the weak reliability of the straight bus design. The
ring bus configuration is an extension of the sectionalized bus system in which a sectionalizing breaker is added in between the two open ends of the bus system. This added section creates a closed loop on the bus, with each section separated by a single circuit breaker. This provides more reliability and flexibility by supplying an additional route of flow. Various designs of the ring bus can be implemented in the form of the breaker-and-a-half system.

Figure 7: Ring Bus

2.3.2.5 Double-Breaker Double-Bus

The double-breaker double-bus configuration primarily focuses on providing a solution to the straight bus system’s unreliability (Figure 8). The double bus does not require two units to alternate in its operation, but rather it can run continuously and maintain reliability due to its N-2 design. Similar to the breaker-and-a-half system, each of its circuits requires two breakers, rather than the one-and-a-half. The added reliability, however, comes at the cost of additional components and breakers, making the double-breaker double-bus configuration the most expensive and complex bus system to implement.

Figure 8: Double-Breaker Double-Bus

2.4 Gas-Insulated Switchgear vs. Air-Insulated Switchgear

High voltage lines present in substations create the risk of electricity travelling through the air and into the ground or to another wire. To prevent such an event from occurring, there are requirements for the minimum clearance between two wires. For example, the clearance required between two 138kV lines (the standard high voltage coming into a substation) is twelve feet, meaning that the three wires of a three phase 138kV line span over 24 feet. There are also great clearance requirements between transmission lines and the ground to prevent the same arcing, requiring substations to not only be wide, but tall as well.

In order to contain the large amount of space required between each wire, substations must be placed on large plots of land. However, the use of a new technology can greatly decrease the size of a substation. The implementation of gas-insulated technology allows the clearance between the infrastructural components to decrease substantially. Gas-insulated switchgear (GIS) insulates the wires with sulfur hexafluoride ($\text{SF}_6$) to compact them into six inch diameter tubes, preventing the arcing effect while taking up much less space. Sulfur hexafluoride possesses stronger dielectric properties than dry air, which is mainly composed of nitrogen. Safer and more compact structures introduce the possibility of implementing the system for indoor placement and allowing the system to be more resistant to air pollution and severe weather. Due to this resilience, GIS guarantees greater long-term operation.

3. The Substation Solution

Urban areas regularly struggle with the need for both power and parking. In Newark, New Jersey, 61.5% of the
population owns at least one car, meaning that Newark contains over 170,000 cars at any given time. The parking situation can be especially difficult in the busiest parts of the city, especially near the airport that the substation is supplying. The Newark Liberty Airport employs 24,000 people and services over 36 million passengers per year. With such heavy congestion, sufficient parking is an absolute necessity. Apart from airport traffic, additional parking is necessary to accommodate the growing population and to encourage economic growth for surrounding businesses. However, communities are often reluctant to approve parking garage plans because commercial initiatives are generally preferred. By addressing two necessities with one design, the chance of approval is drastically increased, cutting the excessive time and money required for approval.

By addressing the issues of the substation and parking in one design, space is efficiently utilized in a congested area. In order to best combine both aspects, the substation is located underneath a parking garage on one plot of land (Appendix A).

In order to encourage environmental efforts, solar panels are placed on top of the parking garage through the use of carport canopies that allow for cars to drive and park underneath. Additionally, electric vehicle charging stations are installed on the ground level in order to attract electric vehicle drivers.

Rather than having PSE&G manage both the substation and parking garage, the project benefits from a joint operation between PSE&G and a business in search of a parking facility. The parking garage, land, solar carports, and all substation facilities are owned by PSE&G to minimize legal conflicts should the substation require substantial maintenance. The garage, however, is not managed by PSE&G. Instead, it is leased to the other business that directly receives the revenue from the garage and is responsible for all parking operations.

Modeled in Autodesk Inventor, the proposed design includes a basement level for the substation and five levels of parking including the roof. Each floor measures 200’x150’. Due to variations such as handicap standards and solar canopies, the number of spaces per floor varies. The ground floor has space for 71 spots (Appendix B). In compliance with the Americans with Disabilities Act (ADA), the first floor contains eight handicap parking spaces, including two van-accessible spaces with designated loading areas that are depicted with blue stripes. Additionally, five electric vehicle charging stations are incorporated, with the potential to incorporate more charging stations in the future should the demand increase. The next three floors have space for 78 parking spaces (Appendix C). The roof has space for 59 parking spots covered by solar canopies for a total of 364 parking spots (Appendix D). The design also includes six bike racks placed outside of the garage. The racks allow seven bikes each and bring the total bike parking capacity to 42 bicycles. This number meets and exceeds even the strict standards of New York City, which represents a bike-friendly urban area.

The garage has a minimum floor to ceiling clearance of ten feet throughout the entire structure. Two ramps go across each floor for the length of the parking garage, and each ramp rises a total of five feet. Each floor rises at an angle of 2.86 degrees except for the first floor, rises at a 5.19 degree angle in order to compensate for the flat ground floor. Each floor falls within the recommended incline of 6.67 degrees.

3.1 Substation Design

The step-down, underground substation design involves the decrease of voltage in electricity that flows through a
Incoming transmission lines enter the main breaker-and-a-half bus system in three phases. Two of the lines currently serve as circuits, while the third line will be implemented when the demand for electricity increases. The electricity moves through the bus system, where sets of three transmission lines transmit the electric flow to the three transformers. After reaching the transformers, the current is stepped down from 138kV to two distinct lower levels. The electricity transfers to two separate feeder rows, where each of these components carries a different voltage level depending on the area to which the electricity is transmitted. In particular, one section carries 26kV power to the neighboring Newark Liberty Airport, while the other carries 13kV to the local community. After reaching their particular feeders, the electricity exits the substation through transmission lines in the form of three phase power to their designated locations.

3.2 Transformers
Underground substations require at least 20 feet of clearance for the transformers, whose dimensions are 15’x20’x15’. The transformers are stored on the basement level toward the rightmost 50’ of the building and require five feet of clearance from the ceiling. Because the ground floor slopes upward, the basement clearance increases going from the left to the right of the garage, providing the transformers with enough room to operate. In a busy urban area, the equipment must be easily accessed for maintenance, replacement, and emergencies. Therefore, a 25’x30’ access hatch is introduced outside along the right side of the garage to access the transformers. This access hatch is located in the center of the 150’ wall of the garage that is closest to the 20’ clearance region. To remove the transformers, pre-installed rubber tracks mobilize the transformers from their locations into this access hatch; then, a crane pulls the transformers up to the surface (Figure 9).

The 150’ width along the basement wall provides adequate space for five transformer spaces and a movement contraption. Transformers A and C are located in each of the two corners along the wall, while transformer B sits next to one of the others along the wall (Figure 9). Should transformer A need to be removed, transformer B can be moved into the space in front of transformer C, allowing transformer A to be moved into the access hatch for removal. Transformers B and C can be moved more easily because they have no obstructions. The transformers do not suffer from flood damage unless the control equipment or the tops are submerged underwater. Therefore, the transformers’ controls are sealed in a watertight compartment inside the control room.

To address the stability of the underground transformer region, a distance of 30’ from the wall is consistent along the right portion of the structure, allowing columns to be placed at least 30’ from the wall. This distance allows for the normal placement of columns, meaning that the building remains structurally sound and only
requires the possible placement of more columns to make up for the increased clearance.

Compared to the alternate option of an entirely underground transformer setup, using an inclined first floor slope is more beneficial than digging two full levels underground. In the latter option, an additional five feet into the ground immensely increases the risk of flooding. Using the slope of the first floor provides a more efficient and cost-effective way to implement the substation. Having two levels of underground space requires unnecessary construction that would not provide a return on investment.

3.3 Comparison between Oil and Gas Transformers

In a standard aboveground substation, transformers are insulated by mineral oil in order to dissipate the heat that is produced, which also separates the transformers from other electrical components. However, this design is dangerous because a rupture in the transformer can lead to a massive oil leak. To prevent oil leaks from causing environmental or mechanical damage, a large oil-holding chamber must be constructed beneath the transformer to collect any leaking oil. This chamber is not an issue for an aboveground design, but it is a source of major problems underground. A transformer contains approximately 2,700 cubic feet of oil, meaning that the chamber underneath must be able capture the same amount of oil.\(^1\)

The chamber’s dimensions must be at least 15’x20’x9’ in order to accommodate the oil. By constructing three chambers for the transformers, the floor reaches almost three stories underground. Digging deeper into the ground increases the risk of flooding as well as the cost of construction. The further into the ground the structure extends, the closer it approaches the groundwater level, therefore increasing the risk of flooding compared to that of the ground level. Furthermore, evacuated oil cannot reside in flooded chambers, which is a major concern for the safety of the complex.

Instead of oil-insulated transformers, gas-insulated transformers are used in the design.\(^1\) The gas sulfur hexafluoride (SF\(_6\)) serves the same purpose as mineral oil: it insulates the transformers.\(^1\) However, it does not require an emergency chamber for leaks. Because SF\(_6\) has a higher density than air, a potential leak results in the gas settling on the bottom of the substation, allowing SF\(_6\) to be easily cleaned and the equipment repaired before any damage is done. Gas-insulated transformers are approximately the same size as oil-insulated models; therefore, there are no additional costs or changes to the structure’s layout. Because of their benefits, gas-insulated transformers are used.

3.4 Disconnecting Circuit Breakers

The traditional arrangement of disconnects and circuit breakers requires three separate parts to function: two disconnects and one breaker. It also occupies a large amount of space. However, the function and structure of both parts can be combined into one component in order to save space by using disconnecting-circuit breakers (DCBs).\(^1\) The DCBs effectively decrease the size of the substation equipment while increasing the efficiency of the system through its compilation of various functions. They also reduce maintenance requirements by 76%, rendering underground substations more cost and labor efficient.\(^1\) The implementation of these circuit breakers along with the GIS technology can successfully convert the traditional substation design into a compact layout best suited for contemporary design and spatial limitations in urban areas.
3.5 Solar Panels

In order to provide a more environmentally friendly alternative to provide energy, solar panels are placed on the roof of the garage in a carport canopy setup. Rather than constructing a normal roof that cannot be used for parking, solar panels on a carport canopy can help to maximize the usefulness of the garage. By mounting columns and beams between the parking spaces, solar panels can be placed across the entire rooftop, allowing for both parking and the use of solar power. There are two main designs for the structure of the canopies: two-column and louvered. In the two-column designs, the panels tilt towards the south, parallel to the spaces. In the louvered design the panels also face the south, but they are perpendicular to the parking spots (Figure 10). For this specific parking garage, using louvered frames across the entire roof maximizes the land’s efficiency.

By placing louvered style frames above the parking spots that face east and west, the perpendicularly placed panels can face towards the south, the most efficient setup. Because New Jersey is in the Northern Hemisphere, the sun’s path across the sky is to the south. Thus, panels that tilt southward receive a more direct line of sunlight than panels tilted northward. A multi-lane louvered design, created by carport canopies, allows for two lanes of cars to drive underneath the frames while also creating adequate space to park. This design is used atop the spaces that face north and south, allowing the empty space between spots to be utilized without obstructing any movement.

Figure 10: Solar Carports

3.6 Solar Profitability

The cost of the solar project can be determined by the number of kilowatts produced. Using the ET-P672280 solar panels in the design, the entire solar field produces about 190.7 kW annually with an estimated cost of $3,500 per kW. This makes the total cost to come out to approximately $667,450. However, PSE&G receives 30% of the cost of the solar project from the government in the form of a green energy investment tax break, reducing the cost of construction and cost of the project down to $467,215.

In order to calculate the amount of time it will take for the solar investment to break even, the annual revenue from the solar panels must first be calculated. The PVWatts cost calculator utilizes the DC rating, DC to AC derate factor, array tilt, and array azimuth, or east-west orientation, of this solar project to calculate the energy output and revenue. The number of panels installed in the array and the size of those panels determines the DC rating of the system, which is 190.7 kW. The DC to AC derate factor accounts for the power lost when switching from DC to AC power, which depends on the construction of the panels, the panel manufacturers, and the power company installing them. For this parking garage, this factor has a value of 0.83 for PSE&G’s technology, meaning that only 17% of the power is lost when converting DC to AC. The setup of the panels determines the tilt and azimuth of the array in order to maximize the production of
the array, with a tilt of 12° and azimuth of 196° in this project.\textsuperscript{16} PVWatts calculated an annual energy production total of 227,886 kWh. From this, the revenue of the solar panels can be calculated.\textsuperscript{17}

Given a market value of $50 per megawatt hour (MWh) from the sale of electricity for PSE&G, the revenue from the solar panels can be calculated with the total energy output.\textsuperscript{16} By converting 227,886 kWh to 227.886 MWh and multiplying by $50, the energy sale revenue comes out to be $11,394 per year. In order to further repay the total cost of the solar project, PSE&G can utilize revenue from the sale of the solar energy and the sale of Solar Renewable Energy Certificates (SRECs), which are obtained from the government by producing solar power.\textsuperscript{14} Power companies that do not produce government-required amounts of green energy buy SRECs in order to financially support the green movement. The number of SRECs produced is determined by the output of the solar grid; 1 SREC is earned for the production of 1 MWh. Producing 228 MWh annually will result with 228 SRECs, after truncation of the value each month. Using an assumed value of $180 per SREC, PSE&G will receive about $40,500 per year from the sale of the SRECs.

Summing the solar credits and sale of energy from the panels, PSE&G will receive $51,894 per year to help repay the cost of the project. By dividing the total cost by the annual revenue to calculate the length of time needed to break even, the project will create a return on investment in 9.00 years.

$$T = \frac{\$467,215}{\$51,894} = 9.00$$

Given that PSE&G is a utility company that often employs projects that take years to break even, this solar project is not out of the usual for an energy investment.

3.7 Electric Vehicle Charging Stations

The parking garage plan includes five charging stations for electric vehicles (EVs), plus wiring for an additional five stations that can be added in the future. There are two types of chargers: “smart” chargers and “dumb” chargers. “Smart” chargers collect data on the chargers’ usage and send information to the vendor. Customers pay for electricity using a special credit card. “Dumb” chargers are simpler because customers simply plug the charger into their cars and begin charging. This can be attractive to paid lots or parking garages where electric vehicle parking fees are slightly higher in order to offset electricity costs. “Dumb” chargers are both smaller and less expensive than “smart” chargers. They do not require as much installation, as they are hung from the wall as opposed to being ground-mounted like “smart” chargers are.\textsuperscript{18}

This parking garage contains five “dumb” chargers. The specific model, Clipper Creek’s LCS-25, is a Level 2 charger, meaning that it provides 10 to 20 miles of range for each hour of charging.\textsuperscript{19} The other charging levels, Level 1 and DC Fast, are either inefficient or incompatible for American EV chargers. A Level 1 charger is very slow, providing only 2 to 5 miles of range per hour of charging, so it is typically used only in homes for overnight charging. DC Fast Charging is the fastest charging rate, giving 60 to 80 miles of range in 20 minutes of charging.\textsuperscript{20} Although DC Fast is significantly faster than Level 2, it is much more expensive than the Level 2 model. Also, not all EVs can utilize DC Fast, because it uses a CHAdeMO model charger, which is used frequently in Japan and rarely in the US.\textsuperscript{21}

The Clipper Creek LCS-25 uses the SAE-J1772 connector, which is used much more commonly in the US.\textsuperscript{21} The LCS-25 is one of the most
economical chargers, costing only $650 plus $1,000 for installation per unit, bringing the cost of five chargers plus five extra wiring setups to $13,250. The Blink Pedestal Charger, the “smart” model, costs $3,145 per charger plus $10,000 in installation costs, bringing the total cost to $25,725 (Table 1). The LCS-25 is also the smallest Level 2 unit in the industry, having a size of 11”x4”x3”, and weighing only nine pounds.

Table 1

<table>
<thead>
<tr>
<th>Name</th>
<th>Clipper Creek LCS-25</th>
<th>Blink Pedestal Charger</th>
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<tr>
<td>Type</td>
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<td>“Smart” Level 2</td>
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<tr>
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<tr>
<td>Total Cost (5 chargers)</td>
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<td>$25,725</td>
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An active charger uses five Kilowatts (kW)/hour. The consumer value of one Kilowatt Hour (kWh) is about 11 cents, bringing the consumer value of each hour of charging to about 55 cents. In the parking garage, vehicle owners are charged one dollar per hour of charging. This produces a profit of 45 cents per hour of charging. In order to enforce the parking fees associated with the charging stations, the chargers are located in designated EV parking spaces. Therefore, EV owners wishing to charge their cars must buy an EV charging ticket as well as pay their parking fee. This ticket must be displayed in the car window while the vehicle is charging and must be surrendered upon exiting the garage. At this time, the vehicle owner is charged one dollar for each hour of parking. New Jersey law prohibits the reselling of power; the parking lot owner cannot directly sell the electricity from the chargers for additional revenue. However, the ticket system skirts this issue because the driver is paying for parking in an EV space, not for the charging itself.

3.8 Flooding Danger

In order to address the risk of flooding, the control room of the substation must be kept out of reach of any potential flood levels. To prevent water damage, the control room is separated from the other parts of the substation and placed above ground near the access hatch. It rests on a 5’ high cement foundation in a 25’x35’ space, eliminating the risk of flooding and allowing the substation to function normally during storms. The control room occupies otherwise wasted space and allows for more parking spots inside the garage. Because it is located outside, the control room has no height restrictions. Still, the room does not require more than 10 feet of clearance.

Although the rest of the substation is not susceptible to water damage, having water in the station is detrimental to maintenance efforts. For this reason, the entire basement level containing the substation is surrounded by a concrete flood barrier that effectively keeps water out.

4. Results and Discussion

4.1 Total Cost of Project

The average cost of constructing a parking garage in an urban area is about $20,000 per parking spot. For 364 parking spots, the total cost of the parking portion of the project is approximately $7.28 million. The average cost of one floor is $1.46 million, which can help to estimate the cost
of constructing the underground level. Considering that digging further into the ground costs more in labor and capital, the basement’s cost should be higher than that of an aboveground floor. Increasing the cost from the average value to account for the larger clearance of the basement leads to an estimate of around $2 million for PSE&G to construct the basement level.

In order to calculate the cost of excavation, an online excavation cost calculator was used that adds up the labor costs, disposal costs, and equipment costs, with each rate unique to Newark, NJ. After inputting the total excavation amount of 16,667 cubic yards of dirt, the expected cost for excavation is about $2.1 million, which is a part of the substation construction cost. Based on previous substation costs for PSE&G of around $60-70 million, PSE&G would pay even more for the substation with the addition of newer variables such as excavation and underground construction. After adding in those two expenditures along with a state tax of 7%, the actual cost range is closer to $67-77 million.1

There are several more costs associated with the construction of the building and substation, but they are small enough to be omitted for the purpose of calculating an estimate. The main costs, such as construction cost, material cost, and labor cost, have been calculated and accounted for. Many other hidden costs would be calculated as the project commences, which means that the actual cost should lay in the higher end of the cost spectrum.

4.2 Profitability

To calculate how long it would take for PSE&G break even from the parking garage project, the parking ticket price must be determined along with the anticipated daily customer quantity in the garage. After researching the prices of many different parking garages in Newark, NJ, the determined price is about $15 for a day of parking. In order to benefit both PSE&G and a potential parking garage company, the company will pay a monthly lease payment to PSE&G in order to utilize the space for parking services. Equations can be set up based on the company’s profit margin to determine the best price for the lease.

Keeping a constant profit margin for the parking company will maximize PSE&G’s revenue from the project. Using a profit margin of 5%, an equation can be set up that relates the occupancy with the lease payments when the cost and maintenance are constant. In the equation, the value 364 represents the number of spots and the value 365 represents the number of days in a year.

\[
p = \text{profit margin} = 0.05 \\
C = \text{cost per spot (daily)} = 15 \\
M = \text{maintenance cost per spot} = 650 \\
P = \text{average percent occupancy (decimal)} \\
R = \text{monthly lease per spot} \\
T = \text{time to profit}
\]

After simplifying the constants in the equation, a linear function relating occupancy and lease payments appears. Using a preliminary occupancy value can help to determine the best value for the lease that suits both PSE&G’s profit margin and the goals of the parking garage company.

\[
R = 434.56 \times P - 54.17
\]

Using an anticipated occupancy value of 75%, the expected monthly lease comes out to $272 per spot each month. To determine the length of time that PSE&G must wait to break even on the project, the cost of the garage is divided by the total revenue. The revenue for PSE&G comes from the lease agreement with the parking garage company.
The breakeven point for PSE&G will occur after 6.1 years, a relatively short time for the parking garage. If the occupancy of the garage differs from the anticipated value, PSE&G will maintain the same profit timeline. The parking garage company, however, will see changes in its profit margins from the estimated 5%.

5. Conclusions

The continuing growth of both the demand for power and the population in New Jersey requires that utility companies invest more in their infrastructure. Because space for substations is gradually diminishing, new substation designs are needed in order to adapt to limited space. Through the research and design that led to the parking garage concept, the idea that a substation can be condensed and placed underground allows for more innovation in substation design.

Through the financial analysis of the different components of this project, the investment margins of the solar panels and the parking garage itself provide belief that this project may eventually come to completion, even though there is no precedent. The thoroughly designed garage shows that several different ideas can be combined into one system; providing a necessary substation, creating parking where needed, and implementing green energy are all intertwined in this garage.

Although much has been accomplished, this project has not yet reached its maximum potential. Many additional steps can be taken to bring the parking garage design from a possibility to a reality. First, a specific lot of land must be selected based on cost, demand, soil conditions, zoning laws, and proximity to the airport. Next, the specifics of the design must be completely finalized. These include the exact structure of the garage, lighting, paving, staffing, wiring, drainage, and ticket machines. PSE&G must also negotiate with a parking company for the lease of the parking garage. Finally, the exact construction cost must be obtained, and a full, in depth cost analysis must be run to determine the financial effect of this project on each group involved.

6. Acknowledgements

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Appendices

Appendix A

Appendix B
References

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