Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 09, September-2020

Design and Simulation of Off-Grid Solar/Mini-Hydro Renewable Energy System using Homer Pro Software: Case of Muyuka Rural Community

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Abstract— **Electrification in remote areas is constrained by technical barriers like long-distant transmission network, rugged terrains, and highly dispersed population. The low population density characterised by a low level of education implies low load density and low revenues. These characteristics hinder investors from investing in the rural sector. In many parts of Cameroon, electricity generation is often non-existent or unreliable and erratic. Cameroonian rural population outnumbers urban inhabitants, and it is precisely in these rural regions that the lack of reliable infrastructures and services is all the more problematic. These shortfalls are persistent and structural, and the amount of capital required to fix them is tremendous. The usual approach to centralised generation and distribution may not be able to solve this problem. Presently, households and businesses that can afford resort to using diesel generators which are not environmentally friendly and very expensive to run. Replacing multitudes of diesel generators with hybrid solar/mini-hydropower plants can substantially reduce cost and climate impact. In this context, the development of off-grid decentralised solar/mini-hydropower systems, or of systems built around a mini-grid, proves to be appropriate. This solution would help to stem the tide of people abandoning rural areas, which is a problem severely affecting the country. This paper is dedicated to the design and implementation of a hybrid solar/mini-hydro renewable energy system for the rural community of Muyuka Subdivision. The consideration evolved from being focused on the concept of hybridisation of photovoltaic (PV) and hydro-electric power plants. HOMER-Pro is used for the simulation. HOMER-Pro integrates components, resources and economic calculations. It simplifies the task of evaluating the design of off-grid for a variety of applications. The result will be a suggestion on how the Muyuka rural community could sustainably be electrified by using renewable energy based off-grid power system. This contribution will be a vital tool to the policymakers and implementers of renewable energy systems in Cameroon, considering the case of the Muyuka rural community.**

***Keywords*—Off-grid; decentralised solar/mini-hydropower systems; mini-grid; Hybrid Renewable Energy System, HOMER-Pro; Simulation.**

I. INTRODUCTION

A. Background of the study

Electricity is an imperative condition for a country's development. Without electricity, people's livelihood options are limited, access to essential services is restricted [1], and quality of life is adversely affected. The traditional approach to serving rural communities with electric power is to extend the central grid. This approach is technically and financially inefficient due to a combination of capital scarcity, poor energy service, reduced grid reliability, extended building periods and construction challenges to connect to remote areas. The governments and other funders have recognised that reaching rural communities through the expansion of the national grid can be costly and slow – and is sometimes not feasible [1]. Adequately financed and operated mini-grids based on renewable energy can overcome many of these challenges.

B. Statement of the problem

The Republic of Cameroon has an ambitious target of providing electricity to everyone in the so-called vision 2035. This is intended to transform the country into a middle-income economy. Regarding renewable energies, Cameroon, in its National Development Contribution (NDC) to reduce greenhouse gas as part of COP21 (leading to the Paris Agreement) decided to have 25% renewable energy in the electricity mix by 2035, from less than 1% today [2].

The development of renewable energies is one of the strategic plans for the reduction of poverty so that the country could end up with a developed economy. One way to contribute to the realisation of this objective is in the design and implementation of a hybrid solar/mini-hydro renewable energy system for rural electrification. Mini-grids can be energised by using renewable energy based on hybrid system technology into which multiple combinations of renewable energy technologies can be integrated. Standalone systems are costly to acquire and maintain [3]. Mixing different technologies with different energy sources provides competitive advantages compared to using a single technology. For example, the solar PV system peaks up when hydro generation drops during the dry season and vice versa. The battery backup system adds stability to the network by storing the energy for peak consumption when there is insufficient production from renewable sources.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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C. Objectives

The main objective of this research is to develop a framework for the optimal design of a Renewable Energy System which incorporates mini-hydro and solar components for the Muyuka rural community. This global objective entails the following specific objectives: (1) To develop a hybrid solar/mini-hydropower model for the Muyuka rural community and (2) To evaluate the performance of the solar/mini-hydropower system performance based on system generation and load demand

D. Literature Review

The initial cost of microgrids is often a barrier to its development. The financial cost of distributed energy resources is perceived to be higher than that of a centralised power generation system. Recent studies, however, have found that the cost of generating power in a microgrid is comparable with present electricity supply as long as support for PV is available [4]. Again, instead of investing in new infrastructure to meet increasing demand, microgrids can be used to solve the peak load problems, especially in low load density rural communities. In developing countries without infrastructure like Cameroon, microgrids are more likely to be cost-effective since the installation cost must be compared with that of installing high voltage transmission lines. In the grid-connected mode, the system voltage and frequency are fixed by the primary grid. In islanded mode, keeping demand and supply balanced to maintain voltage and frequency is a huge task.

Various researchers have used different methods for design, implementation and optimisation of the hybrid renewable-based power system. Kenfack et al. [5] in the study "feasibility analysis of solar photovoltaic and micro-hydro hybrid power system with battery storage, at Batocha (Cameroon)", the authors compared different combinations of component sizes and quantities. They explored how variations in resource availability and system costs affect the cost of installing and operating different system designs using HOMER Pro software. Bilal Abdullah Nasir [6] in the research "MATLAB simulation procedure for the design of micro-hydroelectric power plant" concluded that, as micro-power continues to grow around the world, it is essential to show the public how feasible micro-hydro systems are in a suitable site. Ashish S. et al. [7] in their study on Hybrid Power Generation System concluded that to avoid interruption of power by a standalone renewable energy source, hybridisation of renewable energy sources is the key. The hybrid energy system has good reliability, efficiency, less emission, and lower cost. The papers reviewed shows the degree of concern that scholars have towards this subject. A hybrid system that includes solar PV/small hydro/storage systems is most appropriate for Cameroon, given that these resources are abundant in the country.

II. MATERIALS AND METHODS

A. Study location

Muyuka is a town in Fako Division in the Southwest Province of Cameroon as shown in fig. 1a. Muyuka is the headquarter of the Muyuka subdivision. The specific location is at 4°17.4′ N and 9°24.9′ E. The subdivision is made up of mostly rural communities with sub-villages such as Owe, Ekata, Bafia, Muyenge, Yoke, Malende, Meanja and Mpundo. Muyuka has a population of 86,268, with a rural percentage of 67.5% [8]. Muyuka had a hydropower plant constructed in 1947 at the yoke river known as the Yoke hydropower Plant.

The Yoke Hydropower plant: Yoke had a hydropower plant with a hydro capacity of 3.27MW constructed during the period 1947 to 1949 [9]. It was part of the Electricity Corporation of Nigeria, given that at the time, Southern Cameroons was being administered from Nigeria. The installed power was 2.2MW but the peak demand at that time was only 1.59MW [9]. When the Southern Cameroons left Nigeria, the plant was taken over by POWERCAM Corporation. The installation was dismantled after reunification with La Republique du Cameroon. Presently, with the advent of modern technology, the hydropower plant can be re-harnessed to serve as a mini-hydropower plant to alleviate the regular acute power shortage bugging the country. The scraps of POWERCAM remain standing in Yoke village.

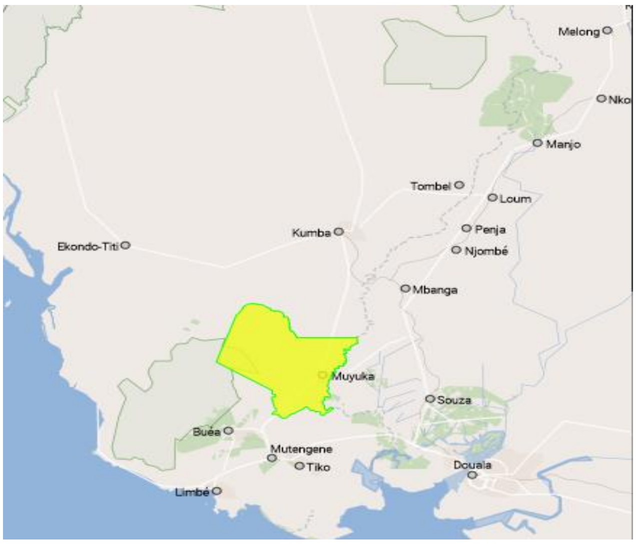

Fig. 1a. Muyuka subdivision, South West region, Cameroon [8]

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B. Resource potential

Cameroon is blessed with enormous and varied resources for electricity production. The hydraulic potential is estimated at 20,000MW according to the Energy Situation of Cameroon (SEC, 2015) – of which only about 5% is exploited – the second-largest in Africa after the Democratic Republic of Congo [10]. The hydraulic potential is sovereign, as all the rivers that can be used are within the frontiers of Cameroon and not shared with any neighbouring country. In the electricity mix of Cameroon, solar/mini-hydro energy contributes less than 1% of the 1,600MW generated [10]. Again, the average solar radiation in Cameroon ranges from 4.5kWh/m^2/day in the southern part of the country to 5.7kWh/m^2/day in the northern part of Cameroon with the highest values in the Far North region [11]. Therefore, the potential to harness solar/mini hydropower systems are hugely available in the country. According to [9], the hydropower capacity of the Yoke power plant is 3.27MW. The considerations for this case study are to design a hybrid solar/mini-hydropower system that can supply 3MW of power to an a.c. Load. The hydropower system is expected to supply a peak power of 2MW in the rainy season and 1.2MW in the dry season leaving enough residual flow for the survival of biota. For a standalone hybrid system in which the load depends on intermittent energy sources such as solar and run-of-river hydropower systems, reliable backup systems are necessary. In this project, a battery bank is included to provide backup. The backup system also helps to optimise the sizing of the hybrid system.

C. Data collection and load profile

Load demand: The rural population of Muyuka subdivision is about 60000 [8]. With an average energy demand of less than 5kWh per month, the maximum demand of the community is about 3MW. The site daily load profile, seasonal load profile and yearly profile are shown in figure 2. The community load profile for the project has a peak load of 3MW, including a random variability of 10% daily and 20% timestep.

Fig. 2: Community load profile

Solar and Hydro resources: The solar resources are obtained from the National Renewable Energy Laboratory database as shown in fig. 2. The site temperature profile is obtained from NASA surface meteorology and solar energy database. As shown in fig. 3, the average solar radiation is 4.49kW/m^2/d, and the average clearness index is 0.51. Figure 4 shows the site temperature profile. The existing data from [9] is used for the hydropower system design. The hydro scaled annual average flowrate is 22.17m^3/s, and the minimum residual flow is 1m^3/s. Fig. 5 shows the hydro resource input.

Fig. 3: Solar resource inputs

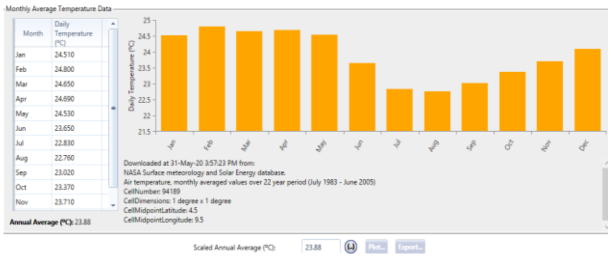

Fig. 4: Site temperature profile

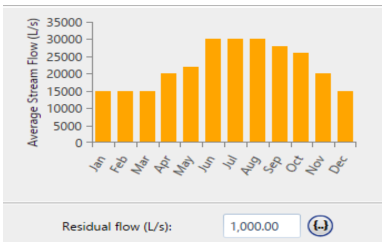

Fig. 5: Hydro resource input

D. Equipment Selection and project optimisation

Photovoltaic Array: The PV modules used is generic. The PV array size is estimated from the load demand. The considered PV system rating is 1800kW, but the sizes considered for the simulation are 1500kW and 1800kW. The initial cost, replacement cost, operation and maintenance cost are adjusted to cover the balance of system cost and others. The solar module parameters are shown in table 1:

Batteries: Batteries are an integral part of hybrid renewable energy systems. The battery backup adds stability to the network by storing energy during peak generation and releasing the energy for peak consumption when there is insufficient generation from renewable sources. The battery considered for the project is a lithium-ion 1MWh capacity battery with supplier integration into HOMER-Pro. The specifications and price are provided in the software. The battery model parameters are shown in Table 2

Converter: The bidirectional converter is used to interface between the DC bus connected to the PV system and the AC bus powered from the hydro system. A generic large free converter was selected from the HOMER database to allow battery sizing without having to size the converter for different ESS and charging configurations such as load following (LF) and cycle charging (CC). The inverter and rectifier efficiencies of the converter were taken as 95% each. Table 3 shows the converter model parameters.

Table 1: The solar module parameters

Module parameter	Value
Type	Generic flat-plate PV
Rated capacities considered	1500kW and 1800kW
Panel type	Flat plate
Output current	DC
Lifetime considered	25 and 30 years
PV derating factor	90%
Tracking system	No Tracking
Azimuth	0 deg
Ground reflectance	20%
Capital Cost per kW	1250USD
Replacement cost	1250USD
Operation and maintenance cost	300USD

Table 2: The battery model parameters

Module parameter	Value
Type	Idealised battery model
Quantities considered	4, 6, 8
String size	2
Expected lifetime	25 years
Nominal voltage	600 V
Nominal capacity in MWh	1.0 MWh
Nominal capacity in Ah	1,670 Ah
Roundtrip efficiency	90%
Maximum charging current	1.67 kA
Maximum discharge current	5 kA
Annual throughput	3,000,000 kWh
Initial state of charge	100%
Minimum state of charge	40%
Capital Cost per unit	700,000 USD
Replacement cost	700,000 USD
Operation and maintenance cost	10,000 USD

Table 3: The converter model parameters

Module parameter	Value
Type	Generic large free converter
Lifetime	15 years
Inverter can parallel with AC generator?	Yes
Rectifier relative capacity	100%
Rectifier/Inverter efficiency	95%
Capital Cost per unit	750 USD
Replacement cost	750 USD

Hydro Turbine: The hydro system is made up of the hydraulic equipment which includes the intake gates and trash screens, the electromechanical equipment which consists of the turbine, generator, transformer and controls. Table 4 shows the parameters of the hydro turbine.

E. Operating strategies

There are two types of dispatch strategies in HOMER Pro: the load following (LF) dispatch and cycle charging (CC) dispatch. In the load following dispatch strategy, renewable power sources charge the battery, but the generators produce just enough power to meet the load demand. In the cycle charging dispatch strategy, whenever the generators operate, they produce more power than required to serve the load with the surplus electricity going to charge the battery bank. With a set-point state of charge chosen, the generators charge the batteries to a set point of about 80%, and the load following dispatch strategy is used to top up the batteries. Table 5 shows the system control inputs for the simulation.

F. Cost

Figures 6 and 7 from [12] shows the total installation cost range for PV and hydropower renewable energy installations. The figures are used as a guide in choosing the cost range for the PV and hydropower renewable energy installations.

Table 4: The hydro turbine parameters

Module parameter	Value
Type	2MW Generic
Lifetime	25 years
Available head	10 m
Design flowrate	22,000 L/s
Minimum flow ratio	50%
Maximum flow ratio	110%
efficiency	85%
Pipe head loss	10%
Output current	AC
Capital Cost (including generator, controls, transformers and transmission system)	3,000,000 USD
Replacement cost	1,000,000 USD
Operation and maintenance cost	100,000 USD

Table 5: The system control inputs

Simulation	Value
Simulation time step (hours)	1
Include hydro turbine in all simulations	Yes
Generator control: Load following	Yes
Generator control: Cycle charging	Yes
Set-point state of charge	80%

International Journal of Engineering Research & Technology (IJERT)
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Vol. 9 Issue 09, September-2020

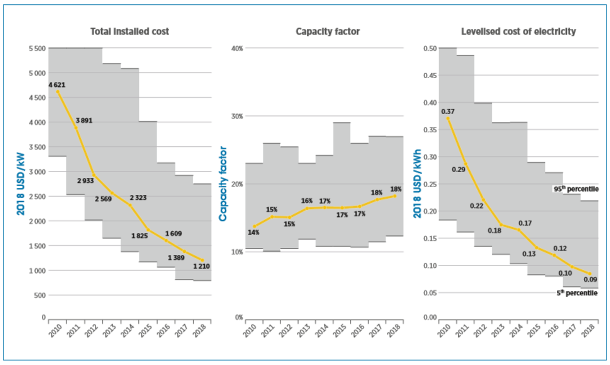

Fig. 6: Global weighted average of total installed costs, capacity factors and LCOE for solar PV, 2010–2018

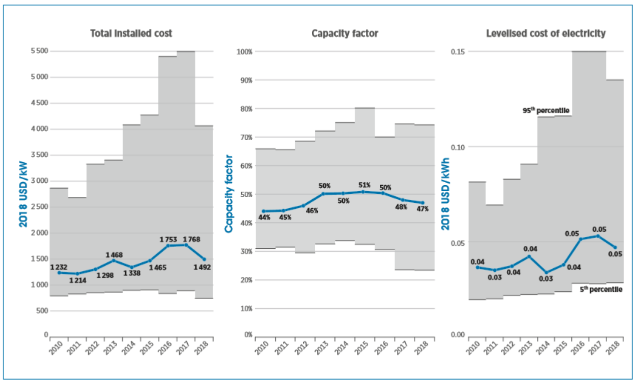

Figure 7: Global weighted average of total installed costs, capacity factors and LCOE for hydropower, 2010–2018

G. *Simulation and optimisation with HOMER-Pro*

Fig. 8 shows the system architecture. Microgrids are by their nature very dynamic systems in which several variables can be changing simultaneously and continuously. The solar resource has a very erratic behaviour following local meteorology, and loads can change rapidly and subject the system to peaks and transients. Batteries and electronic devices have their logic and response to changes in electric parameters. The interaction of all these variables and behaviours can result in a very complex system to analyse. Microgrid modelling and simulation is done to optimise the technical performance and economic viability. The simulation serves two purposes: it determines firstly whether the system is feasible, that is being able to serve the electric load, and secondly, it estimates the lifecycle cost of the system. The lifecycle cost is represented by the total net present cost, which includes all costs and revenues that occur within the project lifetime with future cash flows discounted to the present. HOMER-Pro's one-hour time step is sufficiently small to capture the most important statistical aspects of the load and the intermittent renewable sources and equally appropriate to allow computation to the extent that optimization and sensitivity analysis can be handled.

The hydropower is operated at rated capacity at all times to provide frequency and voltage stability and improve on

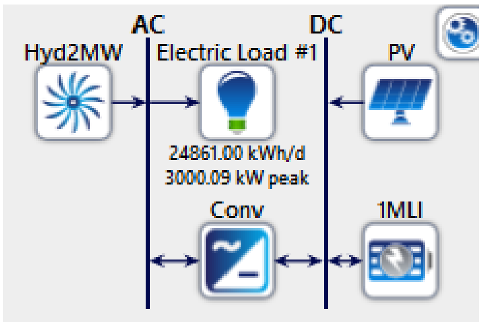

Fig. 8: System components and configuration

system efficiency. The solar PV system is used to balance the supply. At peak load periods, the storage system comes in to support generation. During periods of low demand, excess generation from the hydropower is used to charge the storage systems. The stored energy can then be used to provide energy during periods of high demand.

III. RESULTS

The proposed system involves Hydro, solar PV, batteries and a converter. The energy sources are hydro and solar power sources. The supportive component used to improve stability and reliability is the battery bank. An inverter is included for power conditioning. The mini-hydropower interconnects with the PV solar system. The DC bus voltage is 1.2kV which is converted to 400V, 3-phase, 4-wire by the converter for connection to the AC bus. The local community is powered from the AC bus. Figure 9 shows the simulation result. The results show that the solar PV rating of 1,800 kW, 16 units of 1MLi batteries, 2MW hydro generating 1,834 kW peak and the converter operating at 1,711 kW are the optimal combinations. The dispatch strategy is cycle following (CC). The net present cost (NPC) is $26.3M and the initial capital required is $17.4M. The operation and maintenance cost per year is $823,643. For the optimized system, the cost of energy is $0.628. Fig. 10 shows the optimal result based on least cost of energy (COE).

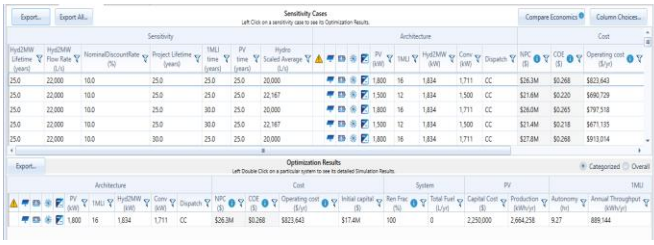

Fig. 9: Best option by HOMER-Pro

Fig. 10: Optimal system based on least cost of energy (COE)

Fig. 11: Cost summary for the selected option

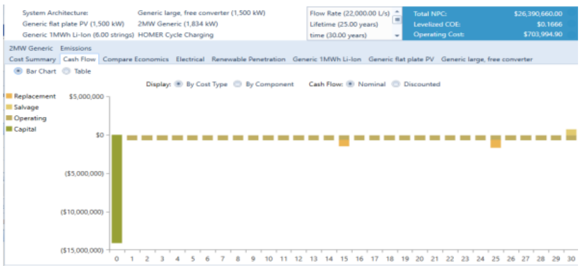

Fig. 12: Cash flow for the selected option

Fig. 13: Electrical Summary showing the energy generated by the hydropower and PV systems, respectively.

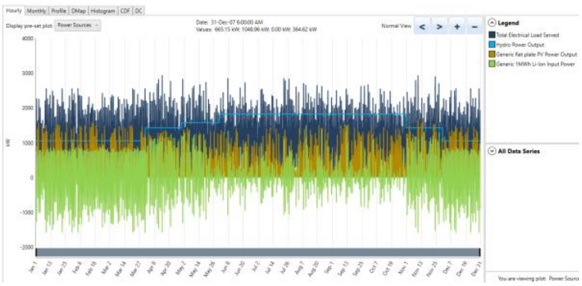

Fig.14: Hourly plot of power sources output illustrating total electrical load served, hydropower output, solar PV power output and ESS output

Fig. 15: Hourly plot of solar PV system and energy storage output illustrating the performance of the solar PV system and ESS

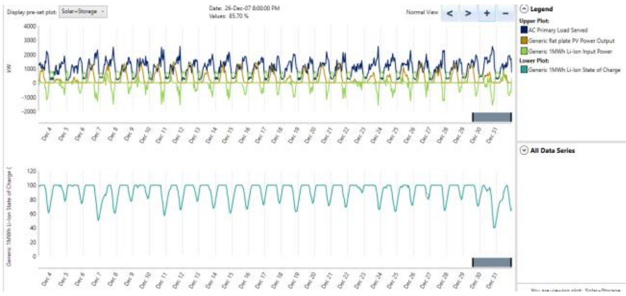

Fig. 16: Hourly plot of solar PV and energy storage output for December

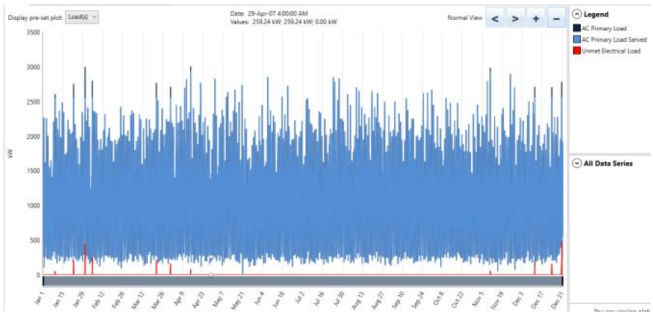

Fig. 17: Hourly plot of primary loads served and unmet electrical load

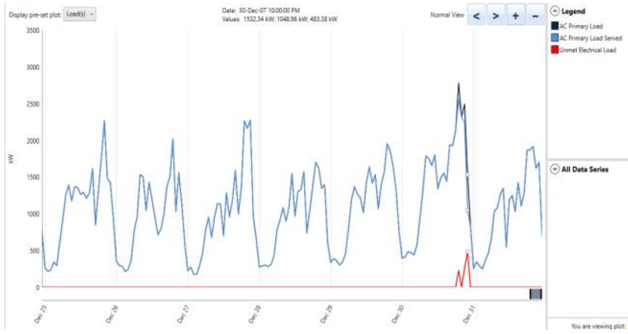

Fig. 18: Hourly plot of primary loads served and unmet electrical load for December 30

IV. DISCUSSIONS

The results highlight the fact that the use of HOMER Pro as a design and simulation tool in the design of microgrids and optimisation of various renewable energy installations is quite extensive. The study covers the design and implementation of a hybrid solar/mini-hydro renewable energy system. The main objective of the research is to design and evaluate the performance of a rural electrification project using hybrid autonomous renewable energy systems. Sources considered were hydro and solar PV systems. The results show that renewable energy can play a satisfying role in providing electricity to rural communities. The results of the design can be improved if actual costs are obtained from the manufacturers and suppliers. The study also illustrates the fact that hybrid renewable energy systems, though small-scaled, are endowed with high operational and constitutive sophistication. However, modern technology allows reliable and cost-competitive energy generation in remote areas, surpassing the convenience of traditional solutions using grid extension or diesel generation by economic and environmental considerations.

The results demonstrate that the system offers the least cost of energy for the required quality and level of service. In some instances, the most practical system might not be the most cost-effective. In the simulation results, the optimal system provided by HOMER Pro has a net present cost (NPC) of $26.3M and cost of energy, $0.268. The researchers found the least cost of energy in the simulation is $0.168. An NPC of $26.4M, which is much lower than that proposed by the software.

The system's supply equally matched the village demand with very little shortages. Adjustment of the DOD of the battery storage system could be used to offset the shortages. Despite the many benefits of the system, the energy cost of 0.162 USD is higher in comparison to the residential grid tariff in Cameroon which ranges from $0.083 to $133 for low energy consumers.

V. CONCLUSION

A careful prospection of resources has to be made, as well as the characterisation and analysis of the loads. This leads to the better design of the generating components and storage system that converts the variable and intermittent availability of resources into a continuous and reliable electric supply. Collecting meteorological data at the site is the first step of the hybrid design. The solar energy potential can be estimated by consulting solar radiation maps, satellite images, NASA and NREL databases, or by measuring global radiation at the site. With this data, it is possible to determine the available solar resource by the calculation of the peak sun hours. Sizing of these sources requires performing multiple simulations in scenarios of days or months.

The use of HOMER Pro as a tool in the simulation and optimisation of various renewable energy installations in a small-power system project has been quite extensive as seen in the results. The software provides much flexibility in defining load, system architecture, energy sources and dispatch strategies. However, the software does have limitations. The models for the load, PV array, battery bank, inverter, hydro turbine and all the renewable energy components must be developed by the designer either through auxiliary programs or by using paper and pencil and manual inputs or obtained through cooperation with research institutions that have developed proprietary models. While HOMER Pro makes simulation and optimisation relatively easy, designers need appropriate data and logical assumptions in order to come up with sensible results. The cost results can be improved greatly if the designer obtains the cost of components from the manufacturers and suppliers. Realistic results can also be obtained if the resource assessments are based on real field measurements, but this demands time and considerable expenditure.

Energy storage is amongst the most expensive component and cost driver of these systems as shown in the cost summary table, not only because of its initial cost that can represent nearly half of the total investment but because of the periodical repetitive renewals along the expected lifetime of the microgrid. The advent of lithium batteries brings the possibility of a better performance at a lower long-term operating cost. This paper has highlighted the potentials of HOMER Pro and its application in the design of mini-power systems. HOMER Pro software can significantly simplify and shorten the process of mini-power system design.

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