GRID COMPARISON AND FEASIBILITY STUDY OF AN OFFGRID SOLAR PV/BIOGAS/BIODIESEL HYBRID ELECTRIC SUPPLY SYSTEM

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Abstract- This paper investigates renewable energy resource potential study, feasibility analysis and existing grid comparison of solar photo voltaic, biogas, and biodiesel hybrid electricity supply system for a rural community. HOMER is used as a modeling and analyzing tool. Electrical primary loads for the community were estimated and forecasted for the project lifetime. The resource potential of solar, biogas and biodiesel feedstock are studied and prepared for simulation. The common biogas feedstock considered were animal slurry, human feces and jatropha byproducts where as the biodiesel is considered from jatropha seed. In addition to the cost of equipments, the hybrid system power distribution cost was also considered. Grid comparison against the hybrid system was done to answer which alternative was economical. The optimization result of the simulation demonstrates that the best optimal hybrid system consists of solar photo voltaic, biogas generator, biodiesel generator, converter and battery under load following system control strategy. The best optimal hybrid system has initial capital cost $116,197, net present cost of $273,887, levelized cost of energy of 0.175$/kWh. Based on the data obtained from universal electricity access program of Ethiopia, the total capital cost of grid extension was estimated as $140,892 and its operation and maintenance cost is 235$/km/yr.

Keywords: Break even distance, Capital cost, COE, Deferrable load, Hybrid system, Load forecast, Net present cost, Optimization result, Photo voltaic, Primary load, Sensitivity analysis.

1. INTRODUCTION

A hybrid system contain more than one power generating unit would enhance the reliability, the renewable fraction and made the system more cost effective and attractive to electrify rural areas. The main goal of this work is potential study and feasibility analysis of biogas, solar PV, and biodiesel as a solution for rural electrification. This is achieved through the uses of HOMER, which simulates energy resources and electrical loads for a specific site, as well as various equipment configurations and financial data to create a cost-based ranking of different energy solutions based on net present cost of the system. Under this study, the site used in the model is a rural community in Jama Woreda at 10.522^o N, 39.30^o E. Various PV, biogas and biodiesel generator, converter, and battery sizes and costs are considered and sensitive values, constraints, and system control mechanisms are selected in order to perform hybrid system optimization and sensitivity analysis. In addition to the cost of equipments, the hybrid system power distribution cost is also considered. Based on the resource, load, hybrid system size and cost data considered and running the simulation in HOMER gives optimization and grid comparison result.

2. SYSTEM MODEL

The Biogas/PV/Biodiesel hybrid power supply system makes use of solar PV, biogas and biodiesel generator to produce electricity as the primary source to supply the load. The configuration of PV-Biogas-Biodiesel hybrid system is analyzed for various biogas generators, PV array, and biodiesel generator sizes with the battery system. The power conditioning units will determine the ac conversion of the dc power following the load profile. The charge controller will charge the batteries with energy from biogas generator, PV modules, and wind turbines as well as from the biodiesel generator. The main objective of Biogas, PV, wind and Biodiesel hybrid system is to reduce the cost of operation and maintenance and cost of logistic by canceling the runtime of each individual component alone. A schematic of a typical Biogas/PV/Wind and Biodiesel hybrid system is shown in **Figure 1**.

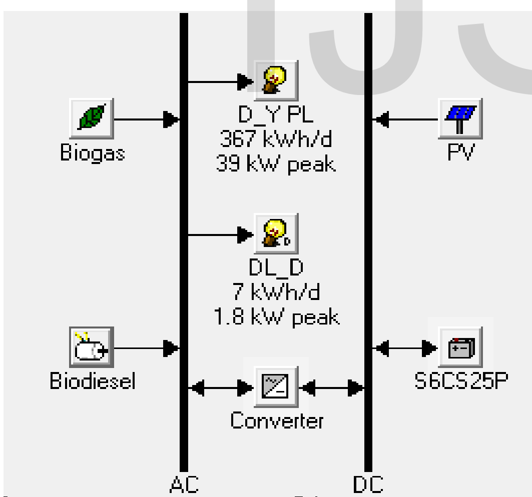


Figure 1: HOMER System Model

2.1. Community Load

About 500 people with 100 families are without electricity in the study area [1]. Daily electrical primary and deferrable load profile was determined based on basic demands of the community such as lighting, cooling, cooking, water pumping, communication, flour mill and other household appliances etc. The total electrical primary and deferrable load consumption is 367kWh/day and 7kWh/day respectively. The primary and deferrable load profile of the community is given in **Figure 2 and 3.**

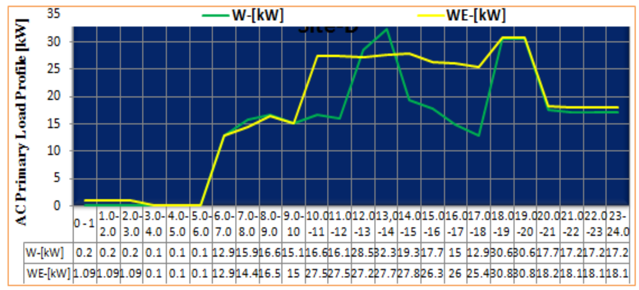


Figure-2: Daily AC primary load profile both in week and weekend days

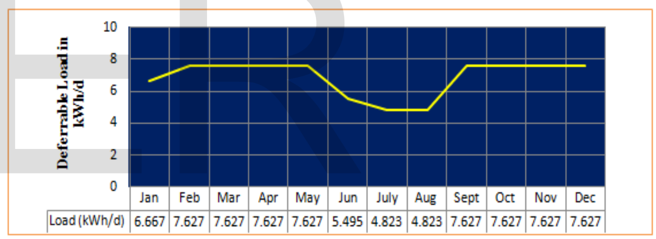


Figure-3: Deferrable load profile.

In this study an end use analysis approach is used to forecast a load growth of a remote area supplied by a hybrid renewable system. This methodology implies the current energy demand of the community was first determined based on customer's end device energy consumption and the demand was projected throughout the project life time based on the population growth rate and the penetration of them to the system. The following relation defines the end use methodology [2, 3]:

$$E_i = E_o + S*(H_i - H_o)*E \qquad (1)$$

Where,

E_i= the i[th] year annual average energy demand in kWh/day
E= annual average energy consumption in kWh/day/household
S= Customer penetration rate
E_o= the annual average estimated electricity demand, in kWh/day, in 2013.
H_o= the number of household on which E_o is estimated, 2013 base year.
Hi=the number of household in the i[th] year.

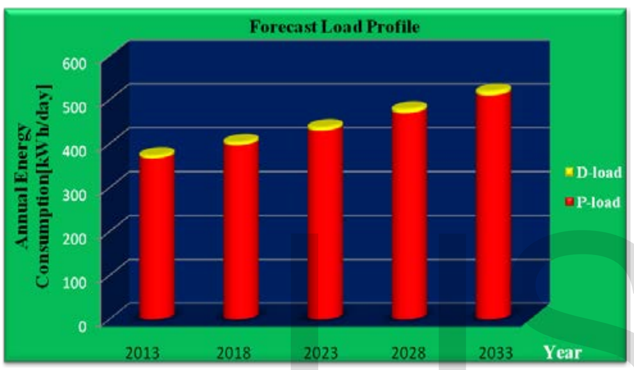
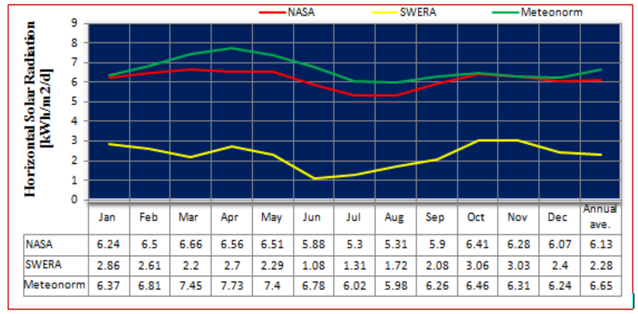


Figure-4: Primary and deferrable forecasted load profile

2.2. Solar PV System

The solar PV panels are connected in series or/and parallel to generate the required power output. When the sunlight is incident on a PV panel it produces electricity. The capital cost and replacement cost for a 1kW SPV is taken as \$2200. As there is very little maintenance required for PV, only \$10/year is taken for O&M costs [4]. Like for all other hybrid system components the per kW costs considered includes installation, logistics and some other costs. The derating factor considered is 95% for each panel to approximate the varying affects of temperature and dust on the panels with a life time of 20 years. The panels have no tracking system and are tilted at 10.55^o (latitude of the site) facing to south.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual ave.
NASA	6.24	6.5	6.66	6.56	6.51	5.88	5.3	5.31	5.9	6.41	6.28	6.07	6.13
SWERA	2.86	2.61	2.2	2.7	2.29	1.08	1.31	1.72	2.08	3.06	3.03	2.4	2.28
Meteonorm	6.37	6.81	7.45	7.73	7.4	6.78	6.02	5.98	6.26	6.46	6.31	6.24	6.65

Figure-5: Solar Radiation Profile

2.3. Biogas System

The capital cost of the biogas system includes the cost of biogas digester and biogas generator plus biogas land, administrative and transport costs and consultancy fees. The capital, replacement and O&M costs for 30kW biogas system were considered as \$26,919, \$26,919, and \$238.4/year (digester) and 0.05\$/hr (for the generator) respectively and also the lifetime of the system was considered 20 years [5-7].

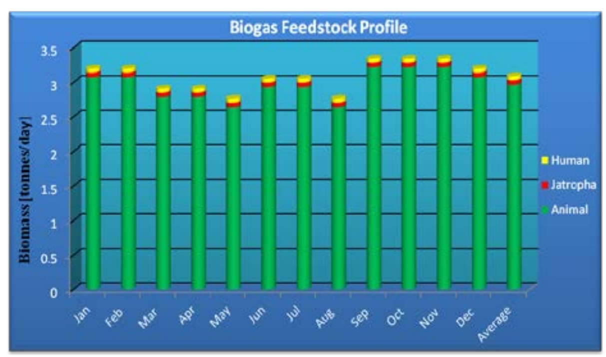


Figure-6: Biogas feedstock resource potential from various feedstock sources

2.4. Biodiesel System

The source of biodiesel is Jatropha. Its seed is pressed and processed to yield biodiesel and used as a fuel for a biodiesel generator. The biodiesel potential of the site from jatropha seed is estimated to be 18.5m3/year. The biodiesel system consists of jatropha oil expeller and biodiesel generator. The capital cost, replacement cost, O&M costs of a 25kW biodiesel generator are taken as $7875, $5875, and $0.1/hr respectively. The per kW costs of BDG include the costs of jatropha oil expeller, installation, logistics and other costs in addition to the generator [8, 9].

2.5. Battery

Batteries are used as a backup in the system and to maintain a constant voltage during peak loads or a shortfall in generation capacity. To model the hybrid system, Surrette 6CS25P rechargeable battery is chosen. It is a 6V battery with a nominal capacity of 1,156 Ah (6.94 kWh). Two batteries per string are chosen in order to get a nominal battery terminal voltage of 12V. It has a lifetime throughput of 9,645kWh. The capital cost, replacement cost and O&M costs for one unit of this battery were considered as $833, $555, and $15/year respectively. [10]

2.6. Converter

A converter is an electronic power device that is required in a hybrid system to maintain the energy flow between AC and DC electrical components. The AC output of the biogas and biodiesel generators are integrated and controlled in such a way that the output can be directly supplied to the connected AC load. When there is excess of energy (mainly from the PV, biodiesel and biogas), it is directed to the battery through the converter and DC center. Similarly, the DC output of the PV panel is connected to the system via the DC center. The DC center is integrated with the system through DC/AC and AC/DC converters, As well as, it is connected to PV and battery components [11]. The capital, replacement and O&M costs for 1kW converter were considered as $700, $550, and $100/year respectively and also a lifetime of 15years and converter efficiency of 95% was considered. [12]

2.7. Grid Comparison

Grid extension is another option to electrify remote loads. Grid comparison with off grid hybrid system was done to select the most economical system. For each stand-alone system configuration, HOMER calculates the breakeven grid extension distance. The study area which is full of mountain and valleys is 12km far from the grid. The total capital costs of grid extension is $ 140,892 and its unit O&M cost is $235/km/yr. The electricity price in Ethiopia is $0.04/kWh. [13, 14]

3. SIMULATION RESULT

3.1. Optimization Result

For the off-grid electrification of the study area various combinations of hybrid systems with solar PV, biogas and biodiesel generator, batteries and converters have been obtained from the HOMER Optimization simulation. Solar PV system, biodiesel generator and biogas plant with battery and converter have the lowest total net present cost of $273,887 and cost of electricity of $ 0.175/kWh under current load scenario which can be presented below in **Table-1** and **Figure 7**.

Table-1: Optimal Solution of the hybrid system under current load scenario

Sensitivity Results | Optimization Results

Sensitivity variables

D_Y PL (kWh/d) 367 PV Capital Multiplier 1

Double click on a system below for simulation results. Categorized Overall Export...

PV (kW)	BG (kW)	BD (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Biodiesel (m3)	Biomass (t)	BG (hrs)	BD (hrs)
20	30	10		20	LF	$ 116,197	13,748	$ 273,887	0.175	0.71	0.00	11	861	5,697	7,503
20	30	10	40	20	CC	$ 149,517	11,513	$ 281,570	0.180	0.55	0.00	17	513	2,126	6,608
	30	10	40	20	CC	$ 105,517	17,082	$ 301,444	0.193	0.53	0.00	17	1,037	4,981	6,882

For this combination if we goes towards the electricity produced by that system then it is observed that PV system produce 41,463kWh/yr about 29 %, biogas plant produces 61,404 kWh/yr about 42 % and biodiesel generator produces 41,923kWh/yr about 29% so only 4.36% excess electricity is remaining.

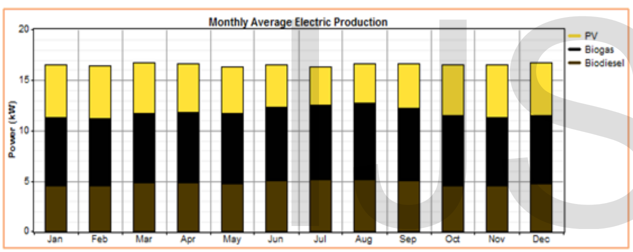


Figure-7: Monthly average electric production

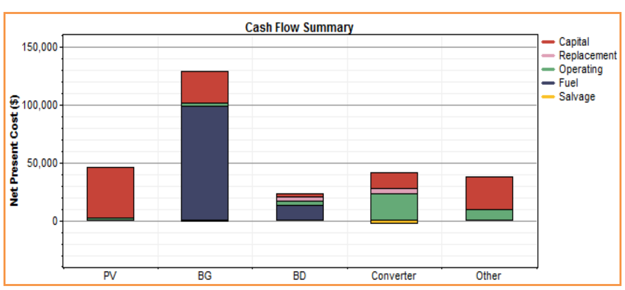


Figure-8: Cash flow summary of the above blue marked system

The optimization result in the case of forecasted load scenario of the community was presented below in **Table 2**. PV system, biodiesel and biogas generator with battery and converter have the lowest total NPC of $375,455 and COE of 0.174$/kWh.

Table-2: Optimal solution of the hybrid system under forecasted load scenario

Sensitivity Results | Optimization Results

Sensitivity variables

D_Y PL (kWh/d) 510 PV Capital Multiplier 1

Double click on a system below for simulation results. Categorized Overall Export...

PV (kW)	BG (kW)	BD (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Biodiesel (m3)	Biomass (t)	BG (hrs)	BD (hrs)
25	45	10	40	20	CC	$ 173,977	17,566	$ 375,455	0.174	0.66	0.01	17	1,088	3,574	6,326
60	45	10		80	LF	$ 259,657	22,308	$ 515,526	0.237	0.85	0.00	10	1,065	4,422	6,390

Average electricity production by each individual's hybrid system energy producing component; PV panel accounts 26%, biogas generator 40% and biodiesel generator 34% of the total 195,748kWh/yr electricity production.

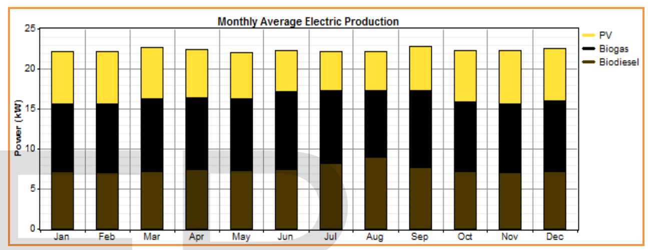


Figure-9: Monthly average electric production

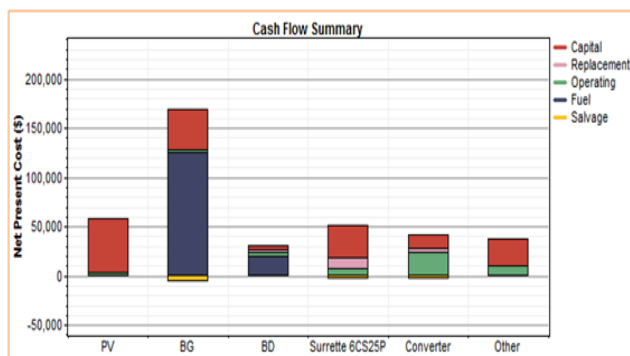


Figure-10: Cash flow summary of the above blue marked system

3.2. Grid Comparison Result

The point at which the total NPC curve of grid extension and optimal hybrid system intersect each other is called breakeven grid extension distance (BGD). At the BGD, the optimal hybrid system and the extended grid have equal total NPC [14]. The simulation result provides a BGD of 14.6km. At the BGD the total grid extension NPC is $273,887 while at the actual distance of the grid from the community load, total initial capital cost of grid extension is $140,892 and its O&M cost is $2,820/yr. The result of the simulation given in Figure-11 demonstrates the BGD is almost close to the actual grid distance of the site. Since the study area is full of mountain and valleys the hybrid system is equally feasible as grid extension.

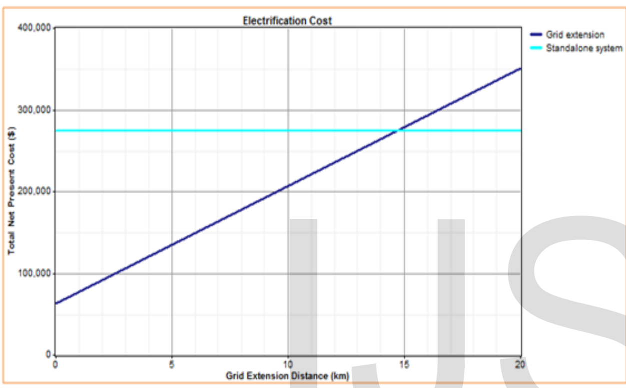


Figure-11: Comparison curve of grid extension with standalone hybrid system

4. CONCLUSION

The feasibility analysis of the renewable energy resources data has been carried out by HOMER software. The resource potential study results confirmed the availability of huge utilizable solar and biogas energy at the site. HOMER simulation result also demonstrates grid extension is optimal over standalone hybrid electric supply system and forecasted load would raise the NPC of the hybrid system by 37% to 88% from the current system. Also, the results obtained from the software give numerous alternatives of feasible hybrid systems with high levels of renewable resources penetration which their choice is restricted by changing the net present cost of each system set up. The COE of the feasible setups in this study, which is in the range of $0.174 to $0.683/kWh, are high compared to the tariff in the country (<$0.04/kWh).

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6. AUTHOR BIOGRAPHY

My name is Demsew Mitiku Teferra. I was born in Jama, Ethiopia, in 1987. I received the BSc. degree in electrical engineering from Hawassa University, Awasa, Ethiopia, in 2010, and the MSc degrees in electrical power engineering from Addis Ababa Institute of Technology (AAiT), Addis Ababa, Ethiopia, in 2014. In September 2010, I was joined the Department of Electrical Engineering, Debre Markos University, as an assistant Lecturer. Since September 2014, I have been with the Department of Electrical Engineering, Debre Markos University, where I was a Lecturer.

My current research interests includes Renewable energy, Distributed Generation, Smart Grid and Distribution System Automation, flexible ac transmission systems, high-voltage dc, and power quality. Currently, I am a member of the Ethiopia Teacher Association (ETA), Ethiopia Space Science Society (ESSS) and Ethiopia Electrical Engineers Associations (EEEA).