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Design and Simulation of Standalone Hybrid (Solar/Biomass) Electricity Generation System for a Rural Village in Ethiopia

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Abstract-This paper presents the design of off-grid hybrid electric power generation system by utilizing both solar and biomass energy resources for a rural village of 420 households in Ethiopia. The work was begun by investigating biomass and solar energy potentials of the desired rural village. The data regarding biomass energy potential of the site is found from the available livestock population and its waste. However, the solar irradiation data is collected from the NASA surface meteorology and solar energy database. According to the results obtained, the site has abundant solar energy potential and there is considerable biomass energy potential that can be exploited for generating electric energy for the village. The design of a standalone solar PV-bio-generator hybrid power generating system has proceeded based on the promising findings of these two renewable energy resource potentials, biomass and solar. Electric load for the basic needs of the community such as lighting, water pumping, a radio receiver, flour mill, TV and refrigerator for the local health post has been suggested. The design and simulation has been carried out using the HOMER software. By running the simulation, the results, which are lists of power supply systems, have been generated and arranged in ascending order according to their net present cost.

Index Terms — Biomass potential, Hybrid system, net present cost, rural village, solar energy potential

1 INTRODUCTION

Energy plays a crucial role in technological and economic development of modern society. It has always been the key to man's greatest dream of a better world. Throughout the history of human race, major advances in civilization have been accompanied by increased consumption of energy. There is a positive relationship between per capita energy consumption and per capita income. Therefore, adequate supply of energy at a reasonable cost is a key factor in the advancement of a country in almost all sectors.

Ethiopia is a country with numerically dominant rural population. From 85% of the rural population only 2% is electrified. The electric energy system of the country, which is mostly dominated by hydropower, is suffering energy shortage from high-energy demand rate and climatic impacts against the water availability. Due to these problems, power shading is common in Ethiopia during periods with lower water levels, even in the capital city and major towns where there are large energy intensive industries. The conditions in the rural areas far from the grid system, where majority of the populations live, is getting worse. The people in these rural areas use human power for water pumping and flour mill, firewood for cooking, kerosene for lighting, and dry cells for radio and tape recorders. Electrification by grid extension of these areas is unlikely in near future [1].

Increasing electricity demands, rising prices of fossil fuels, limited fossil fuel like coal and environmental concerns are the major factors, which motivate to use renewable energy resources for electricity generation. By using renewable resources as alternatives, this would definitely help in overcoming the global warming effect [2]. The current international trend in rural electrification is to utilize renewable energy resources such as solar, wind, biomass, and micro hydropower systems. In rural areas, hybrid system brings reliability in electrical power, cost effectiveness and improvement in the quality of life. Different renewable resources are required to be integrated to meet load demands of any area. Among these, solar and biomass energy systems in stand-alone or hybrid forms are thought to be ideal solution for rural electrification due to abundant solar radiation and significant biomass availability in the rural areas of Ethiopia.

Thus, hybrid power generation systems comprising these renewable energy resources can be used as alternative for rural electrification where grid extension is expensive and the price of fuel is high due to remoteness of the location. Due to the intermittency nature of the renewable energy resources and the load demand, an energy storage device such as a battery, is required.

Several authors have studied solar PV/wind, solar PV/wind/small hydro, Solar PV/diesel hybrid systems with storage. Gelma et.al [1] designed a solar PV/wind hybrid system for electrification of a rural model community in Ethiopia. Samuel et.al [3] studied the feasibility of solar PV/wind/diesel system for electrifying a rural district in Somali Region of Ethiopia. Getachew et al [4] studied the feasibility of small-scale Hydro/PV/Wind based hybrid electric supply system to a rural district in Ethiopia. Zelalem [5] discussed the development of an effective approach of design, simulation and analysis of stand-alone hybrid renewable energy resources for typical rural village with 200 households in remote area situated in SNNPR region of Ethiopia. Sisay [6]

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studied the feasibility of PV-Wind-Biogas hybrid system with battery storage, as a backup, to electrify the village in Adigrat district, Ethiopia. He also compares the cost of the hybrid system against the cost required to electrify the village by extending the grid. In the study, HOMER (Hybrid Optimization Model for Electrical Renewables) is used for optimization and sensitivity analysis.

HOMER is used for designing and modeling of the PV/Wind hybrid system. The software is a micro power design tool that can simulate and optimize standalone and grid-connected power systems with any combination of wind turbines, PV arrays, run-off-river hydro power, biomass power, internal combustion engine generators, and batteries, serving both electric and thermal loads. Biomass and solar data is input to HOMER. In addition, the size, cost and lifetime of power system components are defined as inputs. The HOMER algorithm considers each possible combination of the resources and determines the feasible combinations that can meet the required system load and constraints like minimum capacity shortage and operating reseve imposed by the modeler. In the results, feasible combinations of the hybrid components are displayed according to their net present cost in ascending order. In addition, the performance of each component, cost of energy, excess and/or shortage of energy and sensitivity results can be observed from HOMER output.

The main objective of this paper is to obtain the optimized combination of hybrid (solar/biomass) electricity generation systems that is able to meet the electricity energy demand of a rural isolated village in Ethiopia by determining the electric load demand of the village and the biomass and solar energy resource of the village.

2 Data Source and Analysis

One of the major tasks of this study is the assessment of the potentials of biomass and solar resources, which are then, followed by load estimation and design of the hybrid systems.

2.1 Biomass Resource Assessment

A wide range of biomass resources can be used as substrates for the production of biogas. In Ethiopia, most of the crop wastes like husk is used for feeding animals especially cattle and donkeys and therefore, crop husk is not available for utilizing it as biomass energy resource. Hence, this paper is limited to the consideration of livestock waste as biomass resource from the village.

According to village animal clinic center, there exists about 555 Cows, 712 oxen, 600 donkeys, 2520 sheep and 890 goats. The amount of animal dung varies from month to month. In June and July the cattle, sheep (goat) and donkey dung is 1.85kg/head/day, 0.35 kg/head/day and 0.94 kg/head/day respectively. From September to November, it increases by 10% whereas from December to February it increases by 5% but from March to April it decreases by 5% and in August and May decreases by 10% [7]. This variation is due to the variation of availability of feed intake for these animals in the area. Therefore, by considering the available livestock population and 50% dung collection efficiency [7], the total average biomass potential of the site is shown on table 1.

2.1 Solar Resource Assessment

The solar resource potential of the selected site is found from NASA Surface Metrology and Solar Energy website by inserting the latitude and longitude of the village [8]. It is the 22 year average insolation data as presented on the right most column of Table 1.

Table 1
Quantity of collectable biomass (animal dunG) potential and solar insolation potential of the village

MONTH	CATTLE	SHEEP & GOAT	DONKEY	TOTAL COLLECTABLE ANIMAL DUNG (TONS/DA	SOLAR INSOLATION (KWH/M^2DAY)
JAN.	1.231	0.573	0.439	2.243	6.15
FEB.	1.231	0.573	0.439	2.243	6.49
MAR.	1.113	0.519	0.397	2.029	6.57
APR.	1.113	0.519	0.397	2.029	6.48
MAY	1.055	0.491	0.376	1.923	6.35
JUN.	1.172	0.546	0.4183	2.136	5.8
JULY	1.172	0.546	0.418	2.136	5.24
AUG.	1.055	0.491	0.376	1.923	5.26
SEP.	1.289	0.601	0.460	2.350	5.87
OCT.	1.289	0.601	0.460	2.350	6.28
NOV.	1.231	0.573	0.439	2.243	6.11
DEC.	1.231	0.573	0.439	2.243	6.04

2.2 Electrical Load Estimation

The considered rural village (located at 10° 10′ 00″North and 38° 8′ 00″ East) consists of 420 households with an average of five persons per household, a church, a rural elementary school (1st to 4th grade) and a health post. The electrical energy demand was determined by observation of nearby electrified rural village. To bring a little more improvement to the village, the researchers add more electric loads like grain milling machine and a community water pump. The loads like lighting (CFL), TV, radio, mobile phones, refrigerator, microphone (for the church), office equipment (printer, copy machine, computer for the school) are taken to be primary loads, which should be supplied whenever required. Since most of the residents in the village are farmers and the primary loads are lighting loads, the peak load appears in the evening from 19:00-22:00. The sum total of the daily energy consumption of the community is approximately 234 kWh.

However, grain mill and water pump are categorized as deferrable loads, which can be supplied anytime the system is able to supply them. A total of 15m^3/day of water is suggested for households, health post, school and church. To accomplish this, a pump of 600 W (with a pumping efficiency of 22 liters/watt) operating for 5-8 hours/day, depending on the month of the year (operating for short periods of time from June to September and longer for other months of the year), is to be installed to supply water for the community. The village under consideration is located in East Gojam Zone, Ethiopia where the majority of the population uses injera (local food) as

regular food, which is made from teff (very tiny cereal) flour. Therefore, it is mandatory to have at least one grain milling machine of 2kW rating operating at least for 6 hrs/day to serve all the community without much queues.
In the rainy season rivers and rainwater ponds share up to 25% of water consumption and therefore, the deferrable load decreases proportionally. June to September is the rainy season for this area. The 24-hour primary and monthly deferrable load profiles are given in Fig. 1 and Fig. 2 respectively.

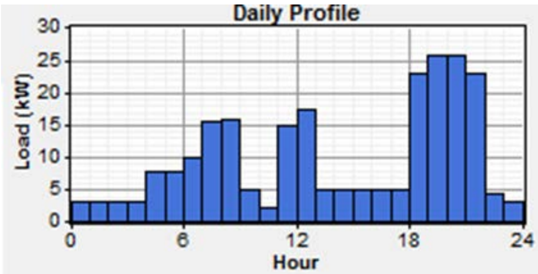

Fig. 1.Daily primary load profile

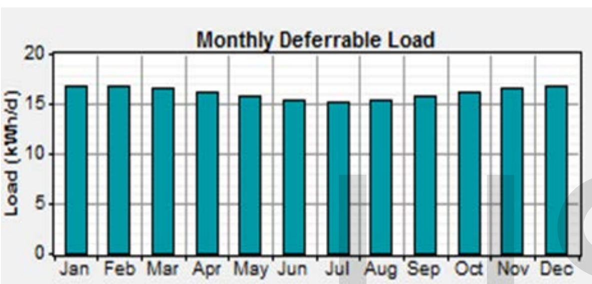

Fig. 2. Monthly average deferrable load profile of the village

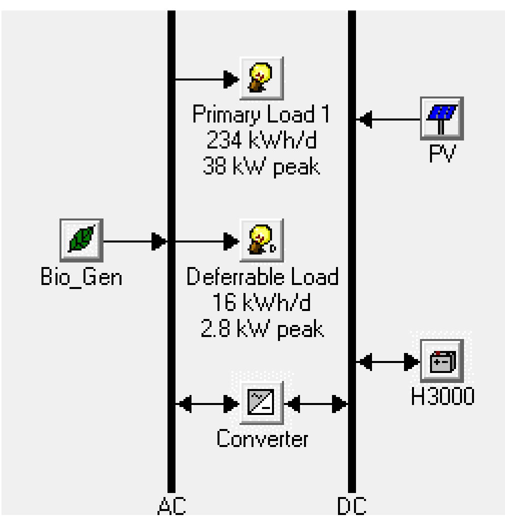

Fig. 3. Developed solar/biomass hybrid model using HOMER

3 Results and Discussion

After entering the necessary inputs, to find the optimum solutions, HOMER is run peatedly by varying parameters that have a controlling effect over the output.

The output of the simulation is a list of feasible combinations of solar PV, bio-generator (biomass as a heat source), converter, and battery. The optimization results are generated in either of two forms; an overall form in which the top-ranked system configurations are listed according to their net present cost (NPC) and in a categorized form where only the least-cost system configuration is considered for each system type. Table 2 shows top ten cost effective possible combinations of system components in an overall form.

TABLE 2
OVERALL OPTIMIZATION RESULT

PV (KW)	BIO_GEN (KW)	BATTERY (3000AH,2V)	CONVERTER (KW)	TOTAL NPC(10^3x$)	COE ($/KWH)	BIO.GEN (HRS)	BIOMASS (TONS)
50	5	48	20	258.4	0.215	2,729	14
46	6	48	20	258.6	0.215	3,102	18
47	6	48	20	260.0	0.216	2,976	18
52	3	48	25	261.1	0.217	2,570	9
49	4	48	25	261.2	0.217	2,852	13
52	3	48	25	261.3	0.217	2,553	14
48	6	48	22	261.4	0.216	2,866	17
53	5	48	20	262.7	0.217	2,474	13
49	6	48	20	262.9	0.217	2,763	17
50	4	48	25	263.0	0.218	3,378	12

The most cost effective system is the PV-generator-battery-converter set-up with the generator operating under a load following (LF) strategy (a dispatch strategy whereby the generator operates to produce just enough power to meet the primary load; lower-priority objectives, such as charging the battery bank or serving the deferrable load, is left to the solar PV source). For this set-up, the total net present cost (NPC) and the levelized cost of energy (COE) is $258,367, and 0.215 $/kWh respectively, the amount of biomass feed stock consumption is 14 tones/year and the generator operates for 2,729 hours per year. The monthly average electric energy production of the first rank system is shown on Fig.4 below.

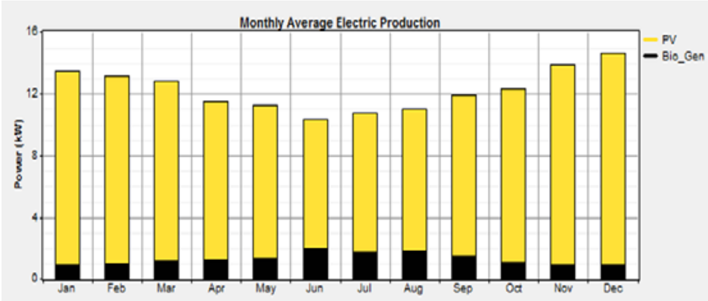

Fig. 4. Monthly average electric production of the system

As shown on Fig. 4, during the months of June to August, due to the reduction in solar insolation, the power generated from solar PV system decreases. On the other hand, the energy generated from the bio-generator increases for these three months to compensate the decrease in the generated solar power. Although the yearly energy production of the bio-generator is 11% of the total energy production, the presence of bio-generator brings an advantage to the system as it is dispatchable as compared to the non-dispatchable solar energy resource. Thereofre, inspite of being small in size, the generator operates during peak load times of the day (in the evening from 18:00-22:00) as shown on Fig.5 below.

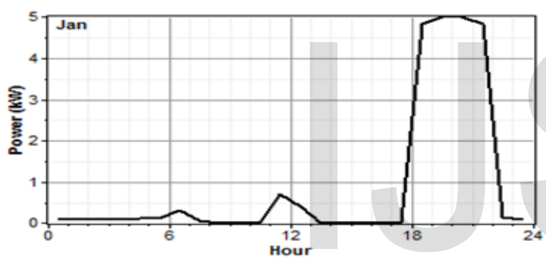

Fig. 5. Bio-generator operating times of the day

In all months of the year, much of the deferrable load is served from 8:00-15:00 when the primary load is relatively smaller and the solar radiation is high enough to supply both the primary and deferrable loads as shown on Fig. 6 below.

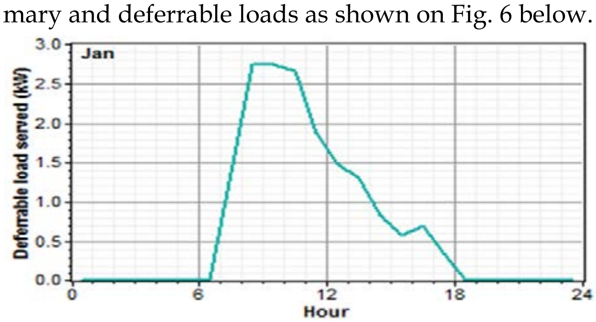

Fig. 7.Deferrable load Service times of the hybrid system

4 Conclusion

The design of hybrid power generation system, which comprises of PV arrays and bio-generator with battery banks and converter, has been discussed in this paperr. The design of standalone electric power supply system has been conducted based on the investigation of solar energy and biomass potentials of the village under consideration.

The study of the biomass potentials of the site is based on the data collected from the village animal clinic center. Whereas the solar energy potential of the site is obtained from the NASA surface metrology and solar energy website.

The analysis of the renewable energy resources data has been carried out by using HOMER software.

The results obtained from the software give numerous alternative hybrid systems with different levels of solar and bio-generator combinations, which their choice is restricted by changing the net present cost and the cost of energy of each set up. The minimum levelized COE of the feasible setups in this study, which is 21.5 cents per kWh, is high compared to the electricity energy tariff in Ethiopia (<2 cent/kWh for residential electricity customers). However, considering the shortage of electricity in the country (<20% coverage) and absence of electricity usage in rural areas (< 2% coverage), this cost should not be taken as a decisive factor.

Instead other issues such as the role of off-grid hybrid system in protecting the environment from degradation, the improvement of life standard of people living in rural areas, supply of relatively clean water, improved health services, development of clean energy, and the future situation regarding fossil fuel sources should be taken in to account. Taking these issues into account the solar and biomass energy of the country should be utilized to improve the quality of life of the communities living in rural areas.

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