Energy for Sustainable Development 17 (2013) 564–571

Contents lists available at ScienceDirect

Energy for Sustainable Development

Off-grid mobile phone charging: An experimental study

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A R T I C L E I N F O

Article history:
Received 8 July 2013
Revised 9 October 2013
Accepted 10 October 2013
Available online 26 October 2013

Keywords:
Mobile phone
Charging
Off-grid
Rural electrification
Inverter
Efficiency

A B S T R A C T

Global demand for electricity and mobile phone (MP) service is increasing rapidly as a result of emerging markets in developing countries. Compared to the growth of mobile networks, the relatively high cost and technical limitations of extending electricity grids have left over 500 million MP users without access to electricity. MP charging has become one of the major end-use demands in rural electrification projects, where MP users spend disproportionate amounts of time and money seeking charging services.

This study investigates the energy and power requirements of MP charging. The energy and power demands of MP charging are determined experimentally using the charge configuration commonly found in developing countries: an inverter powered by a 12 volt car battery. The objective is to quantify the power and energy demand for MPs, and the overall efficiency of the systems used to charge them. By analyzing the charging configurations on an energy efficiency basis and identifying the major losses, recommendations for improvement are made.

Results show that the average energy requirement per MP charge is 7 Wh, but due to efficiency losses in the inverter, the total energy requirement can reach up to 13 Wh. The efficiency of the inverter increases with the number of MPs being charged simultaneously, ranging from 50% for a single phone to 85% for 15 phones. The peak power requirement per MP is 7 W.

Introduction

Global electricity consumption is rapidly increasing, with major growth coming from countries like Brazil, India, and China. Most of this energy demand growth is being fueled by coal, oil, and natural gas in centralized power stations (IEA, 2012). Electricity grids are expanding, but not as fast as the demand for electricity grows. In 2011 there were 1.3 billion people lacking access to electricity, and almost all of them live in rural areas of developing countries, primarily in Sub-Saharan Africa and South Asia (IEA, 2012). The imbalance of electricity supply and demand has created a movement in the energy industry that seeks to empower citizens of developing nations by giving them access to electricity. Sub-Saharan Africa and South Asia are the regions who have the lowest electricity access worldwide.

Rural electrification provides the world's poorest peoples with basic services that drastically improve their quality of life and provide opportunities for economic development (Brent and Rogers, 2010; Cook, 2011). Rural electrification is not only effective as a humanitarian endeavor, but has also been shown to be economically viable in the long run (World Bank, 2008). As electricity networks grow in the developing world, they are restrained by the cost and technical limitations required for deploying infrastructure. Out-pacing the growth of electricity grids are telecommunication networks, due to their ability to transmit data wirelessly. There are now over 5.5 billion mobile phone (MP) connections in the developing world alone (GSMA, 2012). The disproportionate growth of MP networks over electricity networks has resulted in over 500 million MP users living in areas without access to electricity (GSMA, 2011b). This obviously is a problem when users need to charge their MP, but have nowhere to plug them in. In rural areas that have been electrified, one of the major demands for electricity is for MP charging (GSMA, 2012). MP users in areas not serviced by electricity grids must travel significant distances and pay a premium to charge their MP.

This study focuses on the energy requirements to charge mobile phones without access to grid-electricity. The goal of this work is to provide sizing guidelines for off-grid MP charging systems in developing countries. The energy and power demands of MP charging are determined experimentally using charge configurations that are commonly found in developing countries. The system is analyzed on an energy efficiency basis. By identifying the major losses, recommendations are made in order to maximize the efficiency of a charging system. Using the appropriate sizing methodology that this study puts forth, the resources for mobile phone charging can be developed appropriately, and improvements to efficiency can reduce the cost of mobile phone charging to the world's poorest citizens. The article includes a background on rural electrification and MPs in the developing world, a description of the methodology, an analysis of the results, and presents recommendations for system sizing.

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0973-0826/$ – see front matter
http://dx.doi.org/10.1016/j.esd.2013.10.003

Background

Rural electrification

For remote areas, electrification projects often prefer decentralized power generation over the high cost of centralized electricity grid extensions (Mahapatra and Dasappa, 2012). These projects take either the form of stand-alone systems or micro-grids. The former implies a system in a single-home/building that has a dedicated generation source, whereas the latter involves a single generation source supplying multiple homes/buildings of a community. The decentralized use of renewable energy resources is often preferred due to the low operating cost compared to conventional fossil-fuel generators. The low-price and maintenance requirements of solar photovoltaic (PV) modules are making them increasingly common for power generation in rural electrification applications (Palit, 2013). The electricity from the PV modules charges a battery energy storage system (BESS), typically consisting of lead-acid batteries. Electricity end-uses draw energy from the BESS, either at BESS voltage (typically 12 V_{DC}) or through an inverter (typically 100–240 V_{AC} single phase). These systems are mature, so the technical aspects are well understood and reliable. The success of rural electrification therefore often relies on the non-technical aspects of the project, such as economics and community engagement (Kumar et al., 2009). The end-use demand for rural electricity systems is often low, since the end-user previously had little or no access of electricity. The end-uses include lighting, MP charging, and small appliances such as radios, televisions, and refrigerators.

Mobile phones in the developing world

The uptake of MP technology and the resulting connectivity brings social and economic benefits, and in the past decade the uptake has been substantial. Since 2000, the number of people owning MPs in Sub-Saharan Africa has grown from 16 million to 500 million. The number of off-grid telecommunications tower sites in East Africa is expected to grow 60% from 2012 to 2015 (GSMA, 2013). Most of the phones used in developing countries are simple handsets with voice and short message service (SMS) capabilities, rather than internet enabled smart-phones (Rotberg and Aker, 2013). These handsets are ubiquitous even in the most rural areas of developing countries, providing improved conditions for communication and providing access through SMS to other services such as banking, weather forecasts, and news. It has been argued that a 10% increase in MP penetration leads to a 1.2% increase in gross domestic product (GDP) (GSMA, 2011b).

The Global System for Mobile Communications Association (GSMA) suggests that in 2011 there were 538 million mobile connections globally in areas without access to electricity (GSMA, 2011b). Without direct access to electricity to charge their phones, these MP users are severely limited in their ability to access and distribute information. This number is likely to increase due to the speed at which telecommunications network coverage can be deployed, which is faster than expanding centralized electricity grid infrastructure.

In order to charge their MP, mobile users living off-grid typically go through exhaustive measures to charge. Many people travel significant distances by foot, bike, or boat to the closest "phone shop" where they pay a nominal fee of about US$0.20 to have their phone charged (GSMA, 2011a, 2011b; Wyche and Murphy, 2012). The equivalent cost of energy for this MP charging service is US$25/kWh. This inconvenience incurs significant losses in productivity and financial resources. In countries where the GDP per capita is under $800 (such as Uganda and Kenya), some people spend up to $80 a year keeping their phones charged (UN, 2012; GSMA, 2011b). These costs are disproportionate to the amount of energy that is actually required to keep phones energized, and primarily represents a service fee. Table 1 illustrates the expenses related to owning a mobile phone based on data from GSMA (2011a) and the authors' personal experiences in Canada.

Table 1
Expenses related to charging MP in developed and developing areas.

Parameter	Canada	Sub-Saharan Africa
Cost of energy (US$/Wh)	0.00013	–
Charge energy (Wh)	8 Wh	8 Wh
Charges per month	30	30
Cost per charge (US$)	0.001	0.20
Cost per month (US$)	0.03	6.00
Phone plan per month ($)	50.00	6.00
Charging costs as a percentage of total phone costs	0. 06%	50%

Although the example in Table 1 assumes that both parties charge their phone daily, which is less likely in Sub-Saharan Africa, it shows the drastic discrepancy in mobile phone charging between the two regions. Even if an MP user was to charge their phone once a month, they would still be paying nearly seven times the price for it.

Mobile phone charging in the developing world

The MP charge shops that operate in rural off-grid areas of the developing world all use a similar low-tech system. Dozens of phones are charged simultaneously using a series of parallel AC connections on "power-bars". Since the power adapters of the phones require 100–240 V_{AC} power, the power-bars are plugged into an inverter, which is powered by a 12 V_{DC} car battery. An example of this type of system is shown in Fig. 1, along with typical losses listed for each component. Since MP users may have traveled long distance to reach the phone shop, and where theft and battery switching are occasional threats, the phone user typically waits for the 1–2 h it takes to receive a charge (Wyche and Murphy, 2012). Several products also exist that offer alternatives for off-grid users to charge their own phones including human-powered chargers, solar PV chargers, thermoelectric chargers, and DC–DC chargers. However, these rarely used in favor of a phone shop because they are too expensive for the average off-grid mobile phone user (GSMA, 2011b), lack the connectors for certain phones, making them incompatible (Wyche and Murphy, 2012), and can only charge one phone at a time.

The switching losses and joule heating in the inverter are due to the conversion from 12 V_{DC} to 100–240 V_{AC} and then in the MP specific power adapter converting from 100–240 V_{AC} to 5 V_{DC} (typical). While the series connection from DC to AC to DC through the inverter and MP power adapter may be inefficient, it is required due to the range of MP connectors and DC voltage levels. The losses in the battery are a result of the requirement for coulombic "over-charge" and the voltage difference between charging and discharging caused by internal resistance. Several alternatives exist to charge the 12 V_{DC} supply battery at the phone shop: i) charge using the electricity grid and transport it to the phone shop, ii) charge from a diesel generator or car alternator, or iii) charge using renewable energy at the shop, typically from PV modules. For this reason, this present study focuses on the charging of

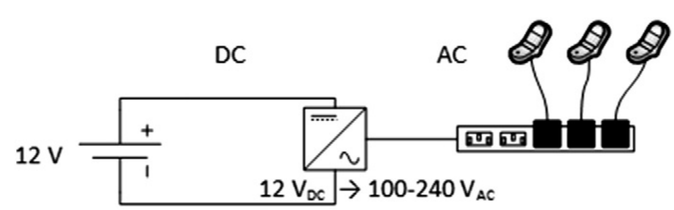

Fig. 1. Typical phone shop charging system components and their associated losses.