End-Use Load Monitoring of a Micro Hydroelectric-Powered Community Micro Grid: A Case Study in Rural Malaysia

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Abstract

Rural electrification designing and planning, especially for micro grid-connected communities, requires quality data to verify results. This data can be difficult to locate in current literature. Case studies which show not only the types of loads encountered in rural off-grid installations, but also the variation of loads and the daily load profile in the context of a limited output system are extremely useful in enabling further research in this field to expand the current pool of knowledge. This paper describes the end-use load monitoring work that has been performed in an East Malaysian village since 2010 and the challenges associated with data gathering and end-use monitoring in a rapidly-developing rural setting.

Keywords: Rural End-Use Load Monitoring; Micro grid; Micro hydro; Micro energy; East Malaysia;

Introduction

As the UNDP states, "Energy is the fundamental prerequisite for achieving the Millennium Development Goals (MDGs) and access to energy, especially in the form of clean and affordable electricity that can help achieve sustainable and economic development" (Takada & Fracchia, 2007). For many developing countries, the high cost of extending the grid to serve electricity to rural communities of low population density can be infeasible (Zerriffi, 2010). To address this issue, micro grids have been implemented increasingly in the last few decades with varying degrees of success. This success is often dependent on the level of planning involved which can lead to improved technical design and the appropriateness of implementation. To support completeness in these areas, it is necessary to have quality, locally relevant, end-use data which can lower the barriers to future development (Cross & Gaunt, 2003; Howells, Alfstad, Cross, Jeftha, & Goldstein, 2002). This research seeks to fill that gap by providing rural energy usage pattern data and a descriptive context that can be applied in broader rural energy planning in the surrounding areas.

In rural villages in East Malaysia, the issue of electrification has been addressed to some extent over the last few years through the installation of community-sized micro grids powered by micro hydroelectric generators, in sizes ranging from 5-12kW. The village shown in Figure 1 is an example of one such installation, its name and precise location being withheld to maintain the privacy of the community. This village, which has an established partnership with Masdar Institute since 2010, utilizes a 12.8kW micro hydroelectric generator (installed in 2009), and today serves an estimated population of 200 people and 30 buildings, both homes and community spaces.

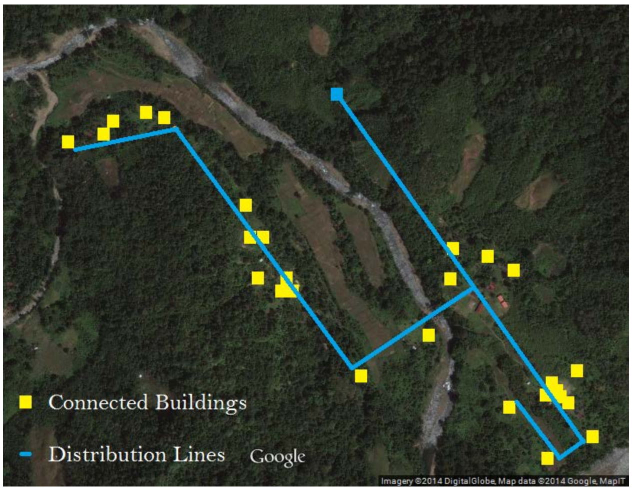

Figure 1: Rural Village End-Users and Distribution Lines, Approximately One Square Kilometer Shown

One of the most potentially useful projects to come out of the Masdar Institute - community partnership to date has involved end-use load monitoring of the buildings connected to the micro grid. The project is encouraging partly due to the robustness of the data loggers, which have been proven to survive the tropical environment that has prevented many more sophisticated technologies from fulfilling their duties, but also because the loggers have been integrated into the community through training and capacity building of individuals. Masdar Institute has relied on the community to retrieve and send data for processing, as well as alert researchers whenever problems occur to enable remote troubleshooting if possible, or mobilization if necessary. Results are then passed onto a community-based organization who can advise the community on best practices and ways to optimize the system for the maximum benefit of its users.

Research Objectives

The objective of this research is to develop a case study for end-use load monitoring in rural Malaysia and thus fill a gap in the current available research on actual energy use in a recently electrified village including usage patterns and specific electricity loads.

Methods

Installing the end-use load monitoring equipment (Onset U12-006's and split-core current sensors) in the village was straightforward. After gaining permission from the households, and installing a current transducer (CT) on the incoming electricity line, the logger was mounted nearby and launched with a laptop. Data was collected on a semi-regular basis by either researchers or villagers who were trained in data gathering. To ensure that batteries could be replaced infrequently and that data collection could occur at the longest possible interval (approximately every 6-8 months), the loggers were set to record instantaneous current measurements every 10 minutes. It was assumed that this interval could be shortened in the future once a reliable collection schedule was established, but this has not yet been tested.

Results

The average results of this data can be found in Figure 2 below. Using quantitative logger data as well as qualitative household device information taken from surveyed homes, four distinct load groups were identified based on average consumption over a four month sample period.

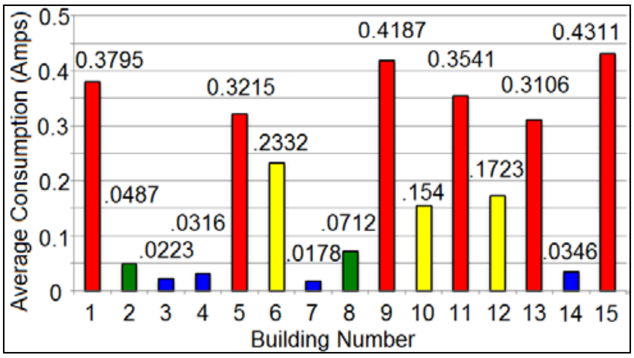

Figure 2: Average Current Values for 15 homes from July 2010 to November 2010.

The color red corresponds to load group A. Homes in this category contain at least one refrigerator or washing machine and all of the appliances found in the subsequent load groups. The color yellow corresponds to load group B. Homes in this category contain at least one television and related equipment and all the appliances found in load groups C and D. The color green corresponds to load group C. Homes in this category contain at least one radio or table fan and the appliances found in load group D. Homes in load group D utilize only lights and mobile phone chargers.

The appliances utilized in homes during this period were very similar in both size and power consumption, enabling accurate grouping of devices, as shown in Table 1 below. The largest differences were found in the lighting category as most users utilized high-watt compact fluorescent lights (CFL's), with a few using incandescent.

Appliance	Watts (or other)	Load Category
CFL Lights	14 W (105mA), 18 W (130mA), 20 W	A, B, C, D
Phone Charger	100-240V, 50-60Hz, 150 mA	A, B, C, D
Portable Radio	220V, 50Hz	A, B, C
Table Fan	39 W	A, B, C
TV	45 W – 180 W	A, B
Satellite Receiver	30 W	A, B
DVD Player	20 W	A, B
VCR Player	20 W	A, B
Refrigerator	100 W (0.48 kWh per 24 hours)	A
Washing Machine	280 W (wash) 140 W (spin)	A

Table 1: Average load ratings of various devices and their corresponding load categories.

The loggers have also been able to record system down time during the four month sample period, as shown in Table 2 below. The 10 minute logging interval constraint means the results may be underestimated somewhat.

#	Start Date/Time	End Date/Time	Down Time
1	7/12/10 19:20	7/13/10 6:10	10 hours 50 minutes
2	7/13/10 23:30	7/14/10 6:30	7 hours
3	7/19/10 17:00	7/23/10 20:40	4 days 3 hours 40 minutes
4	8/26/10 20:30	8/26/10 22:00	1 hour 30 minutes
5	8/27/10 17:30	8/27/10 19:40	2 hours 10 minutes
6	8/28/10 7:00	8/28/10 15:10	8 hours 10 minutes
7	8/29/10 7:50	8/29/10 12:50	5 hours
8	8/29/10 18:40	8/30/10 6:40	12 hours
9	8/30/10 13:40	8/30/10 15:30	1 hour 50 minutes
10	8/31/10 4:30	9/3/10 17:10	3 days 12 hours 40 minutes
11	9/11/10 8:10	9/11/10 14:30	6 hours 20 minutes
12	9/22/10 20:10	9/22/10 21:10	1 hour
13	9/23/10 22:40	9/24/10 19:30	20 hours 50 minutes
14	9/28/10 20:50	9/29/10 10:40	11 hours 50 minutes
15	10/2/10 8:50	10/2/10 12:10	3 hours 20 minutes
16	10/15/10 18:50	10/15/10 20:00	1 hour 10 minutes
Total Down Time			11 days 13 hours 20 minutes

Table 2: Outage Durations from July 2010 to November 2010.

Finally, a sampling of the average daily load profile of the buildings in load groups A, B, C and D can be determined as shown in Figure 4.

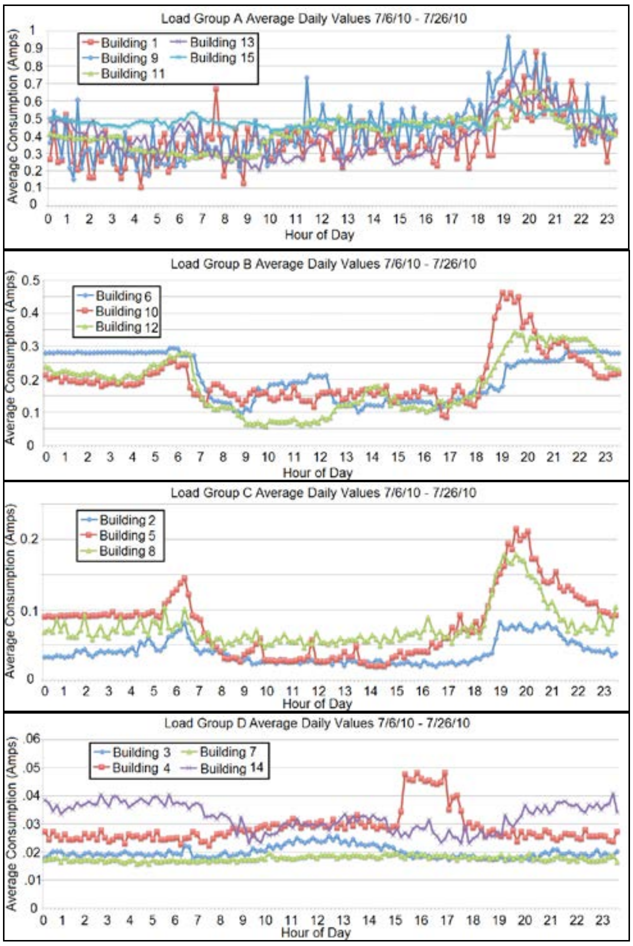

Figure 4: Sampling of Average Daily Load Profiles for buildings in Load Groups A, B, C and D from July 2010.

The fluctuations noticed in load group A are due to the duty cycle characteristic of refrigerators. The information from all of these load groups are aggregated into one system-wide daily load profile as shown in Figure 5 below.

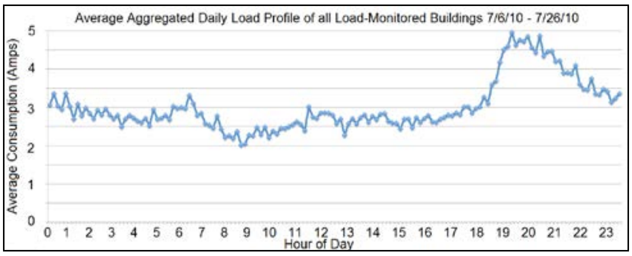

Figure 5: Sampling of Aggregated Daily Load Profiles for Load Groups A, B, C and D from July 2010.

Discussion

The data shown above was taken at a crucial stage in the development of the community's electricity service. At the time, users had effectively surpassed the limits of the system (due to design flaws discussed below) and were feeling the system capacity was inadequate at meeting their needs. In the time since then, the number of appliances and buildings connected to the micro grid has increased, thus putting more strain on an already fragile system.

At least seven of the 15 buildings shown above can now be categorized as load group A. Combined with qualitative data from the community, an electricity development track has emerged in which new users enter at load group D, possessing only lights. They then progress to communication devices such as phones and radios, which are in load group C. After this comes entertainment provided by a television in load group B, and finally items perceived as luxury in load group D. It is important to note that none of these load groups contain devices for productive end-use of electricity for income generation (with the exception of one entrepreneurial user who was previously selling freezer pops at the weekly market). There are now a total of 27 loggers installed in almost all grid-connected buildings as of 2013.

Many additional challenges have surfaced, both technical and managerial in nature. The technical challenges include the seasonal changes in power generation and subsequent difficulty for users in determining the limits of the system at any given time and a maintenance issue with the penstock which caused it to sag and lower the design head for more than a year. The managerial challenges include implementing a fair and accurate pricing scheme for the end-users (the current system is simple, but unfairly priced based on the circuit breaker amp rating in each building), ensuring that fees are collected from end-users, and establishing a clear development plan for the future of the system to meet the needs and satisfaction of the community.

These issues have all created a lack of confidence in the micro hydro system from the community. Combined with the recent connective infrastructure provided by a road, the barriers to fossil fuel and appliance access have been lowered and individuals have taken it upon themselves to meet their own electricity needs in the form of small diesel generators and 12V solar PV battery chargers. This represents an enormous shift in the community, suggesting that because the micro hydro system did not perform as expected, it has forced the village to depart from their traditional communal sharing of resources in the area of electricity and made residents concerned about meeting their own household demand.

To address some of these issues, the community-based organization (CBO) that installed the micro hydro has recently repaired the aforementioned dip in the penstock and diverted additional water resources to the forebay to act as a buffer during seasonal periods of low flow. In the future, the CBO is planning to install end-use electricity meters to support a fair pricing scheme and hopefully encourage payment compliance within the community. It has been suggested by the community that implementing a system to provide automatic load shedding would be extremely useful to account for seasonal variations in generation capacity and the varying loads placed on the system at any given time. Such a system would likely involve a hierarchy of loads in each building, such as is shown in Table 1, where devices in load group D would be most prioritized and devices in load group A least prioritized. The issue of course with automatic load-shedding is that end-users with refrigerators could never be sure of storing perishable food items safely, at least not under the current generation capacity restrictions.

Given the large number of outages suffered, and from qualitative knowledge of the system and its operation, it is clear that reliability is one of the major challenges faced by this micro energy system. Although many end-use data loggers have been installed by Masdar Institute, more are required as well as more up to date and complete information about the other sources of electricity generation to form a complete picture of how electricity consumption has increased over time and the link with overall development. This data is currently being collected and analyzed, and will be made available in the near future in follow-up publications. Some of the long-term goals of this research include the formalization of standard energy profiles for the region, exploring the interplay between reliability and usage trends and designing a migration path to better service in manageable cost increments.

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