Green Energy Distribution in Haiti

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***Abstract*—In support of L'Institut Technique de la Cote Sud (ITCS), with funding through the IEEE Humanitarian Activities Committee, a team from the University of Colorado Boulder (CU Boulder) has led the design/install of a photovoltaic system to provide for daily educational electrical needs while simultaneously serving as a living laboratory for hands-on teaching at the vocational training institute for renewable energy students. The system will exist at the ITCS campus in Coteaux, Haiti, located in the Sud Department on the southwestern peninsula, an area recently hit by a devastating hurricane, Matthew, in the Fall of 2016. Novel to the system will be the inclusing of a Lithium Ferro Phosphate battery bank, which until now has had little exposure to this region. The utilization and performance of this sysetm will be scrutinized throughout its life by the CU Boulder team. Discussed in the following will be the accounts of two trips to Haiti hitherto, the assessment and design processes, as well as community reactions and future plans for further development in the region.**

Fig. 1: An uncharacteristically quiet street corner in downtown Port au Prince, Haiti. Solar powered street lights installed under the previous administration are visible, as well as the piecemeal electrical grid wiring, which currently only supplys power between 7pm - 11pm.

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I. Introduction

At this point in history, Haiti is a country where basic needs such as education, clean drinking water, and electricity, are considered luxuries, particularly in the rural hinterland [1]. Roughly one-quarter of the 10.3 million population has access to electricity; of these consumers roughly half are connected illegally through hazardous splices with the distribution system [1], [2] (Fig. 1). Electricite d'Haiti (ED'H), is the primary load serving entity (LSE) in Haiti, which operates primarily in the Port-au-Prince metropolitan area (see Fig. 2). Reliable electricity access outside the capital is a dream for many Haitians, with only a few small coops operating outside of the limited EDH range. Before Hurricane Matthew decimated the existing grid on the southwest peninsula in the Fall of 2016, the electrification rate in this region was approximately 15% [3]; the tragic event reduced this rate significantly and further displaced the arduous, and extremely capital intensive, installation of a local grid [4], [5].

Recent years of effort through the United Nations Cote Sud Initiative had yielded a burgeoning number of customers accessing the grid; however, Hurricane Matthew dealt the southwest a direct, and consumer diminishing blow [6], [7]. At this point, high voltage, three phase power wires exist along coastal highway 2 in the region west of Les Cayes, but there is no major generating station to accompany this damaged infrastructure. Some small electricity coops, such as SEAC, do exist in the southwest near the Coteaux/Cote-Sud, but production has not yet returned to even pre-Matthew levels.

Fig. 2: A typical concrete wall separating the population from costly investments; in this case, the primary diesel generating station of Electricite d'Haiti (EDH)

There is a well understood causal relation between reliable access to electricy and positive development [8], and in a region with little means for large scale electricity systems, a way to power off-grid communities is through the installation of micro-grids [9]. In the case of Haiti, a solar paradise with an average insolation exceeding 5.0 kWh/m^2/day, solar micro-girds make the greatest case for installation [10], especially with consideration of the $0.50/kWh cost for diesel generation. However, the capital required to install a micro-grid exceeds the typical financial solvency of most Haitian communities, while bankrolling such installations with international funds are often unsuccessful [11]. Micro-grids require constant maintanence; panels must be cleaned, wiring and breakers monitored, batteries maintained and usage relegated to a suitable load for maximal sytem life expectancy. In order to satisfy Haiti's electrical needs through renewable energy microgrids, a green energy educated population needs to emerge which may maintain these investments in local microgrids.

II. Setting

A. L'Institut de la Cote Sud

The Haitian youth is one of the most neglected segments of the population, especially in the rural hinterland sectors where schools are so woefully over-crowded that any juvenile shortcoming is often used as a pretext to expel a student. Young Haitians represent 55% to 60% of the population, the result being a 26 years of age median; however, most of them are lacking education beyond primary school [13]. This situation, combined with a lack of businesses able to offer un-trained workers entry level positions, has created demand for vocational training.

L'Institut Technique de la Cote Sud (ITCS) is a privately funded vocational training center in Coteaux where local Haitians acquire necessary technical skills to participate in a diversifying technical economy. The ITCS began operations in August of 2015 and already has 35 students enrolled in various technical programs [12], the listing of which is shown in Fig. 3. With a foundation focused on sustainability, renewable energy, and environmental management training for young Haitians in the southwestern region of Haiti [14], the ITCS looks to harness local talents to train future generations of sustainability workers and entrepreneurs to tackle Haiti's energy challenges, while developing the local community economy. With a 60-seat auditorium, a computer laboratory, proposed lodging for the professors, and an engaged local community, the ITCS is the first vocational institute of its kind in Haiti [12].

Fig. 3: Shown is a detailed listing of the currently available courses at L'ITCS, including the schedule, costs, and instructors. A tiered course offering is evident, which caters to the wide variety of existing technical skills in the local population.

Aspiring to grow as an incubator for innovation among young Haitians, the ITCS sought out partners in the US such as IEEE and CU Boulder. With

Fig. 4: The first group of Renewable Energy students passes through the gates to L'ITCS after an early morning graduation march through Coteaux in June 2017. The 1000m mountains flanking the institute are seen towering beyond the institute welcome sign.

the help of these partners, the ITCS is indeed growing, and empowering the young Haitian population of the southwestern region of Haiti. The students at the institute are learning sustainable skills to readily participate in the mitigation of the Haitian energy problem.

Although the ITCS started its journey as a renewable energy institute in the summer of 2013, it officially opened to students in August 2015 a renewable energy training program [12], [14]. After a year and half of general courses on sustainability, residential electrical wiring, and troubleshoot the first class of the 'Energie Renouvelables' were exposed to a PV system install with the CU Boulder team in March of 2016. The students eagerly participated in the installation of the system; their hunger to learn was evident. Following this installation and three months of living laboratory system analysis, the first class graduated in June of 2016 (Fig. 4), with members of the CU Boulder team in attendance.

B. Hurricane Matthew

Six years after the devastating earthquake from which Haiti has yet to make a full recovery, Hurricane Matthew sent the southwest peninsula of Haiti back to ground zero [15]–[17]. Approximately 2.1 million people were affected, nearly 20% of Haiti's population, and between 51 and 75% of Haitis southwestern population was abruptly without basic shelter, food, and clean water access [2], [18]. The hurricane made landfall on the TIburon peninsula on October 4, where Coteaux and the ITCS are located, causing widespread destruction (Fig. **??**) Compounded with a destroyed main bridge on the only route between the Sud Department and Port au Prince, the recovery efforts have been excruciatingly slow, and the destruction still complete six months later [19].

According to the index for risk management (INFORM) Haiti has a very high 'lack of coping capacity', which measures the lack of resources available that could help people cope with hazardous events [20]. Moreover, Haiti is the only country that appears in five different global risk indices (INFORM, World Risk Index, Disaster Risk Index, Global Climate Risk Index, and Notre Dame Global Adaption Country Index) among the 25 highest risk countries, with INFORM's 2017 report marking Haiti 'very high' in the risk, vulnerability, and lack of capacity categories [21].

$$\begin{aligned} Risk = {} & Hazard\&Exposure^{1/3} \times \\ & Vulnerability^{1/3} \times \\ & LackofCopingCapacity^{1/3} \end{aligned} \tag{1}$$

Risk, according to equation 1, is a function of hazard existence probability, high vulnerability, and a lack of coping capacity, which are all true in the case of Haiti [22]. All of these metrics were high just before Hurricane Matthew, and as a result the event was a tragedy of massive proportions. The ITCS building took a hit; some structural damage occurred, but it was one of the few buildings in Coteaux still standing after the hurricane and became a place of refuge for the local population.

C. Sustainable Development and AIDME-E

Beyond the more obvious disparities between developing and developed world projects, more subtle aspects such as unchecked assumptions and a lack of community support may jeopardize the success of a project [23], [24]; therefore, the CU Boulder team is employing the ADIME-E approach to ensure a successful result with the ITCS project.The Assessment, Development, Installation, Monitoring, Evaluation, and Exit (ADIME-E) framework enumerates the steps necessary to verify an appropriate project scope, as well as effectively align the project phases for an ideal impact [25]. Awareness of the assets present in the community, using local resources, and distinguishing between the communitys "wants and needs" are crucial steps in the assessment portion of the AIDME-E framework [25], the significance of which can be found in many failings of development endeavors highlighted in Timothy Schwartz's *Travesty in Haiti* [26].

Fig. 5: During the March assessment trip to Coteaux, the CU Boulder team spent time providing courses on photovoltaics and supporting electrical engineering concepts to better understand the current level of engineering knowledge. Seen at the board are Arturo Freydig Avila and Rick Wallace Kenyon (writing).

Although the ITCS/CU Boulder project kicked off in the Fall of 2016, due to hurricane Matthew and subsequent presidential elections in Haiti [19], [27], the assessment trip was postponed twice, first from Nov. '16 to Jan '17, and then finally to March, '17. During a successful trip to Coteaux in March, a provisional PV system (Figure. 6) was installed under the guidance of the CU Boulder team to provide minimal power, due to the lack of basic energy following the hurrican. Addionally, a great effort was expended to facilitate engineering courses to assess the level of understanding of the ITCS instructors and students (Fig. 5). In June of 2017, CU Boulder team members travelled back to Coteaux to assist in the deployment of 5 kW of the full system, distribute training material specifically tailored for the ITCS, and evaluate the performance of the provisional system.

Fig. 6: The power electronics of the 1.5 kW Provisional PV system installed during the the first trip to Coteaux in March of 2017. The inverter will be replaced by two larger Outback inverters in the full system, while the Outback charge controller shown is transferable to the full system.

III. Photovoltaic System

To properly asses the ITCSs need for electricity a detailed houry-load profile of the institute was developed with data gathered from the instructors and personnel at the ITCS, as well as findings from the Spring assessment trip. With this load profile, a suitable system was devised to meet the daily demand with only Solar ouput. See Figure 7 for an overlay of the LFP SOC with these results. At this time, the system is oversized for the consumption of the insitute, because the second floor has yet to be complete and enrollment is reduced due to the hurricane rebuild efforts. However, in the near future such a load profile will be realized, and the entire 11.7 kW system with a 20 kWh battery bank will be at capacity.

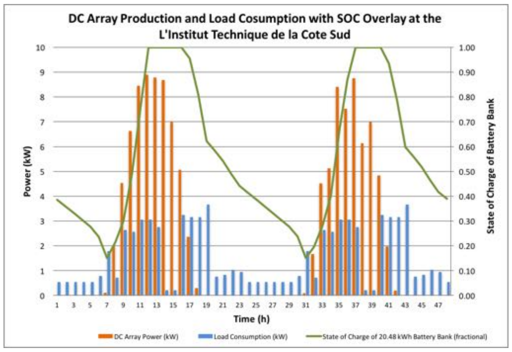

Fig. 7: A overlay depicting three profiles related to the ITCS energy system. In blue is the projected demand profile upon completion and full enrollment. Orange is System Advisory Model irradiance based power output of the 11.7 kW system; first on an ideal day, and then an afternoon thunderstorm day. Finally, the green shows the extrapolated SOC of the LFP battery, with a minimum discharge of 20%, acceptable for this chemistry.

The system was sized with an hourly load profile (Fig. 7) and using the NREL System Advisory Model, HOMER software, and a CVX analysis with Matlab to triple check the results. With a surge of 3.9 kW and daily consumption of 37.8 kWh derived from the load profile, it was determined that a 12 kW solar array with an average daily production of 51.7 kWh would be the ideal system size to satisfy the existing and future needs of the growing ITCS. This solar system could provide sufficient electricity to the institute even with an expansion of 40% beyond the projected consumption. Outback equipment was chosen for the system power electronics, and the bulk of the system would be supplied through LC Renewable Energy Solutions based in Port au Prince, Haiti, to maximize the development potential of the grant. The limited availability of PV panels through LC RES meant that the Sunmodule 260W panel would be used, yielding a balanced system closest to 12 kW of 11.7 kW with three source circuit combiner boxes. See Fig. 8 for a depiction of the panel layout.

As an opportunity for teaching, the optimal fixed tilt angle (15 degrees at a latitude of 18.2 degrees N) was verified by the students under the guidance of the CU Boulder team [28]. Using one of the solar panels from the provisional system, an analog voltmeter, and current meter from the ITCS the

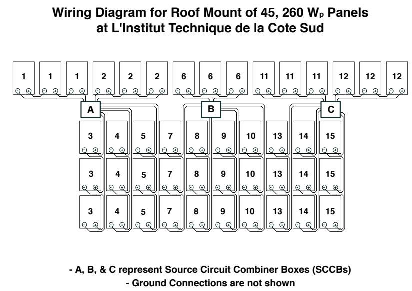

Fig. 8: The photovoltaic panel layout at the ITCS in Coteaux, Haiti. These 260W panels are arranged in 3 panels per string, 5 strings per source circuit in each array. Each array is paired with an Outback FM80 operating with a 48V battery bank.

students were able to gather different voltages and currents according to the panel tilt and solar exposure (Fig. 9). Finally, by calculating power from the values found the students verified the optimal angle. Also, the solar panel distribution over the ITCS roof was determined by measuring the roof and determining which places had the less shadow exposure during the day.

Fig. 9: The optimal tilt measuring apparati set up by the students that the ITCS. With analog current and voltage meters, the power output at various panel tilts could be assessed in real time. This allowed the students the chance to develop a physical relationship with the concept of panel direction.

The system will be installed in three phases: the combined 1.5 kW provisional installation with assessment; the fill out of the first source circuit with 2.25 kW more solar wattage and the backbone of the Outback system installed in June 2017; and finally during Fall 2017 the remaining 7.95 kW will be installed along with the LiPoMnPO4 battery bank and remaining Outback equipment. By dividing the installation process in three phases the ITCS students will have the opportunity to do three solar installations, while spending class time between phases analyzing the current system. Also, courses are being offered during the gaps between the installations in the ITCS, where the students will reinforce what they learned from the installation processes and better prepare for the following installation.

A. LiFePO4 Batteries

The component that limits a solar systems lifespan the most is the battery system [29]. Commonly, lead acid batteries are used in a solar systems battery bank [30]. This makes the photovoltaic system depend on the lead acid battery bank lifespan, which is seldom more than 1000 cycles or about 2 years with a 30% depth of discharge (DOD) [31].

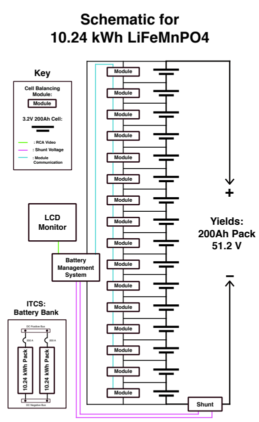

Fig. 10: The electrical arrangement of one portion of the LFP battery bank. This portion is rated at 51.2V, 200 Ah, with a balancing cell module across each cell and a BMS accompanied by a readout screen.

One of the most notable components of this photovoltaic system, particularly in Haiti, is the unusual battery system. The final battery bank will consist of LiFeMnPO4 (Lithium Iron Manganese-Phosphate Oxide) cells as opposed to deep cycle lead acid. The battery bank will have a 51.2V, 400 Ah rating, capable of multiple C discharge rates, rates well beyond the anticipated demand of the ITCS system. The bank will consist of two packs rated at 10.24 kWh each, arraned in parallel. This LiFeMnPO4 system has many advantages compared to lead acid batteries [32] such as:

1) **Long lifespan:** upwards of 2500 cycles with an 80% DOD [32]–[34].
2) **Stable Voltage:** The 3.2V output per cell of the LFP batteries is impressively consistent throughout the discharge cycle, creating a more benign voltage environment for the power electronics.
3) **Transparency:** The system is erected cell by cell in Haiti, allowing a more thorough learning experince for the students.
4) **Monitoring:** The Battery Management System displays the cell voltage and temperature of each cell, complementing the ‘living laboratory’ of the installation.

As prices of LiFePO4 battery cells continue to drop and LiFePO4 distributors around the world keep growing, it is just a matter of time before LFPs to become the go-to battery cell for solar systems [37]–[39]. Unfortunately, these cells are not yet available in Haiti, and this part of the system must be imported [38]. However, this is another opportunity for the ITCS students; with exposure to the newer battery chemistries that are dropping in price, when these systems are available and desired in Haiti, the ITCS graduates will have the requisite knowledge to be leaders in the distribution and installation of these batteries.

B. Plans for Monitoring

Throughout the project, the CU Boulder team will maintain a working relationship with both the instructors/students, and the system at the ITCS. This will consist of detailed messaging through WhatsApp, as well as data transfers from the varioues monitoring systems installed. While the Outback system maintains detailed usage for all of it’s components, the cell resolution of the battery bank is only achievable through the BMS itself, which doesn’t store the data. Currently, an embedded system consiting of an Arduino, Raspberry Pi, and a CANBUS interface is being developed to capture the individual cell performance for a more detailed analysis.

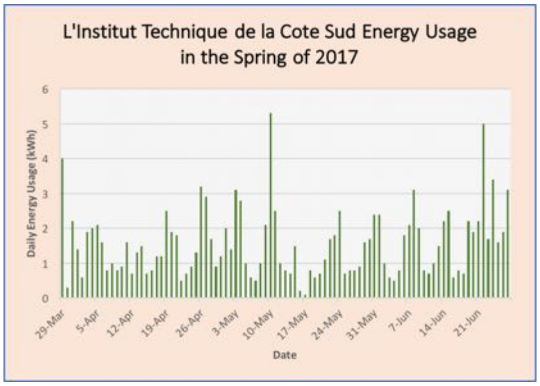

Fig. 11: During the second trip to Coteaux in June of 2017, the data stored by the Outback FM80 charge controller for the previous three months of performance was acquired. Shown is the battery side output of the controller in kWh's for April, May, and June.

IV. Travels

A. March 2017

CU Boulder and the ITCS faculty started travel conversations in September 2016 with the hope to visit Coteaux during the fall break of 2016 if the political unrest surrounding the upcoming presidential election was minimal. Everything was meticulously planned for the assessment trip, but some things cannot be planned, and Hurricane Matthew was one of these. Fall out from Matthew beyond the widespread destruction was a Cholera break out centered in the southwestern peninsula. Combined with the lack of clean water and food, the assessment trip was displaced back by five months. Assessment trip tasks also changed.

Hurricane Matthew destroyed the emerging hopes of reliable electricity from the southwestern region population. The lucky ones had diesel generators, but the vast majority simply lost electricity includ-ing the ITCS. Hence, courses were suspended and the ITCS needed a provisional system to resume operations. It was determined that the assessment trip was a great opportunity to install a 1.5 kW photovoltaic array with a 7 kWh lead acid battery system to fill in the energy gaps. Six 260W solar

Fig. 12: The center of the six 260W panel array installed during the March 2017 trip to Coteaux, Haiti. The installation employs a novel racking design created by local welders with galvanized steel studs that allows easy removal in the event of another tropical storm/hurricane.

panels were installed in addition to four 12V lead acid batteries, a 1500W inverter, and one of the Outback FM80 charge controllers. Although the lead acid batteries and 1500W inverter are not compatible with the full system, they will remain as training equipment for the 'Systeme Renouvelables' courses. An additional benefit from the provisional system has been consumption data from the Spring of 2017 at the ITCS. See Fig. 11 & Fig. **??** for presentations of these data.

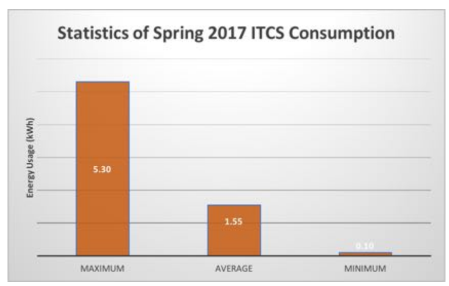

Fig. 13: Comparative representation of usage statistics of the ITCS Provisional PV system, from the end of March 2017 to the end of June 2017.

Througout the assessment trip in March of 2017, the CU Boulder team was able to develop a re-lationship not only with the ITCS students and in-structors, but also the community of Coteaux. These relationships allowed the team to further assess and conclude on the significance of installing such a useful system at the ITCS. Furthermore, iin addition to documenting the physical aspects of the ITCS, two three-hour workshops in French were provided to the students and instructors at the ITCS. The workshops covered basic circuitry theory difference between series and parallel connections, what is alternating and direct current, introduction to Ohm's Law, and Kirchhoff's equations as well as solar energy, safety training, and battery maintenance. From these workshops, the CU Boulder team was able to better determine the appropriate perspective from which to base the training materials under development.

B. June 2017

The second trip to Coteaux was during the second half of June 2017, when the CU Boulder team officially kicked off the installation phase with one on one training and installation of the Outback system with the head instructor, Judeson Rochelin. A second goal for the summer trip was to evaluate the status and usage; this system was found in a satisfactory state, the usage profiles of which can be found in Fig. 11 & Fig. 13. Finally, training material that had been under development since the March trip was distributed to the students and instructors.

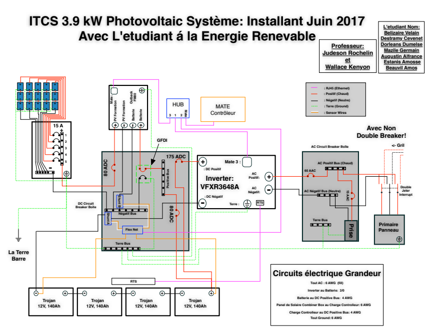

Fig. 14: The full scale schematic of the system installed in June of 2017. The final system will consist of a second inverterd, two more charge controllers, and the LFP battery bank, half of which is depicted in Fig. 10

The system installed consisted of the basis for the Outback system (DC & AC enclosures, local communications equipment, and conduit), as well as one of the two VFXR3648 inverters, and the relocation of the existing FM80 charge controller (three will eventually populate the system) to the main box. One third of the array (15, 260W panels) was installed, yielding a 3.9 kW peak PV output. Finally, a triple pole double throw switch was installed to transfer the main distribution panel source from PV to grid, as the grid is currently active between 7 - 11 pm. The bulk of this work was performed by the lead ITCS instructor, Judeson Rochelin, under the guidance of the CU Boulder team.

Fig. 15: The operational Outback system installed during the June 2017 trip. The final system will consist of a second inverter, and two more charge controllers attached to the right side of the electrically enclosure. Seen is the 7 kWh lead acid battery bank which will be replaced by the 20 kWh LFP bank in the Fall of 2017

While 3G service is often available in downtown Coteaux, the ITCS, which is a mere 5 minute walk for the center of town is a dry spot. Plans to have real time data output of the system, via a prepay smartphone hotspot, were therefore dashed. However, the data for the entire system is locally stored on an SD card, the contents of which will be forwarded to the CU Boulder team by Mr. Rochelin from time to time.

V. Future

Following the final installation trip in the Fall of 2017, the priorities of the project will consist of robust monitoring of the PV system and load, and more importantly the performance of the LFP battery bank. With this data, the CU Boulder team can accurately conclude on the placement of the LFP system in Coteaux, as well as develop an objective set of data on the impacts of the system on the ITCS and Coteaux. Because the region is expected to grow, more of these installations are likely to occur, and with appropriate monitoring of this system, well-informed future systems can be installed, particularly by ITCS graduates.

Fig. 16: The sewing building for the Fond-des-Blancs community, where 10 local workers find steady employment for skilled labor. With PV system, the electricity required could be supplied at a much cheaper, and sustainable, rate than that achieved with the current diesel generation.

While traveling from Coteaux to Port au Prince (a 6 hour journey), the CU Boulder took a detour during the June 2017 trip to visit the community of Fond-des-Blancs. Here, the community leader Ferel Bruno, has successfully implemented multiple self sustaining businesses employing the local population, whom are otherwise often forced to move from the rural community due to a lack of jobs. Entrepreneurship in sewing novel wares (Fig. 16), a boulangerie, water purfication and packaging, money transfers which are otherwise prohibitively expensive, as well as a local grocery store, could benefit enormously from a PV system that would greatly decrease the $0.50/kWh cost of electricity with diesel generation. The ITCS has begun pursuing the option of guiding such an installation, which will provide sustainability to the students through paying jobs, and the Fond-des-Blanc community through solar energy and decreased expenditures.

VI. Discussion

To tackle Haitian energy problems long lasting solutions are required. Developing a solar micro-grid even with a LiFePO4 battery bank is just a temporary solution. What would happen five years after installing such a system were a minor issue to result in an entire micro-grid to failure? The answer, as many abandoned micro-grids display, the system would simply die. However, if there are capable Haitians who could fix these issues the micro-grid would continue operations.

The partnership between the ITCS associates and the CU Boulder team has yielded fruitful installations and trainings for the local population in Coteaux, Haiti. A functioning PV system is in place, with a planned expansion for the Fall of 2017 and robust monitoring systems are installed. Additionally, new battery chemistry, Lithium Ferro Phosphate, is being piloted on the ITCS project with the anticipation of a significanly longer lifetime with greater performance and reduced costs. All of these events have occured, with the ITCS instructors and students actually performing the installations themselves.

The ITCS website says, “Le developpement de nos communautes rurales reste et demeure le premier indice et le meilleur garant de tout processus de dveloppement durable a l’echelle nationale”; “The development of our rural communities remains the first and best indicator of any sustainable development process at the national level. With the help of the CU Boulder team, the ITCS is pursuing the realization of adage.

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