

An Energy Garden

For Commercial Centers

Capstone Project

May 6th, 2014

Steven Grobelny

Anthony Phillips

Michael Ruiz

Hardik Rana

Shirley Davila

Abstract

The focus of the project is to make the most out of solar energy with storage and local generation. There are about 18,000 individual generators at about 6,000 operational power plants in the United States. Power plants today rely mainly on coal, nuclear, natural gas, hydroelectric, wind generators, petroleum, and a small amount rely on solar. The United States' primary source of energy is fuel use. Fossil fuels are a limited source that will soon run out with the usage of electricity rising. Not only are they a threatened source but the cost of labor and materials are high. Along, with the direct costs, they also cause pollution because of the emissions that the burning of coal and oil produce. Solar energy is a resource that the United States needs to take advantage. Our goal in our capstone is to help the solar initiative in the United States. We have designed a "solar garden" solution to allow the sharing of renewable power in a small commercial center in Piscataway, NJ. Designing the energy garden for this commercial center was a challenge because some stores were not willing to share their confidential information such as energy and utility bills. We have tried to be as accurate as possible by estimating the costs by separating the items that use electricity into two categories. Some items have been categorized as critical and others as non-critical. Critical meaning that it is a vital part of the stores income.

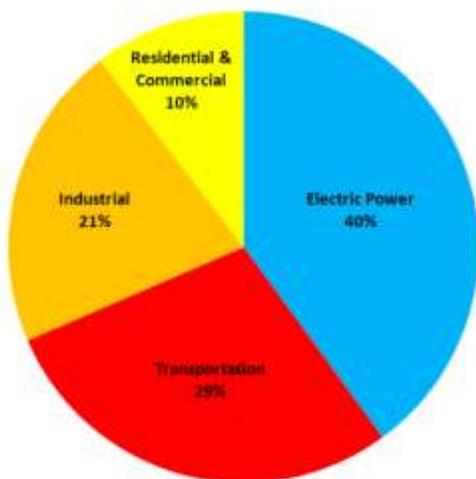
We have designed an efficient photovoltaic system which produces optimum results with minimum costs on the roofs of two large stores in a commercial center. These two stores are Walmart and Sports Authority. The square footage of these two roofs is ample enough to sustain 7,536 photovoltaic panels. Our calculations have shown that this will provide the commercial center with 3,278,160 Watts for storage. Along with choosing the amount of panels per roof, we have chosen the most productive tilt orientation for the panel. We have chosen an angle of 10

degrees for each photovoltaic unit to have. The reason why the panels are almost flat is because Walmart and Sports Authority both have a South East direction to the sun and the roofs themselves are very flat. This will provide the solar panels with optimal sunlight.

1. Introduction and Motivation

For the capstone project it was decided to make the most out of renewable energy with storage and local generation via commercial application. The project included the design a renewable energy based system, including storage, for a local commercial business that will address both normal operations and emergency situations. The system will support energy cost reduction and carbon footprint minimization during normal operation times. In the event of an emergency, such as the Sandy mega storm, the system will supply the commercial center with the energy required to keep critical loads, i.e. refrigerators, lighting, computers, communication, etc., up and running. We decided to title this project “An Energy Garden for Commercial Centers”. Here are a few facts that may not be known or acknowledged by the average United States citizen. The United States was the 2nd largest energy consumer in terms of total use in 2010. The United States ranks seventh in energy consumption per-capita after Canada and a number of small nations. Not included is the significant amount of energy used

**US Energy Consumption
by Sector, 2007**

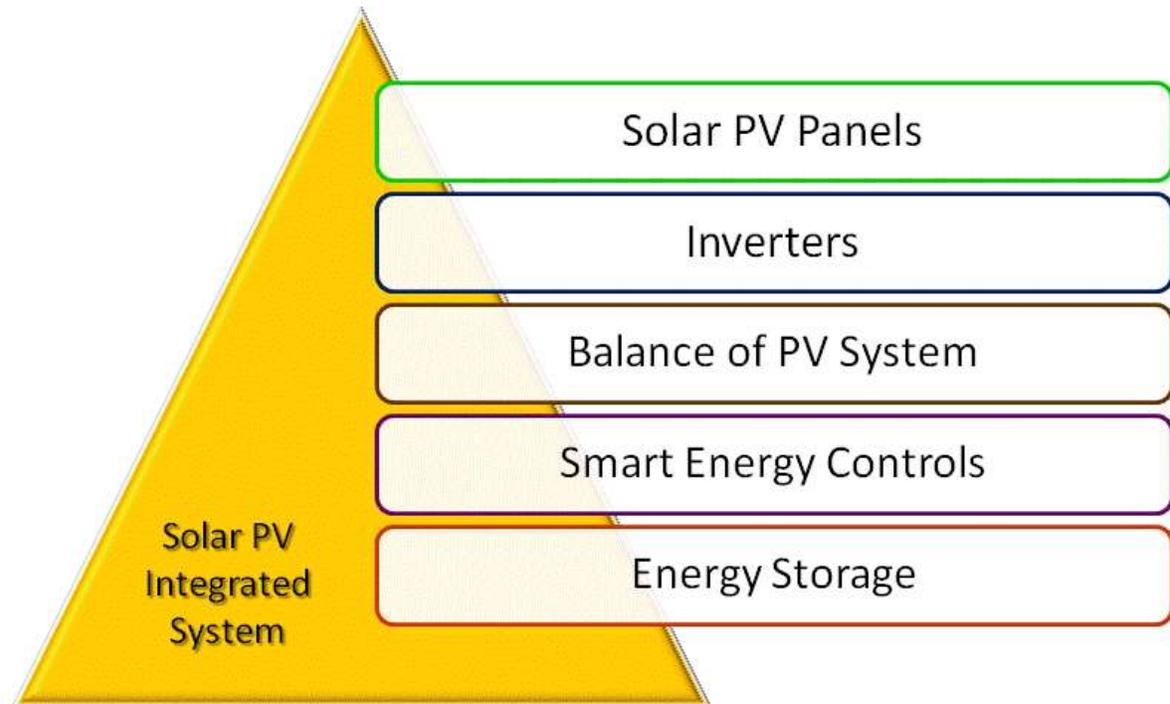


Data source: US Energy Information Administration

overseas in the production of retail and industrial goods consumed in the United States. The majority of this energy is derived from fossil fuel: in 2010, data showed 25% of the nation's energy came from petroleum, 22% from coal, and 22% from natural gas. Nuclear power supplied 8.4% and renewable energy only supplied a sorrowful 8%, which was mainly from hydroelectric

dams but also included other renewable sources such as wind power, geothermal and solar energy. Energy consumption has increased at a faster rate than domestic energy production over the last fifty years in the U.S. and fifty years ago they were roughly equal. This difference is now largely met through imports. So basically the point here is that the United States is a world leader when it comes to energy consumption but drastically falls short when it comes to utilizing renewable energy.

There are approximately 109,500 shopping centers in the United States ranging in size from the small convenience centers to the large super-regional malls. And we hope for this great idea of ours to be accepted and implemented for a huge push for renewable energy use in the United States. Ideally our whole project process would be to approach a commercial center with the objective to have the center's energy being provided by a somewhat hybrid system where at a point it'll be utilizing a form of renewable energy and at another point it'll be consuming energy directly from the local utility company as usual. A team would come to the site of the commercial center and check out and analyze all of the relevant characteristics of the site and from that, we would conclude what the renewable energy garden would be composed of. Whether the renewable energy would be composed of Photovoltaic Panels, Wind Turbines or Fuel Cells. Based on the characteristic of our site which is Centennial Square which sits at 1297 Centennial Avenue, Piscataway Township, New Jersey 08854 and the time permitted to complete our design, we found it optimal to go mainly with the Photovoltaic Panels. Also with Centennial Square being a plaza like complex we would have the cost of our system to be shared by the owners of the associated organizations.



Not only will this help our country go green but our system can be energy independent when the time comes. It also will be compatible with an intelligent power grid. We plan on this system having power stability and independence. The system will produce sufficient for owner's self-consumption independently. Users can be free from interruptions due to cutoffs or blackouts frequently experienced in traditional utility power supply.

2. Review of Photovoltaic (PV) Systems

When people think about solar energy, the first thought that comes to people's minds is solar photovoltaic (PV) Panels. Photovoltaic is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, we obtain electric current results that can be used as electricity. It is believed that enough sunlight falls on the Earth in one hour, to meet the world's energy demand for a year, if it could be collected. We have yet to collect all of this free, vast energy, but we are making

great strides and are on the right track.

Since the beginning of 2011, the average price of a completed PV system has dropped by 33%. Solar is the subject of a great deal of research, so we should expect many breakthroughs sometime in the near future, including things like nano-pillars to lower cost, concentrators to reduce the area required, and more efficient and powerful cells, to reduce both. PV research at the National Renewable Energy Laboratory (NREL), ran by the U.S Department of Energy, has been focusing on boosting solar cell conversion efficiency, lowering the cost of solar cells, modules, and systems, and improving the reliability of PV in any aspect possible. Most solar PV systems today are either made from traditional silicon-based solar cells, or the newer thin-film technology.

Solar PV systems produce DC current, which can be used with DC appliances or converted to AC with the use of an inverter. Many of today's electronics run on DC, which requires those little power supplies that plug into the wall which convert the AC to DC. This could be an opportunity in the future to power these devices directly from solar PV, eliminating the efficiency losses that occur when converting from DC to AC and then back again.

There are many advantages to using photovoltaic systems. Solar energy is considered environmentally friendly because the sun is a natural energy source that does not require the burning of fossil fuels and associated air emissions, reducing the "greenhouse effect". It is considered renewable since the energy produced from the sun does not deplete any natural resources (it never runs out). Also, PV panels require minimum operating and maintenance costs; simply performing some regular cleaning of the panel surface is enough to keep them operating at a high efficiency level.

PV systems can be used as either stand-alone systems or grid-connected systems. The

responsibility of photovoltaics differs greatly in these two types of systems, and the design decisions and performance requirements are very different as well. All of these they of factor were taken into consideration while designing our Solar Garden. Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads. These types of systems may be powered by a PV array only, or may use wind, an engine-generator or utility power as a secondary power source in what is called a PV-hybrid system. The simplest type of stand-alone PV system is a direct-coupled system, where the DC output of a PV module or array is directly connected to a DC load. Since there is no electrical energy storage such as batteries in direct-coupled systems, the load only operates during sunlight hours, making these designs suitable for common applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems. Matching the impedance of the electrical load to the maximum power output of the PV array is a critical part of designing well-performing direct-coupled system. When it comes to the Stand-alone system, it is the batteries that require the most maintenance.

Grid-connected systems are designed to operate in parallel with and interconnected with the electric utility grid. The primary component in grid-connected PV systems is the inverter, or power conditioning unit (PCU). The PCU converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized. A bi-directional interface is made between the PV system AC output circuits and the electric utility network, typically at an on-site distribution panel or service entrance. This allows the AC power produced by the PV system to either supply on-site electrical loads or to back-feed the

grid when the PV system output is greater than the on-site load demand. At night and during other periods when the electrical loads are greater than the PV system output, the balance of power required by the loads is received from the electric utility. This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed back into the utility grid when the grid is down for service or repair.

Unfortunately, solar energy is an intermittent source. It is not always available because of cloudy weather or rain. This is why many systems are designed to store energy, or have a backup source of energy such as the electric grid. These additional features are crucial to the end user to continue operation and what proves a system to be efficient during all times of use. In order for us to design and create such a system we had to start at the basics.

3. System Design and Objectives

We started off designing an efficient photovoltaic system which produces optimum results with minimum costs on the roofs of two large stores in a commercial center. These two stores are Walmart and Sports Authority. The square footage of these two roofs are ample enough to sustain 7,536 photovoltaic panels. Our calculations have shown that this will provide the commercial center with 3,278,160 Watts for storage. Along with choosing the amount of panels per roof, we have chosen the most productive tilt orientation for the panel. We have chosen an angle of 10 degrees for each photovoltaic unit to have. The reason why the panels are almost flat is because Walmart and Sports Authority both have a South East direction to the sun and the roofs they are very flat. This will provide the solar panels with optimal sunlight. In order to design our system, we needed to estimate the size using a variety of tools and methods.

The initial stage was to find out the square footage of each roof where we would

be placing the photovoltaic panels. The commercial center we chose is located in 1303 Centennial Ave, Piscataway Township, NJ 08854. This commercial center contains 18 stores. We decided to place the photovoltaic on Walmart and Sports Authority. The reasoning behind this decision was made by finding the square footage of each store using the Google Earth online tool. The square footage was 146,500 and 42,700 for Walmart and Sports Authority, respectively.



In order to provide solar power to Centennial Square, we decided to place Photovoltaic panels on Walmart and Sports Authority/Panera Bread.

We calculated the number of panels that would fit on each roof by using the dimensions given to us on the spec sheet of the Sun Power E20-435 photovoltaic unit. We calculated that the amount of panels needed would be 7,536 which would provide the commercial center with 3,278,160 Watts. The panel model we chose was the Sun Power E20-435 photovoltaic unit which would be placed at an angle of 10 degrees. The angle of 10 degrees would provide the most sunlight for optimal power generation for this specific location.

An issue we ran across was that there were obstructions on both of the roofs. These obstructions include HVAC systems which are located on the roof that would cause shadowing. We had to make sure that these obstructions were taken into account by estimating the size of

each obstruction and calculating the shadow of each. We divided the needs of each store by separating their energy usage into critical and non-critical power. The information we needed was the total load, total power per square meter, and the critical and non-critical power. The total load consisted of the heating, cooling, electronics, lighting and other miscellaneous power usage. After finding the usage of both these stores, we continued to find the power consumptions made by the other stores. Our project was aimed to work as an energy garden for a commercial center therefore this proposed solar “garden” would be located on the main two stores which would then provide the other stores with their energy needs.

Now that we have configured our methods of renewable energy specific to the chosen location, we can begin to design the “garden” and construct our system. When designing the Energy Garden, it was also decided to implement a Microgrid/Battery Backup system that would be used for emergency conditions in the event of a failure within the power grid. Microgrids have become a very feasible and efficient part of Smart Grid technology that could many could, and have, benefited from. The Microgrid is an electricity distribution system that contains different loads and energy resources. It has the ability to not only be connected to the Power Grid, but also can act as its own grid, generating its own power from the loads it consists of. While the Microgrid can act on its own, it is required to function both grid connected and islanded. The microgrid may consist of different energy resources, such as Photovoltaic panels and fuel cells. It may even consist of non-renewable energy resources, such as generators and batteries. There are even cases where it is designed to consist of a combination of the two, such as the design that was chosen for this Energy Garden.

For the Microgrid designed, battery backup and PV systems were chosen as the energy resources needed to implement the Energy garden. A battery backup system can vary based off of

different elements and components that are required to be considered when including it within a Microgrid. Some features include amp-hour capacity, voltage, and depth of discharge within the average battery. These features are important not only because they allow us to determine the capacity that the system may require in order to store energy in them, but also due to the fact that it allows us to determine that rate and amount that the batteries will discharge over a certain period of time. Knowing this is crucial to designing a microgrid with a battery backup system and having a sufficient amount of batteries to store the energy into in case of emergencies.

When sizing the amount of the battery backup system, the first factor that was required was the amount of energy (in watt-hours) in the PV system that was required per day. This was done during the sizing of the PV system, which is explained the prior sections. The amount of energy required in the PV system per day resulted in 10539.98512 Watt-hours/day. With this amount, the energy obtained after the battery loss was calculated using the following formula:

$$\frac{\textit{Total Watt-hours per day}}{\textit{Battery Average Efficiency}} = \textit{Energy Obtained after Battery Loss}$$

With the average battery efficiency being 85%, the resulting energy of battery loss was 12399.98249 Watt-hours per day. After this calculation, the energy obtained after the battery discharged was also calculated with the formula shown below:

$$\frac{\textit{Energy obtained after battery}}{\textit{Depth of Discharge}} = \textit{Energy obtained after battery discharges}$$

Since the depth of discharge came at 60%, the resulting energy calculated came out to be 20666.63749 Watt-hours per day.

After finding the energy obtained after the depth of discharge, the battery capacity was then obtained using the following formula below:

$$\frac{\text{Energy after Battery discharge}}{\text{Desired Battery Voltage for System}}$$

$$= \text{Battery Capacity before days of Autonomy}$$

In order to obtain this result, the desired voltage for the system also needed to be determined. Since the desire was to obtain the desired power with the minimum amount of batteries possible, it was decided to use a desired battery voltage of 48 Volts. Incorporating this into our battery capacity calculation, 430.554947 Amp-hours per day were calculated. Since the average days of autonomy in New Jersey was not included in this calculation, one more calculation need to be done in order to obtain our required battery capacity for the system, which is described with this formula:

$$\text{Battery Capacity before days autonomy} * \text{Days of autonomy}$$

$$= \text{Required Battery Capacity}$$

Using 3 days of average autonomy, the required battery capacity for the system resulted in being 1291.664843, or 1292, Amp-hours.

With the required battery capacity obtained and our desired battery voltage desired, the number of batteries in the microgrid system was finally determined. In order to accomplish this, however, a specific battery needed to be determined in order to sufficiently obtain a small quantity of batteries. After thorough research, it was decided to use 12Volt, 250 Amp-Hour MK Battery. The specifications are listed below:

SPECIFICATIONS

| | |
|---------------------|-----------------------------|
| Nominal Voltage (V) | 12V |
| Capacity at C/100 | 250Ah |
| Capacity at C/20 | 245Ah |
| Weight | 161 lbs. (73 kg) |
| Plate Alloy | Lead Calcium |
| Posts | Forged Terminals & Bushings |
| Container/Cover | Polypropylene |

Valve-Regulated, Absorbed Glass Mat Technology



With the specifications, the following formulas were used in order to obtain the number of batteries in parallel and in series:

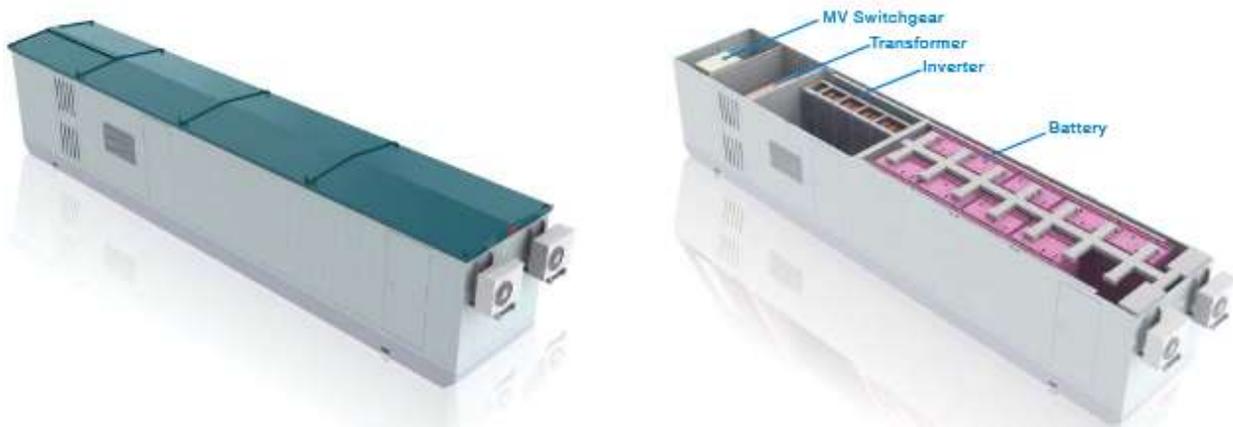
$$\text{Batteries in series} = \frac{\text{Desired Battery Voltage}}{\text{Given Battery Voltage}}$$

$$\text{Batteries in parallel} = \frac{\text{Required Battery Capacity}}{\text{Given Battery Capacity}}$$

The resulting batteries in series were calculating to be 4 batteries in series, and the batteries in parallel were calculated to be 5 batteries. By multiplying these batteries together, the total amount of batteries required to power the micro grid was 20 Batteries, which is described below:

$$\text{Total \# of Batteries}[20] = \text{Batteries in series}[4] * \text{Batteries in parallel}[5]$$

In order to incorporate the batteries into the micro grid, it was required to obtain two energy storage modules (ESS Modules) which have the ability to power up to an 8 MWatt system. This was precisely what was necessary to complete our Microgrid Storage design. An illustration of the modules is shown below:



4. Conclusion

Based on our calculations, the system we have created proves to be efficient and cost effective for this commercial center and can be done for all shopping centers across the United

States. Depending on location and conditions we can create energy gardens, consisting of different types of renewable resources, it is possible to create a system that is even more efficient!

Showing the realization of these Energy Gardens and their capabilities creates hope of starting a chain-reaction of renewable energy resources in our country. As stated earlier, United States is the 2nd largest energy consumer in terms of total use. This leaves lots of room for improvement as well as a safer, healthier lifestyle for America. It's only a matter of taking the next step and implementing it. We are confident that with these facts, Energy Gardens have a great chance of growing and one day becoming a main source of energy for the entire world.

5. References

http://rredc.nrel.gov/solar/calculators/pvwatts/version1/version1_index.html

http://www.sissolarventures.com/PV_Systems.php

<http://www.susdesign.com/sunangle/>

<http://americanhistory.si.edu/fuelcells/basics.htm>

http://www.leonics.com/support/article2_12j/articles2_12j_en.php

<http://www.solarchoice.net.au/blog/which-solar-panel-type-best-suits-your-needs-monocrystalline-polycrystalline-or-amorphous-thin-film/>

http://www.facebook.com/l.php?u=http%3A%2F%2Fwww.fsec.ucf.edu%2Fen%2Fconsumer%2Fsolar_electricity%2Fbasics%2Fhow_pv_system_works.htm&h=PAQG7P2kr