Renewable Energy Solution for Electricity Access in Rural South Africa

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***Abstract*—South Africa has grown from 34% electrification in 1991 to about 84.7% electrification presently, but with least access to electricity in rural areas. The lower rate of electrification in rural areas than urban areas has made dwellers in rural unelectrified areas to be challenged economically, socially, educationally, health-wise, etc. The aging, unclean, non-renewable and constrained traditional grid has necessitated to think out of the box for universal electricity access in the nation through renewable energy sources (RES) such as solar, wind, biomass, and hydro for rural electrification. Therefore, a RES-powered microgrid is designed for rural Jozini municipality with 26.3% electricity access. This proposed Jozini microgrid was found to have a Levelised Cost of Electricity (LCOE) of R0.384/kWh, which is about one-third of grid LCOE in South Africa. Also, the proposed Jozini microgrid has 0 kg/kWh CO_2 emission compared to 0.99 kg/kWh CO_2 emission from the traditional national grid.**

***Index Terms*-- Electricity Access, HOMER Pro Software, Microgrid, Renewable Energy Sources, Rural Area**.

I. INTRODUCTION

Electricity access in South Africa has grown from 34% in 1991 to 76.7% in 2002 and now 84.7% as at 2018, with more urban households having access to electricity than rural households [1]. The higher electrification rate in urban areas than rural areas is due to many factors such as distance from substations, spatial heterogeneity of rural areas, low return-on-investment (RoI) for prospective investors, rough geographical terrains, high cost of electricity production as compared to the significantly low demand for energy in rural areas, low level of affordability electricity bills, etc [2].

The traditional grid continues to face challenges of aging infrastructure, depleting coal reserves and constrained generation that has led to more occurrences of load shedding than in recent years. As an emerging economy, there is continuous increase in demand of electricity from residential, industrial and commercial customers. Load shedding was [illegible] stabilise the grid power, while attempting to still keep the lights on for consumers. Eskom load shedding is in four stages depending on the shortfall in supply with respect to demand. Stages 1, 2, 3 and 4 shed 1000 MW, 2000 MW, 3000 MW and 4000 MW from the national grid respectively across the nation [3]. These experiences have necessitated the power sector to rethink ways to address the issue of load shedding in the country for better customer satisfaction.

One way to solve the present energy crisis in the country is to consider alternative, sustainable and affordable energy sources, of which renewable energy sources (RES) are promising solutions. In a goal to achieve smart cities in the country, universal electricity access is a non-negotiable driver for the implementation of smart cities technology. Hence, there is need to consider ways to achieve sustainable, clean and affordable electricity supply to urban and rural communities.

Jozini local municipality was chosen to be investigated because it is the one of the least electrified municipalities in the country despite its nearness to some substations located at nearby cities or urban settlements.

The rest of the paper is organized thus: an introductory note on Jozini local municipality is presented in Section II, and description of the simulation carried out for the proposed RES-based microgrid is presented in Section III. Furthermore, results and conclusion of the work are presented in Sections IV and V respectively.

II. INTRODUTORY NOTE ON JOZINI LOCAL MUNICIPALITY

Jozini local municipality is located in KwaZulu-Natal province of South Africa as shown in Fig. 1 [4]. It is also the administrative area for Umkhanyakude District within KwaZulu-Natal province. It is made up of twenty wards and a predominant black African population (99.2%) with a population density of 54 persons/km^2.

Electricity access in Jozini local municipality is 26.3% with 10,203 households out of 38,849 households having access to electricity [5]. This has made the residents of this municipality to seek energy sources from wood (64%), gas (9%) and paraffin (1%). With majority of the population depending on wood for energy source, human lives in Jozini and women in particular are prone socioeconomic difficulties, health risk due [illegible] ing of carbon-monoxide during cooking, physical stress and strain due to long hours spent to fetch and bring firewood home for the family use, etc. However, the spatial heterogeneity of Jozini has been reported by the government as one of the reasons for the existing huge backlog in electricity provision in the municipality [5].

Fig 1. Location of Jozini local municipality on KwaZulu-Natal provincial map.

Since grid extension to Jozini will take a long time to come to reality, it is therefore proposed that alternative source of energy through RES microgrid, instead of the traditional grid should be developed for Jozini local municipality. Although there are some stations (Mkhuze substation, Mokhonyeni substation, Nondabuya substation, and Ndumo substation) around Jozini, but the limited power available from these substations, low demand and RoI on power investment in Jozini has impeded universal electricity access in Jozini local municipality.

Therefore, there is need to consider the possible and available RES sources in Jozini that can be used to solve its challenge of electricity access. The details of how this was carried out is presented in Section III.

III. JOZINI RES-MICROGRID SIMULATION

In an attempt to design a RES-microgrid for Jozini local municipality, the renewable energy sources prevalent in the area were identified and simulated. HOMER Pro [6] is used as the simulation software in this design to carry out optimization and sensitivity analyses of the proposed microgrid.

A. Design of Jozini Microgrid

The RES-microgrid for Jozini local municipality is proposed to be on an alternating current (AC) bus. Therefore, the output direct current (DC) from the solar panels shall be inverted to AC. An AC load is assumed for this microgrid.

Also, a battery backup is included in the design so that energy can be stored and for use at a later time when the RES supplies or generation cannot meet the demand by the community. It can also assist in taking care of the variations in RES at different times of the day.

The RES modeled for this microgrid are solar, wind and hydro. Furthermore, a generator was also included in the design as another possible alternative to meet energy demand by the consumers.

All these options are included in the design in order to give HOMER Pro different options for combinations of hybrid sources for the microgrid solution desired. A schematic of the proposed microgrid design for Jozini local municipality is presented in Fig. 2.

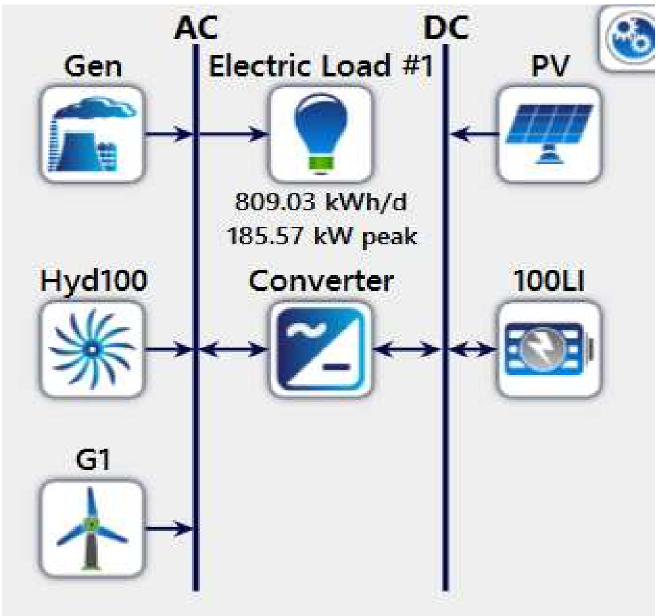

Fig. 2. Schematic of Jozini RES microgrid

B. Jozini Renewable Energy Resources

The renewable energy sources identified in Jozini are solar energy, wind energy, and hydropower. The solar resource for Jozini was obtained from [7], fed into HOMER Pro and presented in Fig. 3. The annual average solar irradiation for Jozini is 6.426 MWh/m^2/day. Also, the wind resource for Jozini was obtained from [8], loaded into HOMER Pro and shown in Fig. 4. The average wind speed for Jozini is 5.17 m/s.

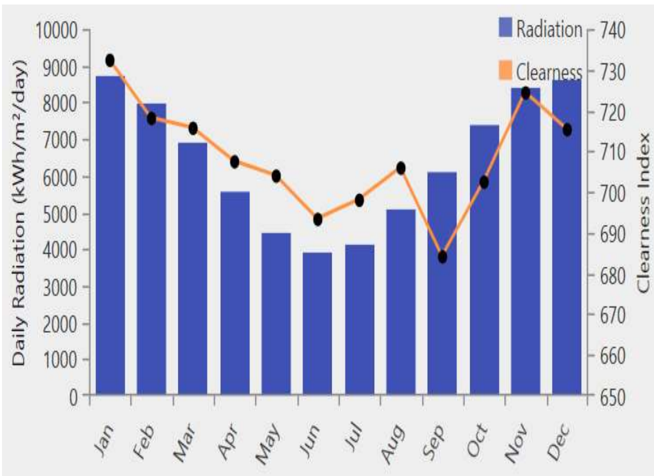

Fig. 3. Average solar irradiance for Jozini local municipality

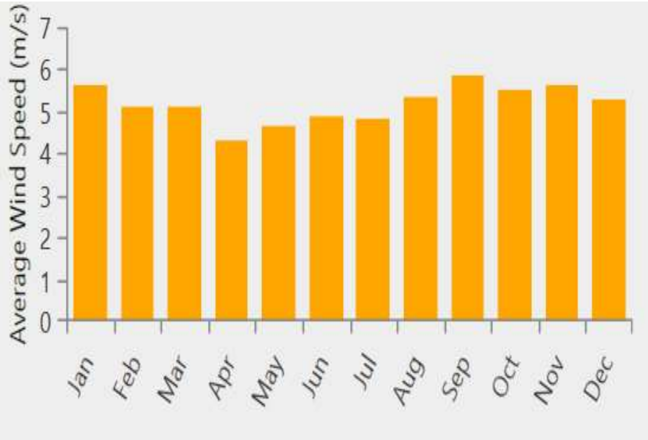

Fig. 4. Average wind speed for Jozini local municipality

Furthermore, the hydro resource available in Jozini was obtained from [9], fed into HOMER Pro and the result shown in Fig. 5. The average stream flow for Pongola river that flows into Jozini is 15,613.5 L/s.

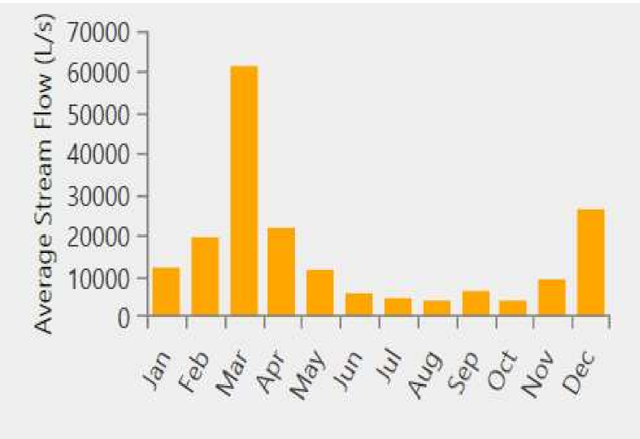

Fig. 5. Average hydro resource for Jozini local municipality

C. *Jozini Load Profile*

The load profile for a typical rural area in South Africa was obtained [10], and simulated for Jozini local municipality. The average daily and seasonal load profiles are presented in Figures 6 and 7 respectively. There are not much activities during the day as most of the adults go to farm and the children go to school. Also, the residents of this municipality go to bed early due to lack of electricity or any other form of entertainment or business. Highest demand happens in winter months (June to August) yearly as shown in Fig. 7. The residential load expected to be connected to this microgrid are bulbs, fridges, televisions, radios, electric stoves, mobile phones, electric kettles, electric irons, fans (in summer), and heaters (in winter).

The load profile presented is for two hundred rural households. Factors of inflation (4.4% projected for South Africa in 2019) [11], [12] was also put into consideration when defining financial constraints for the project. Knowing fulling well, that inflation may affect the cost of operating and maintaining the microgrid. The load profile is expected to grow with improvement in access to electricity due to increase in socioeconomic activities that comes with electricity access.

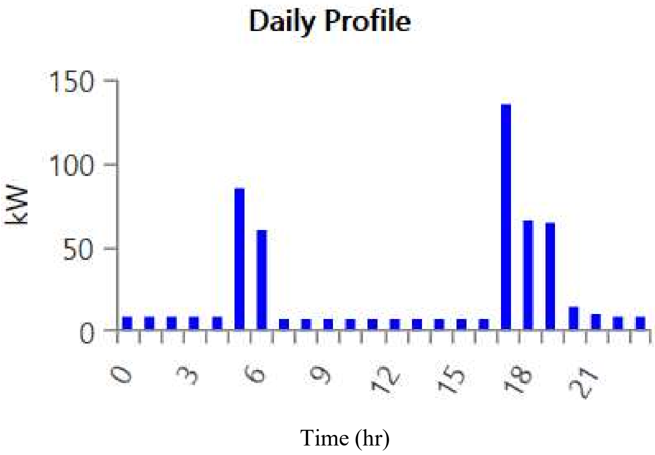

Fig. 6. Jozini average daily load profile

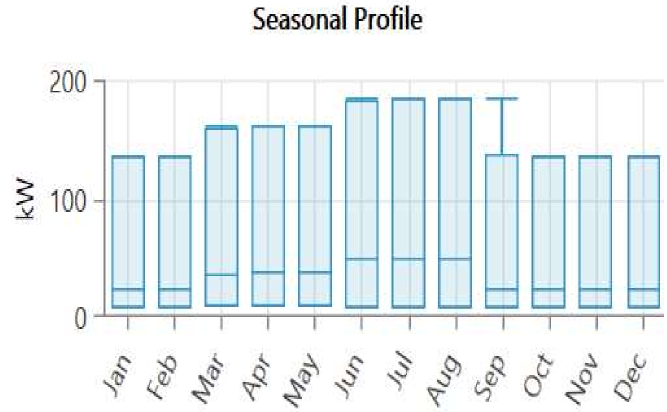

Fig. 7. Jozini average seasonal load profile

IV. RESULTS AND DISCUSSION

The cost estimates for all the RES devices, batteries and generator were obtained and fed into the simulating software (HOMER Pro) so that the optimal microgrid solution can be obtained. One of the advantages of using HOMER Pro for microgrid design before implementation is that it presents its results in the order of decreasing Net Present Cost (NPC) and Levelised Cost of Electricity (LCOE), starting with the most optimal solution. The first ten most optimal results for the microgrid design is presented in Table I. The most optimal solution is presented in the row highlighted green. All costs are expressed in South African rands (R).

The result shows that the optimal microgrid design for Jozini local municipality is a hydropower-powered microgrid. This design is chosen as optimal because of its least NPC, LCOE, and 100% renewable fraction or penetration. This implies that the leadership in Jozini needs to explore the hydropower potential for its universal electricity access. This optimal design has an LCOE of R0.384/kWh, which is still lower than an LCOE of R1.05/kWh for Medupi power station and R1.16/kWh for Kusile power station [13].

TABLE I. OPTIMISATION RESULTS FOR JOZINI MICROGRID

S/N	Microgrid Mix	Total NPC (R)	LCOE (R/kWh)	Operating Cost (R)	Renewable Fraction	CO2 emissions (kg/yr)
1	Hydro	1.90M	0.384	33,121	100%	0
2	Solar/Hydro	1.91M	0.386	33,212	100%	0
3	Wind/Hydro	1.91M	0.387	33,518	100%	0
4	Solar/Wind/Hydro	1.92M	0.389	33,665	100%	0
5	Solar/Generator/Hydro	2.40M	0.484	20,147	100%	0
6	Generator/Hydro	2.40M	0.484	20,147	100%	0
7	Wind/Generator/Hydro	2.41M	0.487	20,604	100%	0
8	Solar/Wind/Generator/Hydro	2.41M	0.488	20,611	100%	0
9	Wind/Generator	8.03M	1.62	306,311	96.9%	8.11
10	Solar/Wind/Hydro	8.14M	1.65	199,909	100%	0

The LCOE for the hydropower only without converter and battery is R0.07/kWh, which shows that this microgrid could be more affordable if the load and supply can be matched 100% without need for converters and batteries. Hence, it will be more profitable for the microgrid provider, be it the municipal government or a third-party independent power producer (IPP) and also result in affordable electricity bills for consumers. The affordability of this microgrid is highly important because 43% of Jozini residents have no income [5].

This microgrid is also cost-saving and can be faster to deploy to meet the energy need of Jozini local municipality because the cost of grid extension in South Africa is R200,000/km or more depending on terrain [14]. Whereas, the nearest big substation outside of Jozini local municipality is more than 100 km from Jozini. Hence, it may not be encouraged as the business case for grid extension is poor in this scenario. This optimal design has a RoI of 1.739.7%, which can be encouraging to prospective investors as this microgrid can last beyond twenty-five years.

A further consideration of the hydropower microgrid showed that it comprised R59,268.26 on Lithium-ion batteries, R615,158.90 on converter, R1,227,314.29 on hydropower generation, which sums up to R1,901,741.45. This type of microgrid has advantage over most of other combinations because its output is AC, hence its output can be connected straight to consumer load with limited demand for conversion/inversion except for instances where its excess generation was stored in the batteries. The average annual state of charge for the battery shows that charging/discharging from the battery was highest during the cold months of June, July and August.

This design is scalable to whatever may be the actual size of the Jozini load. In fact, only 27.2% of energy generated by this microgrid that is connected to load. Hence, all loads are met by the generation and there won't be load shedding for these consumers. Therefore, there is an excess generation of 797.69 kWh/y (72.8%) from this microgrid that can still be connected to additional eight hundred households before adding more hydropower turbines.

This microgrid has 100% renewable fraction and 0 kg/yr emissions from carbon dioxide, carbon monoxide, unburned hydrocarbon, particulate matter, Sulphur dioxide and nitrogen oxides, unlike South African grid with 0.99 kg/kWh (8.9 kg/person) carbon dioxide emissions [15].

V. CONCLUSION

In this work, a RES microgrid was designed for Jozini local municipality in KwaZulu-Natal province of South Africa in order to take her from the present 26.3% electricity access to universal electricity access, a situation in which everyone in the municipality has access to clean, affordable and sustainable electricity access. This was achieved by a hydropower microgrid with a LCOE of R0.384/kWh, which is far below the traditional grid LCOE of more than R1/kWh from all coal plants in South Africa. Furthermore, it is 100%renewable and 0% CO_2 emissions, which makes it aligned with the United Nations sustainable development goals.

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