Annual Report (FY 2014, Q1-Q4)

The Earth Institute at Columbia University

Micro-Solar Utilities for Small-Scale Irrigation in Senegal
(Cooperative Agreement No. AID-OAA-A-13-00063)

October 31, 2014

Main Activities and Accomplishments:

At the beginning of the year, the idea of using a centralized PV array to power separately metered irrigation pumps was a mere concept. By year's end, we have built and tested first pilot solar AC pump controller in the laboratory setting and we are preparing to ship it to Senegal for field testing. To get to this point, we spent most of the first year working through the procurement and technical challenges of developing a pre-paid, batteryless solar AC pump controller to serve multiple irrigation pumps. We also travelled twice to the site, once for preliminary scoping and once to officially introduce the project to the community. The community has warmly welcomed the opportunity for this collaboration and is ready to help with the installation, surveillance and daily operation of the unit.

Figure 1. Overview of pilot site area during dry season (October 2013)

This first year was characterized by the following major activities:

- **Site Selection:**
  The village of Gabar, which is located within the Millennium Village Project (MVP) site of Potou, was selected in early 2014 as the site for the first pilot installation. The selection was based on its long-standing record of collaboration with MVP staff, shallow groundwater with a good recharge rate, and a high number of farmers currently using gasoline-powered pumps. The location also is situated alongside the main road to Saint-Louis, making it highly visible for the surrounding communities.

- **Solar PV Array:**
  The solar array for the first pilot installation was designed to provide 8 kW-peak power. This should allow for the simultaneous operation of at least seven 0.75kW pumps at midday, accounting for expected system losses. However, due to max open circuit voltage limitations of the Sakthi inverter, the final installed array only includes 6.8 kW-peak (2 strings of 17x200W panels). Once the first system is installed and running under various solar insolation conditions, we will be able to determine if all seven pumps can run concurrently and if that is necessary to meet the irrigation requirements, allowing us to better size the solar arrays for the next two pilots.

- **Solar AC pump controller:**
  Our market research came back empty when looking for suppliers that have off-the-shelf solar AC pump controllers that can be used with multiple pump loads. We met with multiple possible

suppliers and finally reached an agreement in late 2013 with Sakthi Stabalizer (based in Coimbatore, India) to design and build a solar AC pump controller to meet our needs. Our design parameters required that the controller be able to simultaneously power seven 1.0 kW pumps, that each pump be independent and that each pump would be separately metered. The only constraint imposed upon us by Sakthi was it provide 3-phase, 415V power.

This was the first time that this company had built such a unit, and so it took much longer than anticipated for them to deliver. By June 2014, their unit reached our lab in New York. It included a 15-kW inverter, eight meters with current transformers (7 for the pumps and 1 master), and a PLC for programmatic control. Since that time, our team has been modifying the unit so that we can control it programmatically using a small plug computer and pre-paid payment system.

AC Pumps:
After much deliberation and given the constraints around the Sakthi controller, we opted to use 3-phase, 415V, 0.75 kW pumps. Three-phase pumps are standard on the local market and should be more robust than single phase models and so this seems like a sustainable solution. We originally contacted Kirloskar who has been a major supplier of pumps with the Senegalese government, but their focus on large (>10kW) pumps that are not appropriate for our applications. After meeting with several different suppliers, we have contracted with FlexNRJ to purchase surface pumps (Grundfos CRI 5-5) and submersible pumps (Grundfos SP8a-5). FlexNRJ is a local supplier that can provide support for installation, operation or maintenance issues. However, we are still in talks with several pump manufacturers in India to find a lower-cost option that will likely be resolved for the 2nd pilot installation.

- **Community Engagement:**
  Following upon initial meetings with the community leadership in Gabar, our project team has developed a tripartite MOU between the local government entity (CR Leona), MVP (proxy for EI) and the Gabar community to govern the installation. Roles, responsibilities and ownership of physical infrastructure are outlined, placing the community clearly at the center of the process. Beneficiary farmers will contribute financially for the right to use the new pumping system but ownership will be retained by the local government council who has a long history of collaboration with the MVP. Tariff setting will be done jointly by community leadership and MVP staff. To date the community has finalized the selection of the final location for the solar array (not a trivial matter given that this occupies valuable farmland and will be a permanent installation) and they have also committed to provide fencing and permanent security for the PV array. The community is also ready to provide all the labor necessary for system installation in November 2014.

- **Smart-meter software and AC pump controller testing:**
  Our programmers began to troubleshoot and understand the workings of the pump controller in July 2014. By September 2014, they had completely overhauled the programmatic control

system. Most significantly, the original PLC gave way to a Raspberry Pi B+ (Pi) plug computer. The Pi gives us more flexibility than the original PLC as we are able to write our own control logic using python and also to remotely communicate without having to pass through a GSM modem that requires a SIM card. The Pi receives signals from the Trinity meters (current) and a pyranometer (to estimate power availability from the PV array) and can make decisions about which pumps to turn on. To facilitate access to the Pi, we have designed a separate user-interface for an Android phone that allows the utility manager to set the order of the queue, view current and historical consumption, and to turn pumps on and off.

To test the system, we built a test setup to simulate DC input and multiple loads using light bulbs and power resistors. This allows us to test the basic functionality of the programmatic controls but the actual pump loads could behave differently given the startup current surge that pumps require. This will be resolved during field testing.

Figure 2. AC pump controller as it arrived in June 2014. Note programmable logic controller (PLC) on the open panel (right).

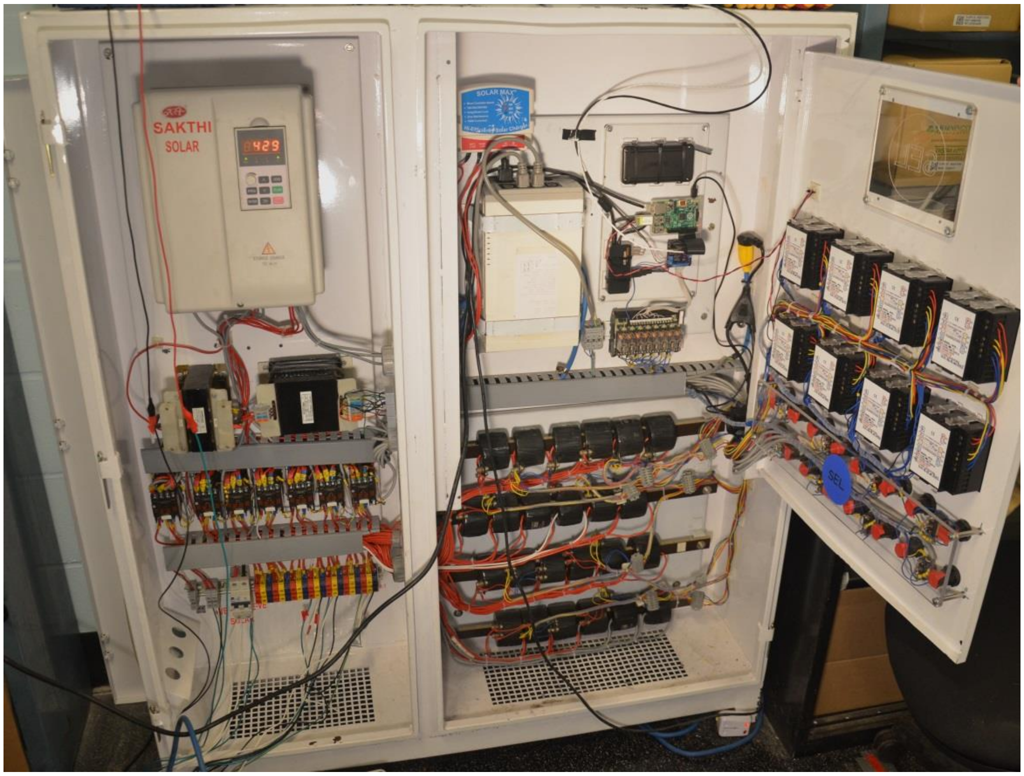

Figure 3. AC pump controller ready for shipping (September 2014). Note absence of PLC, new UPS (white box in upper left of right-side compartment) and Raspberry Pi and other control components on upper right).

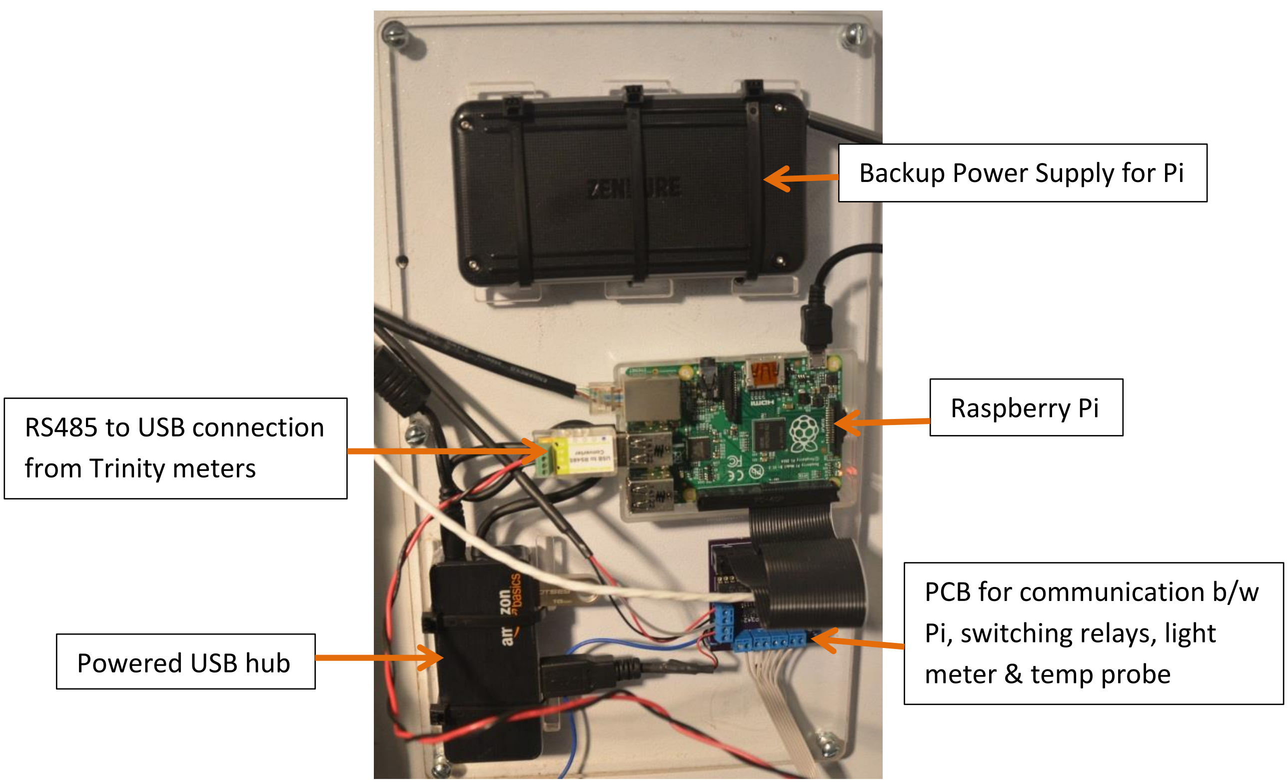

Figure 4. Close-up of Raspberry Pi and control components.

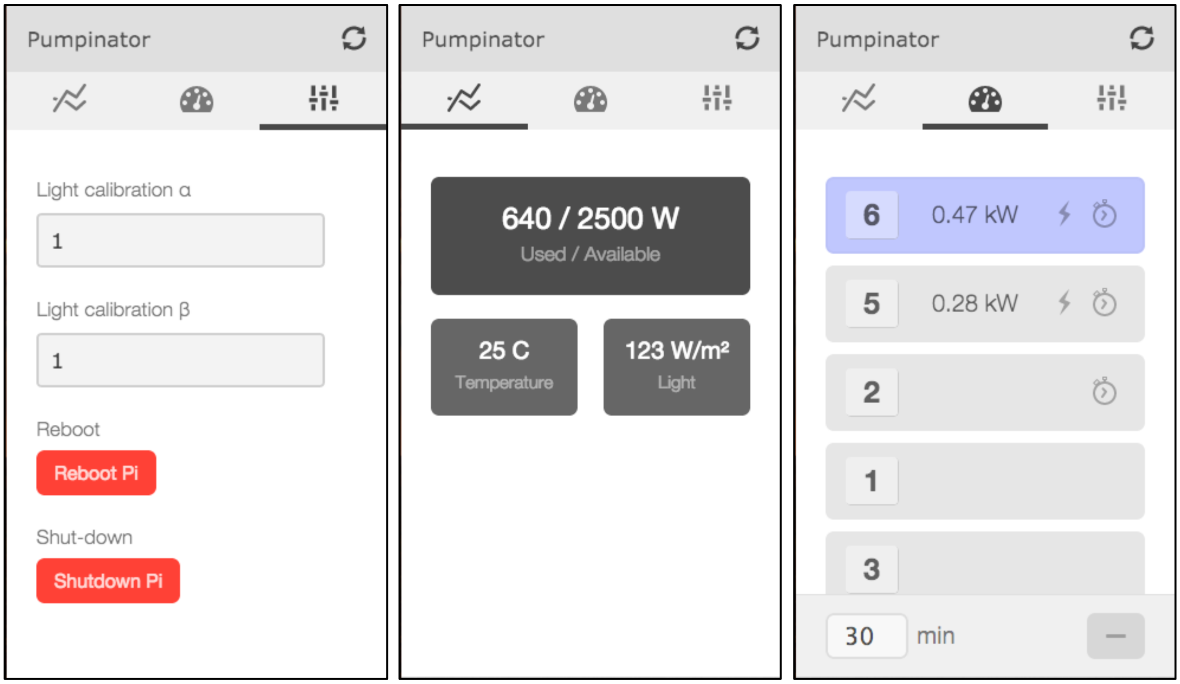

Figure 5. Screenshots of Android phone-based user interface for pump controller.

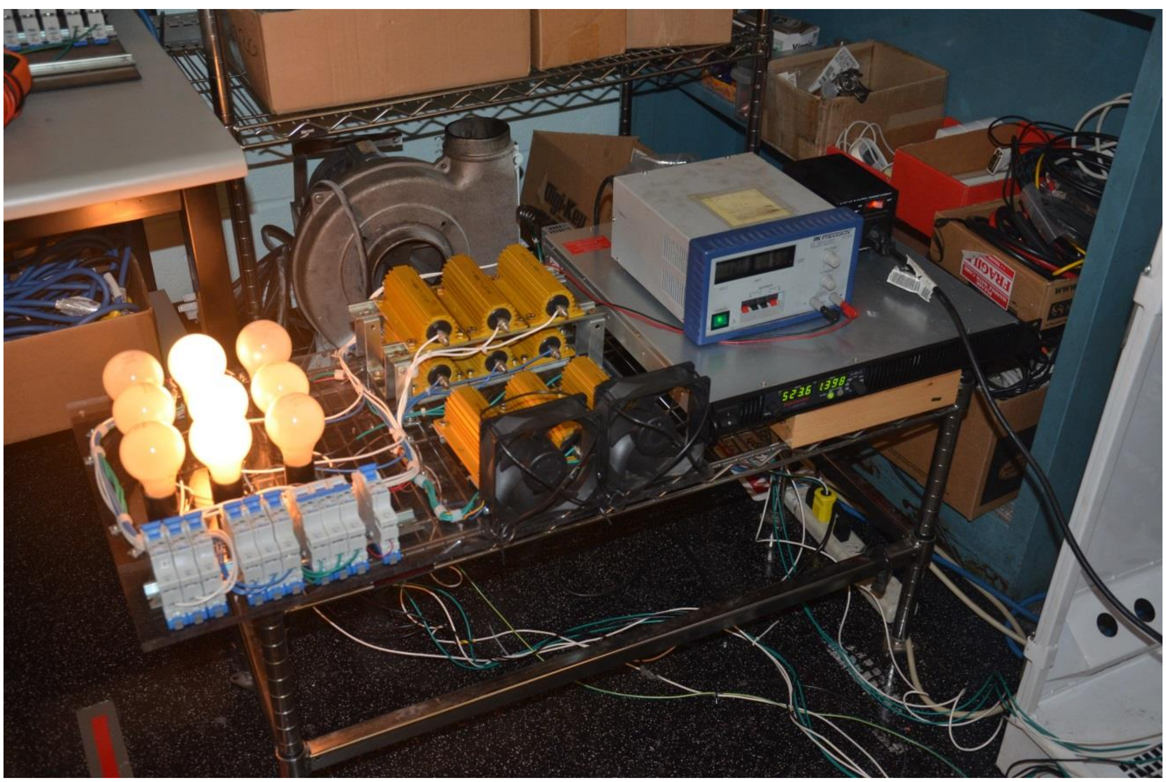

Figure 6. Test setup for Sakthi pump controller in our NY lab.

- **Procurement and Hiring:**
    - *Solar AC pump controller:* The Sakthi Stabalizer solar AC pump controller arrived from India in late June 2014. It has been retrofitted and will be ready for shipping to Senegal in early October 2014. We expect the unit to clear customs and arrive to the project site by early November 2014. A second version of the pump controller was ordered from Sakthi In late September 2014 and we will travel to India to meet with them in October 2014 to finalize design specifications for the new unit.
    - *Solar PV panels:* Solar panels for the first pilot site (40 x 200W, 8kW of Luxor panels) were delivered to the project site in September 2014 and will be installed in November 2014. The panels will be installed on a fixed tilt at 15°. Any additional panels will be used for auxiliary power and also saved for the 2nd pilot installation.
    - *Wiring and Pumps:* Contracts have been signed between FlexNRJ and the Earth Institute to procure seven Grundfos CRI 5-5 surface pumps, 2 Grundfos SP8a-5 pumps (as a backup/alternative), and 3km of $4x6mm^2$ armored cable. The contracts were entered into in September 2014 and payment and delivery is expected by late October 2014.
    - *Sub-award with Millennium Promise:* A budget modification to include an $81,766 sub-award to Millennium Promise was approved by USAID. The sub-award was finalized in August 2014, allowing us to pay the salary of our local field technician, Mahecor Diouf, and to hire local consultants for the installation of the solar array and pump controller.
    - *Hiring:* We currently have the following staff engaged on the project:
        - Mahecor Diouf, Field Technician (Senegal)
        - Brett Gleitsmann, Project Lead (New York)
        - Denis Papathanasiou, Senior Programmer (New York)
        - Jack Bott, Junior Programmer (New York)
        - Francisco Sebastian Rodriguez-Sanchez, Energy Expert (New York)
        - John Humphrey, Solar Expert (New York)

- **Gas-Powered Pump Tests:**
  Our field technician, Mahécor Diouf, conducted a series of pump tests on four existing gasoline-powered pumps in the project zone (see results below). Testing was done primarily to establish a baseline level of fuel consumption for the existing systems. The pumps were tested for one-hour intervals to determine consumption rates and efficiency. We found the pumps are producing roughly $13m^3$ of irrigation water per liter of gasoline at a total dynamic head of approximately 6 meters.

Pump	Gasoline Consumption (L/hr)	Flow Rate (m^3/hr)	Flow per Liter of Gasoline (m^3/L)	Total Dynamic Head (m)
Yamaha YP20	0.9	10.8	12.3	6
Yamaha YP30G	0.8	11.1	13.8	6
ASIA DP80	0.9	10.5	12.3	6
ASIA HT175	0.8	10.6	12.8	6

Challenges:

We remain behind schedule due to the late arrival of the solar AC pump controller. Nevertheless, we are in the process of sending the first pump controller unit to Senegal. The second controller has been paid for and construction should be much faster than it was for the first unit, and so we do not anticipate delays for future units.

The next major challenge will be the actual operation of the first unit in the field. This is of course the challenge that we have been looking forward to since working with the farmers to see how they can adapt to using solar powered pumps instead of their gas-powered pumps is the real point of this entire effort. We are excited to undertake this challenge and don't foresee any obvious procurement or other administrative hurdles that will be in our way.