Sambaza Watts: a nano-grid for accessing and sharing energy

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ABSTRACT

Developing countries and rural areas face an endemic lack of adequate electrical infrastructure. Electrical energy availability is critical in the alleviation of poverty and enables rural residents to participate in the broader economy. Ad hoc solutions form electrical nano-grids *which consist of local electrical generation (typically using diesel generators, wind turbines or solar arrays) with electrical distribution done typically with household extension cords. Usually no metering is performed by the power producers, and therefore a flat rate is charged to all customers. The M.I.T. Media Lab and Schneider-Electric have a proposed low cost solution based on rugged, open source hardware and software which is easily, customized, and enhanced by entrepreneurs.*

INTRODUCTION

Worldwide, 2.5 billion people have no affordable access to a reliable electrical grid. In rural sub-Saharan Africa electrification has only reached one-third of households accounting for 550 million people. In some countries rural access levels to electricity is below 12% [1].

Electrification is associated with an increased standard of living and is needed for charging phone, lighting for handwork and studying in the evening, electric sewing machines, refrigeration, etc.

Figure 1. An ad hoc nano-grid use to charge cell phones from an electrical generator.

Informal electricity connections are commonplace in many developing countries. As shown in Figure 1, a power source may consist of a diesel generator, photo voltaic (PV) cells, banks of batteries, or a single utility connection shared among multiple users. These configurations can be described as *nano-grids*, and have a number of similarities: usually there is no metering; billing is informal, since there is no knowledge of actual use; and there is no automated control over individual circuits.

Having a single utility connection is not always possible for each user, as there are strong political and economic hurtles towards getting connected; therefore, connections are often made illegally. Owning a generator, PV, or batteries faces the same economic challenges. Those willing to make an investment in electrical generation currently do not have access to low cost technology to supervise electrical distribution. The inverse is also true where users are held hostage to unfair billing practices and do not know or understand the true cost of the energy they are using for comparison purposes.

Urban electrification is proceeding with grid-tied electrification to the under-grid population[2], [3]. These areas are near an electrical grid, but the high cost of a grid connection often prevents wide scale adoption. A program started by the World Bank in 2015 subsidizes connections to slum dwellers in Nairobi Kenya. This program lowers cost to an affordable 1,160 Kenyan Shillings ($12USD)[4], and is resulting a significant adoption.

However other solutions are needed for rural areas where villages are far from the existing electrical grid. Nano-grids based on photo-voltaic panels show promise for these rural communities[5], [6].

Sambaza Watts provides low cost, autonomous power distribution for nano-grids which enables energy cooperatives and other business models for electrical generation and distribution. *Sambaza Watts* was developed by a team at Schneider-Electric and the M.I.T. Media Lab. The *Sambaza Watts* prototype provides six branch circuits, each with individual control and metering. Users can control and make payments for an individual circuit using SMS text messaging service from cell phones. Micro payments are done using M-PESA, a mobile phone based micro-payment system ubiquitous in many developing countries. By providing digital access to the nano-grid, customers can now rate competing nano-grids and shop

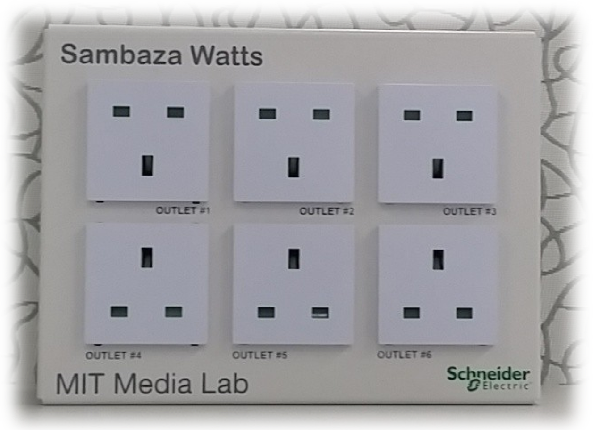

Figure 2. Sambaza Watts electrical distribution for a nanogrid. This prototype supports six independent metered circuits.

for the best provider, bringing a new social aspect to electrical infrastructure.

Urban Electrification

There are approximately 2.5 million slum dwellers in about 200 settlements in Nairobi representing 60% of the Nairobi population and occupying just 6% of the land. Kibera houses about 250,000 of these people. Kibera is the biggest slum in Africa and one of the biggest in the world. Only about 20% of Kibera has electricity[7].

Under a new slum electrification program, customers pay 1,165KES, or 12USD, for a new connection, as compared to 150USD for regular customers. The difference is made up by the Global Partnership on Output-Based Aid (GPOBA) subsidy, a World Bank IDA grant, and Kenya Power's own resources. Consumers under the program can even pay this connection charge in instalments [8].

Most consumers use as pay-as-you-go scheme, buying pre-paid electrical credits, or chits, available at any corner store, and paying for electricity in small increments. In fact, many of the former vendors of illegal electricity are now in the (legal) business of selling Kenya Power chits[9],[10].

Rural Electrification

Rural electrification requires a different approach than urban electrification. Whereas, in the urban areas most people live in an under-grid setting, relatively close to the existing electrical infrastructure, in rural areas the population is so sparse that other solution to electrification must be found.

In the 1930's only about 10% of rural resident in the United States has access to electricity. In 1936 the Rural Electrification Act was passed and now non-profit electrical cooperatives have electrified most of the country's rural areas.

A second approach is to develop micro and nano-grids based on decentralized renewables [5], [11], [12].

Ad-Hoc Nano-Grids

Current electricity sharing solutions consist of a generation source: generator, PV, bank of batteries, or a utility connection, which may be illegal. Sharing is typically done using off the shelf power strips, which act as power distribution units, and extension cords. While this lacks much of what is expected from a modern grid, such as metering and billing practices, it does solve the problem of getting electricity to the underserved. However, this does not come without risk, with long extension cords and overloaded power strips can lead to overloading of circuits and overheating.

SAMBAZA WATTS

Sambaza Watts, shown in Figure 2 and Figure 3 was designed to control low-cost autonomous nano-grids and provide for autonomous mechanism for payment. Sambaza Watts was developed using commonly available, well documented, hardware and software. The architecture was designed to be flexible allowing for various payment systems, and support for DC and AC distribution. Allowing for software customization by the end-user community, facilitates it adoption as a global

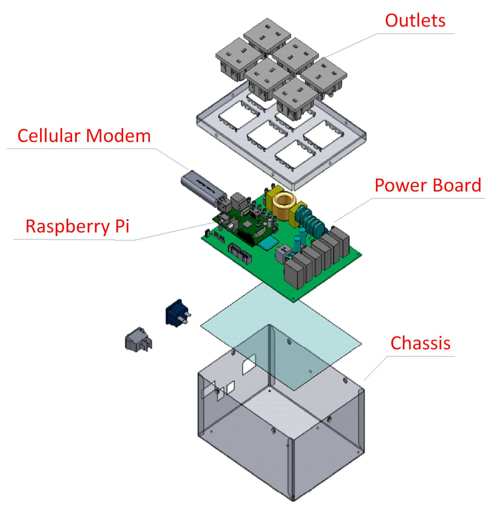

Figure 3. An exploded view of Sambaza Watts prototype. By providing metered power payable using the M-PESA, a mobile phone-based micro-payment system, communities can now more easily establish local energy cooperatives. By using Sambaza Watts to distribute power these cooperatives can more easily obtain capital for purchasing new generation equipment because they now have a consistent and predictable income stream.

nano-grid energy sharing platform.

M-Pesa payment system

The Sambaza Watts prototype was designed to support the M-Pesa payment system. In Kenya 43% of Kenya's GDP flows through M-Pesa with two-thirds of the adult population use this system[13]. M-Pesa allows a customer with their cell phone to pre-pay for their electrical service.

Electronic Architecture

Sambaza Watts is based on a combination of off-the-shelf parts and custom power electronics. Sambaza Watts is controlled by a low cost Raspberry Pi single board computer, which supports the Linux Operating System (OS). The Raspberry Pi was selected because of its low cost, immediate availability, and large community of open-source developers.

We selected ArchLinux for our OS. It contains the necessary drivers for various network interfaces. Our prototype uses a Huawei E173 3G CDMA USB modem for network connectivity. The E173 has strong community support, including libraries for multiple programming languages.

Power distribution, control, and measurement are performed on a circuit board designed and built by the IT Business of Schneider Electric. Power measurement is performed by a MSP430 microcontroller using 16-bit Sigma Delta ADCs to monitor 6 current shunts, and one voltage measurement. Power statistics are calculated (RMS Voltage and Current, VA, Watts, and Watt Hours) in real-time.

Control of an AC electric circuit is done using latching relays and the MSP430. The MSP430 has knowledge of the voltage wave form and is able to switch the relay at the voltage zero crossing, minimizing wear and tear on the relay contacts. The use of latching relays also allow a smaller and more efficient power supply to be designed, because the relay coils only have to be energized briefly during switching events. Also, with microcontroller control only one relay can be switched at a time so the total active power is greatly reduced.

The MSP430 provides a serial interface to the Raspberry Pi, which exposes all measurements, and allows for control of the circuits.

Figure 4. Sambaza Watts being demonstrated at iHub in Nairobi Kenya[13].

Software Architecture

The Raspberry Pi runs the ArchLinux distribution of Linux. The system's software architecture is designed to be simple enough to be modified by a student during their first programming course. The three major components are programmed in Python.

The Event Handler is the main controller. It manages the list of registered users, their account balances and outlet status. The Event Handler updates the user balance when it receives a payment event from the SMS monitor and generates status messages for the users and the owner(s) of the nanogrid. It interfaces with the Power concentrator to control the outlets.

The SMS monitor receives new SMS messages from the GSM modem. When a new message is received, it parses the message and creates an event which it then passes to the Event Handler. Messages are from the user (turn on/ off, request status); owner or the M-Pesa mobile payments.

The SMS monitor also sends outgoing SMS messages, such as low balance warning, power consumption, and status of the device.

The power concentrator gets information from the power monitoring microcontroller using a proprietary protocol over a serial bus. Commands are sent which can get all the power and energy statistics, as well as control of the relays. This information is digested in the event handler to keep updating the balance for the users.

RESULTS

During the summer of 2014, 12 *Sambaza Watts* prototypes were brought to iHub in Nairobi Kenya by a team of graduate students from the M.I.T. Media lab for evaluation. Controlled testing was done showing the prototype was able to accept M-Pesa payments, while metering and controlling power to a community television. As shown in Figure 4 the prototype proved popular with the community of technology entrepreneurs at iHub, and students at the University of Nairobi who received prototypes for field deployments.

FUTURE RESEARCH

Schneider-Electric is looking for additional collaborators that can perform additional field trials with Sambaza Watts. While initial steps were taken to work with iHub in Nairobi, we are seeking to interact with more local communities where Sambaza Watts can be customized to local needs and deployed to communities. Customization can include varying tariffs based on availability of surplus solar power and peak shaving customers who overload the nano-grid. Additional modifications can include hardening the unit to local environments.

More research into hardening Sambaza Watts to the local environmental and operating conditions is necessary. The impact of dust and sand, moisture permeability ratings and high temperature is currently not addressed.

Additionally, the Sambaza Watts prototype was designed with mechanical relays which can be problematic when used in the low voltage DC nanogrids associate with photovoltaic installations. These relays perhaps should be replaced by solid state switches to control DC circuits.

The Sambaza Watts/ design can be further cost reduced by replacing the USB cellular modem that is used for connectivity with old or broken Nokia cell phones. Whereas, a phone might have a broken keyboard or display, the phones can still be used by Sambaza Watts by connecting to the phone via the USB port on the phone and using AT command to send text messages[15].

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