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Review

The 'low power' revolution: Rural off-grid consumer technologies and portable micropower systems in non-industrialised regions

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ABSTRACT

This review analyses the growth in small 'low power' renewable energy and consumer product technologies and their potential utility in rural and remote economic development. The historical legacy of increasingly industrial-scale and expensive centralised high voltage alternating current (AC) systems contrasts starkly against the dynamic plethora of energy efficient portable low power direct current (DC) devices and consumer goods that underpin a modern economy. Advantages of portable DC devices are their inherent utility as a deferrable load and imbedded storage, enabling the appliance to become the balance of system (BOS) component and the power management system when coupled to portable renewable energy system or a microgrid. These developments present the opportunity to revise broad assumptions of appropriate energy system investment models for non-industrialised nations without an expensive historical centralised high voltage AC industrialisation legacy. It also presents the opportunity to revisit appropriate rural clean energy stand-alone or microgrid system designs and configurations, and engage the information and communication technology (ICT) sector as a major new investor in energy services and infrastructure.

1. Introduction

Today billions of portable information and communication technology (ICT) devices, including smartphones, tablets, lights, MP3 players, electric gardening equipment, PCs and many accessories with rechargeable batteries are now in circulation worldwide, and are increasingly associated with user energy autonomy and energy efficiency [1–4]. This includes the most non-industrialised regions of the world. For example, when around 63% of people in sub-Saharan Africa have access to improved drinking water [5], and only around 30% have access to centralised electricity services [6]; access to mobile phones have grown from practically zero to around 50% in only a decade [7,8]. Why is this so? In contrast to the 'hard won' capital-intensive conventional electricity and water infrastructure investments by governments and international agencies [5–7], the swift adoption of ICT and the rollout of the associated infrastructure has occurred relatively autonomously on a largely commercial basis in a very short timeframe.

The relatively low population-wide levels of access to water and electricity services is much more extreme for those living in rural 'off-grid' areas in non-industrial areas. The vast majority of rural poor populations in non-industrialised nations have no access to reliable, safe, healthy, and affordable centralised electricity services [6,9,10]. Where access does exist, economic barriers often predominate, as many rural poor households cannot afford to connect to a centralised electricity network [11–13]. For these households to enjoy the benefits of modern utility services, small-scale systems must become, and are becoming, a cost-effective alternative in remote areas [13–16]. Much of the global focus and effort has been on simple cost-effective technologies like basic lighting, as there remains two billion people without access to modern lighting globally [9]. Sadly households in rural developing areas using traditional biomass lighting pay a similar proportion of their household income for lighting as the average American family, yet only receive around 0.2% of the lumen-hours [17]. Clearly, the economic capacity of families using traditional biomass for lighting will likely find it a challenge to afford the high costs of conventional centralised electricity services when 'it arrives'.

In industrialised and non-industrialised nations alike, conventional electricity infrastructure and networks themselves are becoming viewed as a major limiting factor in the provision of

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efficient and cost-effective electricity services [18]. However, at the small-scale, fundamentally new models of low cost and flexibility of (re)configuration/expansion of small-scale 'smart' and microgrid power systems offer major advantages in multi-user systems for rural areas at lower costs [6,15]. This research focusses on the unique options of including the storage capability and deferrable load options that enable demand side management (DSM) from 'low power' consumer goods and ICT devices as a new form of the continually evolving DC microgrid infrastructure and control system to foster creative electricity system design rethinking [4,18,19]. This new ICT consumer good infrastructure includes the improved functionality, connectivity, and portability of devices such as 'plug and play' balance of system (BOS) components with distributed and portable appliances, effective DC bus regulation, imbedded energy storage, all with major safety benefits and an attractive and user-friendly interface unseen in the traditional energy sector. This enables small-scale renewable energy and smart microgrid concepts to cost-effectively enter the home to enhance both personal and economically productive uses, and reduce the past issues of poor user-friendliness, capacity limitations, and high cost of the previous generations of renewable energy technology.

The historical inability of conventional renewable energy systems to be a cost-effective means to supply traditionally inefficient tools and equipment in rural small-to-medium enterprises (SMEs) has resulted in energy efficiency and low power systems becoming a major unmet market need [9,20–22]. For example, with the development of light emitting diodes (LEDs), using personal portable photovoltaic (PV) modules and batteries in small lighting systems is a practical and more affordable 'disruptive technology' [22,23]. Advancing improvements in ruggedness, low voltage tolerance, small size, high optical efficiency, and low cost of LEDs have enabled small-scale lighting and PV-battery combinations to flourish [23]. These advances have sustained the belief that DC renewable energy will eventually become the preferred generation technology for small stand-alone systems in non-industrialised regions [9], particularly with low wattages and voltages [4,20]. However, LEDs may be simply the first example of a disruptive low power and micropower technology, particularly in terms of facilitating productive applications such as communication, reading, and night-time education. 'Back lit' portable personal devices are largely replacing conventional books and desktop computers as learning and communication mediums of choice. It is also common to use the brightness of some screens and inbuilt LEDs for basic task lighting (making LEDs themselves out-dated in many cases).

In addition to the social benefits of energy and ICT service integration, economically productive rural applications arising from such services (commerce, communications, electronics, agri-business, etc.) will assist further economic development and innovation to capture the greater benefits of improved rural supply chain opportunities [22,24]. At present, small-scale rural development, energy infrastructure, production, communications, capacity building, extension services, and agri-marketing activities remain disaggregated, and their integration is under-emphasised in current approaches [16,25,26]. Conventional models of rural energy infrastructure, mechanisation, education, and extension investments have typically long lead time horizons, and are separated into distinct and isolated fields of planning and funding. In contrast, modern rural development activities require an acceleration of new technology and knowledge adoption and must connect the diverse rural supply chains and inputs (knowledge, energy, agricultural inputs, technology, commodity prices, etc.) [27]. As rural subsistence regions traditionally have poor access to new technologies and productive inputs, a greater focus on creating a suitable environment to enable participation in economically productive applications with appropriate energy and ICT technologies is key [22,28,29].

2. Innovative portable ICT networks, generation, and portability

Many portable personal devices are powered through a computer universal serial bus (USB). Indeed the ICT sector has advanced the USB to already become a pervasive yet largely unplanned DC microgrid rolled out in many global modern workplaces (Fig. 1). The continued development of low voltage DC and USB device coupling multiple small-scale generation for personal ICT device charging is yielding higher efficiency and lower power options suitable for rural and remote regions [30]. The most common USB ports are USB 2.0 and 3.0, and in terms of power the nominal voltage of the USB is 5 V, (USB 2.0 maximum 5.25 V and minimum 4.75 V, with a nominal power of 2.5 W), with a maximum current of 0.50 A. The more recent USB 3.0 is also 5 V, (maximum 5.25 V and minimum 4.45 V, with a nominal power of 2.5 W), and exhibits current variants of 0.150 A, 0.900 A, and 1.5 A. (The 1.5 A port is limited to charging only with no data transfer capability, and the USB charging ports are able to deliver up to around 5 A). Recent developments in the USB standards include the USB Power Delivery protocol, delivering a maximum 20 V and minimum 5 V, (with variable voltage capability) and with a limited output of 5 A, enabling a maximum nominal power of 100 W. The new protocol can provide power in both directions, optimise power management between appliances, and several other advanced enabling capabilities [31]. As such, the ICT sector is now a major new investor in and producer of low voltage DC electricity network infrastructure as a byproduct of their business model.

Many new portable ICT goods for the relatively wealthy 'western', 'consumer' or 'adventure' market are becoming available and now leading the development of many new renewable energy system configurations and designs. For example, the company Goal Zero produces the 'Nomad 27', a 0.151 m^2, 1.5 kg monocrystalline PV array rated at 27 W, V_{SC} ~19 V, with dimensions of 113 × 57 cm unfolded, and able to be folded into a portable package with dimensions 26.7 × 18 × 5 cm (and exhibits a buck regulated USB output of 5 V, 0.5 A, 2.5 W maximum, or a 13–15 V, 1.6 A, 24 W maximum DC unregulated output). The product is aimed at the adventure/camping market and has is designed for portability, interconnectivity, and to power multiple ICT devices. The same company produces the 'Sherpa 50' – a 0.50 kg lithium-ion (nickel manganese cobalt oxide, NMC) 9–13 V DC battery-charger unit, with dimensions 11.4 × 3.8 × 12.7 cm, and a capacity of around

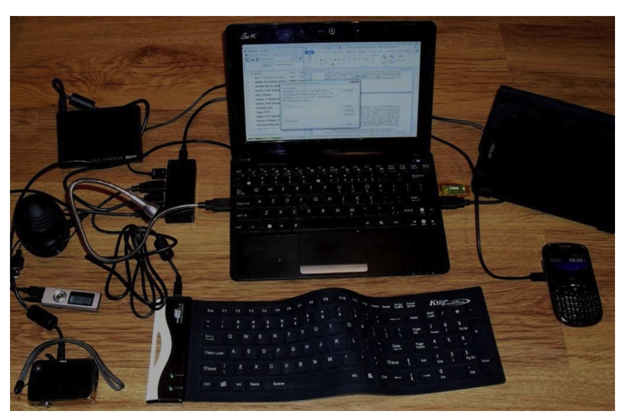

Fig. 1. The PC-USB-dominated workspace is a low power portable DC microgrid. The PC is the AC/DC interface (100–240VAC, 0.8 A/19VDC 1.58 A) with 'island mode' using only DC utilising the battery to power the USB network (5VDC) to several consumptive appliances, five of which have their own imbedded battery storage (tablet, phone, camera, MP3 player, and speaker), and four powered only by the USB ports (flexible second keyboard, thumb drive, external hard drive, and LED light).