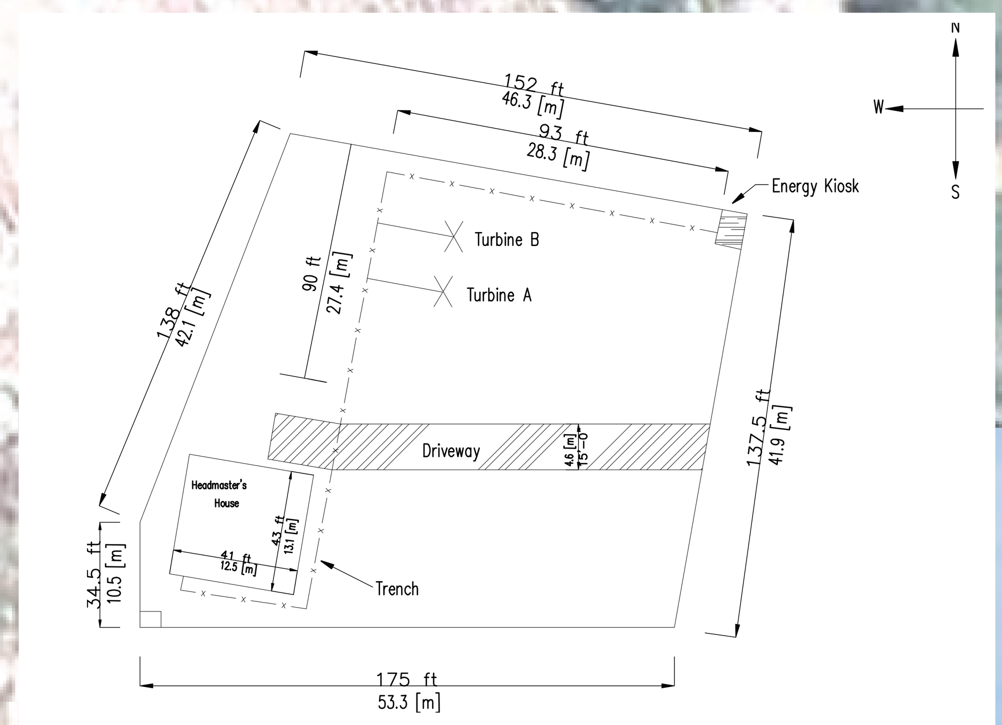
Microgrid System for a Wind and Solar Farm Located In Rural Kenya

Providing electricity for off-grid families



This is an aerial view of the Headmaster's Property. The diagram shows the approximate location of the microgrid components, underground wiring and the energy kiosk.

Kristy's Cape Accademy with headmaster, students, and teachers. The charging station would be built in the area behind this group.

BACKGROUND

In Kenya the average "off-grid" household spends $100 (USD) annually on candles, paraffin, and kerosene for light at night. Total energy spending by off-grid households is greater than that of grid-connected households, despite considerably lower energy consumption. The residents of Muhuru Bay, Kenya, who have a typical monthly income of $59.00 spend about $10.40 per month (18% of their income) on energy.

In the past people in developing countries had no alternatives to kerosene lamps and diesel generators (both of which produce toxic fumes), due to the price of solar power.

The Muhuru Bay community has a population of approximately 4000, including the 300 students who attend Kristy's Cape Academy. While many members of the community have mobile phones, none have access to regular electricity. By providing power to the community, the Muhuru Bay Community Microgrid Project will stimulate economic growth and help the local community read, study and interact at night

Typical school day.

BENEFITS TO PUBLIC HEALTH SAFETY AND WELFARE

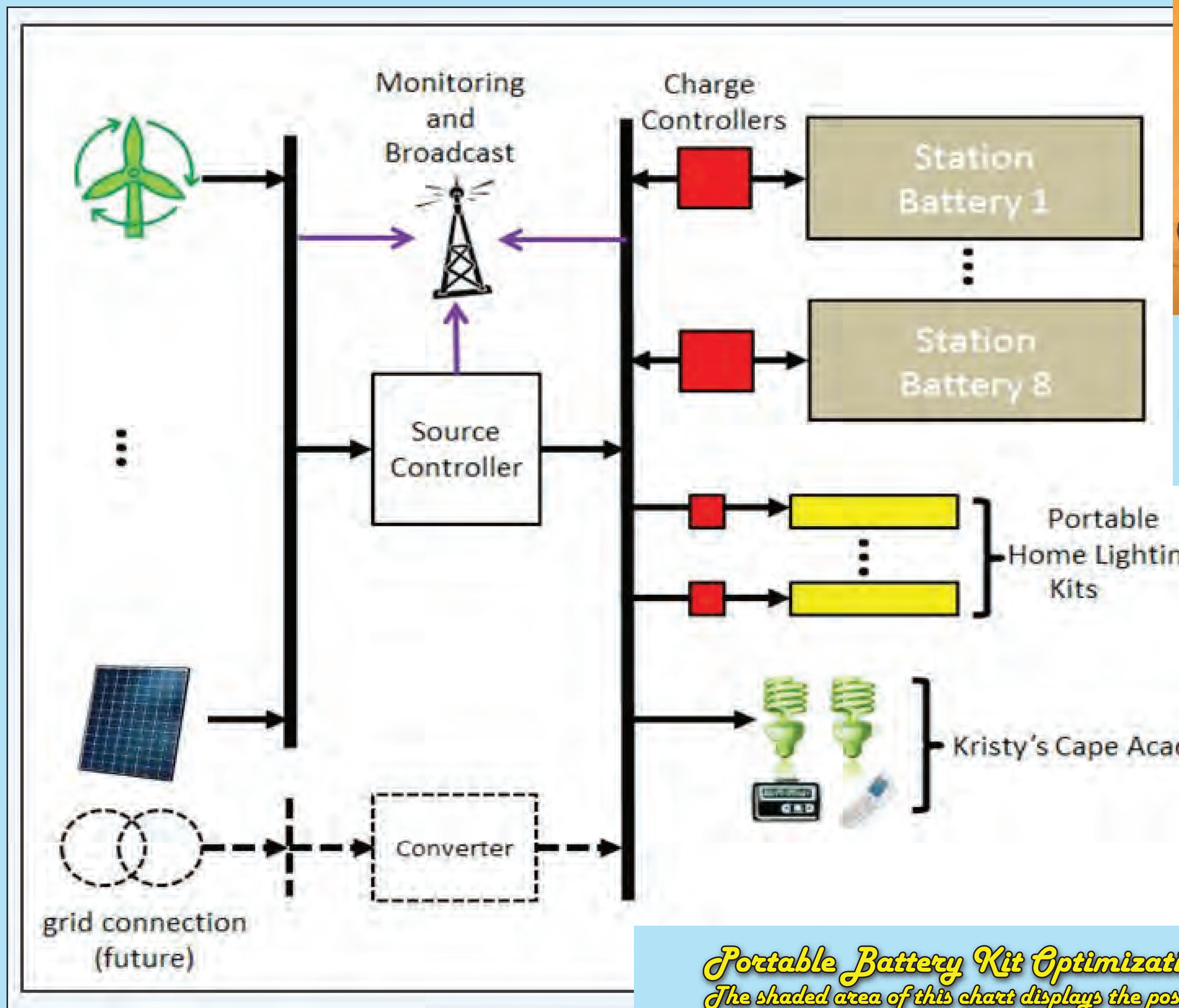
Where there is electricity there is economic growth. Providing electricity to the community of Muhuru bay is just one benefit of installing our microgrid system -- our project goes beyond electricity. With the success of this project, we are able to liberate the community from their dependency on non-renewable products such as kerosene and allow people to educate themselves at night. The project will be providing skilled jobs and training to the local people on wind and solar products. Additionally, the community will save money, time and frustration by being able to charge cell phones in their own homes. The system is built with future expansion in mind to serve more families at a later time and can be replicated in communities that lack access to electricity around the world.

Community members charge their battery kits during the day to be ready for use at night.

LIGHTING FOR STUDENT STUDY

Portable Battery Kits VS. *KEROSENE*

System Block Diagram showing major components of the microgrid system.



DESIGN

The microgrid system consists of 1.5 kW of wind and 1.5 kW of solar capacity. The design has pre-manufactured equipment, complete wiring diagram for the power source, controls, and power transmission to a charging station. This will charge over 60 portable battery kits per day through an energy kiosk as well as provide power to Kristy's Cape Academy and the headmaster's house. The project includes basic telemetry that will use the local cellular network to provide data back to the university for further research. Site information has been gathered in order to complete this design, scheduled to be installed in the summer 2014.

COLLABORATION

Team testing portable battery kit with solar panel and accessories.

The team worked with a group of talented people, with a wide variety of skills and backgrounds. The faculty advisor is an electrical engineering P.E. whose experience deploying humanitarian projects helped navigate the path needed to achieve a practical design. In addition, the team worked with a number of figures in the Muhuru Bay community including the headmaster of the school, a highly respected member of the community. The team also worked closely with two electrical engineering PhDs, both of whom brought considerable knowledge of power systems and humanitarian engineering. One civil & environmental P.E. and one mechanical engineer provided important consulting on key elements of the project. All of the final documents were reviewed by an electrical engineering P.E. registered and practicing in Kenya. An accountant, helped with budgets and planning. This collaboration allowed us to learn about the process of engineering, writing contracts, and changing project requirements; overlaid with the international considerations such as local codes, cultural practices and business development considerations. The MBCM collaborating team pushed the student team to meet high standards of professionalism and responsibility, which helped make this project such a positive and successful experience.

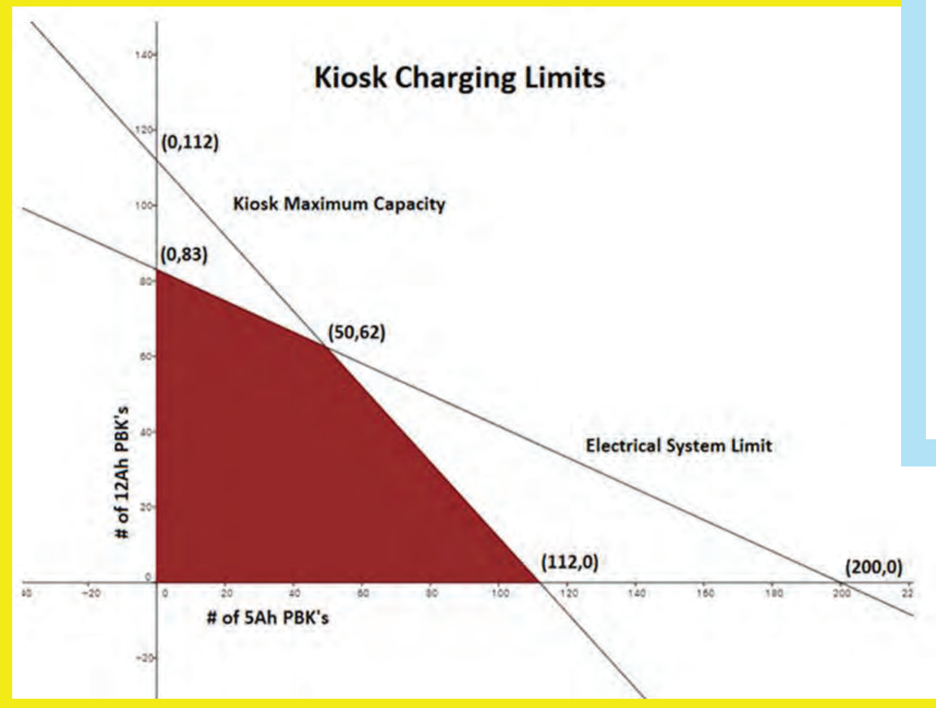
Meeting with parents at Kristy's Cape Academy to present portable battery kit options.

KNOWLEDGE GAINED

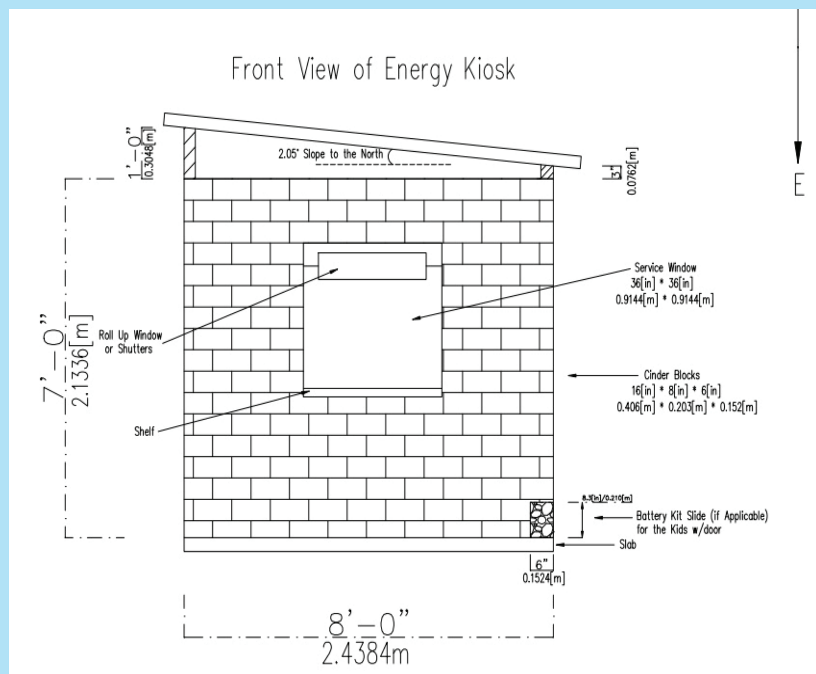
The knowledge we attained designing the Muhuru Bay Micro Grid encompasses various aspects of the electrical engineering profession.

- Application of undergraduate studies
- HOMER Renewable Energy Software
- International business practices for project implementation
- Mentoring under professional engineers and non-engineers
- Writing a Request for Proposal and selecting a vendor
- Electrical codes and their variations by country

Portable Battery Kit Optimization:
The shaded area of this chart displays the possible combinations of portable battery kits the system can support. This data helped the team choose what size and number of portable battery kits to deploy.



CAD drawing of the energy kiosk storefront. Construction will be completed in summer 2014. Community members will charge their portable battery kits here.



Design of the Muhuru Bay Community Microgrid for Charging Batteries and Powering a School

Abstract

This project is the design of a 3 kilowatt hybrid wind and solar power microgrid system to be used to provide electricity to a school and surrounding community in Muhuru Bay, Kenya. Kristy's Cape Academy (KCA) is a primary school with approximately 300 students, many of whom are orphaned due to HIV/AIDS. The school and surrounding area have no grid connection, which hampers the instructors and prevents the students from studying in the evening. Moreover, access the electricity strongly correlates with measures of community development. The project therefore **benefits public safety, welfare and the developmental outlook** for the students and the community.

In addition to supplying electricity to KCA and the headmaster's house, the system is to support a "community charging station" model of electricity distribution in which families of the students at KCA can rent Portable Battery Kits that are brought home at night to power lights and recharge small devices such as cellular phones. The project also includes integrating basic telemetry that will use the local cellular network to provide data to the University for future research.

The team working on the project consisted of four electrical engineering undergraduate students, a University faculty member, engineers from various disciplines, **licensed professional engineers** (P.E.) in both the United Stated and Kenya, **allied professionals** (licensed electrician, machinist and carpenters), and accountants. The complex nature of development projects necessitates such a **multidisciplinary and collaborative team**.

The students' role was to design the system and document its technical specifications. This included determining the capacities of the solar panels, wind turbines and station batteries; developing component specifications for controllers and converters; designing the complete wiring diagram for the power source, controls, and power transmission to the Portable Battery Kit charging station. The students' design accounted for all of the technical issues to provide a safe utility-grade installation using the international and local building codes.

The **knowledge gained** from this project was broad, including designing to meet international and local codes, **collaborating** with many technical experts, and learning the importance of having key opinion leaders in the village understand and support the project. The team also learned about the importance of site information after the assessment team returned; helping to refine the high level design so that the **technical specifications** of the final design could be completed. The project will be implemented in August of 2014, with some of the student team members participating in the construction and management.

Design of the Muhuru Bay Community Microgrid for Charging Batteries and Powering a School

1. Project Description

Muhuru Bay is located on the shores of Lake Victoria, in the southwest corner of Kenya, and has considerable wind and solar resources based on research and measurements on the on the ground at Kristy's Cape Academy (KCA). The data shows frequent sustained wind speeds of up to 10 meters per second (m/s), which suggests that wind power may be a viable energy source at this location.

Based on the knowledge and research of Muhuru Bay, the microgrid design will likely be successful and will benefit more than 640 people living in Muhuru Bay - 300 of them being students.

Figure 1 – Kristy Cape Academy, started under a tree with 12 students, now has 300 students with the highest test scores in the region. The headmaster is shown in the foreground

The project is a 3 kilowatt (kW) community charging station, supplying power for lighting KCA and charging 60 Portable Battery Kits (PBKs) daily. Each PBK has two USB ports for charging cell phones, which are common in the area, and includes two high power LED lights. They each have a capacity of about 12 Amp hours (Ah), which is expected to last about 2 or 3 days based on average expected use. With the help of volunteers, a business plan was developed to distribute and account for the battery packs.

The business plan will be implemented as follows:

1. A monthly fee will be charged for the use and daily recharging of the battery kits.
2. The fee will be collected by KCA and will be used to offset maintenance costs. After a reserve is set aside for replacement battery kits, the school will benefit from the profits earned by the operation of the system, as well as benefit from the power provided to the school.
3. The specific fee amount was determined through a survey and assessment of the project based on income level, willingness to pay and typical cost of kerosene and candles.

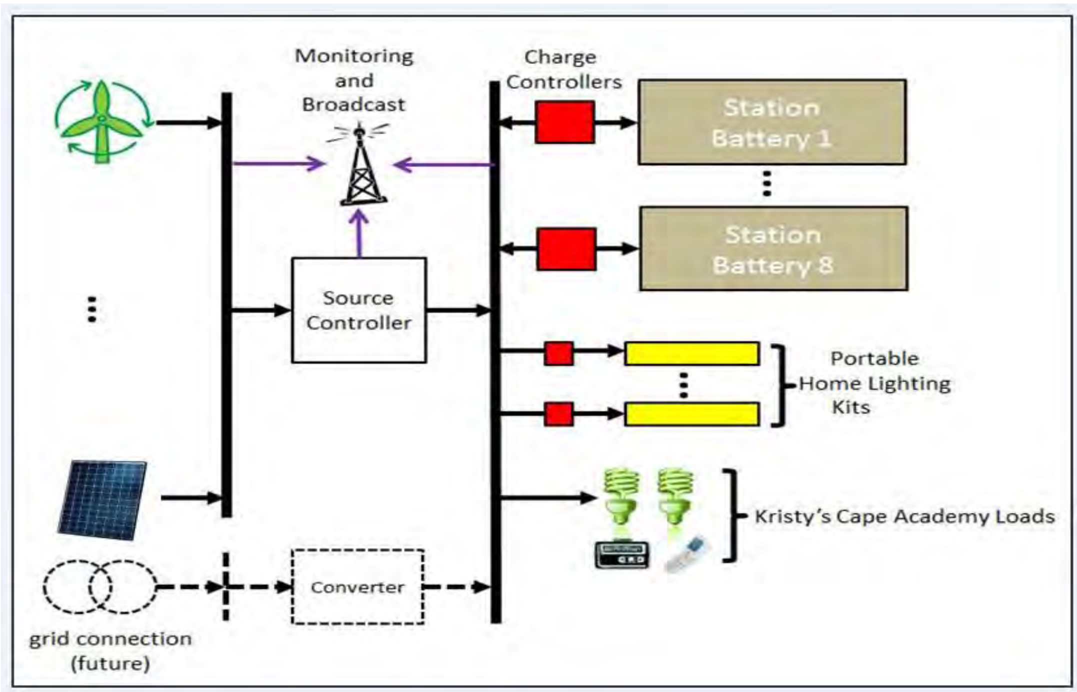


Figure 2: Microgrid Design

HOMER software, a renewable energy modeling program, was used to perform the preliminary microgrid design. HOMER allowed us to choose the most cost efficient combination of station batteries, PV panels, converters, and wind turbines to produce a 3kW system at KCA. During the design process, the team also needed to consider possible addition of PV's and wind turbines in the future to provide more power when needed.

The optimized design uses two 1000 Watt (W) wind turbines plus 1880W of solar panels powering the charging station. Although that connected capacity is almost 4kW, the model shows that with the diversity of the wind and the solar panels that it will be comparable to a 3kW system. The power from the wind turbines and Photo Voltaic (PV) panels is used to charge a large, stationary bank of 400Ah/48 volt (V) deep-cycle lead acid batteries. The home lighting kits will be charged, and distributed to KCA students.

Several team members traveled to Kenya to gather information for the project. This included speaking to vendors who would supply the components for the microgrid system, surveying the community on various aspects of their everyday life that would be affected by the microgrid, and documenting other technical data.

The team visited two different PBK vendors in Nairobi. Each vendor loaned PBK samples, which the team showed to Muhuru Bay residents in controlled focus groups, who were impressed by the hardware and were enthusiastic about the project. The team also surveyed 77 households to gain robust and reliable data to understand the factors needed for successful implementation and sustainable operation.

The team also visited four local companies who design and implement small wind power systems. Based on their observations, three of the four companies could design, install and maintain the system. It was more practical to contract a single company to source, install and maintain the entire system, than for the microgrid team to piecemeal the components together.

Findings from the assessment trip helped redefined the scope of the project. Using the 3kW system design, a Request for Proposal (RFP) was sent to three vendors. In addition to the station, a kiosk was designed by the team for people to bring and charge their batteries. Figure 1 shows the block diagram for the layout and Figure 2 shows the physical plan on the property in Kenya.

The site plan in Figure 3 below shows the property and where the equipment will be located. The PV panels will be located on the roof of the Head Master's house, directly above a control room, which will contain the station batteries and other equipment. The wind turbines will be located approximately 30 meter (m) northeast of the house with a fence for security and the energy kiosk will be located another 30m east of the wind turbines near the road. The kiosk will be supplied with a 240VAC, 50 Hertz (Hz) feeder. Each PBK will be charged using this power source by connecting the power supply that comes with the PBK. Additionally, the 240VAC, 50Hz line will also supply the school once it is constructed across the road from the kiosk.

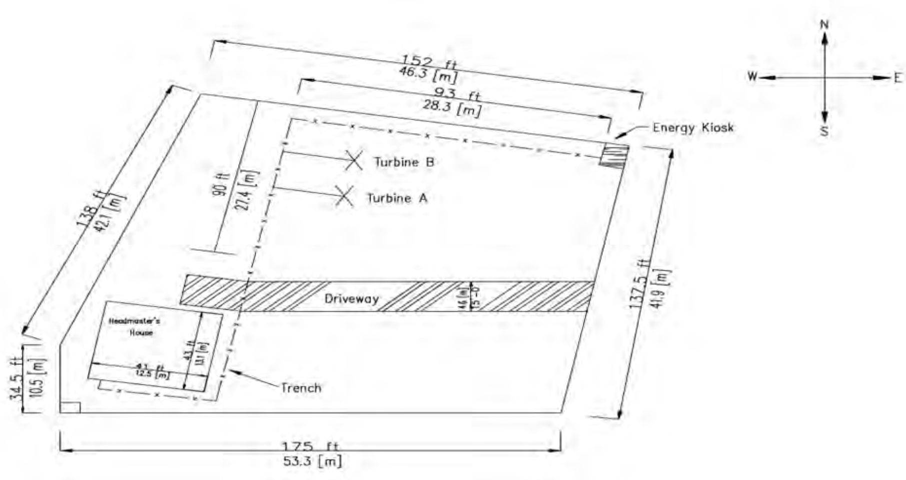


Figure 3: Site Layout

One challenge that came up late was the suggestion to also accommodate smaller sized PBKs, 5 Ah, rather than the design assumption of 12 Ah. This design consideration is that with smaller batteries it would be possible to charge more battery packs; the challenge is ensuring there are not too many large batteries on the charging system. To evaluate the constraints, a simple graph was made to graphically show the correct combination of PBK sizes that could be used at any one time. Figure 4 shows the operating range of the kiosk, shaded in red, for different combination of PBK sizes.

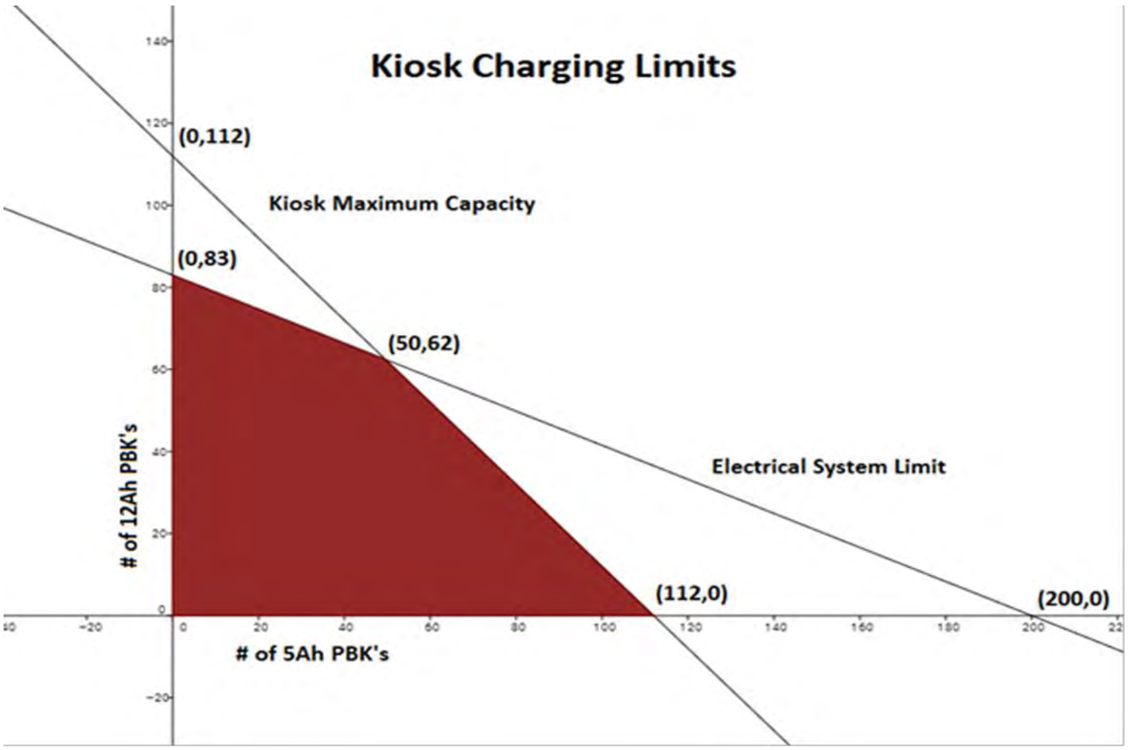


Figure 4: Portable Battery Kit (PBK) combinations for charging 5Ah and 12Ah batteries

2. Collaboration of Faculty, Students and Licensed Professional engineers

The team worked with a group of talented people, with a wide variety of skills and backgrounds. The faculty advisor is an electrical engineering P.E. whose experience deploying humanitarian projects helped navigate the path needed to achieve a practical design. In addition, the team worked with a number of figures in the Muhuru Bay community including the headmaster of the school, a highly respected member of the community. The team also worked closely with two electrical engineering PhDs, both of whom brought considerable knowledge of power systems and humanitarian engineering. One civil & environmental P.E. and one mechanical engineer provided important consulting on key elements of the project. All of the final documents were reviewed by an electrical engineering P.E. registered and practicing in Kenya. An accountant, helped with budget and expense planning. This collaboration allowed us to learn about the process of engineering, writing contracts, and changing project requirements; overlaid with the international considerations such as local codes, cultural practices and business development considerations. The MBCM collaborating team pushed the student team to meet high standards of professionalism and responsibility, which helped make this project such a positive and successful experience.

3. Benefits to Public Health, Safety and Welfare

An estimated 1.5 billion people in the world lack access to electricity today - 800 million of those being in Africa and 3,000 of them are in Muhuru Bay, Kenya. At the moment, the Muhuru Bay community utilizes kerosene lamps to use as lighting. Kerosene is not only expensive, but also exposes people to hazardous fumes. Some of the lamp designs are very dangerous and children have been burned badly from kerosene fires. This project will allow the community to live a healthier lifestyle when reading, studying or interacting during the night.

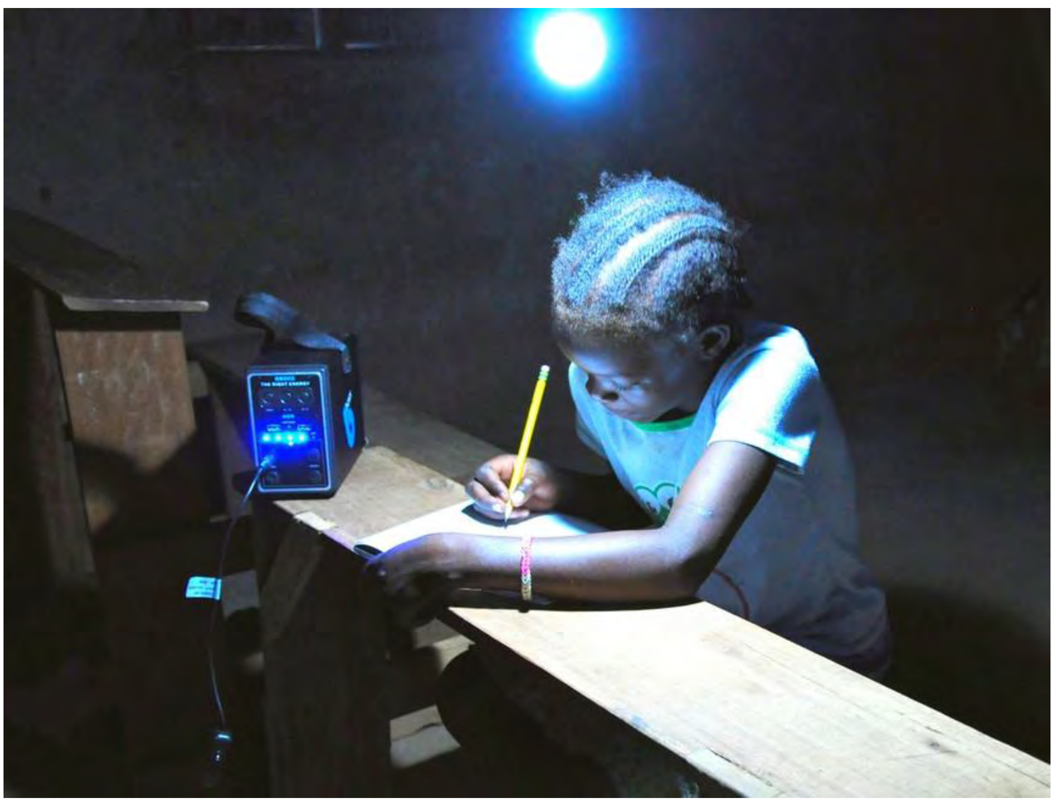


Figure 5 – A student does her homework using Portable Battery Kit and Light during a field test during the second team assessment trip

As a new business in the Muhuru Bay community, the charging station will provide qualified jobs and job training to the local people. The business model supports a supervisor and operator who will be hired from the local community. They will be trained by professionals from the US and Kenya who have customized and simplified operating procedures. The training program will teach the operators how solar and wind products work, how to maintain them, and how to run a sustainable business. The operator will then have the ability to train or employ others in the community. Locals other than the operator will also receive training on the basics of the microgrid system and how to handle a battery kit to ensure it is used properly and lives the maximum possible lifespan. In the future, the installation company in Nairobi will have a maintenance agreement with the school and they can perform additional training if needed.

KCA plans to add a curriculum to the program that teaches about environmental sustainability and use the system as a learning lab. Such activities can be comparing lighting to kerosene, and comparing the charging of cell phones with the system versus a gasoline generator.

Although Muhuru Bay community lacks access to electricity, mobile telephones are prominent throughout the community. Mobile telecom is one of the fastest growing markets in 21st century Africa, and charging a cell phone often takes a long journey to and from the nearest grid or generator. It can also cost as much as $0.50 (USD) per charge, while many local earn around $1.00 (USD) per day. The Muhuru Bay community microgrid will allow the locals to charge phones at their home, saving them time and money.

This project is not the first microgrid system to be installed in a developing community without access to electricity, however combining solar, wind, powering a school and charging battery packs is a very unique combination and packs several design challenges. This microgrid design can be replicated and customized - depending on community needs - to be implemented in any area without access to the grid.

4. Multidiscipline and/or Allied Profession Participation (Community Participation)

The student team encountered many professions throughout the project, but were solely responsible for producing the technical design. There were many teams within the entire Muhuru Bay Microgrid Community (MBCM) group including the microgrid, battery kit, public relations, business model and training teams. Many of those involved in this project have mechanical and electrical engineering backgrounds employed at Fortune 500 companies.

Even though most of the MBCM team members are engineering professionals, there were others involved in accounting, computer science, public policy and business management. The beauty and uniqueness of the project was that some of the collaborating engineers took responsibility of positions that were non-technical, and those that had non-technical backgrounds joined technical teams. This diversity added a productive and fresh perspective to all elements of the project.

The student team began this project with the idea that the scope would be solely designing a microgrid system and not dealing with non-technical aspects of the project. However, many other members of the team were soon asking for input on other components of the project such as the business model and training ideas. As a consequence the team has come to know every aspect of the project - including information on the business model, training and battery kits.

Being involved in all of the different groups within the project was an advantage. By getting involved with the business model team the design was altered to better suit the needs of the Muhuru Bay community. In addition, knowing the training procedures influenced the design to be as simple as possible. This total immersion into the process led to a design that is robust and user friendly.

5. Knowledge Gained

Throughout the project the students learned the value of active listening. The students could not simply show up to KCA and provide a technical solution to the community without first understanding their needs and aspirations both for themselves and their children. Multiple assessment trips to Kenya with meeting listening to local people were required gain that understanding. They told us that access to electricity would bring value to their daily lives. They also collaborated with us on developing the mechanism to do that. Only after that could the team provide a technical solution to meet those needs.

Through the work on the Muhuru Bay Microgrid Project we learned about many of the different aspects of a job that an Electrical Engineer encounters on a day to day basis.

The students learned value of HOMER, the renewable energy modeling software that was used to model the microgrid system and determine which parts were necessary for the wind turbines, solar panels and inverters to supply enough energy to the Muhuru Bay community within the economic constraints price range.

The students also learned a significant amount about the difficulties working internationally, especially in a country where communication can be scarce. Gathering data to be input into HOMER was difficult because Kenyan meteorological data was limited and there was very limited site data that could be gathered. More difficulties arose when working with the Kenyan manufacturers. There were times when it was difficult to contact them because there was insufficient information on their websites or they were slow to respond to communications. The team also learned about the International Electric Code (IEC), which was used for all of the design specifications.

This project also taught how to write and submit a Request for Proposal (RFP). The design created in HOMER was included in the RFP and sent to the three different vendors that the assessment team in Kenya. The RFP encompasses everything needed to take the design through to construction.

Lastly, the students also learned a substantial amount on presenting to a diverse group of people. Over the course of the school year the team gave routine updates to classmates and the MBCM group on progress of the project and on subjects such as HOMER, the RFP and status updates.