Development of a Smart Monitoring and Evaluation Framework for Hybrid Renewable Mini-grids

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Hybrid renewable mini-grids have emerged as a viable solution for providing reliable, environmentally friendly electricity to remote communities. An affordable and grid-quality supply of energy can open new possibilities for socioeconomic progress. As part of a joint project between South Africa's Eastern Cape province and Germany's state of Lower Saxony, with funding from BMZ (Federal Ministry for Economic Cooperation and Development) through GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), a Photovoltaics (PV) hybrid mini-grid was designed and developed in the municipality of Upper Blinkwater in Eastern Cape, South Africa for a rural community of 67 households with 90% living off of social grants and no access to the main national grid.

Successful implementation of mini-grids requires the right technology, access to financing and consumer-friendly payment system, an appropriate regulatory environment, social facilitation, institutional implementation, environmental impact evaluation, human capitalization and training, and implementing a robust, reliable and smart Monitoring and Evaluation Framework (MEF). The aim of this work is to design a systematic approach to development of a smart MEF for hybrid renewable mini-grids by integrating cutting-edge technologies and SMART methods in a scalable platform of replicable solutions towards connecting the mini-grid with diverse stakeholders with enhanced observability of both generation and consumption profiles.

In the first step the main features of MEF and the integrated components are specified. In the second step a set of Key Performance Indicators (KPIs) are developed through a technical workshop with all the stakeholders by first defining two types of data sources, energy and non-energy and then parametrizing the mini-grid accordingly. In the next phase KPIs are categorized into five domains including, technical, operational, financial, social, and environmental according to specific need of each stakeholder for monitoring and evaluation purposes.

The MEF provides the opportunity to streamline the flow of real-time energy data (generation, consumption, and storage) from the system to generate accurate and high-resolution data-driven load profiles for rural households or communities. These profiles are used for studying and analyzing the evolution of demand and making ongoing design optimization. These profiles could also be useful for mini-grid researchers and developers active in Sub-Saharan Africa.

Through the South Africa Wind Energy Programme (SAWEP), the extension of solar hybrid mini-grids with micro wind generation and its positive effects on renewable energy share and battery life time is currently explored. The MEF provides the required measureable parameters to evaluate the extension need of mini grids with further renewable generation capacity during operation.

Simultaneously, the interrelation between energy access and social development will be studied and analyzed.

Keywords: Hybrid Renewable Mini-grids; Monitoring and Evaluation, PV Mini-grids; Energy Access; Smart Mini-grids; Rural Household Load Profiles; Social Development

Hybrid Renewable Mini-grids as a Viable Solution for Energy Access

According to the World Bank's report [1], from 2000 to 2016, the proportion of the global population with access to electricity increased from 78% to 87%, with the number of people living without electricity dropping to just below 1 billion. More than half of this population lives in Sub-Saharan Africa, and rapid population growth is projected to outpace electric grid expansion. In many countries national utilities lack the resources to finance grid extensions to remote rural areas, where low levels of electricity consumption and limited ability to pay often make these extensions uneconomic. Average cost of extending the grid to rural consumers in Africa is estimated at $2,000/connection [2], while the average cost of 11kV power line is around $20,000/km [3]. Africa has emerged as a dynamic, fast-advancing center for renewable mini-grids. The deployment of PV technologies has been a key driver of growth in mini-grid capacity. The abundance of the resource, the distributed nature of technology and decreasing costs are leading solar PV to become a viable choice. The World Bank estimates that 140 million rural Africans will gain access to electricity served by mini-grids by 2040 [4].

As part of a joint program between South Africa and Germany's state of Lower Saxony, a PV hybrid mini-grid is designed and developed in the municipality of Upper Blinkwater in the Eastern Cape, South Africa. The potential for the use of solar energy is extremely favorable in South Africa due to the global solar horizontal irradiation of average 2,100 kWh/m^2 (year) and a sunshine duration of 2,500 hours/year [5]. The aim of the project is to demonstrate a solution for an economically and ecologically sustainable energy supply to non-electrified rural communities.

Monitoring and Evaluation Framework

Successful implementation of mini-grids requires the right technology, access to financing and consumer-friendly payment system, an appropriate regulatory environment, social facilitation, institutional implementation, environmental impact evaluation, human capitalization and training, and implementing a robust, reliable, and smart Monitoring and Evaluation Framework (MEF). A smart MEF can bridge the gap between the design and operation in the long run. It can eventually guarantee the flow of essential data to various stakeholders, including governmental organizations, utility operators, consumers, research institutes, investors, universities, and local authorities to manage, evaluate and optimize the system. The following features have been considered as the base requirements for the MEF system:

- Data collection (economic, automatic, accuracy, resolution, compatibility, etc.)
- Data transfer and storage (economic, reliable, automatic, wireless, etc.)
- Security of data (secure servers, authenticated, etc.)
- Scalability (envisioning the growing demand and size)

Key Performance Indicators (KPIs)

A hybrid approach is used to develop the KPIs including a measurement-based approach, considering the installation of hardware components to measure energy and contextual data required for KPI calculation, and a model-based approach by defining the configuration parameters and mathematical formulas required for KPI analysis. Based on the selected KPIs and the overall project requirements a data flow scheme is designed and the appropriate metering and telecommunication technologies, software modules, data interfaces are integrated as shown in Figure 1.

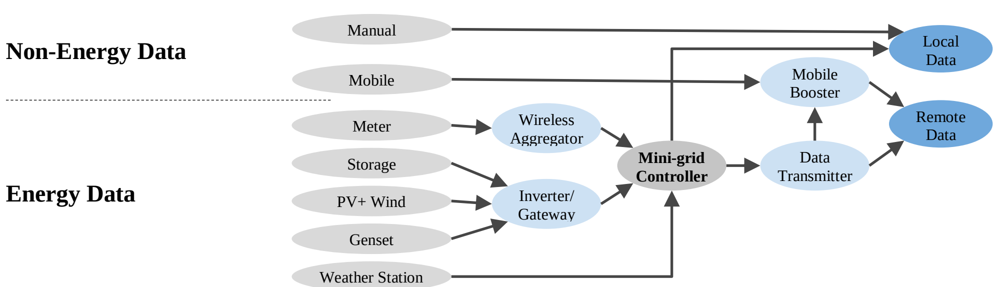

Figure 1: Data Flow Scheme

Data-driven Load Profile Generation and Analysis

Standard urban household load profiles are quite useful and essential in the field of energy research, and there has already been significant scientific contribution to this subject. In contrast, there have been relatively less efforts to address rural load profiles connected to renewable hybrid mini-grids, especially for rural communities with no access to electricity after gaining a reliable grid-quality service, as the load profiles would evolve over time.

The MEF provides the opportunity to streamline the flow of real-time energy data (generation, consumption, and storage) from the system to generate accurate and high-resolution data-driven load profiles for rural households or communities. These profiles are used for studying and analyzing the evolution of demand and making ongoing design optimization.

PV Testing (on-site) and Monitoring

In addition to the extensive monitoring and evaluation of system operation and performance, a detailed baseline evaluation of the PV modules was undertaken. The module and string current-voltage (I-V) characteristic curves were measure on-site. The full plant was inspected for any visual anomalies, UV-fluorescence (UV-F) imaging was also undertaken to assess the status of the modules with respect to cell cracking and / or encapsulant degradation. Lastly, electroluminescence (EL) imaging was also used to further assess the modules. The baseline evaluation will be used as reference for future periodic on-site evaluation to assess degradation of the PV modules.

Integration of the Wind Component

The overall objectives involve the local-to-local knowledge transfer and the provision of technical support in the analysis and sizing of the local wind energy resources, followed by the sourcing and installation of small wind turbines. In addition, wind power system integration with the existing solar-diesel based power system is also included in the project scope. The need for such a project stems from the; 1) lack of public knowledge on hybrid small-scale rural and stand-alone renewable energy system planning, costing, and operation, and 2) remaining national challenge of shortages in technical skills development. The project design and implementation must be done in collaboration with the local community. Herein, the term "community" includes all involved e.g. the villagers, the municipality, the project managers, the owner engineers, etc.

Social Development Study

As a first of its kind service delivery approach in the South African context it is important to evaluate not only the technical success, but also the social and economic impacts of the hybrid mini-grid system in the UB project. To achieve this, the baseline information was established. This is the survey documenting the current and existing state of the community to provide a picture of the status quo, from which changes in the livelihood and wellbeing of the community/households recipients resulting from the implementation of the mini-grid can be measured.

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