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Rural electrification implementation strategies through microgrid approach in South African context

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ABSTRACT

Rural electrification requires high initial capital investments per capita due to its low energy demand and population density. These factors result in a higher cost of electricity than that for urban consumers. Although the solution to the majority of rural electrification financial challenges are with government policymakers, it is equally important for rural electrification project implementers to understand the technical challenges and identify any cost reduction potential. This paper proposes and compares a diverse set of standalone electrification strategies for a variety of consumer load types in the Sdakeni rural area in the Eastern Cape Province in South Africa. The aim of this research is to compare the electrification strategies based on: cost, efficiency, performance, equipment utilization factor, excess electricity produced etc. Based on the findings from the comparison, the paper will provide insight into suitability of such strategies and act as a guideline for balancing cost optimization process and design robustness of such systems. It will also provide recommendations on future research along this line which would include aspects that could not be covered in this work.

Introduction

South Africa struggles to attract private investors to engage in rural electrification investments due to poor market incentives and support from government agencies. Unlike its urban counterpart, rural electrification is a seemingly unprofitable venture as it lacks of consumer demand density and generally consists of low-income groups. It is important for project initiators and planners to provide a design that is attractive in terms of lower capital costs and yet provide an internal development scheme for the rural community such as maintenance training, educational opportunities or business opportunities. This will undoubtedly initiate a stronger reaction from investors or government agencies. Although it is clear that much of rural electrification financial challenges are with government policymakers, it is equally important at the backend for rural electrification project implementers to understand the technical challenges and identify any cost reduction potential.

Xu et al. performed a review on rural electrification approaches in [1]. The review examines various practical rural electrification strategies, consumer profiling and demand methodology. This research presents the analysis and comparison of several renewable-based standalone power systems for a typical rural settlement in the Eastern Cape Province of South Africa.

The conventional urban electrification strategy powered by fossil fuel power stations is unsuitable for the dispersed rural communities embedded deeply in remote regions of the country, far away from the nearest substations or grid infrastructure. Extension of transmission or distribution lines is an expensive exercise and highly dependent on consumer demand and demand density. It proves to be uneconomical to span distribution lines over long distances for a small group of consumers with meagre energy demand. Hence, rural electrification requires an alternative approach to access electricity. In this paper, the authors propose and compare various renewable-based microgrid approaches for electrification of the Sdakeni area in Eastern Cape Province in South Africa.

A Microgrid is defined as an aggregate of loads and a group of dedicated small to medium scale generators usually based on renewable and low-carbon resources. It also possesses the ability

Abbreviations: CHP, Combined Heat and Power; DER, Distributed Energy Resource; DoD, Depth of Discharge; KPI, key performance indicator; LCOE, Levelised Cost of Electricity; MPPT, Maximum Power Point Tracker; NOCT, Nominal Operating Cell Temperature; NPC, net present cost; O&M, operation and maintenance; PV, Photovoltaic; SOC, state of charge; T&D, Transmission and Distribution.

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to create a reliable standalone power network with low greenhouse gas emissions per unit of energy consumed.

Distributed Energy Resource (DER[2]) such as solar and wind energy are readily available in the Eastern Cape Province in South Africa. They can be harnessed with immediate effect. The renewable technologies that utilize the DERs also possess the flexibility and ease of deployment. Moreover; fast build-to-demand scalability to meet the consumer demand with greater accuracy. Hence such renewable energy resources prove to be well suited for standalone microgrid strategy for rural electrification over the conventional means of electrification.

Problem description and approach

Due to the intermittent nature of renewable resources, the iterative design adjustments aiming to balance cost-effectiveness with robustness is a crucial and unique process for every project. Although there is no single approach or solution to any electrification project, there exists an intricate and universal relationship between the renewable DER technologies and its site conditions. The site conditions include but not limited to local DER availability, topography, social and economic characteristics of local residents [2]. An ideal design encompasses energy security, robustness and cost effectiveness. Improving energy security demands expensive energy storages or costly distribution infrastructures. Additional costs for increasing system robustness and building in redundancy become an impeding factor for developing renewable-based electrification strategy [3]. To increase efficiency and reduce energy wastage; the electrification strategy must be optimized with its load demand, with usage and production matched as closely as possible to provide quality power to the consumers [3]. Different renewable technologies should be integrated together to provide complementary support to one another during any DER unavailability or component failures.

The paper analyses consumer load demand and combination of suitable renewable technologies and its related supporting components. It then reports on modelling and comparing various strategies before proposing a recommendation on the optimal rural electrification within the context of the simulated scope.

These strategies are divided into three implementations scenarios as follows: (1) Dedicated Generation – Dedicated generation for a single consumer such as per household, hospital or public infrastructure (2) Microgrid-based Support Generation–A full integration of all loads under the scope into a single microgrid network (3) Village based Support Generation – Similar to case 2 but at a smaller scale. The first implementation focuses on the classical urban household electrification through solar PV[10] array-coupled with energy storage. The second implementation works by unifying all consumers through a centralized network. The third and final implementation consolidates key lessons from the previous implementations and incorporates them within a smaller scale design.

Before simulating the implementation scenarios and testing their effectiveness through simulations with HOMER software, it is important to define the scope and research limitations in the context of this research. Since the research aims to produce a set of realistic results, all information used for simulation such as consumer demand, site conditions and DER availability, equipment specifications and pricing etc. are acquired from latest open source information released by government agencies and manufacturers. Key comparative results from the simulations such as cost, efficiency, equipment utilization factor, excess electricity produced etc., are expected to provide insight into the suitability of the aforementioned strategies and act as a guideline for balancing cost optimization process and design robustness of such systems.

HOMER Energy modelling tool is used as the key computation platform for this paper. It has a dynamic mix of system components, flexibility to allow plug-and-play components, which are easily interchangeable according to design needs. Despite the simplicity in usage, each system component is embedded with complex theoretical principles that guide the computation process, thus producing convincingly accurate results.

Site selection and synthesis of load profile

The first important steps for developing a cost-effective rural electrification strategy consists of (1) identifying the potential site (2) understanding its consumer profile, (3) local resource availability, (4) investigate the transmission costs to link to the grid and (5) investigate the transmission costs to link the sites together from generator sources (standalone microgrid).

Dekker et al. identifies that the most suitable climatic zone in South Africa for implementing and running PV-Diesel hybrid power systems at minimum cost is the arid interior [4]. For this paper, the authors have selected a prominent area of unelectrified rural settlements in Sdakeni in the Eastern Cape Province of South Africa. The geographical analysis suggests that the area consisting of coastal and mountainous terrain may be the main cause for the lack of formal electrification infrastructure despite its settlement density. The satellite image of Fig. 1 shows small-clustered settlements dispersed around the site. It is to be noted that the site in Fig. 1 does not show a physical top view of the settlements. There are in total 51 villages in this site. A 10 km radius scope is centred upon the rural area of Sdakeni to identify the potential sister sites to integrate with the microgrid. The research site is divided into four quadrants as seen in Fig. 1. Each quadrant possesses unique terrain characteristic which constraints the choice of local renewable technology implementation. Nevertheless this creates an opportunity for synergy between the villages within each quadrant [5].

For simulating the implementation scenarios in HOMER, it is mandatory to create a realistic load profile for the site that would reflect as closely as possible the consumer demand profile and the load types. In the absence of available real-time load data for the selected site, the authors have synthesized the necessary load profile taking references from Scottish e7 Group's real-time data capturing and NRECA International's electrification guides as guidelines [2,3]. This is because both references [2,3] are based on actual rural electrification projects implemented in South Africa and other equivalent economies, thus providing a relatively realistic guideline for developing the research's load profile.

The key factors taken into consideration for creating the load profile are as follows:

- Availability of renewable and low-carbon distributed energy resources (DERs) does not influence the consumer demand. Consumer demand is based on consumer needs and its growth

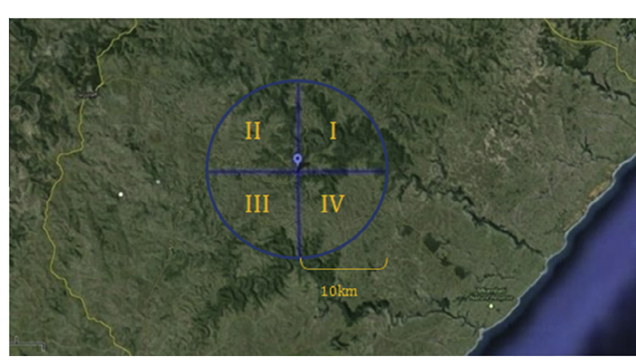

Fig. 1. Research site 10 km radius scope, divided into four quadrants [5].