 TSP, vol.1, no.1, pp.1-5, 2018

Microgrids-As-A-Service for Rural Electrification in Sub-Saharan Africa

Qi Liu[1,3], Kondwani Michael Kamoto[2,*] and Xiaodong Liu[3]

Abstract: The majority of the population on the African continent is unable to access basic electricity services, this despite the abundance of renewable energy sources (RESs). The inability to adequately tap into these RESs has led to the continued dependence on non-renewable energy sources such as coal for electricity generation, and kerosene for cooking and lighting, the resulting use of which is poor health conditions. The use of Microgrids (MGs) is being extensively researched as a feasible means of tackling the challenge of electrification, especially in rural and remote areas. Recent times have seen an increasing number of research works focusing on Sub-Saharan Africa (SSA), which is one of the regions with the lowest electrification rates in the world. MGs provide the most suitable means to integrate RESs into the electricity generation process, paving the way towards clean energy for the African continent. This paper presents a review of recent literature on the usage of MG for rural electrification, with a specific focus on the applicability of MG in the SSA context. The paper additionally presents the challenges and opportunities to date. Research findings indicate that SSA has already begun the transition towards clean energy via implementation of RES-based MGs. However, two resonating challenges in the literature are adequate support via policy, and proper planning of project implementation. These two major barriers are needed to be overcome in order to fully utilize MGs for rural electrification in SSA. The key methodology derived from this study is that any effort towards rural electrification requires a sufficient amount of investigation, incorporating both the technological and socio-economic aspects into a suitable design for the target location.

Keywords: Microgrid (MG), Rural Electrification, Sub-Saharan Africa (SSA).

1. Introduction

[1]School of Computer and Software, Nanjing University of Information Science & Technology, Nanjing, 210044, China.

[2]Jiangsu Collaborative Innovation Center of Atmospheric Environment and Equipment Technology (CICAEET), Nanjing University of Information Science & Technology, Nanjing, 210044, China.

[3] School of Computing, Edinburgh Napier University, 10 Colinton Road, Edinburgh EH10 5DT, UK

[*]Corresponding Author: Kondwani Michael Kamoto. Email: k_kamoto@yahoo.co.uk.

Universal access to electricity remains to be one of the greatest global challenges that needs to be addressed to date. A recent report published by the International Energy Agency (IEA) [IEA (2018)] states that, "675 million people, 90% of them residing in Sub-Saharan Africa (SSA), will remain without access to electricity in 2030, down from 1.1 billion today". It further states that, "in 2030, 2.3 billion will continue to rely on biomass, coal or kerosene for cooking, down from 2.8 billion today. Household air pollution from these sources is currently linked to 2.8 million premature deaths per year, and several billion hours are spent collecting firewood for cooking, mostly by women, that could be put to more productive uses".

There are number of electrification projects that have been and are being initiated and implemented across the African continent, with the World Bank and United Nations playing a major role. The main initiative has been Sustainable Energy for All (SE4All) which is a joint operation between the two entities aiming for: 1) universal access to electricity, 2) higher energy efficiency in homes and businesses, and 3) larger contribution of renewable energy to electricity generation worldwide [SE4All (2018)]. Another well-known initiative is Power Africa, which is facilitated by the U.S. government and aims to provide suitable solutions to this pressing issue [Power Africa (2018)]. Despite the efforts of these initiatives and other lesser-known projects, there is still a large amount of work that needs to be done, and in particular there is a need for technologically viable and scalable solutions for SSA.

When considering the recent trend in technological advancements, Cyber-Physical Systems (CPSs) and Internet of Things (IoT) are revolutionizing the interaction between the cyber world and the physical world [Lin, Yu, Zhang et al. (2017)]. The developments in the energy sector are seen as a key determining factor that will redefine the way we view energy usage both locally and on a global scale. Internet of Things (IoT) is at the forefront of the transformation of electric power and energy systems (EPESs) to provide clean distributed energy for sustainable global economic growth. IoT imparts capabilities, such as real-time monitoring, situational awareness and intelligence, control, and cyber security to transform the existing EPES into intelligent cyber-enabled EPES, which is more efficient, secure, reliable, resilient, and sustainable [Bedi, Venayagamoorthy, Singh et al. (2018)].

The most representative application of the integration of CPS and IoT with regards to electrical energy usage is the Smart Grid, which embodies the ideology of a new way of generating, transmitting, and distributing electrical energy. The Smart Grid provides bidirectional flow of electricity and information between connected entities and utilizes a variety of technologies to ensure reliable and flexible access to electricity. One of the key components of the Smart Grid is the Microgrid (MG). The U.S. Department of Energy (DOE) defines an MG as, "a group of interconnected loads and distributed energy resources (DERs) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid-connected or island modes" [U.S. DOE OEDER (2012)]. Suitable implementation techniques of MGs for electrification are being actively researched on a global scale. This surge in interest has been driven by the need to reduce carbon emissions, and the desire for alternatives to the current structure of electricity generation, and transmission and distribution (T&D).

MGs provide the means through which we are able to fully realize the integration of DERs in the electricity generation, and T&D process. This fact coupled together with the lowering prices of low-carbon technologies shapes a future which enables a larger percentage of inclusion with regards to electricity access. In addition, their ability to operate in connected mode and island mode opens up a lot of possibilities including reliable transmission during or after faults in the grid, caused by accidents or natural disasters, and improved availability of electricity due to their ability to act independently of the main electricity grid. Another added benefit is that initially islanded MGs in remote areas can be integrated into the main grid once the main grid has reached a suitable level of expansion. MGs present a great opportunity to help foster the electrification of rural regions in SSA. They enable reliable provision of electricity by integrating various sources of energy which are in abundance in SSA, and have the ability to scale with demand which makes them suitable to grow in response to the development of rural areas. Given the enormous socio-economics benefits of solutions to rural electrification, this research area has seen active participation across the globe. Such benefits include improved productivity and security via lighting, use of clean energy for cooking, improved telecommunications for remote areas, and community development via improved methods of irrigation for agriculture and provision of basic services dependent on electricity.

This paper presents a review of the recent approaches utilized for the application of MGs towards rural electrification in SSA. The main contributions of this work are to highlight promising approaches, and propose guidelines for future developments towards rural electrification. Section 2 presents an overview of MGs, and DER technologies. Section 3 provides a study of the recent research work that has been conducted with regards to rural electrification, with the main focus being on the works conducted in SSA. In Section 4 we present a summary of the current challenges and opportunities towards rural electrification, and we conclude our research findings in Section 5.

2. Microgrid Overview

2.1. Architecture

Parhizi et al. [Parhizi, Lotfi, Khodaei et al. (2015)] describe a MG as being typically comprised of loads, DERs, master controller, smart switches, protective devices, as well as communication, control and automation systems. MG loads are classified as either fixed or flexible. Fixed loads cannot be altered and must be satisfied under normal operating conditions while flexible loads are responsive to controlling signals. DERs consist of distributed generation units (DGU) and distributed energy storage systems (ESS). MG DGUs are categorized as dispatchable or nondispatchable. Dispatchable units can be controlled by the MG master controller and are subject to technical constraints depending on the type of unit. On the other hand nondispatchable units cannot be controlled by the MG master controller as the input source is uncontrollable. Nondispatchable units are mainly typically solar and wind, which produce a volatile and intermittent output power. ESSs coordinate with DGUs to guarantee the MG generation adequacy. They can also be used for energy arbitrage, where the stored energy at low price hours is generated back to the MG when the market price is high. The ESS also plays a major role in MG islanding applications. Smart switches and protective devices manage the connection between DERs and loads in the MG by connecting/disconnecting line flows. The switch at the point of common coupling (PCC) performs MG islanding by disconnecting the MG from the utility grid. The master controller determines the MG interaction with the utility grid, the decision to switch between interconnected and islanded modes, and optimal operation of local resources. Communications, control, and automation systems are also used to implement these control actions and to ensure constant, effective, and reliable interaction among MG components. MGs are typically classified according to whether they provide alternating current (AC) or direct current (DC). The architecture of a typical MG can be seen in the Fig. 1.

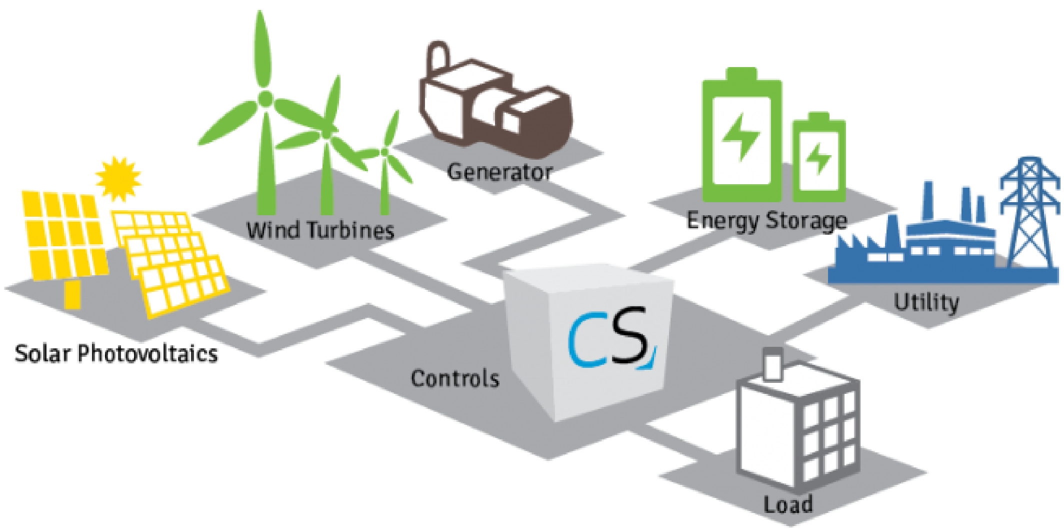

Figure 1: Microgrid architecture (courtesy of Sol-Up - http://www.solup.com)

2.2. Energy Sources

Electrical energy in MGs is generated using available renewable energy sources (RESs) which typically include solar photovoltaic (PV) array, wind turbine (WT), micro-hydro power (MHP), geo-thermal source (GS), thermoelectric generator (TG), tidal or wave energy generator (TWG), biomass energy generator (BEG), and a combined heat & power (CHP) generators. A diesel generator (DG) is typically used in MG configurations as a conventional back up energy source (ES). DGUs can be combined to create various configurations depending on the RESs available and the requirements of the MG implementation. Rezkallah et al [Rezkallah, Chandra, Singh et al. (2017)] enumerate a number of configurations for MGs classified on the basis of the preferred ESs. They considered the use of up to four ESs in the grid design, targeting usage in remote areas.

A majority of the rural regions in Southeast Asia and Africa receive abundant sun-light (above 5.5 kWhr/m^2 per day for most regions) [Jaffery, Khan, Ali et al. (2014); Khan and Arsalan (2014)]. This coupled with lowering prices for solar PV equipment makes electricity generation utilizing solar an attractive alternative to conventional methods. Other commonly cited energy sources are WT, MHP, and DG.

3. Microgrids for Rural Electrification

Wang et al. [Wang et al. (2009)] presented their work which focused on the installation and field measurement results of a 3-kW MHP system with two self-excited induction generators (SEIGs) using the irrigation water flowing in a ditch. This MHP system was stably operated for an extended period of time to withstand higher water-flow rates and various mechanical-electrical tests. The results of their work indicated that MHP can be a useful energy source for rural electrification in Africa, and furthermore demonstrated a financially viable solution for electrification utilizing water resources.

Kumar et al. [Kumar, Singh, Deng et al. (2018)] proposed a novel and simple framework for designing a rural sustainable microgrid for developing nations which considered a scenario where the load increases with time. The framework included a simple, yet very effective method for techno-financial analysis of an energy system. The results obtained after implementation from their case study pointed out the importance of considering not only technical and economic aspects, but also social and environmental issues, when implementing a MG for rural electrification. Additional research work has gone into defining frameworks to enable the successful implementation of MG for rural electrification [Ireland, Hughes, and Merven (2017); Kumar, Sah, Deng et al. (2017); Namaganda-Kiyimba and Mutale (2018); Xu and Chowdhury (2013); Doorsamy, Cronje, and Lakay-Doorsamy (2015)]. These works have re-emphasized the importance of a thorough approach to design and implementation.

In light of the inadequacy of the Nigerian power system, Ogunnubi et al. [Ogunnubi, Ajala and Idehen (2017)] introduced a Microgrid-as-a-Service (MaaS) framework. Their work leveraged the ubiquitous presence of small-scale generators serving as alternative sources of electrical power, such as interconnected homes and small-scale commercial centers, within close geographical proximity to form isolated electrical islands. Research work by Soltowski et al. [Soltowski, Bowes, Strachan et al. (2018)] also considered an approach making use of existing Solar Home Systems (SHS). Their study concluded that connecting such systems using low cost, low voltage distribution networks offers an opportunity to connect new customers and facilitate demand growth for existing consumers.

Pendieu Kwaye et al. [Pendieu Kwaye, Bendfeld and Anglani (2015)] investigated the potential of RESs in Cameroon. Their findings indicated that the northern regions of Cameroon have the highest wind potential. Possible viable locations for wind were also discovered in the North West, and in a few towns in the other regions of the country. This research indicates that Cameroon is a likely fit for a WT-based MG for electrification purposes.

Challenge Driven Education (CDE) was utilized to design an intelligent DC MG that can satisfy the energy demands of small communities in the rural areas of Tanzania [Rwegasira, Kondoro, Kelati et al. (2018)]. This work was part of a project called iGrid which made use of IoT and agent-based architectures in order to design a solar-powered MG that is efficient, reliable, autonomous, and self-sustaining. The outcome of the project work indicated that combining research, innovation, and creativity are the factors which bring development in the community.

Patel and Chowdhury [Patel and Chowdhury (2018)] investigated the used of MHP as a generation source for unelectrified rural areas in South Africa. The results of their analysis showed that the strength of a resource impacts the Levelized Cost of Electricity (LCOE) i.e., the stronger the resource the cheaper the system. The results also highlighted that the LCOE for an implementation scenario where a dam needs to be built, is approximately double that of when a dam already exists. This indicates that utilization of existing dams can result in significant savings in implementation.

Hamatwi et al [Hamatwi, Nyirenda and Davidson (2018)] modelled, simulated, and optimized a hybrid DC MG made up of a solar PV, WT, DG, and a backup battery bank, optimized for Oluundje village, a remote rural area in the northern part of Namibia. Simulation results of the electrical production of the optimal system added up to 330 097kWh per year of which the solar PV system, WT, and the DG contributed 50%, 21%, and 29%, respectively. Based on the economic and environmental impacts comparison, it was evident that the solar PV/wind/diesel hybrid system with 71% RE penetration was cost effective in the long run, and it would avoid or eliminate the addition of 35 tons of greenhouse gases (GHGs) emissions compared to a solar PV/diesel hybrid system.

For MG business models to succeed, appropriate customers need to be identified and connected in order to sustain the business. The work by Otieno et al. [Otieno B, Williams and McSharry (2018)] studied used data from 277 customers over a period of nine months collected from four MGs in Tanzania. The main goal was to segment customers to determine distinguishing characteristics of different groups that would be beneficial for PowerGen, is a leading alternative energy provider in East Africa. Empirical evidence demonstrated that demographic surveys, usually undertaken in advance of setting up MGs, offer a rich source of information about the likely future consumption patterns of customers. It was further highlighted that demographic variables are useful in classifying whether a customer’s connection type is business or home and also for predicting the average hourly consumption.

The use of DC has begun to regain popularity in recent times, especially with its suitability for the rural electrification scenario. Loomba et al. [Loomba, Asgotraa and Podmore (2016)] advocated for the use of DC MGs as an energy efficient off-grid clean energy based decentralized power generation solution for the unelectrified remote villages, and as a technology model that can bring about sustainable rural development. The basis of this is the fact that DC MGS are 25% - 30% more efficient than AC MGs.

Hamza et al. [Hamza, Shehroz, Fazal et al. (2017)] presented a methodology for selecting efficient distribution architecture of solar PV based DC MGs with respect to village orientation. The detailed loss analysis and energy balance model showed that in linearly distributed villages, O-architecture is the most efficient architecture for rural electrification, while Cluster-architecture is recommended for non-linear spatial distribution of houses in a village. Giraneza and Kahn [Giraneza and Kahn (2015)] introduced a new bottom up grid extension approach based on intermediate low voltage direct current (IL VDC). The extension works on swarm electrification concepts, with end users with DGs being part of extension process initiation. The system is said to benefit the less fortunate who cannot afford DGs, but who are able to pay the tariff of the electricity from the local interconnection of generators. Nasir et al. [Nasir, Khan, Hussain et al. (2017)] proposed an optimized DC MG architecture for rural electrification with emphasis on the providing power for purposes beyond those related to subsistence-level living. The results of their analysis showed that the proposed distributed storage architecture could enhance distribution efficiency by approximately 5% more than other low-voltage direct current (LVDC) architectures. Moreover, the proposed distributed generation and distributed storage architecture (DGDSA) was scalable in terms of its design and operation. The grid architecture consisted of several nanogrids capable of self-sustained generation, storage, and bidirectional flow of power within the MG. Bidirectional power flow and distributed voltage droop control were implemented through the duty cycle control of a modified flyback converter.

Cronje et al. [Cronje, Hofsajer, Shuma-Iwisi et al. (2012)] proposed a scalable MG. The architecture was intended for deep rural applications with no utility grid and possibly in peri-urban (close to urban) regions with a supply deficit. One of the salient features was the use of distributed intelligent control as opposed to centralized control requiring the installation and maintenance of a communications backbone. The results of the research identified the measurement and control subsystems required for the stable, smooth, uninterrupted operation of the MG, as major hurdles for implementation.

Adetunji et al. [Adetunji, Akinlabi and Joseph (2018)] proposed an alternative energy source for the community of Tafelkop, a town located in Limpopo, South Africa. The goal of the study was to sustain the community during intermittent utility grid outages, while incorporating high efficiency, low-cost, and minimal emissions. The proposed solution made use of estimated daily load profile, solar global horizontal irradiance (GHI), clearness index, average load, tariff, and grid outage parameters as inputs to the model.

Buque and Chowdhury [Buque and Chowdhury (2016)] analyzed the challenges and opportunities for improvement of grid resiliency in Mozambique. The authors made use of the system average interruption duration index (SAIDI) and system average interruption frequency index (SAIFI) factors, and identified the weakest network regions and prioritization of regional development through the implementation of MGs. It was determined that the northern region of the country presents the biggest need and simultaneously a significant amount of opportunities for improvement of grid resilience, possibly by integrating solar PV MGs and distributed generation. Given that Mozambique is in a key location to supply electricity to the rest of southern Africa, addressing these challenges is of great importance to Mozambique and its neighboring countries.

Williams et al. [Williams, Jaramillo, Campbell et al. (2018)] assessed segmentation among MG customers in Tanzania according to electricity consumption behavior. They made use of the k-means clustering algorithm, and placed 821 customers into clusters according to mean daily electricity consumption and mean normalized load profiles. Three distinct segments by daily consumption level were selected, namely: < 140Wh, 140Wh-450Wh, and > 450Wh. Their findings showed that customers with strong daytime use are valuable for a system because they tend to be high consumers and use power during the off-peak hours corresponding to solar generation, which helps to spread electricity consumption throughout the day and reduce storage requirements. Another important lesson derived from this work is that by better understanding the characteristics of customers with different consumption patterns, MG operators can design interventions to help graduate low consumption customers into higher use categories.

Having access to accurate forecasts of electricity demand at the site level is a key input in designing, managing and up-scaling MG solutions. Otieno et al. [Otieno, Williams and McSharry (2018)] explored the use of daily energy consumption data from seven sites operating in Kenya during 2014-2017. It was established that exponential smoothing offers the best out-of-sample forecasting performance with forecast skill exhibited for horizons up to four months ahead.

Remote monitoring (RM) systems are increasing in popularity in rural microgrids in less economically developed countries. RM systems measure quantities such as battery voltage, source current, energy consumption and other analog or digital signals. Literature suggests that technical challenges can be mitigated to some extent by installing real-time data acquisition, broadcast, monitoring, and actuation systems. Louie et al. [Louie, Goldsmith, Dauenhauer et al. (2016)] discussed the technology, applications and considerations related to off-grid data acquisition and monitoring, and made use of data from several off-grid systems in Kenya and Zambia to illustrate the applications. Given the low availability of internet services in Africa, unique methods of data transmission need to be utilized in order to achieve the desired communication goals. This work showcased that the measurements can be broadcast through the growing rural cellular communication network to a server where they can be used for analysis or archived for later use.

Nwulu [Nwulu (2017)] presented the optimal operational schedule for a CHP, solar PV, battery powered hybrid MG. The investigation of two case studies, Case 1 when the CHP and solar PV jointly powers the battery, and Case 2 when the battery is solely powered by the solar PV, showed that Case 2 yielded lower costs as the solar operational costs are quite high. The author also highlighted that the addition of batteries provided a storage medium in the system, and ensured that there is backup power supply for the islanded system.

Backes et al. [Backes, Idehen, Yardley et al. (2016)] developed a power system model of the rural village of Katumbi, Tanzania. The proposed MG was powered by DERs such as a solar PV, WT, and GS. Simulation via Real Time Digital Simulator (RTDS) showed that the MG is able to withstand a variety of disturbances, and is built for a population and geographic expansion of Katumbi. The MG allowed for the addition of community resources such as a hospital, freezers to store the catch of fishermen, a school, and a tower for wireless communication within the community. This work revealed that such solutions can bring economic, social, and health benefits to rural, impoverished communities.

Lai and McCulloch [Lai and McCulloch (2017)] presented a deterministic approach for sizing a solar PV and ESS with anaerobic digestion (AD) biogas power plant (BPP) to meet a proportional scaled-down demand of the national load in Kenya. The aim was to achieve a minimal LCOE for the system while minimizing the energy imbalance between generation and demand due to AD generator constraint and solar resource. The system also aimed to maximize the sizing of PV as to follow the future trend of high penetration of PV. An in-depth study of the optimization problem was given and particle swarm optimization (PSO) with the interior point method was chosen for solar panel sizing. The results showed that a hybrid system will be cost effective compared to an AD-only system, when the discount rate drops below 8% with the current technology costs.

In the context of Africa and rural areas in general, MG has high potential for social and environmental good. Avrin et al. [Avrin, Yu and Kammen (2018)] proposed that a data-informed, participatory framework can assist in site selection and design process for deploying MGs. Such a framework can be used to maximize the likelihood that electricity provision will lead to positive social and environmental outcomes, including the reduction of tensions and the promotion of peace in conflict prone regions. The framework was applied to communities in the Democratic Republic of the Congo (DRC).

Orajaka [Orajaka (2013)] presented the Green Village Electricity Project as a suitable model for providing off-grid solar electricity to remote settlements in Nigeria, while mitigating climate change on a micro-scale. The author also highlighted the possible challenges, implementation barriers, and operational lessons learnt in embarking on humanitarian energy projects in developing countries of the world. Most importantly, the paper presented a bottom-up scenario of the actual needs and expectations of the “bottom of the pyramid” inhabitants of rural West Africa towards ensuring the implementation of acceptable and sustainable energy development projects in the region using the Niger-Delta Nigeria as a case study.

Lukuyu [Lukuyu (2012)] proposed the use of WT-DG hybrid MG to achieve rural electrification. A power flow model was developed to analyze the reliability of the MG system as demand grew over a period of time. The remote village of Marsabit, in Northern Kenya, was used as a case study to investigate how the percentage of wind and diesel energy input to the system, due to varying diesel unit sizes and wind capacity, affects system reliability as demand increases. The results obtained from the comparison of the different scenarios showed that the proposed MG tends to be more reliable if the DG capacity is increased as opposed to WT capacity during power system expansion to meet the growing demand. This is owing to the fact that wind power tends to have a low capacity factor and has an intermittent nature.

Onai and Ojo [Onai and Ojo (2017)] proposed a vehicle-to-grid (V2G) technology assisted MG system as possible solution to some of the factors preventing the "green revolution" in Ghana. Given the unidirectional and bidirectional modes of operation, it was concluded that the bidirectional mode of operation offers the most advantage when used in a MG. The bidirectional scheme though advantageous, poses some challenges such as anti-islanding protection and battery degradation. Plug-in Electric Vehicles (PEVs) were shown to be capable of acting as electrical energy storage elements in a microgrid. Furthermore is was discovered that the PEVs acting as electrical energy storage elements would enhance the operation of the microgrid in islanding mode since it will ensure that grid voltage and frequency are kept within acceptable limits of operation.

4. Challenges and Opportunities

4.1. Challenges

The design and implementation of MG for rural electrification is a multi-faceted task. The main considerations are policy, politics, social, financial, and technical.

Approaches to rural electrification via MGs first and foremost need to be backed by policy. These policies need to adequately detail the works/projects that can be carried out and the processes that they are comprised of. A definition of stakeholders and participants and the roles they take is also necessary to commence and maintain the necessary work. A large number of nations in SSA maintain a structure where a state owned company has a monopoly on the national grid and therefore electricity generation, and T&D. This usually means that policies to enable the implementation of MGs do not currently exist, or are limited in their writing. Governments therefore need to present an adequate policy framework which will empower the use of MGs for rural electrification.

Politics plays a major role in the realization of electrification projects. Furthermore, the progress of such projects can be subject to presidential terms, as those in charge of the country define the goals for their time in power. It is therefore imperative that rural electrification efforts via MGs receive continued support across presidential terms from the respective government and various recognized bodies that help to drive the project through to its envisioned capacity. Another challenge is political stability, which can have adverse effects on project implementation, and operation and maintenance (O&M), with the magnitude of the effects depending on the severity of instability.

When considering rural areas in Africa, the social aspects play a vital role and can make or break projects. Literature strongly suggests the buy-in of the local population and the establishment of a solid relationship that turns into future growth in demand. The needs of the local populations need to be well-defined so as to ensure successful implementation.

As with any implementation the bottom line is the costing. The MG needs to be cost-effective which mainly entails maximizing the return on investment (ROI). The recommendation in literature is to thoroughly investigate the target area and gain a solid understanding of it by using geographic and demographic data. Such an investigation provides stakeholders with better information and can help to solidify their buy-in. A common requirement is for the MG to be self-sustainable, which looks minimizing the O&M costs. This work is normally done via surveys and consultations with various experts.

With various advancements in enabling technologies for IoT, there are a wide number of possibilities for MGs today. The main challenge with SSA, and rural areas in particular, is the lacking ICT infrastructure. Therefore the MG configurations that are put in place need to be robust and integrate the capabilities of their operating environment into the design. A well-known challenge is availability of adequate internet services which is normally used for communications and monitoring of system health. GSM technology can be utilized to address such an issue.

4.2. Opportunities

The African continent provides a unique landscape requiring innovative solutions due the limited capacity with regards to infrastructure and economic operations. SSA presents the opportunity for researchers to truly define resilient MG solutions that make full use of available RESs while fully incorporating the diversity of the local population. Such solutions expand upon the capabilities of the Smart Grid, and CPSs and IoT in general. The African continent has limited access to internet and thus GSM, 2G, and 3G are communication technologies that can be integrated into solutions to fully realize capabilities such as remote monitoring of systems. Furthermore with the increase in usage of mobile money platforms across the continent, its integration into the financial workings of MG implementations could prove to be beneficial to project success.

We recommend the approach utilized in the framework by Kumar et al. [Kumar, Singh, Deng et al. (2018)] in order to fully realize the appropriate MG for various rural areas in SSA. The framework consists of four stages: 1) selection of energy alternatives using decision analysis tools, 2) load growth projections, 3) detailed techno-financial analysis of energy system, and 4) application of decision analysis tools for final project selection. Taking such steps should ensure the successful implementation of MG projects for rural electrification.

5. Conclusion and Future Work

This paper discussed the various methods and techniques that are currently in use and most viable to solve the rural electrification problem in Sub-Saharan Africa, through the use of Microgrid technology. Given the enormous socio-economic benefits to rural populations and developing nations, the importance of the research work in this field of study cannot be understated. Furthermore sufficient solutions to electrification in rural areas present further steps toward the envisioned Smart Cities, integrating a wide range of services far and wide. While there are number of challenges that are still to be addressed, the utilization of Microgrids seems to be an important step towards improving access to electricity.

For our future work we aim to perform a case study on a country in Sub-Saharan Africa.

The proposed work will entail the design of a Microgrid which utilizes solar photovoltaic energy sources and an energy storage system in order to provide electricity services to the local population.

Acknowledgement: This work has received funding from the European Union Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement no.701697, Major Program of the National Social Science Fund of China (Grant No.17ZDA092), Basic Research Programs (Natural Science Foundation) of Jiangsu Province (BK20180794), 333 High-Level Talent Cultivation Project of Jiangsu Province (BRA2018332) and the PAPD fund.

References

Adetunji K. E.; Akinlabi O. A.; Joseph M. K. (2018): Developing a Microgrid for Tafelkop Using HOMER. *2018 International Conference on Advances in Big Data, Computing and Data Communication Systems (icABCD)*, Durban, South Africa, pp. 1-6. doi: 10.1109/ICABCD.2018.8465442

Avrin A.; Yu H.; Kammen D. M. (2018): Supporting Social and Gender Equity Through Micro-Grid Deployment in the DR Congo. *2018 IEEE PES/IAS PowerAfrica*, Cape Town, South Africa, pp. 646-651. doi: 10.1109/PowerAfrica.2018.8521112

Backes M.; Idehen I.; Yardley T.; Panumpabi P. (2016): Off-grid microgrid development for the village of Katumbi in Tanzania. *2016 North American Power Symposium (NAPS)*, Denver, CO, USA, pp. 1-5. doi: 10.1109/NAPS.2016.7747901

Bedi G.; Venayagamoorthy G. K.; Singh R.; Brooks R. R.; Wang K. (2018): Review of Internet of Things (IoT) in Electric Power and Energy Systems. *IEEE Internet of Things Journal*, vol. 5, no. 2, pp. 847-870, doi: 10.1109/JIOT.2018.2802704

Buque C.; Chowdhury S. (2016): Distributed generation and microgrids for improving electrical grid resilience: Review of the Mozambican scenario. *2016 IEEE Power and Energy Society General Meeting (PESGM)*, Boston, MA, USA, pp. 1-5. doi: 10.1109/PESGM.2016.7741488

Cronje W. A.; Hofsajer I. W.; Shuma-Iwisi M.; Braid J. I. (2012): Design considerations for rural modular microgrids. *2012 IEEE International Energy Conference and Exhibition (ENERGYCON)*, Florence, Italy, pp. 743-748. doi: 10.1109/EnergyCon.2012.6348249

Doorsamy W.; Cronje W. A.; Lakay-Doorsamy L. (2015): A systems engineering framework: Requirements analysis for the development of rural microgrids. *2015 IEEE International Conference on Industrial Technology (ICIT)*, Seville, Spain, pp. 1251-1256. doi: 10.1109/ICIT.2015.7125269

Giraneza M.; Kahn M. T. E. (2015): Intermediate low voltage direct current based decentralized grid extension. *2015 International Conference on the Industrial and Commercial Use of Energy (ICUE)*, Cape Town, South Africa, pp. 272-276. doi: 10.1109/ICUE.2015.7280278

Hamatwi E.; Nyirenda C. N.; Davidson I. E. (2018): Cost Optimization and Design of a Hybrid Distributed Generation System for a DC Microgrid. *2018 IEEE PES/IAS PowerAfrica*, Cape Town, South Africa, pp. 384-389. doi: 10.1109/PowerAfrica.2018.8521011

Hamza M.; Shehroz M.; Fazal S.; Nasir M.; Khan H. A. (2017): Design and analysis of solar PV based low-power low-voltage DC microgrid architectures for rural electrification. *2017 IEEE Power & Energy Society General Meeting*, Chicago, IL, USA, pp. 1-5. doi: 10.1109/PESGM.2017.8274134

IEA (International Energy Agency) (2018): World Energy Outlook 2017, https://www.iea.org/Textbase/npsum/weo2017SUM.pdf, last accessed 2018/11/08.

Ireland G.; Hughes A.; Merven B. (2017): A techno economic renewable hybrid technology mini-grid simulation and costing model for off-grid rural electrification planning in Sub-Saharan Africa, *2017 International Conference on the Domestic Use of Energy (DUE)*, Cape Town, South Africa, pp. 179-186. doi: 10.23919/DUE.2017.7931842

Jaffery S. H. I.; Khan M.; Ali L.; Khan H. A.; Mufti R. A.; Khan A.; Khan N.; Jaffery S. M. (2014): The potential of solar powered transportation and the case for solar powered railway in Pakistan. *Renewable and Sustainable Energy Reviews*, vol. 39, pp. 270–276. doi: 10.1016/j.rser.2014.07.025

Khan J.; Arsalan M. H. (2016): Solar power technologies for sustainable electricity generation–A review. *Renewable and Sustainable Energy Review*, vol. 55, pp. 414–425.

Kumar A.; Singh A. R.; Deng Y.; He X.; Kumar P.; Bansal R. C. (2018): A Novel Methodological Framework for the Design of Sustainable Rural Microgrid for Developing Nations, *IEEE Access*, vol. 6, pp. 24925-24951. doi: 10.1109/ACCESS.2018.2832460

Kumar A.; Sah B.; Deng Y.; He X.; Kumar P.; Bansal R. C. (2017): Application of multi-criteria decision analysis tool for design of a sustainable micro-grid for a remote village in the Himalayas. *The Journal of Engineering*, vol. 2017, no. 13, pp. 2108-2113. doi: 10.1049/joe.2017.0702

Lai C. S.; McCulloch M. D. (2017): Sizing of Stand-Alone Solar PV and Storage System With Anaerobic Digestion Biogas Power Plants. *IEEE Transactions on Industrial Electronics*, vol. 64, no. 3, pp. 2112-2121, March 2017. doi: 10.1109/TIE.2016.2625781

Lin J.; Yu W.; Zhang N.; Yang X.; Zhang H.; Zhao W. (2017): A Survey on Internet of Things: Architecture, Enabling Technologies, Security and Privacy, and Applications. *IEEE Internet of Things Journal*, vol. 4, no. 5, pp. 1125-1142. doi: 10.1109/JIOT.2017.2683200

Loomba P.; Asgotraa S.; Podmore R. (2016): DC solar microgrids — A successful technology for rural sustainable development. *2016 IEEE PES PowerAfrica*, Livingstone, Zambia, pp. 204-208. doi: 10.1109/PowerAfrica.2016.7556601

Louie H.; Goldsmith G.; Dauenhauer P.; Almeida R. H. (2016): Issues and applications of real-time data from off-grid electrical systems. *2016 IEEE PES*

PowerAfrica, Livingstone, Zambia, pp. 88-92. doi: 10.1109/PowerAfrica.2016.7556577

Lukuyu J. (2012): Wind-diesel microgrid system for remote villages in Kenya. *2012 North American Power Symposium (NAPS)*, Champaign, IL, USA, pp. 1-6. doi: 10.1109/NAPS.2012.6336319

Namaganda-Kiyimba J.; Mutale J. (2018): Sustainability Metrics for Rural Electrification in Developing Countries, *2018 IEEE PES/IAS PowerAfrica*, Cape Town, South Africa, pp. 1-6. doi: 10.1109/PowerAfrica.2018.8521140

Nasir M.; Khan H. A.; Hussain A.; Mateen L.; Zaffar N. A. (2017): Solar PV-Based Scalable DC Microgrid for Rural Electrification in Developing Regions. *IEEE Transactions on Sustainable Energy*, vol. 9, no. 1, pp. 390-399. doi: 10.1109/TSTE.2017.2736160

Nwulu N. (2017): Multi-objective optimization of a CHP-PV-battery islanded microgrid. *2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS)*, Chennai, India, pp. 98-102. doi: 10.1109/ICECDS.2017.8389607

Ogunnubi O.; Ajala O.; Idehen I. (2017): A proposal for a microgrid service in urban Nigeria. *2017 IEEE PES PowerAfrica*, Accra, Ghana, pp. 474-478. doi: 10.1109/PowerAfrica.2017.7991271

Onai K.; Ojo O. (2017): Vehicle-to-grid technology assisted microgrid in Ghana: Opportunities and challenges. *2017 IEEE PES PowerAfrica*, Accra, Ghana, pp. 341-346. doi: 10.1109/PowerAfrica.2017.7991248

Orajaka I. B. (2013): Unified green village electricity project concept: A suitable model for reliable renewable energy deployment in Nigeria. *2013 IEEE Global Humanitarian Technology Conference (GHTC)*, San Jose, CA, USA, pp. 87-91. doi: 10.1109/GHTC.2013.6713660

Otieno B.; Williams N. J.; McSharry P. (2018): Customer Segmentation for East African Microgrid Consumers. *2018 IEEE PES/IAS PowerAfrica*, Cape Town, South Africa, pp. 468-473. doi: 10.1109/PowerAfrica.2018.8521082

Otieno F.; Williams N.; McSharry P. (2018): Forecasting Energy Demand for Microgrids Over Multiple Horizons. *2018 IEEE PES/IAS PowerAfrica*, Cape Town, South Africa, pp. 457-462. doi: 10.1109/PowerAfrica.2018.8521063

Parhizi S.; Lotfi H.; Khodaei A.; Bahramirad S. (2015): State of the Art in Research on Microgrids: A Review. *IEEE* Access, vol. 3, pp. 890-925. doi: 10.1109/ACCESS.2015.2443119

Patel H.; Chowdhury S. (2018): Cost Effective Microhydro-based Microgrid Schemes for Rural Electrification in South Africa. *2018 53rd International Universities Power Engineering Conference (UPEC)*, Glasgow, Scotland, pp. 1-6. doi: 10.1109/UPEC.2018.8541952

Pendieu Kwaye M.; Bendfeld J.; Anglani N. (2015): Assessment of renewable energy resources in Cameroon and special regards on energy supply. *2015 5th International Youth Conference on Energy (IYCE)*, Pisa, Italy, pp. 1-7. doi:

10.1109/IYCE.2015.7180807

Power Africa (2018): The Roadmap, USAID Report, www.usaid.gov/powerafrica/roadmap, last accessed 2018/11/08

Rezkallah M.; Chandra A.; Singh B.; Singh S. (2017): Microgrid: Configurations, Control and Applications. *IEEE Transactions on Smart Grid*, doi: 10.1109/TSG.2017.2762349

Rwegasira D.; Kondoro A.; Kelati A.; Ben Dhaou I.; Mvungi N.; Tenhunen H. (2018): CDE for ICT Innovation Through the IoT Based iGrid Project in Tanzania. *2018 IST-Africa Week Conference (IST-Africa)*, Gaborone, Botswana, pp. 1-9.

SE4All (Sustainable Energy for All) (2018): https://www.seforall.org, last accessed 2018/11/08

Soltowski B.; Bowes J.; Strachan S.; Anaya-Lara O. L. (2018): A Simulation-Based Evaluation of the Benefits and Barriers to Interconnected Solar Home Systems in East Africa. *2018 IEEE PES/IAS PowerAfrica*, Cape Town, South Africa, pp. 491-496. doi: 10.1109/PowerAfrica.2018.8521058

U.S. DOE OEDER (United States Department of Energy Office of Electricity Delivery and Energy Reliability) (2012): Summary Report: 2012 DOE Microgrid Workshop, https://www.energy.gov/sites/prod/files/2012%20Microgrid%20Workshop%20Report%2009102012.pdf, last accessed 2018/10/31.

Wang L. et al. (2009): A micro hydro power generation system for sustainable microgrid development in rural electrification of Africa. *2009 IEEE Power & Energy Society General Meeting*, Calgary, AB, USA, pp. 1-8. doi: 10.1109/PES.2009.5275244

Williams N. J.; Jaramillo P.; Campbell K.; Musanga B.; Lyons-Galante I. (2018): Electricity Consumption and Load Profile Segmentation Analysis for Rural Micro Grid Customers in Tanzania. *2018 IEEE PES/IAS PowerAfrica*, Cape Town, South Africa, pp. 360-365. doi: 10.1109/PowerAfrica.2018.8521099

Xu Z.; Chowdhury S. (2013): A review of rural electrification through micro-grid approach: South African context. *2013 48th International Universities' Power Engineering Conference (UPEC)*, Dublin, Ireland, pp. 1-6. doi: 10.1109/UPEC.2013.6714883