Power Instability in Rural Zambia, Case Macha

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Abstract. This paper provides insights on the nature of electricity supply in the rural village Macha, Zambia. It reports on case study research. Use of Information and Communication Technologies and access to e-services are constrained by the availability of electricity. In Zambia's rural areas, 3.5% of households have access to electricity supply. This paper shows such electricity supply can be erratic. When supply is available, it follows a diurnal pattern. The electricity supply varies considerably, including voltage dips and brown outs. It can cause equipment to enter into unstable states, to fail or to damage.
Qualitative engineering aspects interact also with social factors, especially in rural Africa. Interventions must be sensitive to the complex array of challenges for people to be able to appropriate the benefits of ICT and e-services.

Key words: Rural electrification, Power outages, Community development

1 Introduction

This paper reports on engineering and ethnographic case study research from within the rural community of Macha, Zambia. The work encompassed literature review, interviews, and technical measurements between 2009 and 2013.

Zambia harbours a range of indigenous energy sources, including hydropower, coal, woodlands and forests, and renewables. The country's hydropower resource potential stands at an estimated 6,000 Mega Watts (MW) while the installed capacity is a mere 1.9 MW [1]. Hydroelectric plants represent 99% of electricity production in the country with the major sources being Kafue Gorge, Kariba North Bank and Victoria Falls Power Stations, and developments at Kafue Gorge Lower, Itezhi-tezhi and Kalungwishi.

The major electricity users are the mines, which consume up to 68% of the total load. Industry and commerce account for 4%, households for 19%, and agriculture and forestry consume 2% of the supply. Government services use the remaining 7% [2]. Woodland and forests cover about 66% of the Zambia's land area and provide about 70% of its energy requirements. Zambian households mostly consume wood-fuel. This leads to deforestation to serve the (urban) demands for charcoal [3].

Zambia's developments have been guided by the Fifth National Development Plant, published in 2006 [4], and the Sixth National Development Plan in 2012 [1]. The plans position access to electricity equal to the need for shelter and water for every Zambian on a daily basis.

A 2009 ZESCO investigation assessed the degree of electrification in Zambia and determined the percentage of those with direct access to grid electricity and isolated electric systems. In 2009, 22% of all Zambian households had direct access to grid electricity, a small increase of 2% since 2005 [1]. Isolated electric systems serve a mere 0.03% of the population while the remaining 78% of the population has no access to electricity supply [5].

2 Zambia's Production Capacity

The Zambian electricity system is part of an interconnected regional power system that links it with its neighbors. The Zambian electricity supply industry was predominantly run by a single state owned company, the Zambia Electricity Supply Corporation (ZESCO). ZESCO was created in 1970 through the Zambia Electricity Supply Act. The Electricity Act, the Factories Act, and the Energy Regulation Act are the main governing legislation for electricity suppliers.

Liberalization in 1995 aimed to attract private sector companies to participate in the generation, transmission and distribution of electricity in Zambia. In order to promote this policy, the government set up the Energy Regulation Board (ERB) and the Office for the Promotion of Private Power Investors (OPPPI). The ERB regulates operations and pricing and the OPPPI promotes new players within the electricity market.

Three major players dominate in electricity provisioning in Zambia:

- ZESCO generates, transmits, distributes and supplies electricity throughout Zambia
- Copperbelt Energy Corporation (CEC) distributes electricity purchased from ZESCO through a network to the mining industry based in the Copperbelt
- Lunsemfwa Hydro Power Company, an independent power producer, generates about 48 MW of power and sells it to ZESCO

The Rural Electrification Authority (REA) focuses on increasing access to electricity in rural areas. Other participants in the industry include small-scale generators and hydro and solar based energy service enterprises supplying power in a limited number of rural areas. Examples are providers in Zambezi and Mwinalunga districts, which are located far from the national electricity grid.

2.1 Distribution Systems

The main transmission system runs at 66kV, 88kV, 132kV, 220kV and 330kV (figure 1). All three companies use the transmission system which is operated by ZESCO and CEC. The Zambian Transmission System connects with Tanzania and Botswana on 66kV, Namibia on 220kV, with the Democratic Republic of Congo on 220kV and Zimbabwe on 330kV.

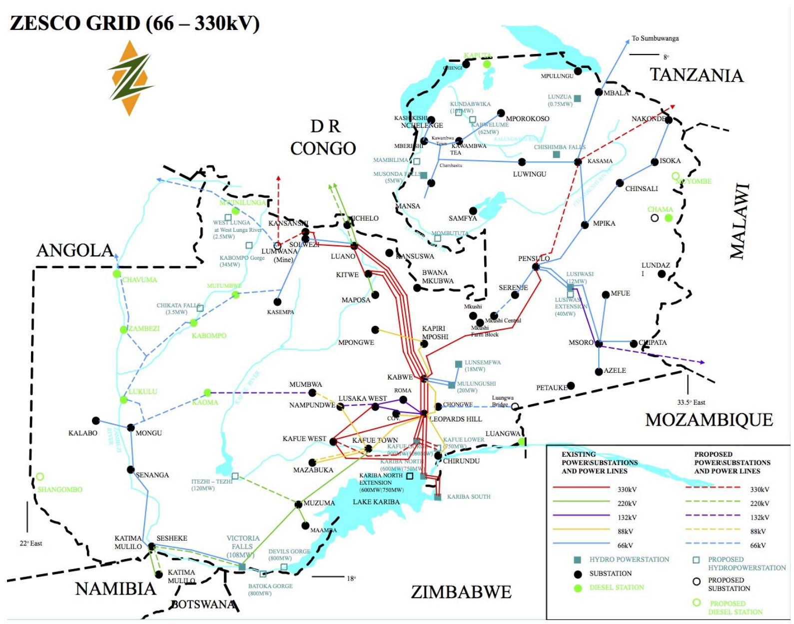

Fig. 1. ZESCO Power Grid [6]

The ERB licenses the transmission companies. The transmission grid is operated and monitored by the control centres of the various owners of the systems. Each of the companies has its own control and operations center, and monitors the performance of their respective transmission networks. There is no supervising or independent transmission systems authority. The Zambia Electricity Supply Act guides the cooperation. Additionally, like members of the Southern African Power Pool, the electricity suppliers operate within international operating guidelines.

3 Rural Electrification

Zambia strives for universal access to clean, reliable and affordable energy. Its development is consistent of the country‘s national development goals of sustained growth, employment generation and poverty reduction [4].

3.1 Definition of Rural Areas

There is no standard definition of the term *rural* [7]. In Zambia, 93.9% of the surface is designated as customary, rural land [8]. Others texts estimate that 61.2% of Zambia's population live in rural areas [9]. In 2005, Zambia reported that 6,268 (83%) out of 7,576 schools were located in rural areas [10]. In 2008, Zambia operated 1,564 health facilities, of which 1,029 were classified as a rural health centres [11].

The definition of a rural community is "the smallest spatial group which encompasses the principal features to society, being a group of people interacting socially, with common ties or bonds with the geographic limited rural territory in which they live" [7]. Rural areas are often defined as 'non-urban areas', and that includes geographically isolated communities that are separated from central clusters (i.e. towns) and are deprived of modern amenities available in an urban or peri-urban environments. Zambians commonly designate these areas as 'deep-rural', distinguishing them from urban or peri-urban areas.

3.2 Rural Electrification Plan

The passage of the Rural Electrification Act of 2003 provides a platform for rural electrification efforts in Zambia. Rural electrification became the responsibility of the Rural Electrification Authority (REA), which manages the Rural Electrification Fund.

REA prepared a detailed Rural Electrification Master Plan (REMP) that serves as a blueprint for Zambia's electrification efforts for the period 2008 – 2030. The REMP indicates the electrification targets, the roll out sequence, and the methods, timing and budgets required. The REMP sets ambitious targets for increasing access to electricity by 2030. The plan identified a total of 1,217 'growth centers' in rural areas throughout Zambia. These are the targets for electrification during the plan period. The target is to increase the electrification rate in rural areas, from the current 3.5% of households to 51% by the year 2030. The plan targets three principal methods of electrification:

1. extension of the national electrical grid
2. creation of stand alone electricity systems supplied from renewable sources such as Mini Hydro Power Stations and Biomass Generation
3. implementation of solar energy systems

The REMP focuses on system extension as the main vehicle for expansion of access. The total investment required to achieve its target is estimated at USD 1.1 billion. This translates into an annual expenditure of USD 50 million (ZMW 250 billion) between 2008 and 2030.

4 Electricity in rural Macha

In Zambia, most rural areas do not have electricity. If at all available, electricity supply is not stable because of frequent power cuts, and brown outs caused in part by load shedding. Regularly, the power fluctuations damage electrical equipment. Repairs result in extra costs for maintenance, shipping and replacement of parts that are not found easily in the province or country [12][13].

Macha is located in the Southern Province of Zambia, 70 km from the nearest town of Choma and 350 km by road from the capital city of Lusaka. The topography of the area is undulating, primarily open savannah woodland averaging 1,100 meters above sea level. The climate is tropical. The Macha area is populated by traditional Tonga villagers, living in small scattered homesteads which usually consist of one extended family. There are no corporate farmers or industries in the area. The primary livelihood is subsistence farming with maize being the main crop. There is an estimated population of 135,000 within an approximate 35 km radius around Macha. Overall population density in this area is 25 per square kilometre. 50% of the population is under 12 years of age. In the areas surrounding Macha, the average income for a person in the village is less than the equivalent of USD 2 per day.

5 Measuring Electricity

In Macha, since 2009, there were many dedicated attempts to measure the quality of the grid electricity supply for research purposes. Sourcing and installing measuring equipment took two years, with difficulties in funding, acquiring and transporting of such equipment to this remote area. Fluke measuring equipment was supplied through a research cooperation with UC Santa Barbara. However, the equipment broke down within several hours of the start of measurements. Replacement involved an other period of sourcing and transporting issues. At last, longitudinal quantitative measurements started in 2011. These measurements include a sample every second. They confirm the general community experience that the quality of power varies drastically.

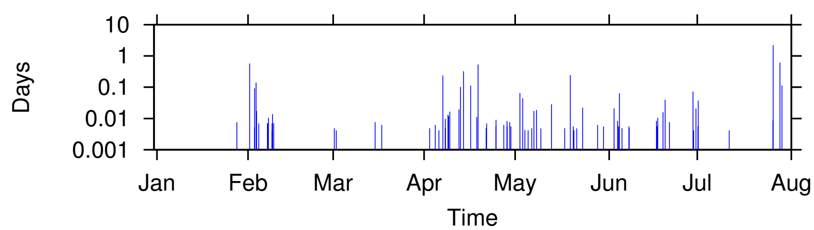

Fig. 2. Timeline of power failures in Macha.

Figure 2 shows a time line of power failures during in Macha during 2011. The y-axis shows the duration of the power failure. Figure 3 shows that, on average, the period between power failures is about 1 day, but this is skewed by the fact that when power is restored there are often repeated failures. The cumulative distribution function (CDF) of duration of power failures in shown in Figure 4. The average duration is approximately 1 hour but 10% of power failures do last longer than 12 hours. The longest power failure in the data set was 2 days.

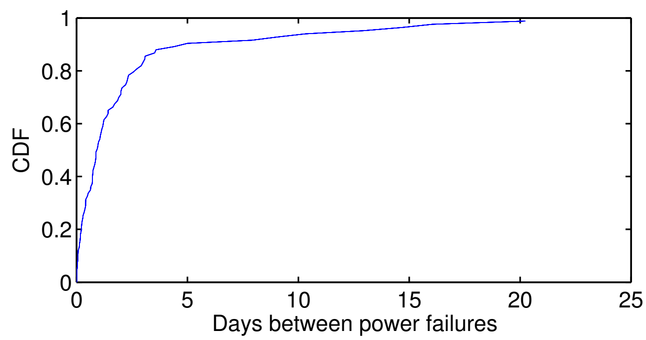

Fig. 3. CDF of time elapsed between power failures in Macha

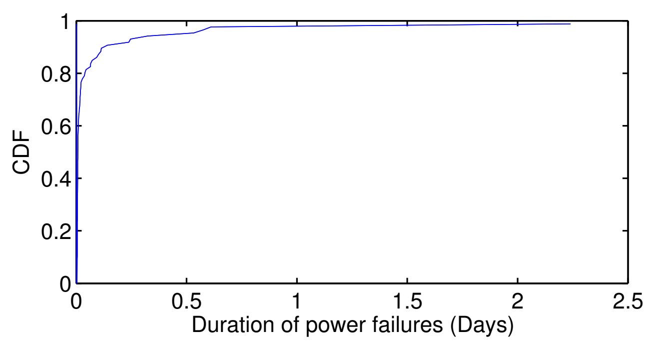

Fig. 4. CDF of duration of power failures in Macha

Figure 5(a) shows the measurements in a sample two week period in 2012. The x-axis plots time in days and the y-axis plots voltage. The gray areas on the plot indicate periods of a power outage. Voltage is sampled each minute with recording of the maximum and minimum voltage. The standard voltage in Zambia is 230V. Measurements show the voltage varies from 150V to 240V, with frequent power failures. Furthermore, there are long periods of power brown-outs in which electricity is available, but the voltage is continuously low. Three brown-outs are clearly seen in this diagram. They have the much potential to put e-infrastructure in an unstable state. Voltage tends to follow a diurnal pattern with voltage dips most noticeable during evening periods when electrical stoves are used for cooking. These patterns are typical of a system that is overloaded.

Relatedly, Internet availability is shown in Figure 5(b). It is clear that there is often no connectivity to the outside world even when power is available. The lack of Internet connectivity is often due to upstream problems in the grid or connectivity infrastructure in Zambia. Often, local equipment needs to be reset after becoming unstable after power failures or brown-outs.

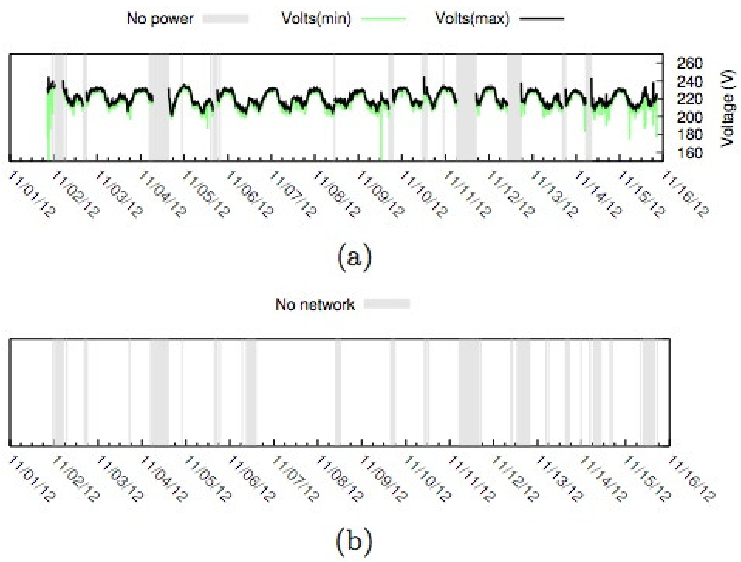

Fig. 5. Power and Network Quality [14]

Assessment of the implementation of electricity networks in Macha buildings shows additional challenges. Improper loading and wiring, improper grounding, bad connections, improperly sized wire used, overloaded circuits, and insufficient supply all resulted in power sagging effects, especially due to 'in surge' currents from heavy equipment loads. Sagging effect are amplified when wiring is too small and when the feeding lines are too long.

6 Equipment Quality

In practice, there are many different standards and levels of quality of electronic and electrical equipment arriving in rural areas. Assorted batches of donated Information and Communication Technologies (ICT) equipment arrive with all kinds of levels of ruggedness and susceptibility to dirty power. Standard Uninterrupted Power Supplies (UPS), meant to protect equipment from energy disruptions, are easily damaged in the first line of defence. In Macha, out of over 40 high quality UPS systems, only 5 remained after one year of operation. Most UPS systems failed within the first month of use. Clearly, for rural areas, equipment that is rugged enough to withstand dirty power is a key issue that warrants further research.

7 Social Practice

It is not only the availability of the electricity source, but also the issue of *sharing* of electricity that plays a significant role. When bringing electricity in an area that was previously without electricity, priority areas need to be thought through carefully. For instance, meeting the needs for electricity of the chief might be regarded of a higher priority than use for ICT or the needs for an existing school or rural health center. Back up procedures also raise issues related to the prioritizing of access to electricity in the community. For example, when the main power supply is interrupted, why would only ICT equipment be provided with uninterrupted power and not the health clinic or the schools? The question of which constituencies in the community should be connected to the electrical grid is not only a pragmatic issue but can pose social and political challenges as well.

8 Alternative Energy Supplies

In practice, solar equipment proves difficult to source. Solar technology is plagued with battery issues as they falter due to high temperatures and abuse. Battery replacement requires much effort in the sourcing of funding, acquiring the right batteries, travelling to remote places. Solar installations typically involve equipment that necessitates specific training of engineers. Further, solar panels are vulnerable to physical damage or theft. Representatives of UC Santa Barbara donated 60 small solar-powered LED lights in July 2013 to assess their viability and utility among those who are not connected to the electrical grid. These solar powered lights were designed by the Institute for Energy Efficiency at UC Santa Barbara. It is anticipated that they will be very useful in Macha given that so few homes are connected to the electrical grid and given low incomes many cannot afford to purchase candles as often as they are needed.

9 Discussion

It is impossible to think about or use the Internet or mobile phones for e-Governance, e-Infrastructure, and e-Business in Macha (or anywhere) without thinking about electricity. Zambia currently is short of power, power goes on and off unpredictably almost every day in Macha. This paper shows that fluctuations and inconsistencies in the voltage occur. They can cause damage to electronic devices such as computers, large appliances such as refrigerators and can even causes dangerous fires in homes and other buildings. Power outages regularly interrupt Internet and mobile phone services, and thus access to services[1].

Rural communities such as Macha are particularly vulnerable to load shedding, the centralized practice of shutting off services to one area to support demand in another area – often urban areas or neighbouring countries. Almost every day the power goes out in the community at unpredictable times, sometimes for a few minutes but often for hours. Most Internet users expressed frustration with this situation and described their use as punctuated by these frequent disruptions. Web browsers are used for services such as web-based email, social networking or other cloud services and frequent disruption of Internet access interrupts work flow and becomes debilitating. Far from being a universal service, homogeneous in its durations, the dynamism of access to e-services is contingent upon the harnessing of resources, the timed flow of electrical currents, and the regulation of voltage.

The integration of Information and Communication Technologies within daily, rural lives is contingent upon the conversion of water, sun, fossil fuels and other materials into electrical power. While most rural households and community facilities live 'off the grid', ZESCO charges ZMW 75,000 (USD 15,000) to connect electricity to a school. In view of these high costs, most people in rural villages power their devices in other ways. Some use power outlets at the outdoor market in the village center to charge their electronics and pay a fee to do so. Some use solar panels to power up radios, lights, and other small appliances. Others jerry-rig car batteries to energize TV sets and stereo systems. Thus, consumer electronics are fueled by the manual labour of people who take time and energy each day to devise ways of empowering their devices on or off the grid [16].

It is important to recognize that the digital economy is layered upon the resource economy. The success of e-Governance, e-Infrastructure, and e-Business relies upon electricity and a multitude of other physical and social resources. Each of these resources presents challenges in its deployment and/or use. For ICT services to be sustainable in rural Africa, attention to all these factors is crucial, and access to electricity supply, in all its facets, should be a central priority.

For rural areas, deeper understanding of priority areas for electrification based on community input is required in order to avoid the situation of supplying IT equipment before supporting other vital areas such as a health clinic or the community's chief. Reviewing Information Systems implementations in Malawi, Mpazanje et al. confirmed that project success is achieved only when stakeholder interests are strongly interwoven with the project's needs [17]. The incorporation of electricity provisioning in rural areas must take into account the characteristics of local cultures, including social habits, employment, language and cuisine. Apart from well-trained engineers at the power utilities, the

[1] Other common causes of Internet downtime in Zambia are: adverse weather conditions, low or shared bandwidth, and poor quality of copper cables/telephone connections [15, p.24]

training of the rural electricians is crucial since they will be responsible for laying power cables in a village from transformers or alternative energy supplies to other sites. Their proper training will help to ensure that correct gauge cable and cable lengths are used for the expected load. However, currently there are no obvious places for formal apprenticeships of electricians in rural areas.

There are a number of alternative energy options. However, in Macha, none of the alternative energy implementations remained operational for an extended period due to various constraints. A robust UPS is required for rural areas, one that can handle dirty power. Research and development are needed to assess which components in the UPS are vulnerable to unstable rural power. Further, there are opportunities for smart local grids that protect equipment by disconnecting sections of the grid when voltage discrepancies are detected.

10 Conclusion

Description of the current context and observations on electricity is scarce in rural Africa. Electricity in rural areas is notoriously unstable. It has caused serious damage to equipment and can shorten its life span due to frequent power outages. However, electricity is a foundational resource that is necessary for any application of ICT and access to e-Infrastructure and services. This paper provides input through cross-sectional analysis of information gathered in rural Macha, Zambia by Macha Works and other researchers working in the community.

Quantitative engineering mixes with social factors, and we find that both play key roles. Research, development, and evaluation must be sensitive to a complex array of challenges if all rural areas are to receive usable access to electricity and ICTs.

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