Modelling Elements of Smart Grids for sub-Saharan African Countries

Long Abstract

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This paper discusses the potential role of Smart Grids to electrify the poor. It showcases potential benefits specific to smart grids and provides a framework to quantify some of those for a stereotypical case. This is achieved by developing a simple energy systems model using the Open-Source Energy Modelling System (OSeMOSYS). The model and source code are made available for analysts and planners to test and extend the analysis. Finally, the paper interprets the results of the modelling, describes the limitations of the approach, presents the major findings and suggests a way forward.

In 2009, 70% of the population of sub-Saharan Africa did not have access to electricity (IEA 2010a). The significant need for accelerated electrification rates has been identified by regional economic communities and their power pools as well as national governments[1]. National electrification policies underpin related ambitions, with more than 75% of sub-Saharan African countries having defined targets for electricity access (WHO and UNDP 2009). The importance of regional and national electrification initiatives is clearly understood at the policy level. The priority is to translate this understanding into provision of electricity services "on the ground".

The lack of electricity infrastructure required to connect these 70% offers significant opportunities to successfully shape such "on the ground" action. This is because of the limited "legacy infrastructure" to be accommodated as the electricity system expands, which may in turn allow for a radical departure from traditional electrification approaches. Expanding access to national electricity grids usually constitutes the cheapest option for providing electricity services. However, decentralized power, often based on renewable energy sources, is likely to continue to be an important component of any significant expansion in electricity access, especially for rural and remote areas (Deichmann et al. 2010). Both system types can benefit from aspects of Smart Grid concepts, which constitute such a departure from historic deployment pathways.

Smart Grids have received significant attention in industrialised countries in the last years. The claim is that Smart Grids offer considerable opportunities. They help to dynamically balance and optimize power generation, delivery assets and loads (EPRI 2009). Associated technical benefits include: improved reliability and resilience; greater integration of renewable energy (IEA 2010b); increased efficiency of system operation (ETP SmartGrids 2010); and optimised utilization of both generation and grid primary assets (U.K. House of Commons 2010). In addition to these technical benefits, other claimed benefits include reduced climate change impact (IEA 2010b) and job creation (McNamara 2009). In particular, Smart Grids may deliver all these benefits at potentially lower overall cost than would be possible under business-as-usual assumptions (IEA 2010b). However, the detailed monetary implications of Smart Grids – and their role in electrification in particular - are not yet fully understood (IEA 2010b).

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[1] Such as: The Forum of Energy Ministers of Africa's (FEMA) Position Paper on Energy and the MDGs (WHO and UNDP 2009); The Southern African Development Community's (SADC) Protocol on Energy (L. Kritzinger-van Niekerk and E. Pinto Moreira 2002) and its Regional Indicative Strategic Development Plan (RISDP) (SADC 2003); The Economic Community Of West African States' (ECOWAS) Energy Protocol (ECOWAS 2003) and its White Paper for a Regional Policy (ECOWAS 2006); The Common Market for Eastern and Southern Africa's (COMESA) Energy Programme (COMESA 2009); The East African Community's (EAC) Regional Strategy on Scaling-up Access to Modern Energy Services (EAC 2009) and its Power Master Plan Study (BKS Acres 2005); The Treaty Establishing the Economic Community of Central African States (ECCAS n.d.); The Economic and Monetary Community of Central Africa's (CEMAC) Energy Action plan with energy and electricity access goals (WHO and UNDP 2009); The Africa-EU Energy Partnership (AUC and EC 2008; AUC and EC 2007);

Many of the potential benefits motivating Smart Grid development in industrialised countries would be equally valid for sub-Saharan Africa according to Bazilian et al. (Bazilian et al. 2011). However, certain concepts and associated policies would require targeted refinement to optimise the cost-benefit balance in a sustainable manner. Concordantly, Bazilian et al. (2011) provide a refined definition of Smart Grids. Their concept for sub-Saharan Africa "…embraces all measures in support of immediate and future integration of advanced two-way communication, automation and control technologies into local, national or regional electricity infrastructure. The concept aims to optimise grid systems and their operation, integrate high levels of renewable energy penetration, and improve the reliability and efficiency of electricity supply."

Smart Grids are composed of complex and integrated systems, but often build to a large degree on proven advanced technologies[2], enabling potential leapfrogging to the latest grid concepts, systems and technologies. This could benefit sub-Saharan Africa in various ways. The often significant technical and non-technical losses could be reduced through improved power lines and transformers (Niez 2010). Distribution automation technologies could help minimise the extent of outages and increase the speed of restoration (SCE 2010). Charging prepaid consumption credits via mobile phones using scratch cards or comparable devices may help specifically address the needs of the poor, and reduce administrative costs related to meter readings and billing. Further, reliable and low-cost access for the poor could be assured during off-peak hours, while only curtailed access would be provided during times of higher demand. Conceivably, tariffs may even be delineated by service to allow for targeted subsidies. In addition, on-bill financing of energy efficient appliances may be an important tool to help consumers overcome the associated high upfront costs.

Smart Grid technologies may further contribute to improving the performance of mini-grids by helping maintain an adequate power quality. This can often be a challenge, for example due to spikes associated with the starting current of motor loads (Makarand, Mukul, and Banerjee 2010) or the need to provide some form of back-up power. Smart components could help cushion such effects and better balance the overall system through integrating demand side management options. E.g., load control switches at industrial or institutional facilities can contribute to optimising the quality of energy services and reducing load-shedding. Radio-controlled interruptible institutional water heaters or water pumping systems constitute just two examples for such load control. At the household level, for example, smart refrigerators that hold enough thermal storage to withstand interruptions or avoid power use during peak loads could be deployed.

The concept of Smart Grids needs to be well integrated into national and regional energy planning in order to take advantage of these significant opportunities. Planning is expected to increase in complexity as the grid evolves into an active layer between supply and demand. In addition to optimizing electricity systems from a technical perspective, Grids need to be optimized from a development perspective. Ensuring services for marginalized and rural communities will often not be the most cost-effective solution, so new constraints (or different objective functions) need to be added to traditional least-cost optimization models. The required expansion and adaptation of the traditional approach to energy planning needs to include a more active role for demand, linkages with storage, and the integration of mini-grids into plans for grid expansion. In addition, modern energy planning needs to balance sustainable development plans carefully with regional energy integration and national and local Smart Grids.

According to Bazilian et al. (2011), the current Smart Grid discourse in sub-Saharan Africa is at a nascent stage and targets mostly the conceptual level, lacking a solid technical and practical foundation based on an elaborated business case. With this paper we therefore aim to provide an element of this foundation by modelling specific technical elements of Smart Grids in rural sub-Saharan African contexts for a stereotypical case, using the Open Source Energy Modelling System (OSeMOSYS)[3]. The effort starts by focusing on mini-grid electrification and subsequent linkages to a national grid. Implications for national electricity planning are then considered.

[2] This is especially true for integrated communication technologies like cable modems or WiFi networks. For a comprehensive overview of Smart Grid technology components and their time to market use refer to NETL (2009).

[3] OSeMOSYS was designed to fill a gap in the analytical toolbox available to the energy research community. At present there exists a useful, but limited set of accessible energy systems models. These tools often require significant investment in terms of human resources, training and software purchases in order to apply or further develop them. Their structure is such that integration with other tools, when possible, can be difficult. OSMOSYS is a fully fledged energy systems optimisation model, with no associated upfront financial requirements to extend the availability of energy modelling further to the communities of students, business analysts, government specialists, and developing country energy researchers (Strachan et al. 2010).

The modelling considers demand side management options which build on the advances in power systems, like load control switches for larger consumer loads, smart appliances and a prioritisation of consumer loads. Various distributed storage options constitute an integral component of the model, e.g., through local battery charging stations. The paper further explores novel market approaches, like time-of-use pricing and schemes based on the provision of low-cost electricity with reduced quality of supply during on-peak hours. We show how such elements may help improve access to, and quality of, electricity in rural electrification schemes with reduced overall costs through an optimised allocation of resources.

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