Solar Photovoltaic Array Design: A Multidisciplinary Constructed Project for Haiti

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Abstract

Designing a solution to a problem for use internationally, particularly for impoverished locations, presents challenges beyond the norms of what would be expected for the exact same project under circumstances typical for the US. Almost a year ago, West Indies Self Help, also known as WISH, approached Ohio Northern University looking for a design of a solar photovoltaic array which would be built in La Gonave, Haiti. Upon completion of the design the system will provide power to the WISH guesthouse, medical facilities and a number of other buildings under WISH's supervision. This paper explores the design process used by our team to reach a viable design, the unique challenges that must be overcome when working in impoverished and international locations, and some of the experiences gained from the team members throughout the process. Two main disciplines, civil and electrical engineering senior students, worked together to create a final solar array design, and the technical aspects of this paper reflect those two areas.

Introduction

In fall the of 2012, Frank Illingworth, an alumnus of Ohio Northern University (ONU) approached the T.J. Smull College of Engineering with a request as a representative of the West Indies Self Help (WISH) mission organization and their efforts in Anse-a-Galets, Haiti. Anse-a-Galets is a city of about 40,000 people on the island of La Gonave, northwest off the coast from Port-au-Prince. WISH had an interest in determining the feasibility of building a solar photovoltaic energy system on the island to reduce their dependency on the costly diesel fuel which was their only source of power generation. Illingworth initially approached the college asking if there might be interest from students in doing this feasibility study.

Early on, the study was undertaken by a student organization that focuses on international service learning projects: Northern Engineers Without Borders (NEWB). Through NEWB, two junior civil engineering students, Josh Bryan and Stacy McClelland, became involved in the project. Throughout the fall and spring semesters of 2012-2013, NEWB gathered research, worked with WISH and completed an initial feasibility study which included an estimate for how much it would cost to construct an off grid solar system. Although solar power was requested by WISH right from the start, during the feasibility portion of this project, a number of alternative methods for creating power were considered as options, but only briefly. The one alternative that was considered the most was that of wind power. With the location in question, wind turbines were quickly dismissed due to the lack of equipment available to make construction possible.

With the feasibility study complete, WISH confirmed the investment in solar power was a step they were willing and able to pursue, and a senior capstone group formed in the spring of 2013 to take on the design of this system. It is here that the journey truly began, with a team of the two civil engineering students who worked on the project with NEWB and two electrical engineering students, John Beaschler and Bridget Davis.

There were many questions and concerns approaching this project. Would a project aimed at solving a problem in a developing country use the same engineering process as it is utilized in the classroom and in projects throughout the United States? Could this project be approached in the same manner when there would clearly be a significant amount of other hurdles to contend with? How much would the vastly different cultural dynamic of a third world country affect the design process? Answers to these questions would eventually be found by each student along their respective journeys throughout the design of the system.

Background

Haiti officially became a country when it usurped the colonial control of the French in the early 19th century. However, since then, Haiti has experienced chronic instability. Dictators and natural disasters, such as the earthquake in 2010, have left Haiti the poorest nation in the Americas. The repercussions of the earthquake were compounded by a cholera epidemic. The money that was raised and pledged to Haiti during the aftermath of the earthquake has been slow to make its way to the Haitian people. There are other major concerns for the Haitian people such as poor building infrastructure and environmental degradation. The wealth gap is also a major concern. “And the huge wealth gap between the impoverished Creole-speaking black majority and the French-speaking minority remains unaddressed. With unemployment running at around 40%, many Haitians seek work and a better life in the US or other Caribbean nations, including the neighboring Dominican Republic, which is home to hundreds of thousands of Haitian migrants.” [1]

Figure 1: The island of Hispaniola which is comprised of Haiti and the Dominican Republic[2]

La Gonave is an island off the coast of the main land of Haiti that has a reputation as the poorest area in the western hemisphere. In 1968, Tony Wolf's vision to emphasize the need to provide a foundation for the local Haitians to improve their living conditions was born in the form of WISH. **"**WISH is a non-profit, inter-denominational mission governed by a thirteen-member volunteer board of directors, with full-time field directors serving on the island. The mission employs over twenty full-time Haitians and numerous part-time help through its involvement in a wide variety of community service and construction projects. These jobs provide steady income for the employees who support large extended families. A major focus of the mission has been to provide a safe and reliable source of water for the hospital and village of Anse-a-Galets, population 25,000." [3]


Figure 2: Aerial view of the WISH compound on La Gonave, Haiti

Among other costs, at present, WISH spends between $6500-7000 a month ($0.40/kW) on diesel fuel to provide reliable electricity to their facilities. They provide power to many services for the Haitians in Anse-a-Galets which currently include: a weld shop, ice plant, dental clinic, WISH mall, WISH compound, and soon, the newly built library. The WISH mall is the equivalent of a strip mall, that local Haitian's can rent to provide needed services to the community. Some of those services include a local barber shop and a shop that sells cold drinks. Through NEWB's initial feasibility study, it was estimated that a 120kW system would be needed to meet the needs WISH had, although that estimate has changed a number of times throughout the design process as more information comes about. The projected solar farm is designed to accommodate all of the electrical needs of the WISH's facilities with the exception of the weld shop as well as to provide opportunity for future expansion. Below is a pie chart showing the expense distribution for WISH in 2011.

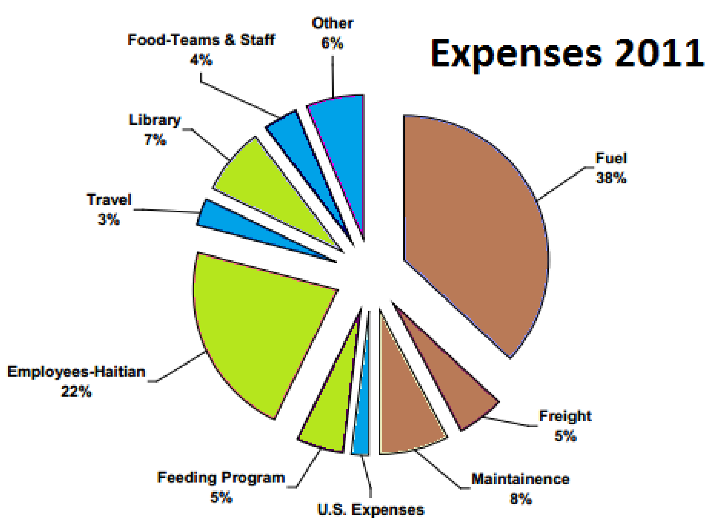

Figure 3: Expenses of operating for WISH in 2011[3]

As can easily be seen from the pie chart above, the cost of fuel is by far most significant single cost WISH faces, and for every dollar spent on fuel, that is one less dollar that could be spent on programs and resources that could directly impact the Haitian community in Anse-a-Galets. The projected solar panel system, once built will reduce the fuel costs significantly. The funds to build the photovoltaic system will be raised by WISH from various donors.

Initial Work

By the time the project of designing a solar panel system was handed over to the senior design group, NEWB had done a good job of gathering background information and some general estimates related to the costs and power requirements of the system. All of the early information gathered was from general research, interviews with WISH and educated assumptions. Unfortunately, the more progress that was made, the more evident it became that a site visit would be vital to gain an understanding of numerous factors encompassing the project including things as basic as the environmental conditions, concrete numbers for things like the actual power requirements.

A simple example of this from early on, was the concern over whether or not there was enough land to house an array large enough to provide power for all of WISH's needs. In the US, a problem like this would be fairly simple to solve. A deed could be pulled for the land to get an idea of acreage, or a surveying team could be sent out to the site to determine how much land was available. Similarly, a reading from electrical meters and the past year's electrical bills could determine the power usage at any given time. But because the array was intended for WISH, located in Haiti, those simple solutions were not available. Meters, if they existed at all, were not guaranteed to be giving accurate readings. Sending a team out to do a quick survey simply was not possible because the equipment was not available.

In the end, Google Earth was utilized to determine a rough estimate of how much land would be available for a solar field, and some best guesses were made by WISH in regards to their powered consumption, so that the feasibility study could be completed.

Figure 4: Current WISH compound and the proposed site for the solar field.[4]

Once it was determined that a senior capstone project would complete the design of the project from NEWB, students were selected to work on the project, and a trip was organized to make sure the initial findings NEWB had gathered were correct.

For each of the members chosen, the decision to work on this project was not a difficult one. As Davis put it "Looking through the list of available projects there were a couple of choices that popped out and sounded interesting. But there was one that absolutely screamed my name and that was the solar design in Haiti. I just knew this project was going to be challenging and rewarding. It was also going to take me on the journey of a lifetime."

For Josh Bryan and Stacy McClelland, who had both worked on the project with NEWB, it was assumed that the feasibility study would be the end of the involvement for two civil engineers. Once it was realized that there were many civil design elements needed for things like the foundation and mounting structures, both eagerly joined the project.

Once the team was finalized, everyone was tasked with becoming familiar with the project and what work had already been done, and a trip to Haiti under the supervision of one of the faculty advisors, Brian Henderson was arranged. The plan was to meet Frank Illingworth and Dale Holzhausen, a member of the WISH board, en route, and to gather all of the data needed to complete a solar system design. The electrical engineers were going to collect information about the existing system (i.e., loads, voltages, etc.) while the civil engineers focused on surveying the proposed site. In a period of 3 short months, all of the logistics were worked out and it was time to head to Haiti.

Experiences gained while in Haiti

The trip was planned for July 26th-August 2nd 2014 and was paid for using funds from the T.J. Smull College of Engineering. While the focus was intended to be a data gathering trip, so much more was learned in the process that cannot be simplified down to numerical values.

In preparation, each of the team members researched some of the history basics of Haiti, attempted to learn a little bit of Haitian Creole, got the necessary immunizations, and soon enough found themselves arriving at the airports to board planes. This would be the first time both Beaschler and Davis had been to a third world country doing service work. For Beaschler, the experiences started before he even made it out of the US. “I arrived at the airport and had my first experience with Haitians. The boarding gate was full of Haitians waiting to go home. They were loud and boisterous. When we were called to board, I also found they were very pushy and borderline selfish. I did not know this at the time, but they were probably all raised in situations where if you did not push and fight to get what you need, you probably were not going to get it. Waiting in line for a plane, where everyone’s seat is reserved, is a concept completely foreign to them. I suppose that was my first experience in our differing cultures and lifestyles. I knew that what I needed would be there once it was my turn; the Haitians were not going to take that chance.”

Similarly, Davis’s first eye opening experience was on the plane. “Before we even landed I realized how different things were down there. I knew that Haiti would be much less developed than the US, especially in Anse-a-Galets, but I was surprised, upon descent into Port-au-Prince, to see so many shacks that were practically on top of each other. I could not fathom how people could live like that.”

Those eye opening experiences only continued from those moments on. Coming out of the airport was a major culture shock. There were people everywhere offering to carry your bags for a little money. There were people everywhere trying to sell random stuff to anyone who would stop to listen. Most of the cars had people crammed into them; many more than would ever be legal in the United States. The ride up the coast from the airport to the dock was done in the back of a truck with a cage covering the bed. The ride caused sensory overload of what life looked like for the typical Haitian. They live in shacks and use the river to wash their clothes. This is the same river that is also used for bathing and as a bathroom. Animals roam freely, rarely fenced in. Sometimes they are left tied to a pole while the owner was away. Children walk around naked and dead chickens are sold in the street. There are no real traffic laws and people drive like maniacs.

Both Bryan and McClelland had traveled in the past to the Dominican Republic on service trips through ONU, but even with those experiences, the extent of Haiti’s poverty still came as a shock. As Bryan recalled afterwards, “I thought that my two summer trips to the Dominican Republic gave me an understanding of poverty, seeing as they are both third world countries and share the island of Hispaniola, but I was unprepared for what Haiti, unofficially a fourth world country, had to offer. I was instantly enveloped in the possibilities I realized our project could offer to these people, and that motivation (certainly built up over my stay there) has kept me going even to now, as it is 4°F, I am surrounded by inches of snow, and probably as culturally and physically removed from Anse-a-Galets as I could be.”

Arriving on the island of La Gonave showed an environment much like the mainland and further perpetuated the reaction that started when walking out of the airport. Conditions were very much the same, except the island had no paved roads and the town seemed to be more densely populated. No work was done with the project directly that first day, but the effects of finally seeing the island allowed the project to progress further than any day of studying the system could have. It was learned that WISH provides basic services to the local people that would not be there without WISH. After seeing how impoverished the Haitians live, even with the help of WISH, it motivated the entire group to ensure that this great organization would be able to continue to help the Haitian people as much as they possibly could.

In addition to witnessing the environment and conditions of the island, and getting a taste of the Haitian culture, a great deal of data gathering was done. A detailed land survey was taken of the site to allow for a topographic map to be created later on. Electrical mapping of WISH's micro grid was completed to mark what existed. Meters were read, and adjusted to provide better readings for the future. A sun tracker was used to get an idea of the year round shading, soil samples were taken for later testing, and some percolation tests were completed in the field. All of this information was recorded for use in the Fall 2013 semester when the true design process would start.

Observations made and realistic constraints learned after the trip

As it turned out, as a team, a great deal was learned from the week in Haiti, but surprisingly little of what was learned would likely be considered traditional in the average engineering design project. Before even leaving for Haiti we knew this was going to be unlike any project any of us had ever undertaken. After the fact, Beaschler commented, "All I knew about Haiti before working on this project was that it was a poor country, it was in the Caribbean, and that it was devastated by an earthquake in 2010. I had seen the video footage and pictures, knew of the devastation surrounding the island, but did not really comprehend what the people had gone through or what they still continue to endure. I thought I did, I thought I could imagine the poverty and struggles, but the fact of the matter was that I grew up privileged in Ada, Ohio: American and middle class. Without ever being outside the United States, there was no way I could ever relate to the Haitians, then or now, without seeing everything with my own eyes."

Even after we all returned home, there were lots of discussions about how the impoverished environment would affect the final design of the solar system. Those discussions often included elements of how the language barriers, education levels and cultural elements would have huge impacts on the final design. Most of those elements had been given little consideration up until this point. Surprisingly though, the more we dug into the design, the more obvious it became that those topics that were not originally even in the scope, were the most important ones. If it were not for the poverty, the cultural elements, and the fact that there is no power grid to tie into, designing a solar array to meet specified power needs would be a simple matter of plugging data into equations, and picking out the wanted models through decision matrices.

Instead, as a team, we found ourselves needing to focus on the cultural elements the more our design progressed. In the end, while we considered many traditional constraints like functionality and reliability, we spent as much time considering the social, cultural and economic constraints.

The functionality constraints are readily defined in the problem statement and project scope. Simply, the selected panel array must provide power to cover WISH's needs. The array must fit on the land that WISH currently owns, and be spaced so that the WISH staff is able to easily access and maintain the individual panels. In terms of reliability, the typical solar panel should produce power for a lifetime of approximately 20 years. The system will meet at least these requirements to allow for an acceptable payback time period. The foundation, which must survive earthquakes and hurricanes, will last at minimum as long as the panels do.

The social and cultural constraints are perhaps the greatest concern here. This project is predominantly an international one. The country where the final product will exist is Haiti, and as such the social and cultural elements of Haiti must be taken into consideration. The native language of Haiti is Haitian Creole. This means that any final product, from drawings to instructions, will need to be not only in English but also in Haitian Creole. Also to be noted is that the Haitian culture is dramatically different from the culture found in the US, from the way that they view time to the way that resources are used. The resource end of this cultural divide is probably the element that will affect this project the most. In Haiti, nothing is wasted. Every resource and even things others might not consider a resource, has a purpose, and will be used. Keeping that thought in mind, it will be very important to make sure all resources are used efficiently.

Along with using resources well, it will be best to use resources that are readily available on the island. There are two major reasons for this. The first is that if the items used can be found on the island then if something fails, WISH will not have to wait for months for a replacement to come. Second is that if the materials used are local, then the local people will likely have worked with those materials in some other capacity and will already have a working knowledge on how best to go about future repairs.

Another social constraint is the education level of the average Haitian. As Davis recalled, "I remember we had a discussion about education. In Haiti, if you want to go to a good school you have to pay for it. Some families have to make a decision as to which child they will send to school because they cannot send them all. I am thankful that I have never had to think twice about getting a good education." By global standards, Haiti has a very poor level of education. Therefore, one cannot assume that the people who will be helping to build and maintain a solar array system will have equal cognitive skills expected from an average laborer in a fully developed country. This includes working with some who may be illiterate or not understand the dangers surrounding powerful electrical systems. This becomes especially true when working in an area where the general population does not even have basic electrical lighting in their own homes. WISH has indicated that much of the construction for this project will be done by locals or by individuals who donate their time, by nature of WISH being a non-profit organization. In the case of the individuals who are donating their time, they will likely be from the US and may have some experience in similar construction projects, which will require English plans and instructions. However, copies of these documents will also be needed in Creole for the locals.

The final major constraint that should be focused on is the economics. This project was requested by WISH, which is a non-profit organization. That said, the resources available are limited and will be highly dependent on donors of both time and money. The cost of the system must be kept as low as possible and using local parts available in Haiti will help immensely with part of the cost. Standard US values for construction costs will not be applicable, as the cost of labor in Haiti is dramatically different. It is understood that this project will provide a reasonable payback period to make it worth installing this new system, and with that understanding the best possible plan available to meet WISH's needs will be implemented.

The obstacle of designing a system that dealt with all of these constraints could be daunting to overcome. The fact is we are not specifically taught how to deal with the extent of these environmental constraints while in school. The challenges become even more difficult to grasp when you consider trying to quantify them without visiting the actual location where the solution is intended to reside. And to be frank, even visiting does not even come close to answering all of the questions; more often than not it raises more. That was exactly what we experienced onsite in our prep visit to Anse-a-Galets. Visiting and talking with locals and mission workers more than confirmed many concerns we had undertaking this project. On the surface it was the lack of resources, location, transportation of materials (which may or may not include putting a backhoe on a homemade sailboat), and disconnectedness once we return to the States. But deeper than that we found environmental and cultural issues that were also added to our design considerations. Little things like the existence of certain “fees” to get items through customs; or the fact that the locals know nothing of electricity (there is basically no state provided electricity) let alone be familiar in how to work with it. That creates the need for us to educate them just as much as create a suitable design because both are imperative for a sustainable project.

Another concept that we were pleasantly surprised to encounter was the concept of “Haitian ingenuity”; the local factor. What it boils down to is their mindset that their sweat and hands can accomplish most tasks. Our team spent the better part of the morning trying to figure out how to lift a concrete telephone pole with the available backhoe, and in the end about 30 locals came and just pushed it up themselves with some guide ropes. Another example of Haitian ingenuity was evident we visited a cavernous mine that was excavated entirely with 5 gallon buckets and pickaxes.

The Solution

With all of the experiences and new insights from the trip to Haiti, the team jumped into the design of the solar system head on, upon return to school in the fall. All of the data taken while in Haiti was examined; some of which was useful, some not. It was quickly discovered how much more complex this project was going to be. Solar power is a whole different beast compared to other types of power. Sure, the electrical engineering students had taken a photovoltaic class, but that material focused predominantly on grid systems, and how to tie into a grid, which does not help much when you need an off grid system. But utilizing all of the resources available, the design progressed. One of the challenges was simply in deciding the size of the array that would actually be needed based the on present and future usage. NEWB had made an estimate of the needs, but after taking more detailed measurements it was realized that some adjustments on that size would be needed.

To decide upon the size of the system, the electrical engineers looked at the actual data usage of WISH that was accumulated from their meter readings. Calculations were performed using the AC to DC derate factor, the size of the panel, the efficiency of the panel, the number of days per month, irradiation data for each month, and the number of panels to find the kWh produced each month. The actual usage was then increased by 25% to allow for growth. For WISH, this growth will immediately include the new library. In the future, the system may need to be able to support more buildings as WISH does more to help the Haitian people. This is the primary reason for an overdesign of this magnitude. To achieve this extra 25%, it was found that the system would need to be at least 100 kW to create enough power for each month of the year.

During the winter months, the amount of solar irradiation is less and therefore there is less power that can be produced. To account for this shortcoming, the system has to be expanded until the lowest month is at or above a 25% increase in kWh per month so that it is ensured that WISH is getting the power it needs at any time during the year.

The design as it stands will be made up of 10 arrays, each of which will provide 10 kW of DC power, for a total of 100 kW. Each array will have a total of 36 panels rated at 285 W each. This system will be broken up like this to allow WISH to slowly phase in each array as they raise the funds for it. Initially they plan to install one array to power the new library. They will then install more panels based upon the amount of funding they have available. The panels will be mounted on ballasted footings because this will be the simplest and most stable design that can be made without the use of heavy equipment.

The panels will be connected to inverters where the voltage will be transformed into 208 VAC. This will then be sent into the SMA Multicluster box which contains a set of control circuitry to determine which method of power will be used. Also connected to the Multicluster will be the existing 60 kW generator and the DC batteries. From the Multicluster box, three phase AC power will be sent to the load. It is still being discussed with the client the size of the batteries. This will be determined by WISH's preferences and the amount of funding they have available. The design is illustrated in Figure 5. The manufacturer's diagram of the SMA Multicluster box can be seen in Figure 6.

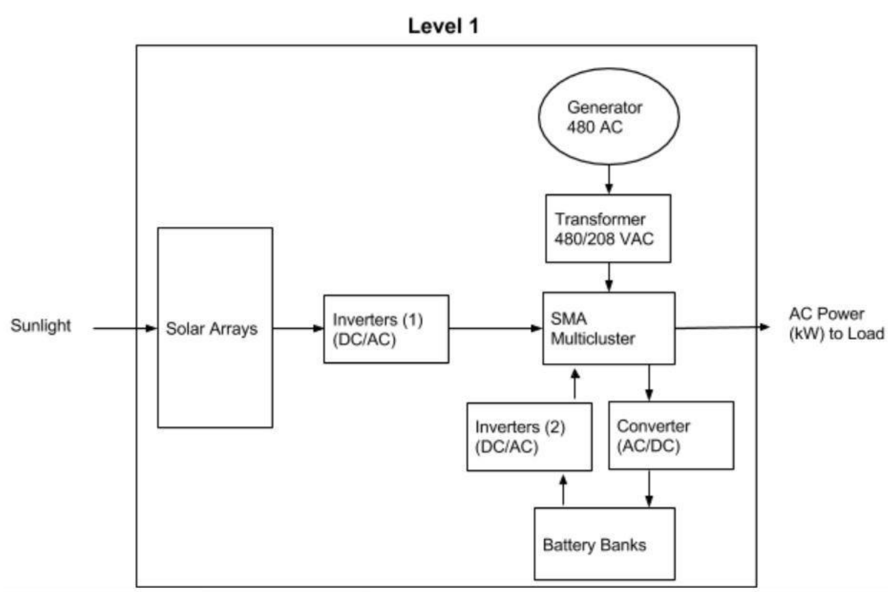

Figure 5: Line diagram of the design.

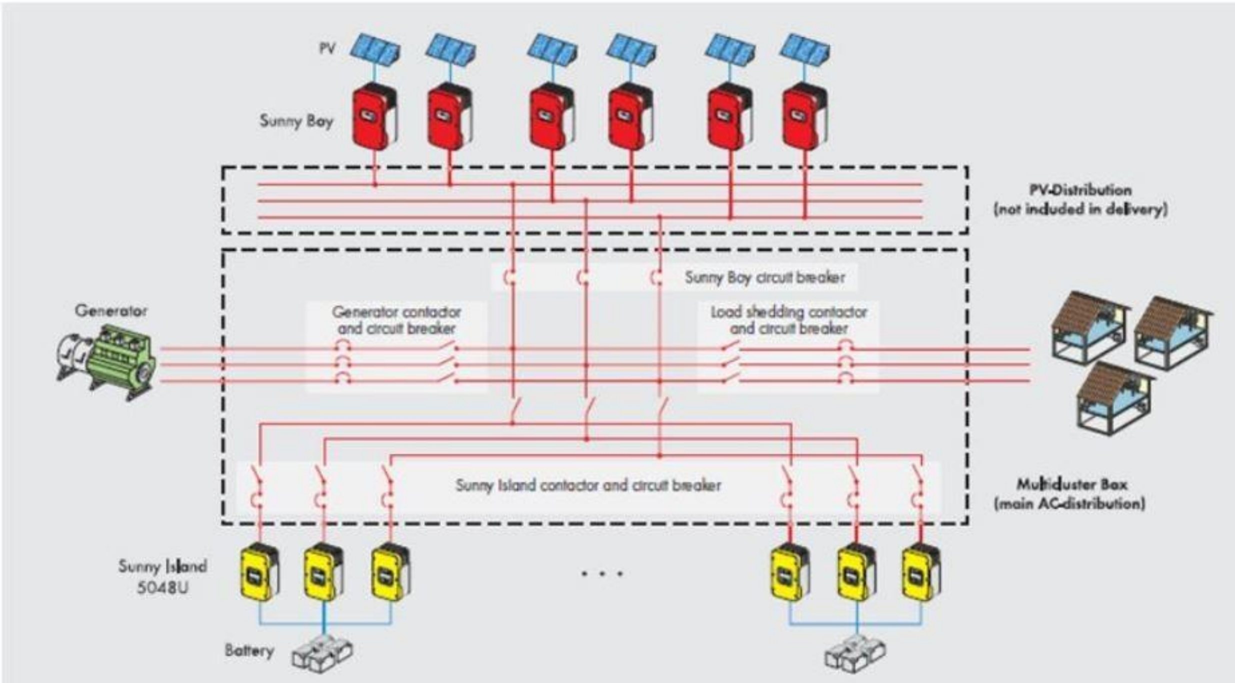

Figure 6: Manufacturer's diagram of the functionality of the SMA Multicluster box.[5]

If all goes according to plans, and the required funds have been raised, the final design will be implemented beginning in the summer of 2014, with a first phase installment of 10 kW. WISH will continue to increase the size of the system, as they have money available from their fundraising. The cost of the entire project was not given a set limit, as WISH is fairly confident they will be able to raise the funds they need for the system. However, keeping the cost of the project as low as possible while still designing the necessary system, was a forefront consideration in the design process.

Conclusions

"It did not matter how much research was done, how many statistics I looked up, how many pictures I looked at, or who I talked to. Nothing could have prepared me for what I would experience in Haiti." That was a common statement from each member of the group after the trip to Haiti. It is easy to jump onto the internet and see pictures of humans in poverty and need, but to see it firsthand is completely different. After spending a week in a third world country (and even at that, being missionary visitors, it was like living a life of luxury compared to the Haitians) the team gained a better understanding of how difficult life can be for people in impoverished places, and through working on this capstone project each person has gained a better appreciation for the design process and all that it truly entails.

Each student was taught all about the engineering process virtually from the first day of stepping on campus as freshmen in the engineering program. However, unspoken assumptions that have always been made in the classroom, such as having a structured environment, could not be made as a design was worked towards in this project. In classroom designs, materials are always readily available and any resources that might be needed were always an option, though cost may factor in at some point. In Haiti, it would be ridiculous to assume that these assumptions still held true.

The same guidelines were taught when approaching a problem in virtually every class. However, this project was unlike any other. This was known when the project was approached, but it did not really sink in how different it was until that first day on the island. Would the tried-and-true process still hold? Could the problems and hurdles still be approached in the same way?

The answer to these questions turned out to be a resounding ‘yes’. Not only would the learned engineering process still work, but using it seemed to still be the most effective method of studying the project. The end goal is known, as well as the current situation and resources (however limited). Now, as engineers, all that is left is to use the knowledge gained, through research and first hand experiences to transform the current situation WISH has into what they desire it to be. Any problems encountered while on the island, and when back in the States, could all be creatively approached in a similar manner. The engineering process is and would be adapted and modified to give the team the best tools to accomplish this project.

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