SOLAR MICROGRID IN RURAL ZAMBIA WITH REAL-TIME CLOUD-BASED MONITORING

Providing a remote Data Acquisition System that connects to the Internet

PROJECT DESCRIPTION

Undergraduate engineering students designed a 2.25kW solar-powered microgrid with integrated Data Acquisition System (DAS) for implementation in Chalokwa, Zambia. The DAS is the innovative feature of the microgrid. The self-contained DAS is easy to install, autonomously self-calibrates and automatically connects the microgrid to the Internet. Engineers can remotely review diagnostic data from the microgrid on a web-based interactive on-line dashboard. This is important because microgrids in developing countries are prone to premature failure due to overuse, economic issues, miss-operation or lack of maintenance. Access to real-time diagnostic information allows engineers to identify incipient failure modes and recommend preventative corrective action, thereby prolonging the lifespan of the microgrid and the life-changing electricity it provides.

The students designed the microgrid system and DAS, and documented their technical specifications. The students worked on the two designs in parallel. The microgrid system was designed based on the needs of the local village, budget constraints and the geography of the site. The DAS design consisted of four parts: hardware design, software design, alert/relay capability and documentation for planned distribution in other locations in Zambia, Cameroon and the Philippines. The DAS is production ready, complete with installation guide and instruction manual.

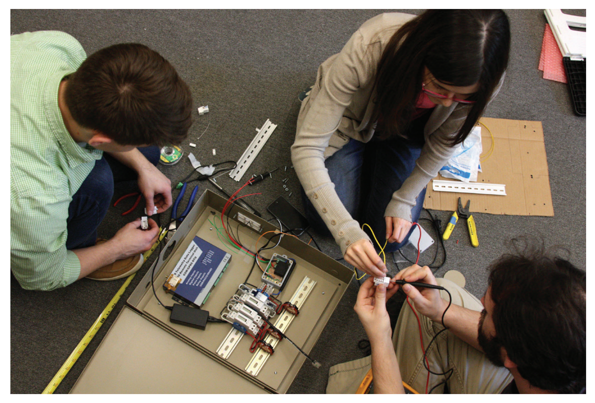
Why is this significant? *The Data Acquisition System allows engineers to monitor the health of the microgrid anywhere in the world. This significantly improves the sustainability and reliability of remote microgrids in developing countries because potential failures can be avoided, leading to longer service life and higher reliability. The system is autonomous and self calibrating and can be used on any remote microgrid in the world.* ***The system has gained the attention of the industry and to date there have been requests for over 20 DAS units for existing and future remote microgrid installations.***

COLLABORATION

The students collaborated with an international team of multi-disciplinary professionals. Their faculty advisor is a P.E. in electrical engineering. The students met with their advisor weekly and with a group of professionals every other week. A practicing electrical engineer in France mentored the students on software aspects of the DAS, and a faculty member and licensed professional engineer in Zambia advised the students on the contextual aspects. The final design was reviewed by another electrical engineer practicing in Zambia.

Although the project is largely related to electrical and computer engineering, energy development projects are inherently cross-disciplinary. Two civil & environmental P.E.s and one mechanical engineer provided the mentoring needed to design key features of the microgrid and DAS. An accountant helped with budget and tracking expenses. Two licensed electricians and an experienced mechanic provided practical insights to the final layout of the DAS.

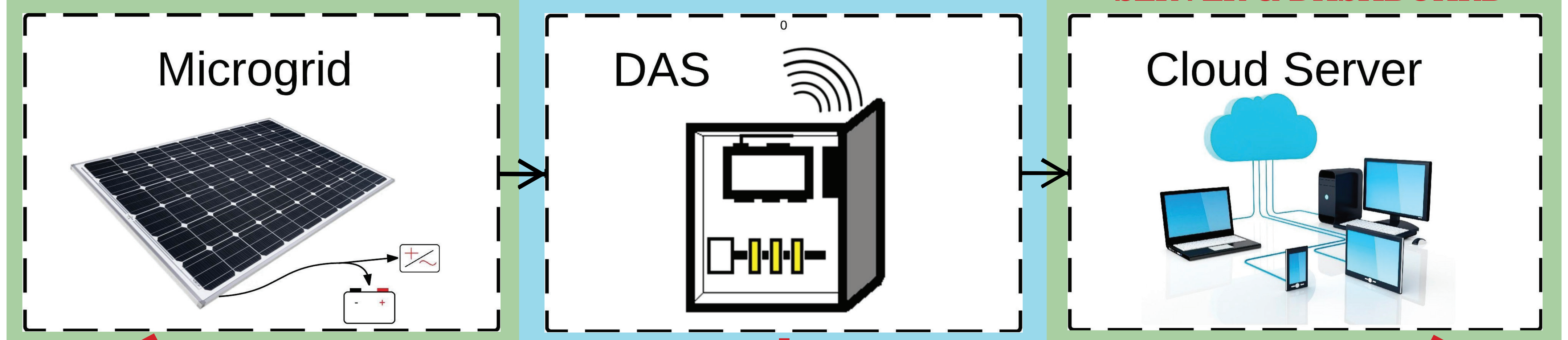
This international effort was a success thanks to the participation of so many passionate professionals in four countries. They put in the time and energy to mentor the students by sharing their expertise and guiding them in the use of industry standards. Over the course of the project the students developed working knowledge in technical documentation, writing contracts, dynamic project requirements and engineering processes; in addition to experience facing international challenges including local codes, culture practices and sustainable business development.

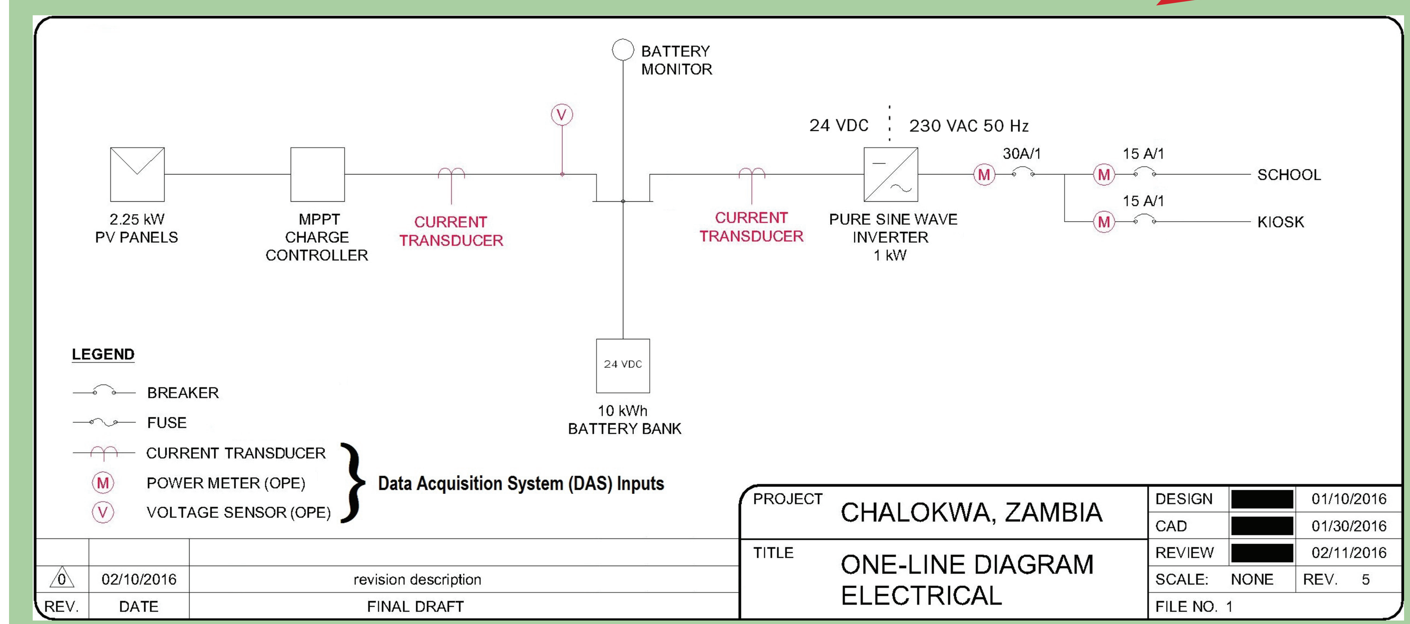


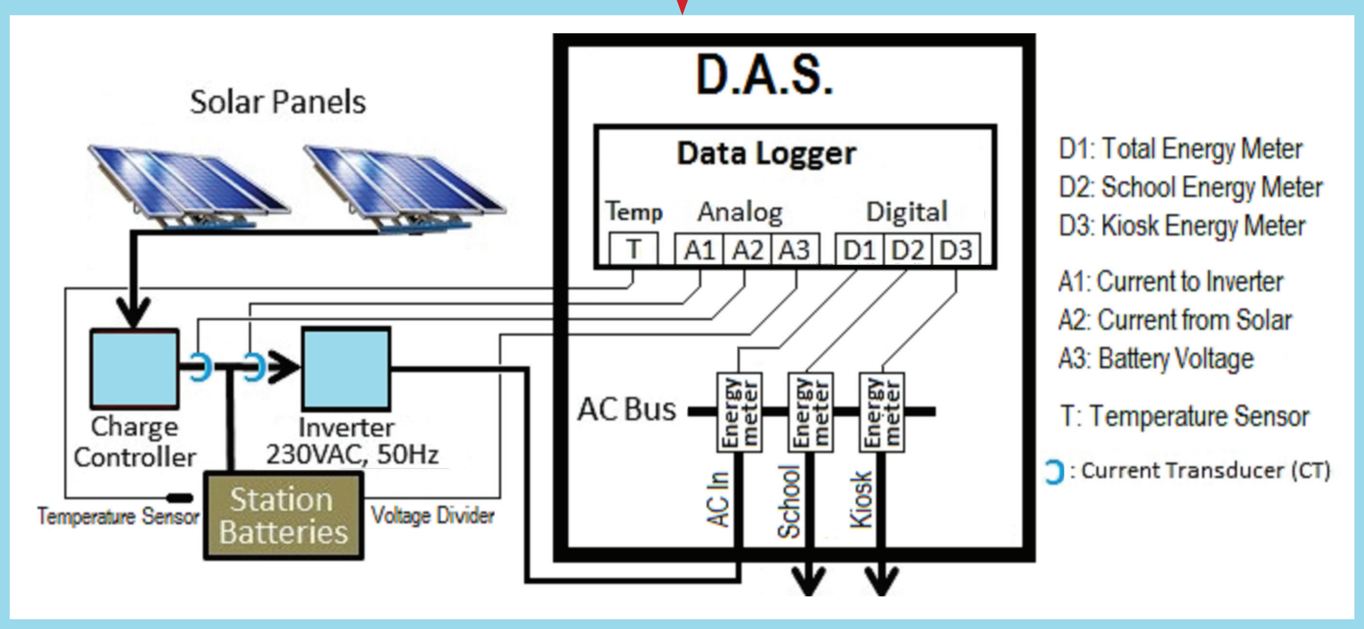
DESIGNING THE MICROGRID

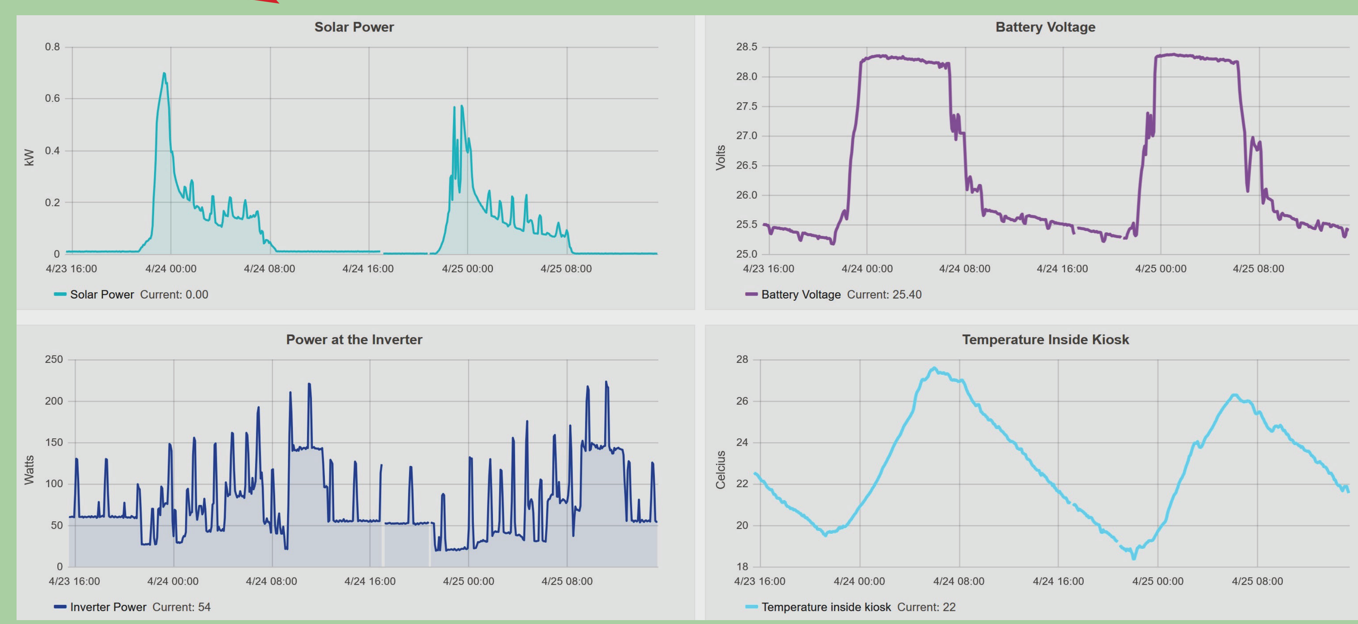
BUILDING THE DAS

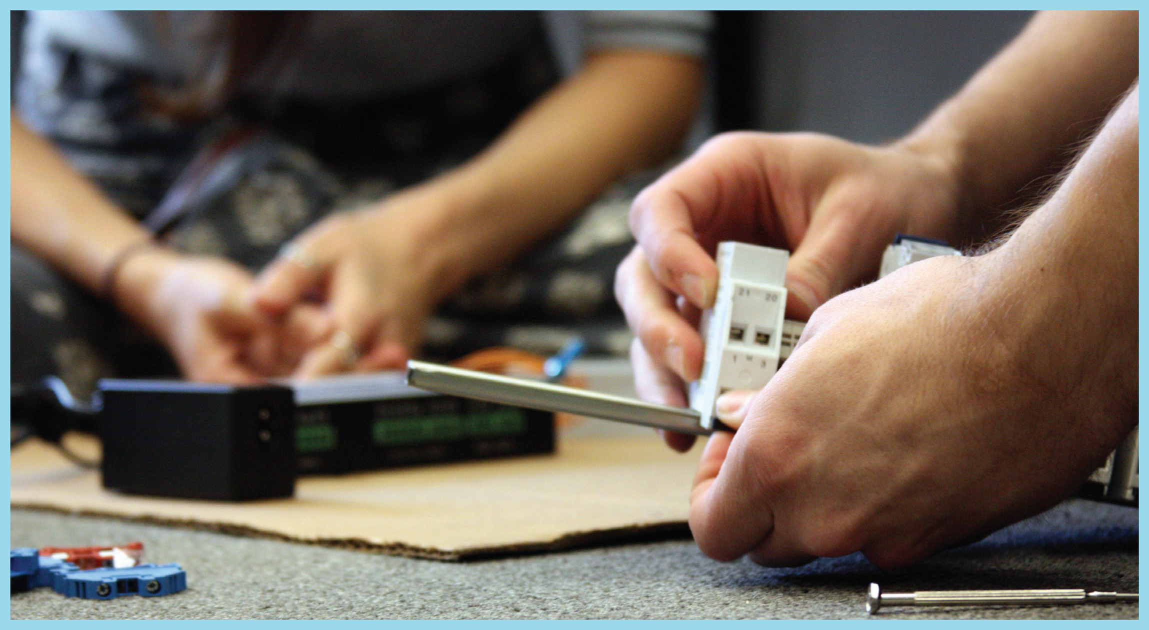
PROGRAMMING THE CLOUD SERVER & DASHBOARD





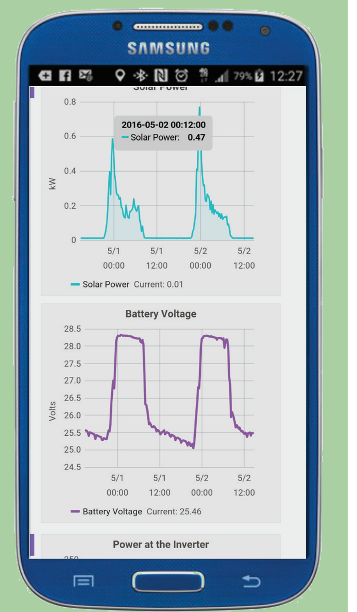






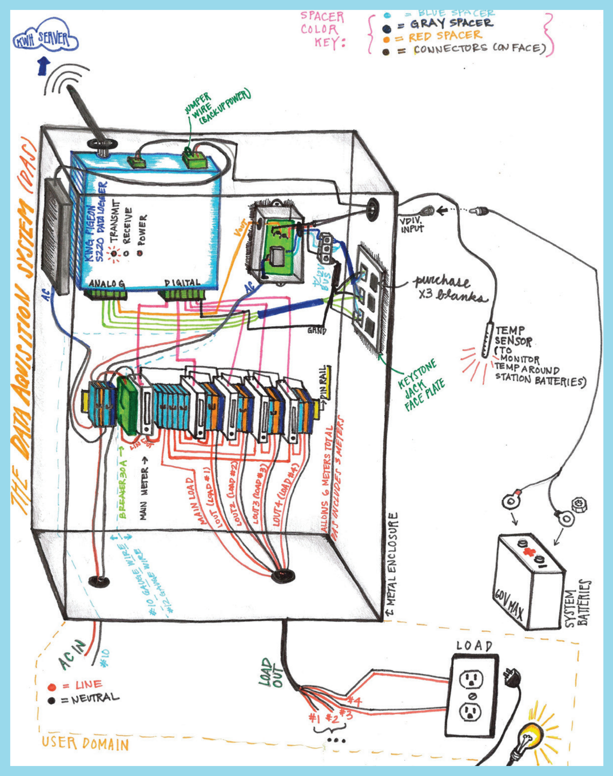
Assembly

Demonstrating the mobile dashboard to the new microgrid operators.

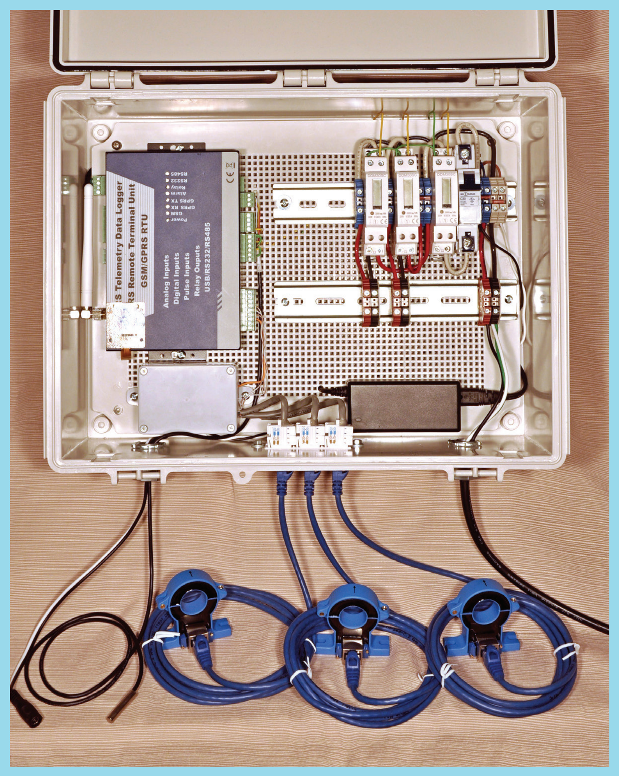


KNOWLEDGE AND SKILLS GAINED

- Applied electrical power engineering, controls engineering, computer engineering and software engineering.
- Applied international and local electrical codes.
- Gained insight about the challenges and opportunities to provide sustainable and reliable access to electricity.
- Used state-of-the-art computer tools to design the microgrid.
- Learned about international business acumen for project implementation.
- Acquired skills to prepare a request for proposal and selected a vendor.
- Wrote the specifications for manufacturers to produce custom parts.
- Experienced the entire product delivery cycle including specification, iterative design, proto-typing, assembly and final production.
- Learned the importance of international teamwork and good verbal and written communication.



Planning



Final Product

BENEFITS TO PUBLIC HEALTH, SAFETY AND WELFARE

The microgrid uses sustainable energy to significantly reduce poverty and improves the outlook for human development, safety, and welfare in the following ways:

- Electricity service to the Chalokwa Primary School improves the educational outlook for the children.
- Household lighting provides security, allows children to study longer, and extends productive hours into the evening for adults.
- Local electricity access eliminates need to travel long distances to recharge mobile phones, saving time, effort, and expense.
- Refrigeration services preserve fish, allowing local fishermen to sell their catch at distant markets for a higher price.
- Because there is little local technical expertise, the DAS is a critical tool for engineers to remotely monitor the on-going operation of the microgrid, improving the outlook for sustainable operation, and providing remote monitoring for energy projects around the world.

Solar Microgrid in Rural Zambia with Real-Time Cloud-Based Monitoring

Abstract

Undergraduate engineering students designed a 2.25kW solar-powered microgrid with integrated Data Acquisition System (DAS) for implementation in Chalokwa, Zambia. The DAS is the innovative feature of the microgrid. The self-contained DAS is easy to install, autonomously self-calibrates and automatically connects the microgrid to the Internet through a cloud server. Engineers can remotely review diagnostic data from the microgrid on a web-based interactive online dashboard. This is important because microgrids in developing countries are prone to premature failure due to overuse, economic issues, miss-operation or lack of maintenance. Access to real-time diagnostic information allows engineers to identify incipient failure modes and recommend preventative corrective action, thereby prolonging the lifespan of the microgrid and the life-changing electricity it provides.

The students designed the microgrid system and DAS, and documented their technical specifications. The students worked on the two designs in parallel. The microgrid system was designed based on the needs of the local village, budget constraints and the geography of the site. The DAS design consisted of four parts: hardware design, software design, alert/relay capability and documentation for planned distribution in other locations in Zambia, Cameroon and the Philippines. The DAS is production ready, complete with installation guide and instruction manual. The DAS has gained the attention of the industry. To date requests have been made for over 20 units for existing and future microgrid installations.

Presently the people of Chalokwa, Zambia have no access to the electrical grid. The microgrid improves the outlook for human development, safety and welfare in several ways. A primary school will have electricity service for the first time, improving the educational outlook for the children. Indoor household lighting allows children to study longer and adults to extend productive hours into later in the evening. Outdoor lighting improves security and reduces encounters with dangerous wildlife. Villagers will no longer be forced to travel several kilometers to the nearest electrified town to recharge their mobile phones, saving time, effort and expense. Refrigeration services powered from the microgrid will let the local fishermen preserve their catch allowing them to be sold at more distant markets for a higher price. Because there is little local technical expertise, the DAS is critical in monitoring the on-going operation of the microgrid, improving the outlook for its sustainable operation. In short, this project **benefits public safety, welfare and the developmental outlook** for the entire Chalokwa community.

The project was led by four electrical engineering undergraduate students, under the mentorship of a University faculty member and dedicated liaison engineers in France and Zambia. The large scope of this project and complex nature of development projects in general made it necessary to have an international, **multidisciplinary and collaborative team**. The broader team consisted of engineers from various disciplines, **licensed Professional Engineers** (P.E.) in the United States and Zambia, **allied professionals** (licensed electricians, machinists and carpenters), and an accountant.

The **knowledge gained** by the students reflected the multidisciplinary nature of the project. The students learned how to design off-grid solar-powered systems. They designed the innovative DAS hardware and software. They gained insights on the influence that social, economic and geographic factors can have on the sustainability of microgrid projects in developing countries. More specifically, the knowledge gained included designing to meet international and local codes, **collaborating** with technical and business experts, planning for long-term sustainability and learning the importance of community involvement and education. The students also learned how to collect and analyze site information from community surveys. The students participated in the field testing, construction and deployment. The DAS has been field tested and is operational; yielding the expected results.

Solar Microgrid in Rural Zambia with Real-Time Cloud-Based Monitoring

Project Description

A. Motivation and Context

Currently, 1.1 billion people worldwide live without access to electricity. This form of energy poverty disproportionately afflicts those living in rural communities. Grid extension comes at a high cost—up to US$20,000 per kilometer—and is often not economically justifiable in isolated rural areas. Stand-alone microgrids are being increasingly deployed in rural areas as solution to energy poverty. This project consists of the design of a microgrid for the community of Chalokwa, Zambia and a Data Acquisition System (DAS) that monitors and transmits diagnostic information from the microgrid to a remotely-viable dashboard. The DAS is important in prolonging the life of the microgrid by providing engineers with the information they need to identify incipient failure modes and recommend corrective action before damage is done.

Chalokwa is an energy-impoverished village located along the Zambezi River in the Southern province of Zambia, as shown in Figure 1. Approximately 300 families—2000 individuals—live in and around Chalokwa. The residents are mostly fishermen or farmers. Team members conducted a site assessment in September 2015 to collect preliminary feasibility data. Forty-eight community member surveys were conducted, along with focus groups and meetings with the chief and government officials. The information collected showed that Chalokwa met the basic developmental requirements, and was found to have sufficient solar resources and the cellular network coverage needed to monitor the system post installation.

Figure 1: Chalokwa is a fishing village without access to electricity.

The microgrid will be installed in a kiosk in the center of the village near a primary school. Basic energy services such as refrigeration, mobile phone charging and battery kit rental will be offered. There are several families living close enough to be powered through wired connections.

The students produced the high-level design of the microgrid, which was turned over to an in-country contractor for implementation. Using in-country contractors improves the outlook for sustainability by fostering technical capacity-building and establishing a supply chain should components need replacement. The DAS, however, was designed, prototyped, and tested by the students. The DAS was a considerable design challenge for the students, and as such the majority of this document is dedicated to it.

B. Microgrid Design

Zambia has a high average insolation (5.5 kWh/m^2/day) making solar-power the obvious choice for the microgrid. The students used HOMER—a microgrid design computer program—to design the system. The design accounts for the budget, solar radiation and load profile along with component cost estimates and assumptions for several factors and parameters, such as the tilt of the photovoltaic (PV) array.

The resulting one-line diagram is shown in Figure 2. A PV array of 2.25 kW powers the microgrid. A charge controller with Maximum Power Point Tracking capability is used to maximize the collected solar power and to safely and efficiently charge the battery. The battery is 24VDC AGM (Absorbed Glass Mat) rated at 10 kWh. AGM batteries were specified over traditional flooded lead-acid batteries in order to improve safety by reducing spillage, maintenance and minimizing environmental impact. A 1 kW inverter supplies 230VAC at 50 Hz to the loads. The detailed design adheres to the IEC standards and local electrical code. The design was reviewed by a licensed professional engineer in Zambia.

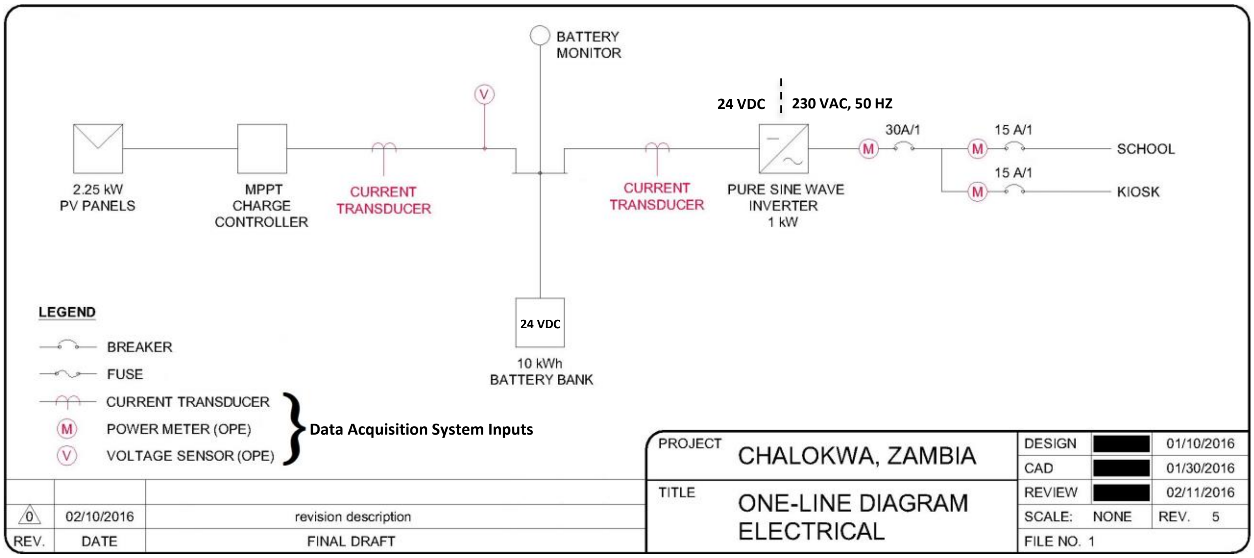


Figure 2: Microgrid system one-line diagram

C. Data Acquisition System – Hardware

The technical requirements of the DAS included:

- Capable of measuring battery voltage, energy consumption for up to five circuits, inverter input current, charge controller output current, and kiosk temperature
- Be powered by the kiosk, self-calibrating and autonomous
- Be compatible with all GSM cellular network bands and transmit data on a minutely basis
- Be self-contained, easily installed, remotely configurable
- Be weather and pest proof
- Have a DC operating range of 10-60V, and a AC operating range of 100-600V

The Data Acquisition System (DAS) was custom-designed because there are no commercially-available products that met the design specifications. The DAS collects samples from the microgrid such as battery voltage and branch current, and transmits the signals to a cloud server via the cellular network. The data are processed, archived and displayed via an online interface for viewing in real-time (see Figure 3). This section discusses the hardware aspects of the DAS.

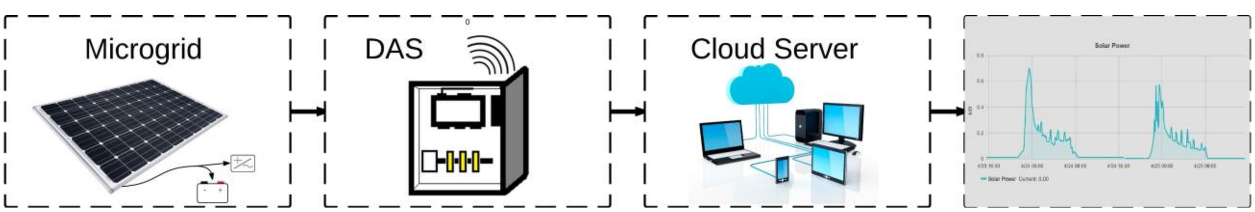


Figure 3: Data Acquisition System (DAS) concept diagram

The DAS hardware consists of a data logger, Current Transducers (CTs), pulse energy meters, an analog voltage divider and a temperature sensor, as shown in Figure 4. The 12:1 voltage divider scales the battery voltage to be compatible with the data logger. The temperature sensor voltage output is internally converted to degrees Celsius within the data logger unit.

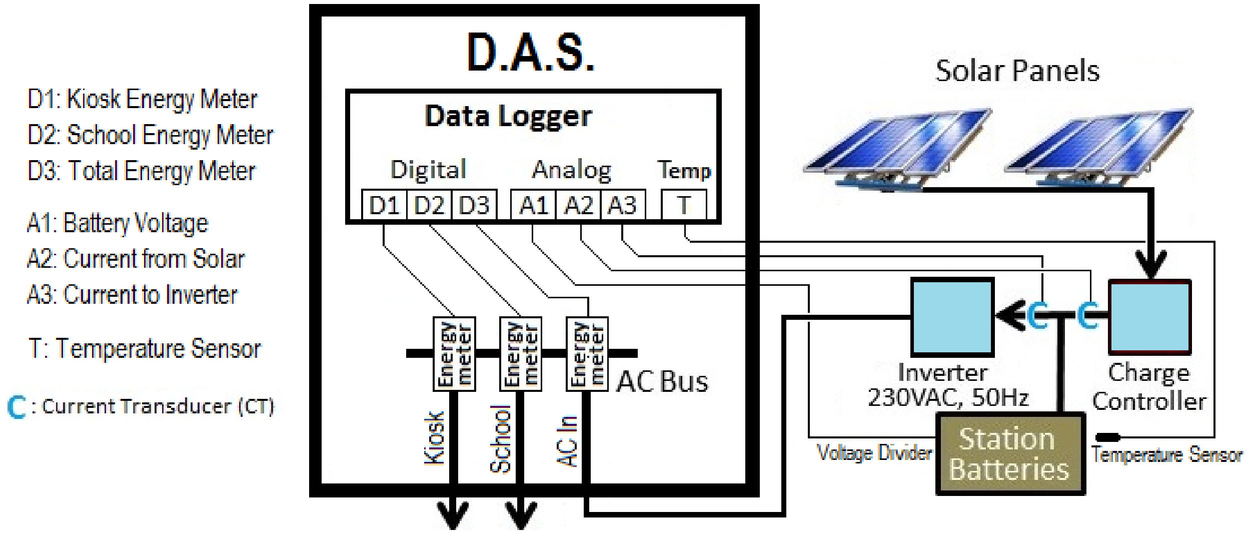


Figure 4: DAS system overview showing data logger device and terminal functions

Data Logger

The DAS includes the King Pigeon S220 model data logger device. The data logger has six digital inputs, six analog inputs and two temperature sensor inputs. Figure 4 shows the data logger terminals which are used for the DAS.

The data logger was programmed by the students to utilize its monitoring and alarm control features. The ports of the data logger have been configured to read incoming signals from the DAS and to respond autonomously if any of these signals indicate abnormal operation. For example, if a temperature sensor reaches high reading, the data logger can send an SMS message to the local technician on site that there is a potential problem. The engineers monitoring the system can also remotely access and interact with the data logger with SMS text commands.

Current Transducers

The DAS includes three CTs. Two CTs measure the current from the charge controller and current to the inverter, and a third CT is included as a spare. The locations of the CTs are shown in Figure 4. To make the DAS easy to install, the CTs use Ethernet jacks rather than the standard Molex connectors to connect the power and signal cables. Ethernet cable is widely available and is capable of carrying the low-current signal and power wires required by the CT. The students worked with a CT manufacturer to custom produce the CTs with Ethernet jacks at low cost. The ratios of the CTs are nominally rated 50 VAC to 4 VDC, with adjustable zero bias and gain. The students discovered through testing that although the factory-shipped CTs had acceptable gain accuracy, the zero bias was large enough to be problematic. To keep the installation simple, the zero bias is corrected by post-processing the data.

Energy Meters

The DAS contains three pulse energy meters: the main meter (measuring the total consumption of the microgrid), the kiosk meter (measuring the consumption at the kiosk) and an additional meter (measuring the consumption of any additional load – for example, a school). The DAS housing allows for up to two additional optional meters. The meters are rated for 230VAC, 32A, and output 2000 pulses for every 1 kWh. They display the cumulative energy consumed on their face for convenience. The pulse output is connected to the data logger.

Wiring

The internal components of the DAS are pre-calibrated, wired and tested before distribution. Users will only need to make the line and neutral connections from the 230VAC of the microgrid to two designated terminal blocks in the DAS, and extend any wires out from additional terminal blocks in the DAS to any desired load. Each load connection is pre-wired to a meter within the DAS as shown in Figure 5. On the final design, the team used two DIN rails in order to accommodate easier wiring.

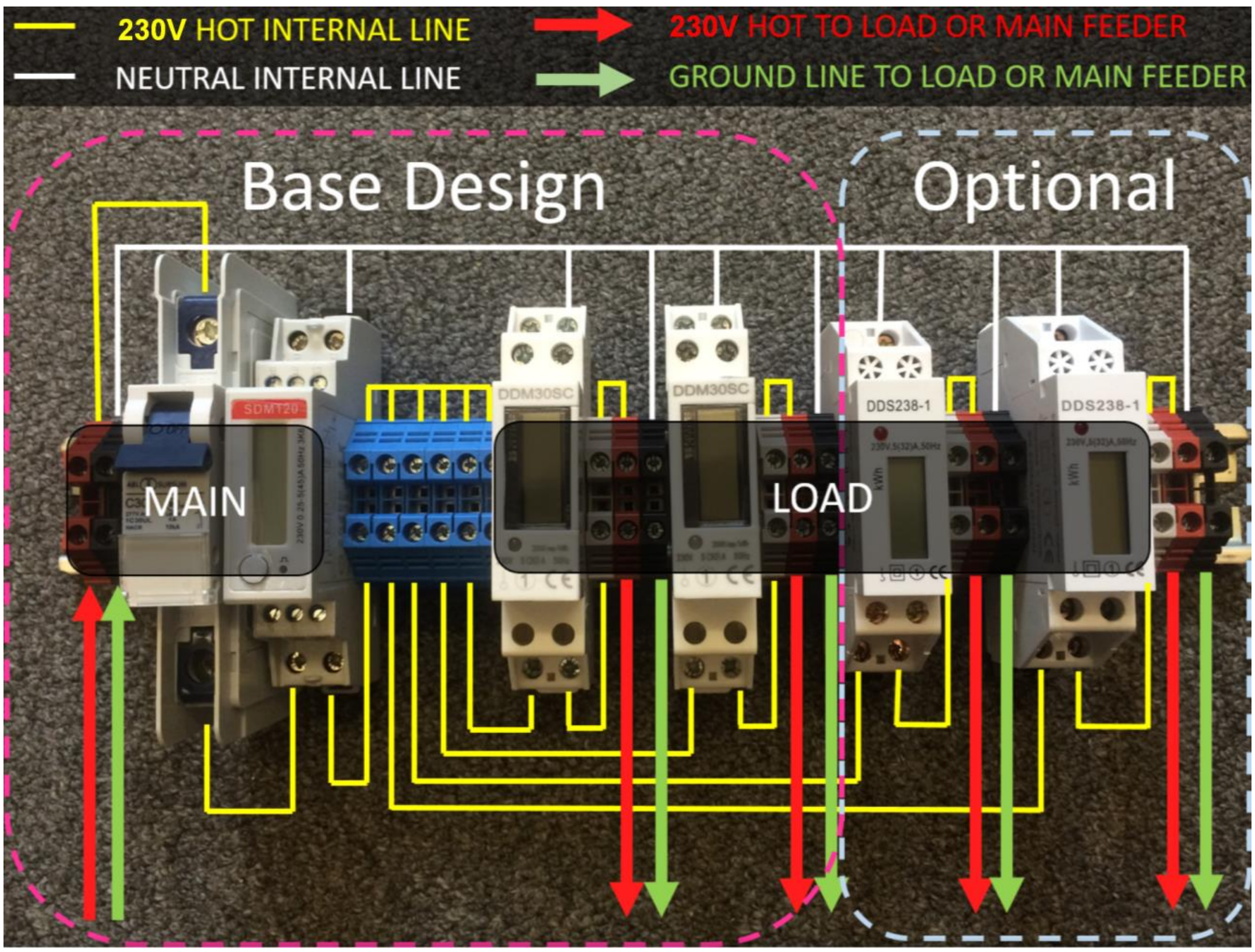


Figure 5: Wiring of a Five Meter System on the Din-Rail in the DAS

After wiring the DAS, the user places a SIM card into a designated slot on the faceplate of the data logger device. The SIM card enables the data logger to communicate with the server. The data logger meters and terminal blocks are installed in a weather and pest proof (NEMA 13) enclosure. Figure 6 (Left) below shows the sketch of the DAS that the students created prior to building the prototype. Figure 6 (Right) shows the completed DAS unit for the Chalokwa microgrid in June 2016.

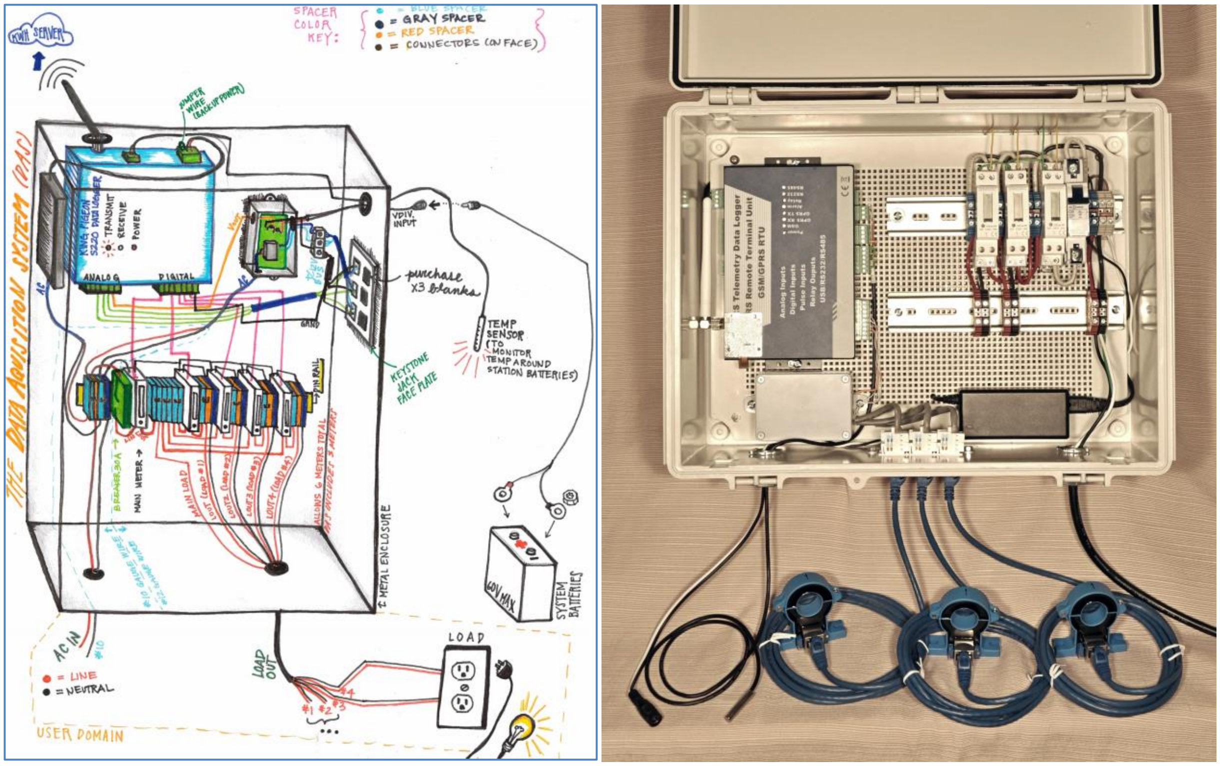


Figure 6: DAS concept sketch (left) and DAS completed (right)

D. Data Acquisition System – Software

The server is based on an open-source operating system built around the Linux kernel. It also uses open-source software that is configured to run services (e.g. web server, secured remote access and data receiving and processing services). The server listens to the port that the DAS is transmitting to and records all the data it receives. To facilitate a useful dashboard, the server also stores the data in a structured way that can be easily and quickly accessed using open-source database software. To implement data protection, as well as improve reliability of data access, multiple computers are utilized via a server farm that provides scalable cloud computing services.

The team chose to utilize active scaling cloud services provided by New Dream Networking's DreamCompute. The team configured the DreamCompute cloud to run Graphite — an open-source software package, written entirely in Python — which is designed to database and serve time-series numeric data. Graphite launches additional cache daemons on demand to support numerous data queries from our dashboard users. This feature, combined with the active scaling of the DreamCompute cloud, means that the number of microgrids we can serve and protect is nearly boundless.

The online interactive dashboard allows the data to be graphically displayed (see Figure 7) on a computer or mobile device, and can also be downloaded as a .csv file. Engineers monitor the data for signs of over-use, incomplete charging or other abnormal conditions. The system is also capable of sending SMS alerts when certain conditions occur. The local operator can correct these conditions before they damage the system, improving the service life of the microgrid and the life-changing electricity it provides.

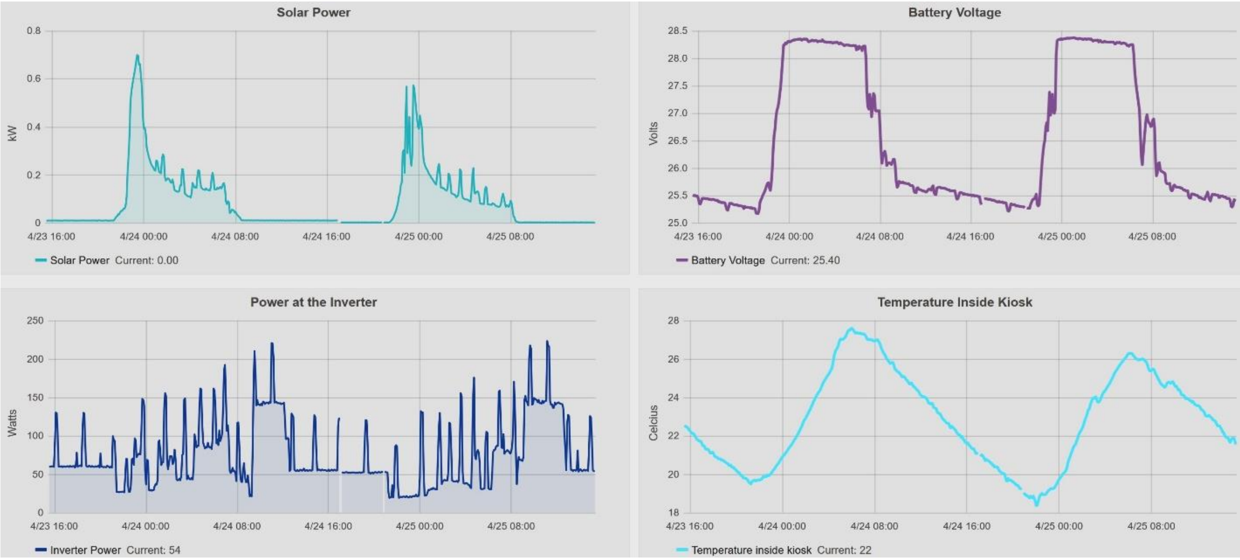


Figure 7: Diagnostic data from a microgrid can be monitored to prevent failure.

Collaboration of Faculty, Students and Licensed Professional Engineers

The students **collaborated with an international team of multi-disciplinary professionals**. Their faculty advisor is a P.E. in electrical engineering. The students met with their advisor weekly and with a group of professionals every other week. A practicing electrical engineer in France mentored the students on software aspects of the DAS. A faculty member who is has a Ph.D. in electrical engineering, and is a licensed professional engineer in Zambia, advised the students on the contextual aspects.

Although the project is largely related to electrical and computer engineering, energy development projects are inherently cross-disciplinary. Two civil & environmental P.E.s and one mechanical engineer assisted with the design of the microgrid and DAS. An accountant helped with the budget and tracking expenses. Two licensed electricians and an experienced mechanic provided practical insights to the final layout of the DAS.

This international effort was a success thanks to the participation of so many passionate professionals in three countries. They put in the time and energy to mentor the students by sharing their expertise and guiding them in the use of industry standards. Over the course of the project the students developed working knowledge in technical documentation, writing contracts, dynamic project requirements and engineering processes; in addition to experience facing international challenges including local codes, culture practices and sustainable business development.

All student team members have either taken the FE exam or are scheduled to take it by the end of May 2016.

Benefits to Public Health, Safety and Welfare

Sustainable energy approaches serve such populations by significantly reducing poverty levels. This project was designed to address the energy needs of the Chalokwa community, and to provide remote monitoring for energy projects around the world. There have already been requests for over 20 DAS units for existing and future installations.

The microgrid improves the outlook for human development, safety and welfare in several ways. A primary school will have electricity service for the first time, improving the educational outlook for the children. Indoor household lighting allows children to study longer and adults to extend productive hours into later in the evening. Outdoor lighting improves security and reduces encounters with dangerous wildlife. Villagers will no longer be forced to travel several kilometers to the nearest electrified town to recharge their mobile phones, saving time, effort and expense. Refrigeration services powered from the microgrid will allow the local fishermen to preserve their catch allowing them to be sold at more distant markets for a higher price. Because there is little local technical expertise, the DAS will be critical in monitoring the on-going operation of the microgrid, improving the outlook for its sustainable operation.

It will also allow other energy projects in the future to foster sustainable practices by monitoring system behavior post-implementation, out of country and in real-time.

Multidiscipline and/or Allied Professional Participation (Community Participation)
The students worked with various teams of people that helped with the business and training aspects of this project – however, the technical design of the microgrid and the DAS were solely from the students' work. The students worked hand-in-hand with professional engineers (electrical, computer, mechanical and civil). They were mentored in International Electric Code (IEC) as well as technical drawing and schematic drafting. Students also worked with other professions including academics, electricians, and a mechanic.

The diversity of professional participation in this project allowed students to prepare for successful careers by taking a real-world project and using their education to make it a working product. In this case, the product will go on to continue changing lives of many people for years to come.

Knowledge Gained
The knowledge students gained was broad. Students gained appreciation for the diverse skills that energy development projects require. The students learned and applied elements of electrical power engineering, computer engineering and software engineering. They experienced the design process from specification through iterative design, proto-type construction and final production.

The four students learned the importance of team work and good oral and written communication, as they interacted with professionals across the globe. They were exposed to the interaction between engineers and the public they serve—in this case the community of Chalokwa.

This project was not just a technical or academic problem. There were aspects of the Chalokwa community and culture that needed to be captured and incorporated into its design – this required patience and active listening. It required students to value the needs and real desires of the locals. The context of this project challenged the students to step away from their lives and image or even experience what life is like without access to electricity.

The students learned that post-implementation plans are just as, if not more, important than pre-implementation design. The data collected from the DAS will be monitored to improve the technical outlook of the kiosk for years to come.

Furthermore, clean energy solutions are not only applicable to rural villages in developing countries – this is an issue that concerns all of humanity. Clean energy solutions are the future of humanity. The knowledge gained from this project will allow students to apply their sustainable design approaches into their own communities. The world is a global village and in order to satisfy its energy demands, without depleting the environment of its natural resources, renewable energy approaches need to be adopted.