A Prepaid Architecture for Solar Electricity Delivery In Rural Areas

Daniel Soto
Columbia University
New York, NY, USA
1-212-854-3179
ds2998@columbia.edu

Matt Basinger
Advancing Energy
Dover, DE, USA
1-646-450-0506
m.basinger@aeconsults.com

Sebastian Rodriguez-Sanchez
Columbia University
New York, NY, USA
1-212-854-3830
seb.rdz@gmail.com

Edwin Adkins
Columbia University
New York, NY, USA
1-212-854-2956
jea98@columbia.edu

Rajesh Menon
Columbia University
New York, NY, USA
1-212-854-2956
rajeshmenon.mrg@gmail.com

Natasha Owczarek
Columbia University
New York, NY, USA
1-212-854-2956

Ivan Willig
Columbia University
New York, NY, USA
1-212-854-7306
ifw2104@columbia.edu

Vijay Modi
Columbia University
New York, NY, USA
1-212-854-2956
modi@columbia.edu

ABSTRACT

This paper demonstrates a model for electricity delivery and revenue collection in a rural context with the potential to increase the reliability of service delivery and lower operating costs compared to traditional fixed monthly fee utilities. The microutility in this paper provides power on a pre-paid basis similar to the way cellular phone air-time is sold. This system uses Short Message Service (SMS) messages sent over the Global System for Mobile Communications (GSM) networks for communication allowing installation in any place within reach of a GSM tower. Several of these individual microutilities are monitored and administered via a central server. These consumers in these systems are using modest amounts of power consistent with lighting usage. Some customers are are unable to maintain positive account credit suggesting a benefit to the prepaid approach. These microutilities are currently installed and have been providing power to approximately 170 households in Mali and 38 households in Uganda beginning in April–August of 2011.

1. INTRODUCTION

Modern electricity services are almost absent from rural areas of developing countries. Some 1.4 billion people lack access to electricity with 85% of them living in rural areas.[3] Rural customers gain access to energy services by purchasing kerosene and drycell batteries and by paying for battery charging services. Survey data in the Millennium Villages show that these expenditures are a significant fraction of household spending. Despite this evidence of spending on energy services, grid extension has not occurred in many areas. Even modest levels of electricity bring the benefits of clean lighting and communication through cell phones.[4] Higher levels of electricity allow for mechanized power and can directly increase incomes in rural areas.[9]

One barrier to the extension of the existing grid to rural areas is cost. Grid extension costs can exceed $2000 USD per household, prohibitively high even for many governments in developing nations.[12] Moreover, grid extension to remote areas requires that capital be allocated in large lump sums to pay for the installation of the expensive, high voltage power lines that are necessary prior to individual connections. Even if capital costs are raised and grid extensions constructed, reading meters and collecting tariffs in remote locations pose significant logistical problems, driving up operating and maintenance costs for power customers.

Lacking grid connections, customers turn to costly alternatives for power: batteries, kerosene, solar panels and travel to grid connected locations are relied upon for services that would be more efficiently (and usually cleanly) delivered via a grid connection. Such substitutions are often at a much higher price per unit of service than grid connections in the same country.[10, 5, 16] Chemical energy sources such as kerosene, candles, and dry cell batteries are often used for lighting. Kerosene, a very common lighting fuel, carries the drawbacks of heat, soot, and fire risk. While single-use chemical fuel is used for lighting, rechargeable batteries are often used to power communication and entertainment devices such as cell phones and televisions. Since electrical energy production does not exist in most remote areas, the devices themselves, or large rechargeable batteries, are instead carried to stores that offer charging services. Such recharging of cell phones and lead-acid batteries carry small purchase costs, but the cost per unit of electricity is much

higher than that of electricity provided via a grid connection. For cell phone charging, the equivalent per kilowatt-hour cost can exceed $20. Wealthy consumers in some markets are able to purchase solar home systems that provide modest amounts of convenient power but these require a large initial investment. In Kenya, investment in individual solar home systems has been considerable, but such systems are primarily owned by the wealthy.[8] Solar home system users in Bangladesh report that the costs of financing associated with solar home systems are a hardship.[11] At a lower price, solar lanterns with rechargeable batteries are available and can provide light and cell phone charging but cannot provide power for television or other common demands.

In an environment in which the most common affordable energy sources have significant drawbacks and household electricity generation services remain out of reach for most consumers, an opportunity for a new service model arose. By combining distributed generation with cellular communication, we demonstrate that a modular microutility can deliver power to remote locales using a robust prepaid collection system. This effort builds on previous work in prepaid electricity and GSM-based communication in rural areas. Prepaid metering for grid electricity has been successfully demonstrated in South Africa and proven as a viable business model.[15] We also build on previous work using SMS to gather data from remote areas.[1, 7] Also related are efforts to build autonomous metering systems using GSM and SMS.[13] Researchers have demonstrated a system for gathering of solar panel electricity production and battery health over SMS networks.[14, 6] Simpa Networks is also providing a solar home system that can be paid for in installments.[2] Our contribution is the demonstration of a prepaid system in a rural microgrid.

Distributed solar generation, though costly, can be deployed gradually, without the large lump expenditures required for grid extension. By using the telecommunications networks that have been established in many rural areas of developing countries, these systems can operate with remote supervision and administration. With customer billing and monitoring of the system done remotely using wireless communications protocols such as SMS, the travel costs to the site can be reduced by eliminating routine visits and restricting travel to necessary maintenance visits. If manufactured at a cost-effective scale, this architecture could make for an attractive business proposition for a utility, which could deploy the systems as an alternative in areas where grid extension is prohibitively expensive. The concept is similar to that of a power-purchase agreement whereby an outside investor provides the capital to pay for solar generation, while the power is consumed by a private party that pays solely for the electricity. By focusing on an approach that aggregates several households together, we hope to circumvent the difficulties of end-user finance by creating an investment opportunity for an enterprise. The selling of excess power from cellular towers is a similar idea to this where the capital for energy generation is paid by a cellular communications provider and the electricity services are sold to consumers. Meanwhile, this architecture allows for the construction of a rich data set on power consumption following the introduction of near-grid-quality power to previously unelectrified sites. Such data is of use to researchers and business people seeking an understanding of energy purchasing patterns in rural, unelectrified areas.
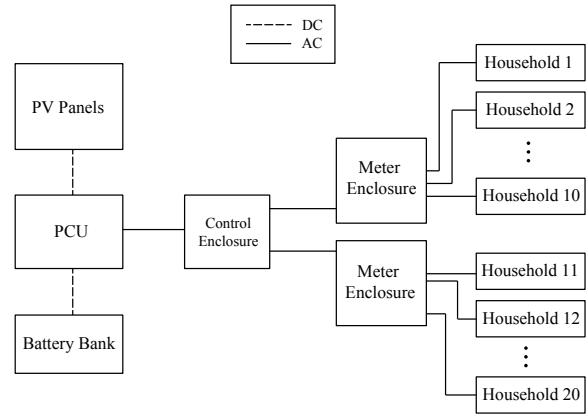

Figure 1: Power Generation and distribution. Power is generated by an array of photovoltaic panels. Output of these panels is used to charge a bank of batteries. An inverter is powered by the batteries and power is distributed through busbars and meters before distribution to the households.

2. ARCHITECTURE

This section describes how the system allows for the generation, metering, distribution, and switching of photovoltaic-generated electricity for consumption by households. As implemented, the system allows power to be sold to consumers on a pre-paid basis. Each generation and metering system provides power to a small network of up to 20 homes. Payment and monitoring takes place via local cellular networks, with commerce functions performed by a central server that allows for the remote administration of multiple generation and metering systems.

2.1 Generation, Metering, and Distribution

Power is generated and distributed locally from a small central facility placed near a group of 10 to 20 customers. This facility consists of a weatherproof structure to protect the electronics, solar panels, batteries, a power conditioning unit (PCU), and three custom cabinets containing metering and communications electronics. Figure 1 shows the power flow and voltage levels between the generation and metering components and the households. The battery bank has a nominal voltage of 48 VDC and power is delivered to consumers at 230 VAC.

The central facility is approximately two meters by two meters by three meters tall with solar panels mounted on the roof. Electricity generation is provided by an eight-panel array of 175 W monocrystalline panels, yielding 1.4 peak kW (Sharp NT-R5E3E 24 V 175 Wp). The array power is received by the power conditioning unit inside the structure, which carries out the functions of battery charging and conversion to AC power. The PCU (PPS Enviro Power, Single Phase SOLA ECO Inverter) contains a battery charger, inverter, maximum power point tracker, generator input, and an RS-232 interface for data collection. The inverter supplies power to the system and the customers at 230 V and 50 Hz. Power produced while the sun is shining is stored in a bank of valve regulated lead acid (VRLA) (HBL T Series

Tubular Gel VRLA 48 V 360 Ah) batteries. This battery bank provides power to the inverter during the nighttime hours. The output from the inverter is fed into the first of the three custom cabinets. The first cabinet is the control enclosure which contains communications hardware and a plug computer. As shown in Figure 2, power enters this control enclosure, where it is measured in order to monitor the total power consumption of the system. The AC power is then distributed from the central control enclosure to each of the two metering enclosures. Inside the two metering enclosures, the power is distributed by bus bars and is individually metered before being sent to households. Each metering enclosure is capable of distributing metered power to up to 10 households, which are individually wired to a meter in a star topology where each house has an individual wire running to the generation site. Each connected household is provided with energy-efficient light bulbs (5 W Philips LED), switches, and a plug outlet for appliances. Power to each of up to 20 households flows through a commercial metering product (Smart Circuit SC20, EED) that communicates via an ethernet interface. This device measures consumed power and switches a relay, disconnecting consumers from the power supply. Each metering enclosure has 10 SC20 devices on an ethernet switch, which is connected to another ethernet switch in the control enclosure. A Linux plug computer, (SheevaPlug) which is connected to the switch, runs a custom Python software application to monitor loads, switch circuits and communicate with a central server. The plug computer polls each of the 20 meters as well as the main meter for power consumption data. Information on each household's balance of remaining credit is stored on the computer. As power is consumed, credit is subtracted from each account according to the per-kilowatt-hour price of electricity. The custom metering software allows for the electricity tariff to change based on the time of day, the instantaneous power drawn, or the overall daily energy demanded.

This software also controls communication between the local system and the central server. The system communicates with a central server via SMS messages sent over the GSM network. At hourly intervals, the computer sends the accumulated daily consumption of each household to a central server for storage in a central database for later data retrieval. The meter also listens for messages from the central server over the GSM network. These messages include commands to add credit to an account or to turn a circuit on or off.

2.2 Communication

The proposed architecture allows multiple installation sites to be monitored and administered from a central server (see Figure 3). The central server communicates with customer cell phones and the local meters using Hypertext Transfer Protocol (HTTP) and SMS messaging over the GSM network. For communication to occur between either the customer and the server or between the meter and the server, a communication gateway is needed between the GSM network and the internet. The communication gateway can either be provided by the local telecommunications operator or by employing custom software in conjunction with a modem. In Mali, we initially used the latter to relay messages from SMS directly to HTTP before contracting with the local telecom operator to create a service that converts
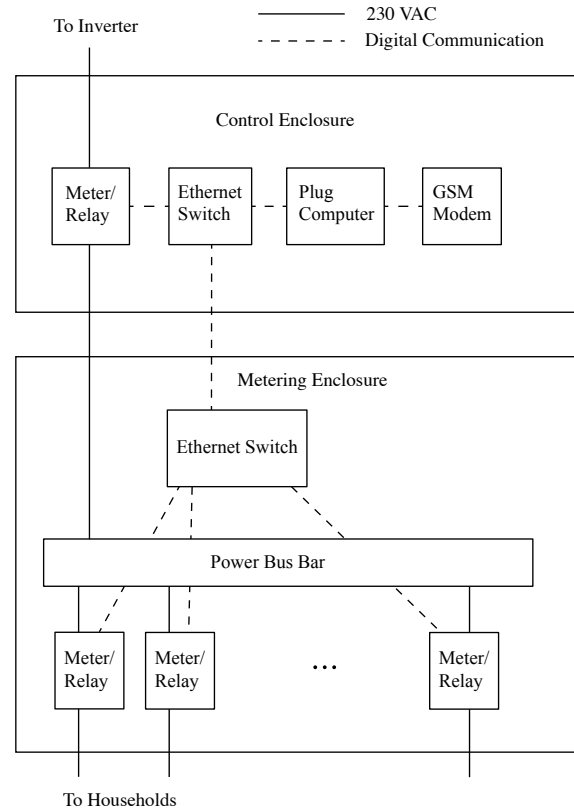

Figure 2: Schematic of the power and information flow in the metering hardware cabinets. Power flows from the inverter to a main metering circuit. The power is then distributed by bus bar to up to 20 individual metering and switching circuits. Information is collected from each of these metering and switching circuits via an ethernet network and is aggregated on a plug computer. The plug computer controls the accounting and communication functions and communicates with the central server by a GSM modem.
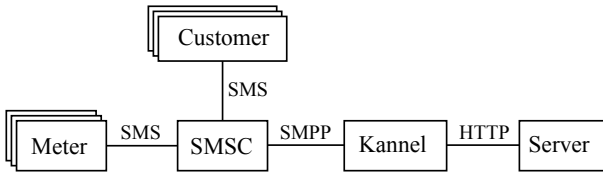
Figure 3: Diagram of a network of meters and customers administered by a central server. Multiple meters communicate via SMS messages that are relayed through a short message service center (SMSC). These messages are received by a server running the Kannel gateway software that relays the messages in HTTP format to a server. Customer messages also communicate through SMS and the SMSC before messages are sent to the server.

SMS messages to Short Message Peer-to-Peer (SMPP) protocol messages. The local telecommunications operator can provide a system that is more reliable than our custom solution by housing it in a location with more robust power and communications. A custom server running the Kannel package forwards these SMPP messages from the local telecom to our central server over HTTP. This system's server uses a Python-based Web application and a PostgreSQL database to store information received from customers and meters on their power consumption. The server also has a web interface (Figure 4) that allows for the configuration of consumers' circuits and a visualization of their electricity consumption by the electricity provider.

2.3 Transaction and Reporting Descriptions

The system uses the functions described (generation, metering, switching, and communication) to create a pre-paid microutility that builds on the successful and locally familiar model of pre-paid cellular phone air time. To purchase power, the customer buys a scratch-card from a local vendor. Scratch cards (Figure 6) are available locally in amounts as low as $1 USD and as high as $4 USD. The cards contain instructions on how to recharge the buyer's account and a concealed authorization code. The customer enters the revealed code into his mobile phone and sends it by SMS to the central server for validation. Once validated, the central server sends a message to the local meter instructing it to add the scratch card's credit amount to the customer's account. The meter sends an acknowledgment back to the central server that credit has been added, and the central server in turn notifies the customer by SMS that the transaction has been successful. The consumer can then access electricity until her credit is exhausted, at which time the household meter automatically turns off its relay.

As energy is consumed, the plug computer reduces the consumer's credit accordingly. When the credit level reaches a low setpoint, a message is sent by the meter to the central server, which in turn sends a message to the consumer warning that her account is low and should be refilled soon. Customers are also able to interact with their accounts to inquire about their balance via SMS. The customer sends a text message to the server, which responds back with a message containing her credit balance. She can also send a
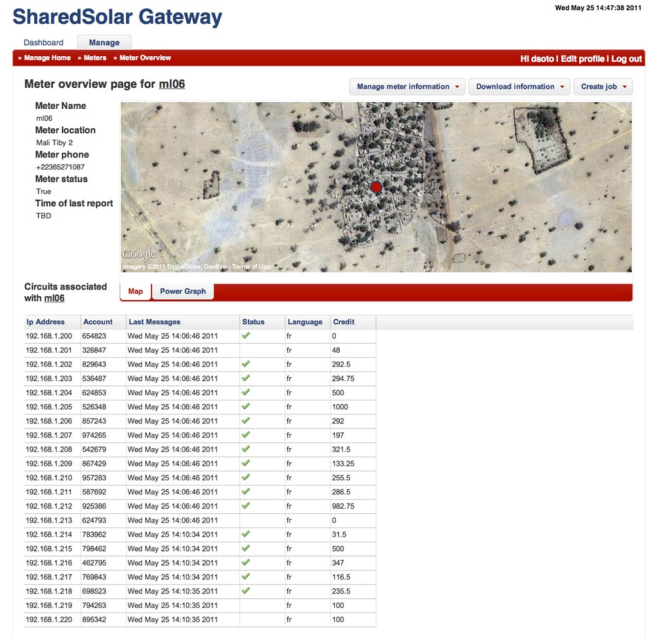

Figure 4: Screen shot of the administration interface. This web application allows the administrator to view the information collected from the installed systems. Information on the household electricity consumption and credit purchases can be viewed.

message to the central server requesting that the household's connection be turned on or off. This allows the customer to protect against unauthorized power use during an absence.

The system is programmed to collect and store information about customer electricity consumption on the central server. Hourly, a message is sent from the meter to the central server containing information on each household's accumulated daily energy usage. The meter can also send data regarding photovoltaic energy production and battery voltage. To guard against depleting the batteries, the meter can shut off a consumer circuit that is using more electricity than the system is designed for. The meter software can turn off electricity to the household if the consumer's power or daily energy is over an agreed maximum. The meter also listens for incoming SMS messages from the central server, which are often diagnostic requests.

3. DISCUSSION

At the time of this writing, we have 9 systems installed in Mali and 4 systems installed in Uganda. This discussion section will focus on the experiences in Mali. These systems have been providing electricity since as early as April 2011 with the latest systems being installed in August 2011. One of these systems is near a city and eight of the systems are in the Tiby Millennium Village. The consumers in this area are largely farmers and herders with per person daily incomes near the $1 USD per day mark. These households are large, with a mean of 14 members per household. This area is well suited for the system since it has a plentiful solar resource and though remote, has dense settlement patterns that allow for short wire distribution lengths.

3.1 Installation

The installation process began with an assessment of a potential site for suitability followed by planning and installation. Consumers were approached about their willingness to pay a connection fee and a service fee for electricity. Those customers who agreed to these fees made an initial deposit and were connected. The connection fee of $60 USD is a subsidized fee that helps pay for a wire from the central meter location to the home, the internal wiring in the home, and two 5 watt LED light bulbs and a power outlet. Each customer has a unique wire running from the central meter location to the home that is their property and responsibility. Wires were primarily run underground in these installations. The soft soil made digging trenches for installation more cost-effective than installing utility poles with the added benefit of increased security for the wiring. Customers were also provided with a card with their account number. They were instructed to save this account number since it would be used for electricity purchase transactions.

3.2 Consumer Training

Although consumers are familiar with mobile phone technology and the purchasing of mobile phone airtime, we conducted trainings (Figure 5) to instruct consumers on account management. These trainings were conducted to be sure that customers knew how to purchase credit and inquire into their account using their mobile phones. Training sessions were conducted in Bambara, the local language, with the help of translators. At the training sessions, customers were provided with scratch cards (Figure 6) that contained a numeric authorization code and instructions for sending the code to the central server for validation. To purchase credit, the scratch card instructed customers to send a short alphabetic command code, followed by their assigned account number, followed by the authorization code. This scheme was modeled after the purchase of cell phone airtime. During training, customers reported that the combination of numbers and letters was cumbersome to enter and that our instruction cards were verbose and difficult to understand. We also discovered that not all villagers in Mali were as comfortable with SMS messaging as we initially assumed. Anecdotally, we noticed a higher level of familiarity with SMS among some of the younger members. In response to these reports, we modified the format of our SMS messages to adhere more closely to the messages used by cell phone providers for recharge and eliminated letters from the message formats. The most familiar message format is the USSD protocol used by cell phone providers for users to manage their accounts. Unfortunately, the USSD protocol used by the providers was not available to us so we could not create a system that was identical to the existing systems that the villagers had experience with. In the future, most of these issues can be greatly simplified by integrating with an existing mobile money solution. In order to purchase credit or inquire about the balance on a customers account, an SMS message must be sent. During this training period we observed that while most people owned cell phones, they often did not carry a balance of usable air-time on their phones. This validated our choice to provide a toll-free number for SMS messaging.

Figure 5: Photo of local training session. Sessions were held to train users on the use of mobile phones and scratch cards to purchase electricity.
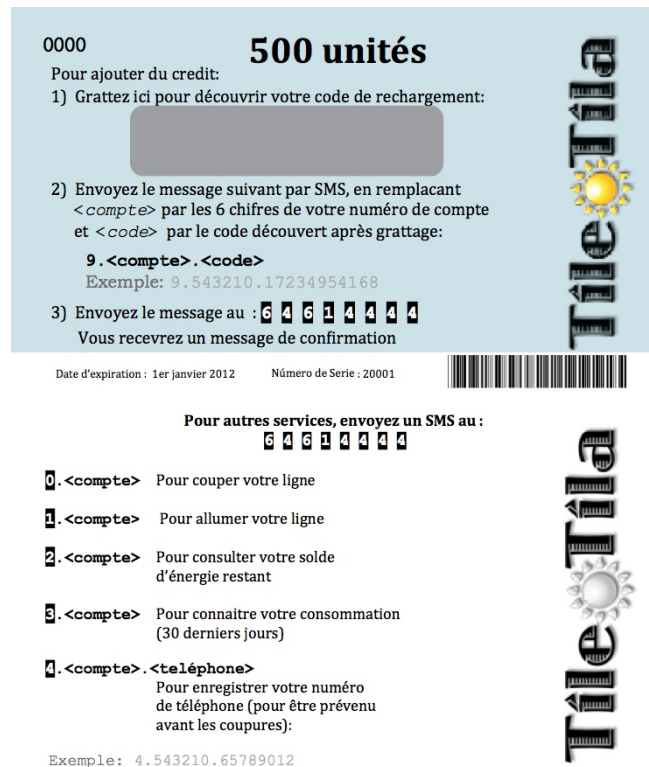

Figure 6: Scratch cards for electricity purchase. Cards contain a concealed authorization code as well as instructions on how to add credit to the customer account and how to get account information.
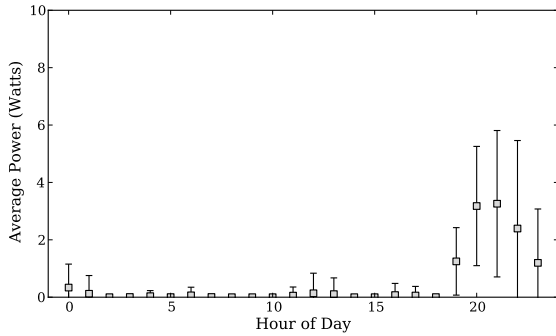
Figure 7: Hourly power use for a single household averaged over October 2011. Each datapoint is the average power consumed for that hour over the time period. Error bars indicate the standard deviation for the data set.

Figure 8: Histogram of daily consumption. The watthour consumption of households in increments of 5 watthours in plotted on the x-axis. The y-axis is the number of days of where this level of consumption is observed.

3.3 Electricity Consumption Patterns

Using the data collected on our server, we can examine the electricity consumption patterns of the households participating in the project. A more complete look at consumption patterns over all participating villages will be published in the future. For now, we present a few preliminary results from the initial data in the Tiby Millennium Village site in Mali. The data presented comes from two villages in the Tiby cluster, Farakou village and Tiby II village. We start by looking at a typical consumption pattern for households using lighting only. To understand the usage patterns of consumers during the day we averaged the hourly power consumption reported to our server of households over several days. Figure 7 shows the averaged hourly power readings for a single representative household in Mali over the month of October 2011. In this figure we plot the average power over a one hour period on the y-axis and the hour of day from 0–23 on the x-axis. The box shows the mean power over the hour and the whiskers indicate the standard deviation of the day to day readings. The plot shows that most of the power consumed is at night with a wattage level that is consistent with the use of the 5 watt LED light bulb that we provide. During the day there is almost no electricity consumption by the consumer. This pattern of primarily nighttime use necessitates battery storage of the photovoltaic energy generated.

If we integrate the power in Figure 7, we get the average energy consumed per day. To see the range of total daily energy consumption levels in our Mali proof-of-concept sites, we plot a histogram (Figure 8) of the non-zero daily energy consumed by customers served by a meter in the Farakou village over the month of October 2011. The data excludes days with incomplete data and days with no electricity consumption. (On average, villagers did not consume any power on 25% of days.) The x-axis shows the energy consumption and the y-axis displays the number of days that total energy amount was observed in any household. The histogram shows that the most frequent non-zero daily usage is in the range of 10–15 watt-hours. This energy consumption is equivalent to 2–3 hours of use of the 5 watt LED light bulbs installed with the system. The households that dis-
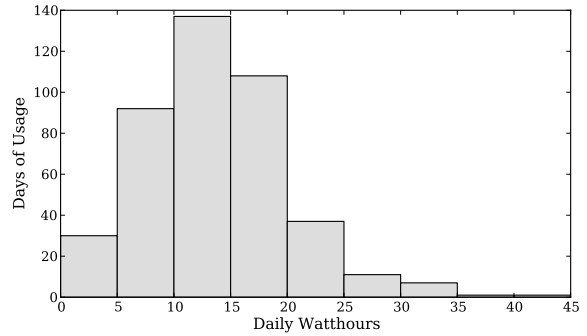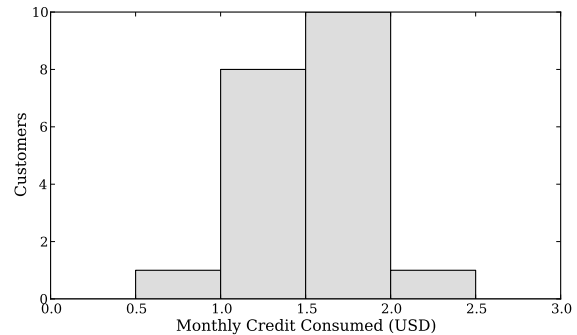

Figure 9: Histogram of money spent per household over one month period in Farakou. Most customers spend between $1 USD and $2 USD per month.

play usage above this level likely own a separate appliance such as a television or radio.

In addition to the power usage, we are able to track the credit being consumed by the customers, allowing us to calculate the average expenditures. Figure 9 shows the number of customers consuming a given amount of credit monthly in the Farakou village over the month of October 2011. The x-axis shows the credit consumed in USD while the y-axis shows the number of customers who have spent that amount. The most frequent expenditures are from $1 USD to $2 USD corresponding to electricity consumptions on the order of 200–400 Wh per month. For comparison, customers in the Tiby Cluster Millennium Village spend a monthly average of $4.50 for kerosene and $1.80 for dry cell batteries.

These electricity expenditures are not necessarily constant and customers that spend the same monthly amount may have different consumption patterns. Customers must maintain a non-zero amount of credit in their accounts in order to use electricity. By tabulating the time that customers have zero balance in their account, we can measure how long they will go without power either by choice or necessity. In the following two figures we show the data from a
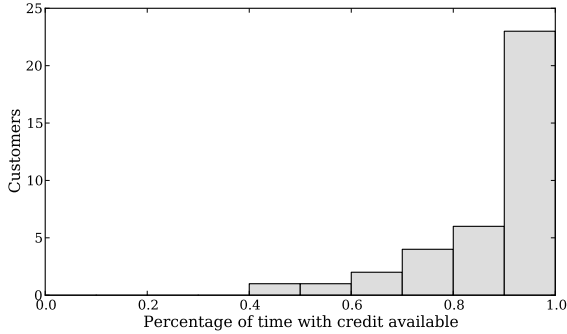
Figure 10: Histogram of percentage of time customers have a positive non-zero balance of available credit in their accounts. The majority of customers have electricity available in their homes over 90% of the time. Other customers take advantage of the flexibility of the system and let their accounts fall to zero more often.
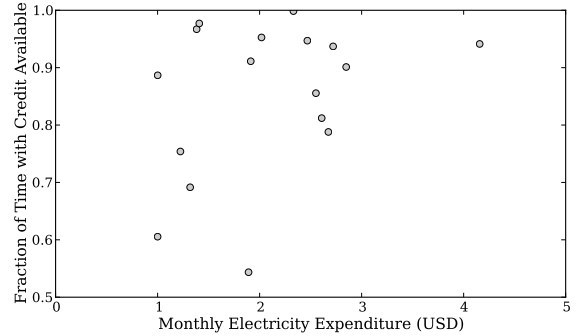

Figure 11: Scatterplot. Each point represents a household. The percentage of time that the household has available credit is plotted on the y-axis while the monthly monetary value of electricity consumed in USD is plotted on the x-axis. Customers who regularly maintain non-zero balance have both high and low spending patters.

different site, the Tiby II village in Mali where customers displayed more variety in their consumption patterns. In this village there are some customers with greater monthly expenditures than those in the Farakou village. The histogram in Figure 10 plots the number of customer households that have a given percentage of time with credit available. The histogram shows that over half of the consumers maintain non-zero amounts of credit over 90% of the time. While many of the customers were able to maintain credit for much of the time, the prepaid model allowed the other customers to consume power only when they had the funds available.

To understand which customers are able to maintain non-zero balances, we plot the fraction of time a customer has credit available against that customer's monthly expenditure in Figure 11. This plot shows that among the customers that are able to maintain a balance over 90% of the time, we find both high and low expenditure customers. However, those customers with credit available for lower fractions of time had lower monthly expenditures. This shows that there are customers that spend modest amounts but spend these amounts consistently and customers that spend the same monthly amount on a more sporadic basis.

4. CHALLENGES

We have identified several areas needing further work in order to have a robust and economically viable system. The cost of the additional hardware to provide metering and communications must be reduced. Also, the power consumption of the hardware is currently too high, requiring excess power generation capacity. Lastly, problems with communication can prevent consumers from replenishing their accounts causing an interruption of service and frustration.

4.1 Hardware and Installation Costs

For this system of electricity payment to make an impact on electricity distribution, the economics must be appropriate. Metering and communications add to the capital cost of the system. In this proof-of-concept demonstration, we used commercially available electronics to provide the pre-

paid functions at a cost of approximately $250 USD per household. This cost includes the meters, relays, modems, computer, and enclosures but does not include the power generation, storage, or distribution. These generation costs are important, but are common to any efforts at rural electrification. We are developing custom hardware that can be manufactured at a cost of $30 per customer in quantities of 1000. At this cost, the fraction spent on metering is small compared to the cost of generation. Also, this system requires skilled engineers for the server and communications maintenance. The additional salary of these individuals must be added to the cost of electricity delivered. The last cost unique to this type of delivery system are the scratch cards and the data traffic to create a prepaid commerce system. Currently we are using custom printed scratch cards and SMS messages purchased at retail costs. A scalable system would include partnerships with local telecom providers for inexpensive data rates and access to mobile money networks to mitigate these costs.

Another challenge is reducing the cost of wires for power distribution. In Mali, nucleated settlement patterns make it easier to wire homes but other rural areas have longer interhousehold distances that make distribution costs significant. We use a star topology for power distribution where each household has an uninterrupted line to the meter. The main reason for this choice was to clearly define the boundaries of ownership between the utility and the consumer. In the current model of the system, the consumer pays in part for the wiring leading from the central production shed to the household and is responsible for its integrity. Any tampering of the wire will result in lost power for the consumer rather than lost revenue for the utility. This reduces the risk of one common type of fraud and uses social pressure as a deterrent. One disadvantage to this approach is the potentially higher cost of distribution. A bus distribution scheme would in most cases lower the total length of cable needed. However, long sections of above-ground and accessible utility-owned cable are vulnerable to unauthorized splicing. This could be mitigated by monitoring along the network but would

increase the complexity of the system.

4.2 Power Consumption

Any electricity that is consumed by the metering, communication, and switching components adds to the capital cost for energy generation and storage. We have chosen commercially available components for integration into these systems. The metering components are designed for developed markets and consume 1.5 W–2.5 W. This power consumption is acceptable in markets where the loads are usually on the order of 100 W but are not well suited for the more modest energy consumption in these rural areas. In total, the off-the-shelf metering and switching electronics consume 50W of power adding up to 1.2 kWh of AC energy daily. Approximately 80% of this consumption is due to the metering units with the remainder consumed in the plug computer, the modem, and the ethernet switches. This consumption can be reduced by the development of metering units with lower power consumption, which we believe could operate at a continuous load of 0.25W. If the meter consumption per household is brought to 0.25W, the daily use is 6Wh. If the same household uses a 5W light bulb for 5 hours each day, the fraction of energy spent on metering is 20%. In a more efficient system, these lighting-only customers place a upper bound on the fraction of generation necessary for the metering and communications. Thus, this metering and payment architecture may not be cost effective for a household that only uses lighting services.

Another aspect of the electronics that influences the economics of the system is the lowest amount of power the meter can detect. The commercially available meter we use cannot detect a load below 2.0 W. An undetected 0.5 W vampire load of a cell phone charger can consume 12 Wh in a day, equivalent to over 2 hours of LED lighting. If this load is not measured, there is no possibility of collecting revenue and we have generation capacity that cannot be amortized.

4.3 Network Reliability

These systems are intended to run uninterrupted and unattended in remote locations. Communication uptime is very important to the function of the system. We have observed problems with communications reliability and latency in the GSM networks. These latency issues frustrate consumers by making transactions unreliable. Problems with network reliability have prompted us to explore other means for information flow in the presence of intermittent connectivity. We are considering both queueing information until the network becomes available as well as using physical information movement such as flash drives. We have also created an application running on an Android tablet that allows us to communicate locally with the meter over a 802.11 connection and then relay that information to the central server when the tablet is in a location with a reliable internet connection.

5. FUTURE WORK

Our work so far has been concerned with the provision of solar electricity with low operating costs and robust revenue collection. However, the framework we have constructed allows for a much richer set of features. A demand response system using text messages and discounts would be straightforward to implement within this framework by incorporating logic at the meter or central server that could monitor the energy generation, send demand response requests to customers, and credit accounts accordingly. In this pilot study, solar electricity is the good that is being metered and delivered by our system. It is also possible to adapt this architecture to the provision of other generation technologies like hydropower or diesel generation. Application to other easily metered and valuable goods like purified water is also possible. Such a clean water kiosk could enable carefully measured amounts of water to be provided in an automated fashion. The open software tools we have developed can also be adopted for remote monitoring. This work could be adapted to create server storage of weather stations, agricultural monitoring, or other measurements where GSM coverage exists. To address the problems of power consumption by the meter, we are developing custom electronics that have lower power consumption and are capable of measuring loads below 1 watt.

6. CONCLUSION

We have designed and deployed a system that allows for the deployment of microutilities in remote areas. These microutilities can be monitored and administered by a central server. Approximately 170 households in Mali and 38 in Uganda are purchasing solar-generated electricity using this prepaid business model. Since communication takes place over the GSM networks via SMS messages, these microutilities can be deployed anywhere that GSM coverage exists.

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