Modelling and Optimal Sizing of Grid-Connected Micro grid System using HOMER in Bahir Dar City, Ethiopia

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Abstract: – The expansion of renewable energy is continuing powerfully. The inspiration on the power supply system by the variability of the in feed must be met with new concepts called smart grid. In this study, we explore the potentials of integrating microgrid as a cooperating unit in the power supply network to support further expansion of renewable energy sources (RES). The main concern and backbone of the smart grid is micro grid, which integrates different distributed generation systems, storage units and electrical loads. The main objective of this study is modelling a micro grid system from a combination of renewable energy resources such as Solar photovoltaic and wind with Storage battery which are operated in a grid-connected mode in Bahir Dar city, Ethiopia. There is a need to use storage system or grid system for providing incessant power supply to the load. The system is designed to meet the customer load demand of the city in a reliable manner and good power quality, which cannot be met using conventional system generation alone. Residential, institutional, commercial, agricultural, and small-scale industrial loads with an average electricity demand of 15,467 KWh per day are estimated. The Optimal sizing of the micro grid system components are done using HOMER (Hybrid optimization multi-energy resource) pro software. The simulation results showed that the PV-wind based grid-connected micro grid system with a storage battery in meeting the load requirements in relation to the optimal sizing of PV panel and the wind turbine is sustainable, techno-economically viable and environment friendly

Key-words: **-** Microgrid, HOMER, PV Panel, Wind Turbine, MATLAB/Simulink

1 Introduction

In the present life of modernization and financial development, energy is the main ingredient. Thus, the increasing energy demand is stressing the transmission and generation system capabilities leading to frequent power outages and hence developing reliability, stability, and quality problems of the power system. Moreover, the efforts using renewable energies integration have been commonly used. But such alternatives are istribution systems will benefit both the grid and the customers [1].

As load demands are fluctuating with time, the variations in solar or wind energy generations do not always match frequently unable to meet the needs of customer's sufficiently and reliably due to the volatility of renewable resources [2]. The micro grid system involving generation systems, storage units, and controllable loads can minimize the randomness nature of renewable energy sources (REs), resolve oversizing issues, and improve the reliability of the supply [3]. Therefore, it is predictable that electricity generation, transmission, and customers demand. Thus, there is need to use storage system or other components including grid for providing incessant power supply to the load [4].

In this study, we consider Bahir Dar city in Ethiopia which has unreliable power generation. Despite this, the country is endowed to experience with a solar resource potential between 5.16 and 6.69 kWh/m^2 /days with an average sunshine duration of 6.00 kWh/ m^2 / day and wind speeds of 5.7 miles per hour [5]. The aim of this study is then to model and find the optimal size of micro grid components from the available resources in the city to meet the energy demand in a sustainable and reliable manner. Our contribution originates from four novel features despite our reliance on HOMER:

1). Two renewable energy resources namely Wind and solar with battery storage are considered and explored to model a grid-connected micro grid system.

2). Power quality and reliability of the conventional supply system which has yet received adequate attention in the literature, is considered as the main objective.

3). Estimating the loads in Bahir Dar city in terms of residential, commercial, and institutional thereby enlarging the scope of the study and hence determine the total load profile required for HOMER.

4). Determination of optimal sizing of a wind turbine, solar panel, and storage batteries to meet the load.

The paper is structured as follows: section 2 presents the literature review, section 3 describes the methodology, section 4 presents the optimization result and discussions, and finally section 5 contains the conclusion.

2 Literature Review

If the systems are optimized, designed, and modeled accurately, it could be more cost-effective and increased performance reliability. There are various optimization methods that have been applied in hybrid systems of renewable energies. For example, Hybrid optimization model for electric renewables (HOMER) [4-7], Genetic Algorithm (GA) [8], Linear programming (LP) [9], Particle swarm optimization (PSO) [10], simulated annealing (SA) [11], and Tabu search (TS) [12].

There are a lot of studies on optimization techniques for hybrid systems and a detailed investigation of this literature is beyond the scope of the paper. So, we focus on a selected technique for our purpose HOMER (Hybrid Optimization Multi Energy Resources). HOMER, which is developed by NREL (National Renewable Energy Laboratory, USA) is a preferred analytical tool to model the micro grid system to meet the load requirements [13].

Kumar Sahoo et al [14] discussed a case study of Chennai City in India, where they addressed the objectives of reduction of diesel cost, emission of carbon and increase the usage of renewable energy to about 50%. Their study considers an academic Institution base connected load 450KW with a peak load of 280KW. Through simulation using HOMER Software, the investigation found that the usage of renewable energy is increased to 50 % and the cost of the solar, wind, and diesel hybrid system decreased compared to the grid price. However, the study focuses only on the institutional system application and does not include either a grid or storage system for peak load and poor resource periods which will result in unreliable supply and poor-quality power.

Lawrence and Iqbal [15] presented diesel and a stand-alone PV based hybrid system for thermal modelling of a house in Nigeria. They used HOMER pro software for optimum sizing of the hybrid system. The results showed that the Photovoltaic is capable of supplying the house effectively. However, the study does not involve storage devices that make less performance of the power system due to poor power quality and less reliability during night time and rainy season as well as a high cost because of diesel. And also the study focuses only for one house but not embrace the dynamic use of energy

Nurunnabi and Roy [16] compared a case study of Bangladesh where they designed autonomous and grid-connected solar and wind-based hybrid systems. This study uses HOMER software for the analysis of data and economic feasibility of the designed system. The result showed that the net present cost (NPC) of the grid-connected hybrid system is less than the autonomous hybrid model. Although the grid-connected hybrid system is more suitable and cost-effective than the off-grid system, the study doesn't include a battery or any imbalance voltage control method(s) due to intermittent nature of solar and wind to improve the voltage stability, as a result, it will confront the poor power quality and less reliability. And also the study focused on the objective of a cost analysis of the off-grid and on-grid systems.

Hafez and Bhattacharya [17] studied planning and optimal design of the microgrid system based on renewable energy sources for a rural community application with a base load of 600KW and a peak load of 1183KW with a daily energy requirement of 5000KWh per day. The study considers diesel, hydro, solar, and wind resources for energy generation. Even though the analysis considers the demand for electricity over 24 hours, the purely hypothetical nature of the findings makes the work impractical for many developing countries ' off-grid areas.

Lau et al [18] studied the case of the remote residential area in Malaysia and used HOMER to analyze a hybrid system's economic viability. The study uses 40 households with a peak demand of 2KW. The peak demand is 80KW, and the analysis takes into account the basic demand of around 30KW. Although such high rural demand may be typical of the conditions in Malaysian, it is certainly not true for others. The study also does not consider the use of electricity to be productive.

As we observed from the above literature, studies mostly concentrated on supplying electrical energy just home purposes and do not take into consideration the demand for institutional purposes, irrigation application, community and commercial activates for socio-economic development and the studies didn't focus on the power reliability and quality of power. The total load profiles are not also carefully modeled or estimated. All the indicated issues are solved in this study.

3 Methodology

3.1 Introduction

In this study, HOMER (Hybrid optimization multi-energy resource) which is developed by NREL (National Renewable energy laboratory) is used to model the grid- connected micro grid system. The comprehensive assessment of the city load and available resources found in the city is conducted and fed as input before running the simulation using the software. Moreover, the range of components with different constraints, sensitivities and life cycle costs (LCC) which comprises initial capital, replacement, maintenance and operational costs are fed into the HOMER. Then HOMER executes the required simulation to meet the required load demand. Fig. 1 below illustrates the analysis framework of HOMER.
The system resizes the components if the demand is not satisfied by the given situation and then optimal component size with its maximum energy production is revealed.

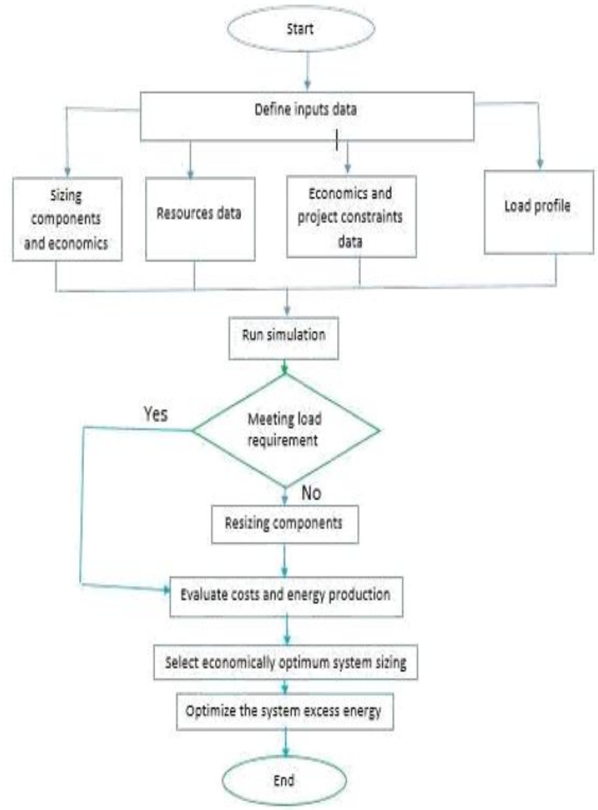

Fig. 1 Framework of HOMER [19]

We have considered a combination of Solar PV, Wind, batteries and grid. The Optimized Micro grid system configuration diagram is shown in Fig. 2.

In the micro grid system, the demand from the city is AC, the wind turbine and grid are connected to the AC side of the network and the solar PV and batteries are connected to the DC side. The Grid system is used to supply power for peak loads and during poor resource periods and absorb the surplus power generated by the micro grid system. The converter is used to convert DC to AC and the battery is used to store electrical energy and can also be used to power quality improvement because of the intermittent nature of solar and wind power. The system is not only for sustainable energy generation but also important for clean, and environment-friendly as well as providing good quality power which makes this study also different from others.

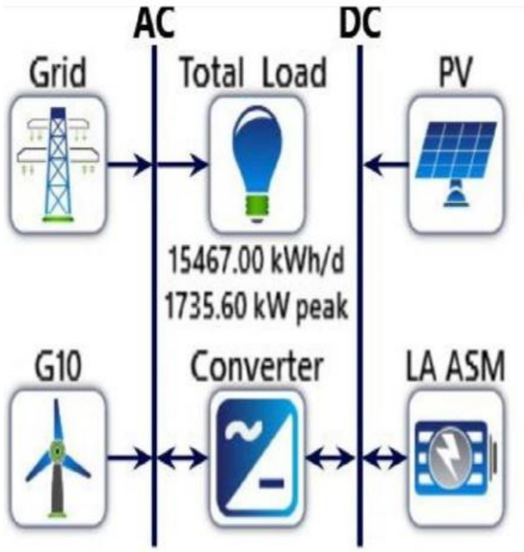

Fig. 2 Optimized Grid-Connected Micro grid system configuration

3.1.1 Site Description and Load Estimation

3.1.1.1 Site Description

Bahir Dar is one of the regional states of Ethiopia, which is located at 578Km north-west of Addis Ababa. It is the leading tourist destinations due to the landmark of Lake Tana and Blue Nile River. The main source of income is mainly fishery, tourism, and agriculture. This study considered one county of Bahir Dar city located on the eastern part of it at latitude of 11^{o} 34.5'N, 37^{o} 21.7^{o} E where the major source of income is mainly tourism, coffee and teff exports. The total number of households in the given county considered is 1500 with a total population of 8013. The number of males and females in the site are 3770 and 4243 respectively. Although grid electricity is available in the city, a prolonged outage and poor reliability are a usual problem.

3.1.1.2 Load Assessment

In Bahir Dar city, being it is an urban area the demand for electricity is very high. It is demanded for residential (for appliances like lightings, ceiling fans, TVs, Radios, smoothing iron, Stoves, water heater, electric enjera Mitad), commercial and small scale industrial activities (like milk processing, cold storage, cottage industry, and shops,),Community loads (community halls, primary Schools, health centers, churches, mosques etc.) and agricultural activates (water pumping and irrigation pump). In this work, the load profile data is estimated considering the existing available load. The estimated load consumption of the city is provided in the Appendix.

The total Energy demand per day (ED) can be computed as shown in equation (1)

$$ED = \frac{\sum_{i=1}^{N} A_i P_i Q_i \times C_i}{1000} (KWh) \quad (1)$$

Where,

i = Index of each type of load;

A_i = number of hours i^{th} device type used per day

P_i = power rating of i^{th} device type; number of device of i^{th} type;

C_i = Considered number of houses, schools, health centers etc.

Therefore, based on the information given in table 1, the average daily energy demand per day is 11970KWh, 2114.4KWh, and 1382.6KWh for the gross residential, Commercial, and community respectively. And the overall consumed energy is 15,467KWh per day with a 1725.5KW peak load at 0.73 derating factor. Fig 3 and Fig. 4 below illustrate the daily and monthly load demand profiles generated by HOMER pro Software.

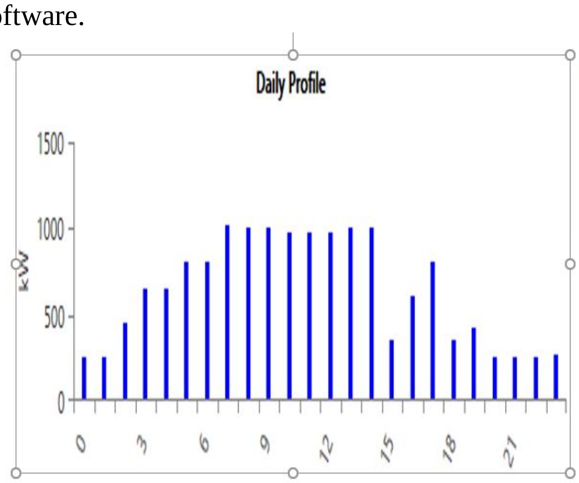

Fig. 3 Total daily load demand profile of Bahir Dar

From Fig. 3, we observed that a load varies for different months. According to HOMER simulation results, the off-pick period runs from 12 a.m. to 6 a.m. and from 10 pm to 18 pm while the peak load time is 1 pm to 8 pm

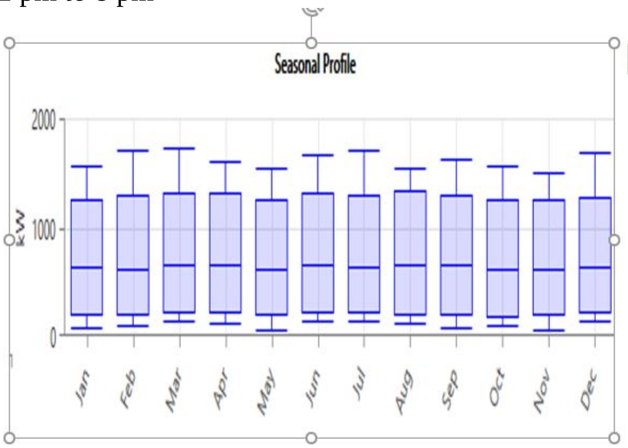

Fig. 4 Monthly load demand profile of Bahir Dar

The monthly average load profile of our system is presented in figure 4. From this diagram, we can observe that the maximum value achieved in March with a value equal to 1725.50 kW. For May, June, November, and July the value is low and is around 1400KW.

3.1.2 Meteorological Data Assessment

In this simulation, we considered mainly the resources of wind speed, Temperature and Solar radiation. The resource analysis is described below:

3.1.2.1 Solar Radiation and Clearness index

The solar insolation of Bahir Dar at a location of 11^o $34.5^{'}$ N latitude and 37^o $21.7^{'}$ E longitude was obtained from the NASA meteorological and solar energy wave sight. Based on the value of the average radiation, the month of the year, and the latitude, HOMER calculates the clearness index which indicates the fraction of the solar radiation striking the top of the atmosphere that makes it through the atmosphere to strike the Earth's surface. The high solar radiation appears in February, March, and April while the low is in July and August. The large value of the clearness index appears within October to May with the maximum value of 0.694 in February. July and August have the least clearness index of 0.495. Fig. 5 and Fig. 6 explain the solar radiation and clearness index of the month.

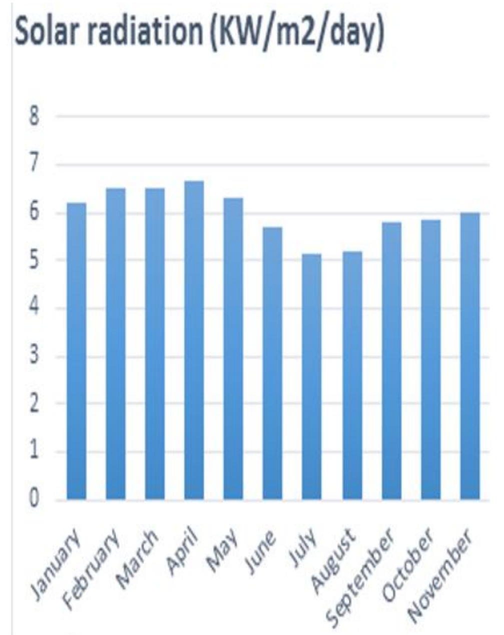

Fig. 5 monthly solar radiation

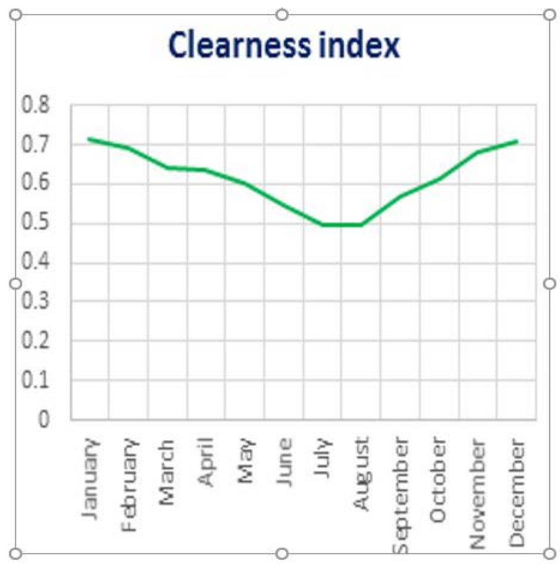

Fig. 6 clearness index of Bahir Dar

3.1.2.2 Temperature

The monthly average temperature of Bahir Dar, which is required for HOMER Software simulation, is obtained from NASA surface meteorology. The annual average temperature of the site is 18.77 ^{o}c. Fig. 7 shows the average monthly temperature of Bahir Dar, Ethiopia.

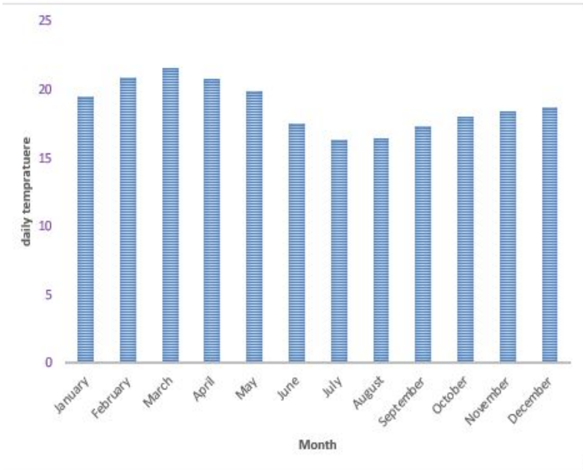

Fig. 7 Average Monthly Temperature Resource of Bahir Dar

3.1.2.3 Wind Resources

On the basis of the longitude and latitude of Bahir Dar, the average monthly wind data from an average of ten years were taken from the NASA database website. The location's average annual wind speed is 3.78 m / s with the 50 m height of the anemometer. Fig. 8 below shows the monthly average wind speed.

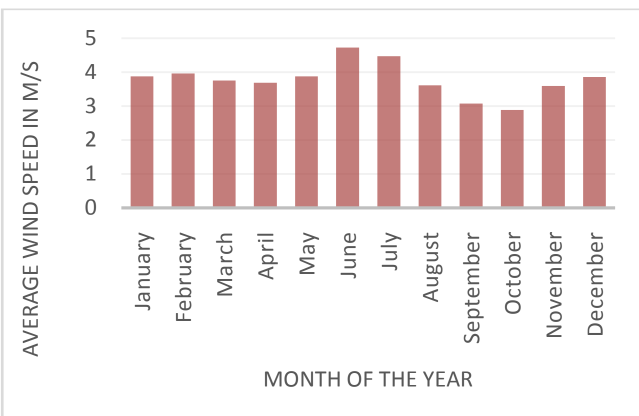

Fig. 8 Wind energy resources (monthly average)

3.1.3 Component Details

The microgrid components are used to generate, convert, store, and supply electrical energy. They are chosen from HOMER Add/Remove window. For the big grid power system, the microgrid is equivalent to a controllable unit, which solves the problem of large-scale grid-connected of clean energy. The study comprises a Photovoltaic panel, wind turbine, Power converter, storage device, and grid as described below.

3.1.3.1 Photovoltaic Panel

In this paper, Generic Flat Plate PV are connected in series. It is manufactured by Generic with efficiency, lifetime, initial capital cost, and operation & maintenance cost of 1KW PV; is taken as 13%, 25 years, $ 1200 , and $ 0 respectively. The derating factor considered for PV is 80 % for each panel for the varying effects of temperature and dust.

3.1.3.2 Wind Turbine

For this paper, Generic 10kw horizontal axis wind turbine, the hub height of 34m, and a lifetime of about 20 years, the initial capital cost of $4,320 and operation and maintenance costs of $400 is considered. The amount of electricity produced by the wind turbine is highly dependent on wind speed availability and variations.

3.1.3.3 Power Converter

The converter's capital cost, replacement cost, and O&M costs for 1 kW systems are respectively estimated to be $700, $550 and $100/year [20].The converter's lifespan is 15 years, 90% inverter efficiency and 85% rectifier efficiency.

3.1.3.4 Battery Storage

Batteries are used in the network as a backup and for maintaining a constant voltage during peak loads or a power shortfall. In this study, lead Acid battery manufactured by Generic with a capacity of 2.4KWh, and 66 V, the initial cost of $300/kwh, operating and maintenance cost $10/kwh, and a lifetime of 20 years is considered.

3.1.3.5 Grid System

The Grid system is used as a backup power element or surplus power absorber. The main grid system feeds power when there is not adequate power from Renewable energy sources such as Solar PV and Wind to meet the energy demand and grid consumes power when excessive power is generated. The selling price of the electricity from the grid is estimated at 0.04$/kWh and the selling back price of electricity from the microgrid is estimated at 0.05$/kWh [21].

3.2.4. Homer Pro Software

HOMER Pro software developed by the U.S, the national renewable energy laboratory (NREL) is a microgrid optimization tool for technical and financial assessments. It is established to model both grid-connected and isolated microgrid using renewable and conventional energy sources to supply loads [22]. To obtain accurate and optimized component sizes, HOMER needs input information such as solar insolation, wind speed, load data, storage, and microgrid component details with their corresponding costs.

4 Optimization Results and Discussion

From the HOMER analysis, the optimum size of microgrid components for our system is mainly selected based on the lowest values of Net Present Cost (NPC), CoE (Cost of Energy), and the Operation and maintenance (O&M) cost. The total NPC of this simulation is $5,912,997. This is the values of all costs incurred during their lifetime minus the present values of all the income it earns during its lifetime. The included costs are capital costs, replacement costs, O&M costs, fuel costs, and emission penalties. So that HOMER calculates the NPC by summarizing the cumulative discounted cash flows in the contract life of each year. On the other hand, COE is the average cost per KWh of energy produced by the system. Homer estimates the Cost of Energy (COE) of the system by using equation (2).

$$\mathrm{COE} = \frac{AnC - Cs}{WT} \qquad (2)$$

Where; AnC - is annualized cost; Cs - is the cost of serving, and WT - is electric energy production. And the HOMER simulation output of COE is then, 0.27217 $/kWh which is indicated in table 2 below. The combination of penalty for capacity shortage and penalties for emissions of pollutants are called O& M cost.

To calculate maintenance and operation cost of a system, the software uses equation (3).

$$C_{\mathrm{om,other}} = C_{\mathrm{om,fixed}} + C_{\mathrm{cs}} + C_{\mathrm{emissions}} \qquad (3)$$

Where: $C_{\mathrm{om\ fixed}}$ – is the system fixed O&M cost [$ / yr.]; Ccs- is the penalty for capacity shortage [$/yr]; and Cemmissions- is the penalty for emission [$/year]. The operation and maintenance costs (O&M) of our system are $207,355. Table 1 shows NPC, COE and M& O cost values of the system simulated by HOMER pro software.

Table 1. Cost of the optimal system

Costs	Description	Value
Cost of Energy (COE)	Cost per KWh or per unit of energy	$0.27217
Net Present Cost (NPC)	Total life cycle cost for the full lifetime of the project	$5,912,997
Operation and maintenance (O&M)	Cost for operations and maintenance	$207,355

Based on the optimal costs of the system as seen in Table1, the optimal sizing of the components of the Microgrid system is selected from the optimization result of HOMER and depicted in Table 2.

Table 2. Optimal Sizing of the Proposed Microgrid components

Microgrid component	Capacity	Type
PV	750KW	Flat plated PV panel 1Kw type
Wind	500KW	Generic 10kw type
Battery	33String, 2.4KWh	Lead Acid Battery
Converter	650KW	System Converter
Load	1,735.6KWp	Peak Load
Grid	6000KW	Grid

Fig.9 below presents the average monthly electricity production by each microgrid components such as PV, wind and grid. It is clear that all wind energy, solar energy and grid power output vary from season to season, but they always produce enough energy to meet the required city load demand. From the input data it can be estimated that this system generated maximum electricity of 6,399,042kWh/yr from wind, solar and grid and the consumption power by the load is 6,337,657 kWh/yr. The yearly production of electricity by the solar PV, Wind , and Grid system as well as electricity consumption by the load are provided in the Appendix.

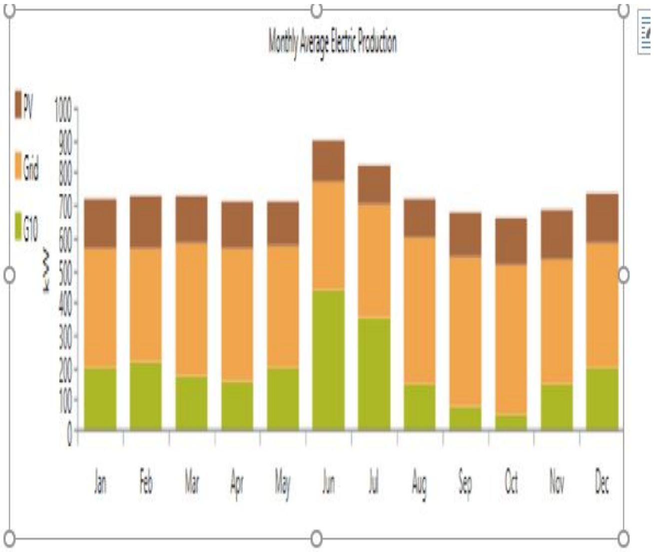

Fig. 9 Monthly average electricity production

5 Conclusion

In this study, the utilization of renewable energy resources including solar PV and wind turbine based grid-connected microgrid system for Bahir Dar city is modelled and sized using HOMER Pro software. There are several parameters taken into consideration when proposing a microgrid system for the city. The residential loads, commercial loads, and community loads are modelled depending on a total load of Bahir Dar city of 15,467kWh per day is determined. Homer Pro is used to optimize the size of microgrid components for solar PV, wind turbine, and storage battery using MATLAB simulation. The simulation process procured in to account the lifetime of the component, cost of the component from manufacturer's websites as well as the available solar insolation, wind speed and temperature of Bahir Dar was downloaded from NASA database with HOMER resource window. Additionally in HOMER pro system, sizing of the components, system configuration, lifecycle of the system, Net Present cost (NPC), Cost of energy (COE), Operation and maintenance (O&M) costs, annual operating cost of the microgrid power system is considered in determining the optimum sizing of microgrid components to meet total modelled load of the city. The simulation results obtained indicate that the grid-connected microgrid system is capable of powering the total estimated load of the city and serve as an appropriate solution to the energy need of Bahir Dar city.

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Reference:

[1] S. Edalati, M. Ameri, M. Iranmanesh, H. Tarmahi, and M. Gholampour, "Technical and economic assessments of grid-connected photovoltaic power plants: Iran case study," Energy, vol. 114, no. 2016, pp. 923–934, 2016.

[2] H. A. Kazem, T. Khatib, and K. Sopian, "Sizing of a standalone photovoltaic/battery system at minimum cost for remote housing electrification in Sohar, Oman," Energy Build., vol. 61, pp. 108–115, 2013.

[3] D. Akinyele, J. Belikov, and Y. Levron, "Challenges of Microgrids in Remote Communities: A STEEP Model Application," Energies, vol. 12, no. 2, pp. 2–35, 2018.

[4] G. Suresh et al., "Photovoltaic based flexible microgrid," Int. J. Multidiscip. Res. Mod. Educ., vol. II, no. II, pp. 535–544, 2016.

[5] N. Argaw, "Estimation of solar radiation energy of ethiopia from sunshine data," Int. J. Sol. Energy, vol. 18, no. 2, pp. 103–113, 2014.

[6] L. M. Halabi, S. Mekhilef, L. Olatomiwa, and J.Hazelton, "Performance analysis of hybrid PV/diesel/battery system using HOMER: A case study Sabah, Malaysia," Energy Convers. Manag., vol. 144, pp. 322–339, 2017.

[7] F. Fazelpour, N. Soltani, and M. A. Rosen, "Feasibility of satisfying electrical energy needs with hybrid systems for a medium-size hotel on Kish Island, Iran," Energy, vol. 73, no. 2014, pp. 856–865, 2014.

[8] M. S. Ismail, M. Moghavvemi, and T. M. I.Mahlia, "Genetic algorithm based optimization on modeling and design of hybrid renewableenergy systems," Energy Convers. Manag., vol. 85, no. 2014, pp. 120–130, 2014.

[9] D. Torres, J. Crichigno, G. Padilla, and R.Rivera, "Scheduling coupled photovoltaic, battery and conventional energy sources to maximize profit using linear programming,"

Renew. Energy, vol. 72, no. 2014, pp. 284–290, 2014.

[10] A. Stoppato, G. Cavazzini, G. Ardizzon, and A.Rossetti, “A PSO (particle swarm optimization)-based model for the optimal management of a small PV(Photovoltaic)-pump hydro energy storage in a rural dry area,” Energy, vol. 76, no. 2014, pp. 168–174, 2014.

[11] R. Velik and P. Nicolay, “Energy management in storage-augmented, grid-connected prosumer buildings and neighborhoods using a modified simulated annealing optimization,” Comput. Oper. Res., vol. 66, pp. 248–257, 2016.

[12] Y. A. Katsigiannis, P. S. Georgilakis, and E.S. karapidaks, “Hybrid simulated annealing-tabu searc method for optimal sizing of autonomous power systems with renewables,” IEEE Trans. Sustain. Energy, vol. 3, no. 3, pp. 330–338, 2012.

[13] B. Bhandari, K. T. Lee, G. Y. Lee, Y. M. Cho and S.H Ahn, “Optimization of hybrid renewable energy power systems: A review,” Int. J. Precis. Eng. Manuf. - Green Technol., vol. 2, no. 1, pp. 99–112, 2015.

[14] A. K. Sahoo, K. P. Abhitharan, A. Kalaivani, and J.T Karthik, “Feasibility Study of Microgrid Installation in an Educational Institution with Grid Uncertainty,” Procedia Comput. Sci., vol. 70, no. 2015, pp. 550–557, 2015.

[15] L. O. Aghenta and M. Tariq Iqbal, “Design and dynamic modelling of a hybrid power system for a house in Nigeria,” Int. J. Photoenergy, vol. 2019, no. 2019, pp. 1–13, 2019.

[16] M. Nurunnabi and N. K. Roy, “Grid connected hybrid power system design using HOMER,” in Proceedings of 2015 3rd International Conference on Advances in Electrical Engineering, 2016, pp. 18–21.

[17] O. Hafez and K. Bhattacharya, “Optimal planning and design of a renewable energy based supply system for microgrids,” Renew. Energy, vol. 45, no. 2012, pp. 7–15, 2012.

[18] K. Y. Lau, M. F. M. Yousof, S. N. M. Arshad, M.Anwari, and A. H. M. Yatim, “Performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions,” Energy, vol. 35, no. 8, pp. 3245–3255, 2010.

[19] A. Q. Santos, Z. Ma, C. G. Olsen, and B. N. Jørgensen, “Framework for microgrid design using social, economic, and technical analysis,” Energies, vol. 11, no. 10, pp. 2–22, 2018.

[20] R. M. Burkart and J. W. Kolar, “Comparative Life Cycle Cost Analysis of Si and SiC PV Converter Systems Based on Advanced η-ρ-σ Multiobjective Optimization Techniques,” IEEE Trans. Power Electron., vol. 32, no. 6, pp. 4344– 4358, 2017.

[21] B. E. Türkay and A. Y. Telli, “Economic analysis of standalone and grid connected hybrid energy systems,” Renew. Energy, vol. 36, no. 7, pp. 1931–1943, 2011.

[22] O. Boqtob, H. El Moussaoui, H. El Markhi, and T. Lamhamdi, “Optimal sizing of grid connected microgrid in Morocco using Homer Pro,” 2019 Int. Conf. Wirel. Technol. Embed. Intell. Syst. WITS 2019, pp. 1–6, 2019

Appendix

Cost Estimation of Residential, Community, and Commercial loads of the proposed system

Table 4: Total Estimated Load consumption for Bahir Dar City

No	Types Of Load	Total Number	Power Rating	Operating Time	Consumption Kwh/Day
1). Residential Purposes					
1	Lighting	8	60	6	2.88
2	TV	1	120	8	0.96
3	ceiling fun	1	105	8	0.84
4	computer/laptop	1	150	2	0.3
5	Refrigerator	1	150	24	3.6
6	Coffee Maker	1	1000	0.3	0.3
7	Ethiopian Electric Mitad	1	1000	1	1
8	Washing machine	1	400	0.5	0.2
9	water heater	1	3000	0.5	1.5
10	Rice cooler	1	220	1	0.22
11	Iron smoothing	1	1000	1.5	1.5
Considered number of houses		**1500**			
2). Community purposes					
	a). Primary School				
1	Lighting	20	40	6	4.8
2	Security lamps	12	60	12	8.64
3	Submersible water pump	1	420	4	1.68
4	Refrigerator	1	80	8	0.64
5	Television	1	120	7	0.84
6	VCR	1	500	0.5	0.25
7	Space heating and cooling	1	1200	1	1.2
9	Radio communications	1	40	0.5	0.02
10	printer	1	100	1	0.1
11	Computer	1	100	1	0.1
12	Photocopy machine	1	1000	1.5	1.5
	Considered Number of schools	**20**			
	b). Primary health clinic				
1	Vaccine refrigerator	1	60	12	0.72
2	Security lamps	20	60	12	14.4
3	Lighting	20	40	10	
4	Submersible water pump	1	420	4	3.25
5	Refrigerator	1	120	1	0.12
6	Television	1	80	1	0.08
7	Microscope	1	140	1	0.014
8	Medical centrifuge	1	250	1	0.25
	Desk top computer	1		1	200
9	Radio communications	1	40	0.5	0.02

10	Water pump (1500 liters/day	1	100	6	0.6
11	Electric sterilizer	1	1500	2	3
12	25” Color TV	1	130	4	0.52
	Considered number of clinics	**30**			
	c). Churches and Mosques				
1	Lightings	60	60	4	14.4
2	Ceiling Fan	4	50	4	0.8
3	Sound system	8	200	4	6.4
4	PC	4	200	4	3.2
5	LCD	2	270	3	1.62
6	Charger	10	10	4	0.4
		20			
	Considered Number Chu.& Mos.				
3. Commercial and agricultural purposes					
1	Shops	10	500	8	40
2	Small manufacturing units	4	2000	12	96
3	Street lights	5	30	10	1.69
4	Hotel and Restaurants	10	800	8	67
5	Water pump	8	745.6	5	29.824
6	Irrigation pump	4	1491.2	5	29.786
Considered number		**8**			

Yearly Electrical energy production of the proposed system

Table 1 Production and consumption scenario

a). Electricity Production summary		
Component	Production (KWh/yr)	Percent
Generic flat plate PV	1,227,703	19.2
Generic 10KW	1,701,431	26.6
Grid Purchases	3,469,909	54.2
Total	6,399,042	100
b). Electricity Consumption summary		
Component	Consumption (KWh/yr)	Percent
AC primary load	5,645,455	89.1
DC primary load	0	0
Grid sales	692,203	10.9
Total	6337,657	100