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Feasibility Study and Design of Solar PV-biomass Hybrid Power Generation Systems: A Case Study of Ilu Aba Bor Zone

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ABSTRACT - *A large proportion of Ethiopian population lives in remote rural areas that are geographically isolated and sparsely populated. This research described a photovoltaic-Biomass hybrid power generation system suitable for remote area application. The concept of hybridizing renewable energy sources is that the base load is to be covered by largest and firmly available renewable source(s) and other intermittent source(s) should augment the base load to cover the peak load of an isolated mini- electric grid system. The study is based on assessment, design, modeling, simulation and optimization of renewable energy system in rural area of Ilu Aba Bora zone about 600km far from Addis Ababa, Ethiopia. The model is designed to provide an optimal system configuration based on hour-by-hour data for energy availability and energy demands. Biomass and solar energy sources, energy storage and their applicability in terms of cost and performance is described. Finally, the findings and recommendation stated and presented for practical implementation*

Key Words: *Energy demand, Photovoltaic, biomass, hybridizing, optimization*

1. INTRODUCTION

Most of population of Ethiopia lives in rural areas far from the national electric grid. So, it is not possible to satisfy the energy need of the population taking the current situation in Ethiopia. So we have to go for alternative sources of energy. Renewable energy sources offer viable alternative to the provision of power in rural areas.

Most of rural areas of Ethiopia are not fully electrified yet. Of the widely available alternate energy sources, solar, wind and biomass energy are the best option in Ethiopia. There is no question that solar energy is available in Ethiopian since the country is found at equator and particularly in Ilu Aba Bora zone there are huge sources of biomass energy. Hybridization of solar and biomass energy for power generation has significant advantage that it reduces the size of the battery used for energy storage. Unavailability of solar energy at night time can be compensated by biomass energy which is available day and night.[1][2][6]

The abundant energy available in nature can be harnessed and converted to electricity in a sustainable and clean way to supply the necessary power to elevate the living standards of the people without access to national electric grid. If stability is concerned with available voltage and power variation, these problems can be solved by integrating possible alternative renewable energy sources.

1.1 Objectives of the Study

The primary objective of this proposal is to study the feasibility, design and model standalone solar photovoltaic – biomass hybrid power generation system for the community in the western part of Ethiopia specifically rural villages of Ilu Aba Bora zone.

The specific objectives of the research are:

- Assessing the solar and biomass energy potential for western part of Ethiopia
- Estimates loads of the rural villages of Ilu Aba Bora zone
- Design hybrid renewable energy system for the communities in the area
- Simulate and optimize the designed system
- Analyze cost of the designed system
- State the findings and give recommendation for practical implementation.

1.2 Scope of the work

The research starts from data collection (assessment of energy demand of the community of the specified area and necessary renewable energy resources) to the design and optimization of the stand-alone solar photovoltaic-biomass hybrid power generation system.

2. ENERGY DEMAND ASSESSMENT AND SYSTEM DESIGN

After feasibility and impacts of the renewable energy resources studied, the system is designed by considering energy demand of the community.

The methodologies used for the design processes are estimation of local energy demands for villages and estimation of available resources.

The solar energy resource of the area and availability of biomass resource studied before the design process starts. This requires biomass resources and solar energy assessments of the specified areas.

- Solar energy resource data can be found from NASA (National Aeronautics and Space Administration)
- Biomass resources are assessed and studied by surveying the areas to gather the sample data for estimation of the followings.
- Estimation of woody biomass
  - ✓ Estimation of non-woody biomass; like agricultural residues
  - ✓ Estimation of animal dung

2.1 Study location

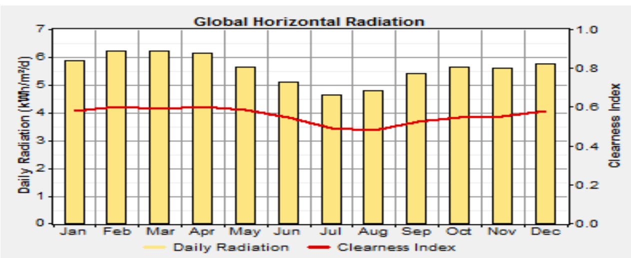
Beddele is located in western part of Ethiopia at longitude 36.35 east and latitude 8.43 north as shown in fig2.1 below.

Fg2.1 Location 0f the Study Area

2.2 Study *area* resources

2.1.1 Solar energy resources in *beadle*

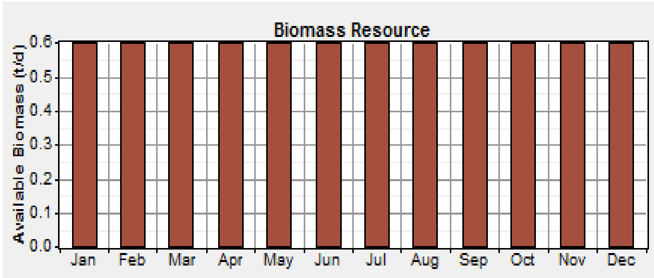
The average daily radiation of the study area throughout the year is as shown in figure 4.2 below. The average daily radiation in kwh/m^2/d is around 6.5 which is potentially feasible for electric power generation using photovoltaic panel [1][5][8].



Fg2.2 Average daily radiation of study area throughout a year by bar graph

2.1.2 Biomass resources

The main sources of biomass energy are wastes (agricultural wastes) and animal dung. By considering the number of animals and estimating agricultural residues the total biomass resources shown on fig2.2 below. As it can be seen from the graph about 0.6 ton per day can be found according the estimation done.



Fg2. 3 average daily biomass resource of the year

Population Profile of the Specified Village

The survey is done in three villages to understand information in energy consumption. Resource data and load data is collected in three of the villages.

Table2. 1 population profile of the study area

Information	Villages		
	Chefa Jelela	Guba Kaba	Abo Kombelcha
Population	>1140	>1500	2400
Number of house holds	190	250	400
Average Number of family per house hold	6	6	6
Average Number of livestock per house hold	5	5	5
Distance from grid in kilo meter(km)	35	21	25

2.2 Energy Demand assessments and scheduling

As one of the data input to the software, the load demand of each corresponding village is very essential. With data of the total number of households in each village and using typical household appliances that these people may use, this section discusses how the load profile of each area is obtained. For all the three sites, the types of loads used are similar, except for some of them which may vary with the number of households in each village and hence while giving input to the software; this is taken into consideration. Table 2.2 and table 2.3 below shows the type of loads used and their power consumption

Number of the families living in the specified area should be assessed through survey and total energy required is calculated and specified for design purpose.

The system contains power generation system which contains biomass energy and solar energy. The storage system stores energy for the case of emergency. The loads type will be identified from the survey. Dc- loads are to be supplied after ac- dc converter and the AC loads are supplied directly from the bus. Each of the components needs to be designed by considering the energy requirement and available resources.

The term load refers to a demand for electric or thermal energy. Serving loads is the reason for the existence of power generation system (solar PV and biomass), so the modeling of power generation system begins with the modeling of the load or loads that the system must serve. HOMER models two types of loads. These are primary and deferrable load.

Primary Load

Primary load is electrical demand that the power system must meet at a specific time. Electrical demand associated with lights, radio, TV, house-hold appliances, computers, and industrial processes is typically modeled as primary load. [14][15]

Deferrable Load

Deferrable load is electrical demand that can be met anytime with in a defined time interval. Water pumps, ice makers, and battery-charging stations are examples of deferrable loads because the storage inherent to each of those loads allows some flexibility as to when the system can serve them. The ability to defer serving a load is often advantageous for systems comprising intermittent renewable power sources, because it reduces the need for precise control of the timing of power production. If the renewable power supply ever exceeds the primary load, the surplus can serve the deferrable load rather than going to waste. [15]

I. Domestic load

Taking Café Jalela village as a model village the domestic load is estimated per one family. The total load can be estimated by considering the number of hose holds in a village.

Table2. 2 Domestic load of the village

materials	Number	Power Rating(w)	Total power rating (w)	Time Schedule		Energy (kwh)
				Am	Pm	
Lighting	4	10	40	5:00-6:00	18:00:23:00	0.24
TV receiver	1	70	70	6:00-10:00	18:00:22:00	0.56
Refrigerator	1	400	400	Deferrable(6 hours)per day		2.4
Cooking	1	3000	3000	5:00-7:00	19:00-22:00	15
Radio	1	15	15	6:00-10:00	18:00:22:00	0.12
Cd player /g pass	1	85	85		18:00:22:00	0.34
The total daily energy consumption in kwh per one house hold is=15.46 kwh/d						
The total daily energy consumption of load in the village is= 4.1MWh/d						

Community load of the village

Table2.3 Community load of the village

Gadget		Number	Power rating (w)	Total power rating(w)	Time Schedule		Energy (kwh)
					Am	Pm	
Wood work		3	180	540	Deferrable (8hrs per day)		4.32
Grinding machine		1	6000	6000	6:00-12:00	13:00-24:00	102
Irrigation pumps		5	300	1500	Deferrable (8hrsper day)		12
One primary School	Florescent lamps	20	60	1200	8:00-12:00	18:00-20:00	2.4
	TV receiver	1	270	270	8:00-12:00	13:00-17:00	2.16
	Computers	3	240	1200	8:00-12:00	14:00-17:00	8.4
	Cd player	1	85	85	8:00-12:00	13:00-17:00	0.68
	Printer	1	30	30	deferrable (2hrsper day)		0.06
	Copy machine	1	30	30	Deferrable(2hrsper day)		0.06
Church	Florescent lamp	6	60	360	4:00-8:00	18:00-20:00	2.16
	Mega phone	1	15	15	6:00-8:00	17:00-19:00	0.06
One Clinic	Florescent lamps	20	60	1200	0:00-8:00	17:00-23:00	16.8
	Computers	3	240	720	8:00-12:00	13:00-17:00	5.76
	Laboratory material	1	600	600	Deferrable(6hrs per day)		3.6
	TV receiver	1	280	280	6:00-12:00	13:00-22:00	3.08
The total average daily community deferrable load of village in kwh =18KWh/d							

Domestic and deferrable load profile of the village

By considering daily energy consumption of households, the daily load profile of the village is as shown on fig2.4 below. The deferrable load profile is also shown on fig2.5 below.

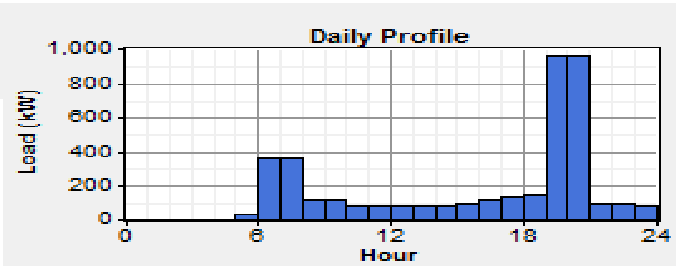


Fig2.4 daily load profile of the village

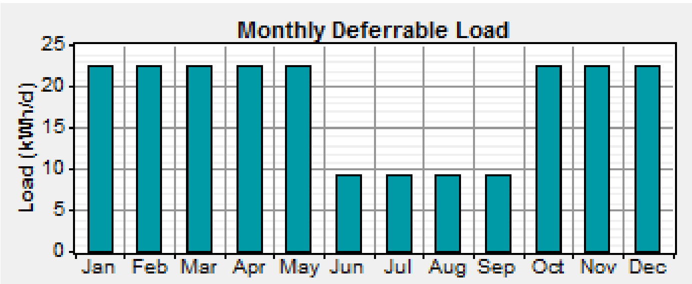


Fig2.5 Monthly Deferrable load profile

3. SYSTEM DESIGN AND OPTIMIZATION

The major components of PV- solar designs are PV modules, dc to dc converter, battery and inverter. The capacity of these components can be determined by estimating the load to be supplied. The size of the battery bank required will depend on the storage required, the maximum discharge rate, and the minimum temperature at which the batteries will be used. [4][7] For choosing a battery size, all these factors should be considered. Lead-acid batteries are the most common in P.V systems.

3.1 Photovoltaic system components

Sizing of solar array

Before sizing the array, the total daily energy in Watt-hours (E) is calculated, the average sun hour per day T_{min}, and the DC-voltage of the system (VDC) must be determined by considering losses and efficiency of each components.

To avoid under sizing we begin by dividing the total average energy demand per day by the efficiencies of the system components to obtain the daily energy requirement from the solar array.

$$\text{(required energy)}E_r = \frac{\text{daily average energy consumption}}{\text{product of components efficiency}} = \frac{E}{eff_{overall}} \quad 5.1$$

The total current (I_{DC}) needed can be calculated by dividing the peak power by the DC- voltage of the system.

$$I_{DC} = \frac{\text{peak power}}{V_{DC}} = \frac{P_p}{V_{DC}} \quad 5.2$$

Modules must be connected in series and parallel according to the need to meet the desired voltage and current.

First, the number of parallel (N_P) modules which equals the whole modules current divided by the rated current of one module.

Second, the number of series modules which equals the DC voltage of the system divided by the rated voltage of each module Vr.

$$N_s = \frac{\text{System DC voltage}}{\text{module rated voltage}} = \frac{V_{DC}}{V_r} \quad 5.4$$

Finally, the total number of modules Nm equals the series modules multiplied by the parallel ones.

$$N_m = N_s * N_p \quad 5.5$$

Sizing of the Battery Bank

The amount of rough energy storage required is equal to the multiplication of the total power demand and the number of autonomy days (no- sun day). [2][10]

$$E_{rough} = E \times D \quad 5.6$$

For safety, the result obtained is divided by the maximum allowable level of discharge (MDOD).

$$E_{safe} = \frac{\text{energy storage required}}{\text{maximum depth of discharge}} = \frac{E_{rough}}{MDOD} \quad 5.7$$

The capacity of the battery bank needed in ampere-hours can be evaluated by dividing the safe energy storage required by the DC voltage of one of the batteries selected. [9][12]

$$C = \frac{E_{safe}}{V_b} \quad 5.8$$

According to the number obtained for the capacity of the battery bank, another decision has to be made regarding the capacity Cb of each of the batteries of that bank. The battery bank is composed of batteries

The total number of batteries is obtained by dividing the capacity C of the battery bank in ampere-hours by the capacity of one of the battery C_b selected in ampere-hours.

$$N_{batteries} = \frac{C}{C_b} \quad 5.9$$

The connection of the battery bank can be then easily figured out. The number of batteries in series equals the DC voltage of the system divided by the voltage rating of one of the batteries selected:

$$N_s = \frac{V_{DC}}{V_b} \quad 5.10$$

Then number of parallel paths p is obtained by dividing the total number of batteries by the number of batteries connected in series.

$$N_p = \frac{N_{batteries}}{N_s} \quad 5.11$$

Sizing of the Voltage Controller

According to its function it controls the flow of current. A good voltage regulator must be able to withstand the maximum current produced by the array as well as the maximum load current.

Sizing of the voltage regulator can be obtained by multiplying the short circuit current of the modules connected in parallel by a safety factor.

The result gives the rated current of the voltage regulator I.

$$I = I_{sc} * N_p * F_{safe} \quad 5.12$$

The factor of safety is employed to make sure that the regulator handles maximum current produced by the array that could exceed the tabulated value. And to handle a load current more than that planned due to addition of equipment, for instance. In other words, this safety factor allows the system to expand slightly. The number of controller equals the Array short current Amps divided by the Amps for each controller:

$$N_{controller} = \frac{I}{\text{amps of each controller}} \quad 5.13$$

Inverter sizing

Inverter is used in the system where AC power output is needed. The inverter size should be25-30% bigger than total watts of appliances. In case of appliances type is motor or compressor then inverter size should be minimum 3 times the capacity of those appliances to handle surge currents during starting.

3.2 Model of the System

The architecture of the model of the system is shown in fig4.1 below. As it can be seen from the figure the system contains AC bus and DC bus for supplying loads. The power generated from PV is DC so it is connected to DC bus. On the other hand the power generated from biomass is AC so it is connected to AC bus. In between the two buses we have converter which can convert AC to DC and vice versa. There battery storage which charge and discharge depending up on the requirement for optimization.

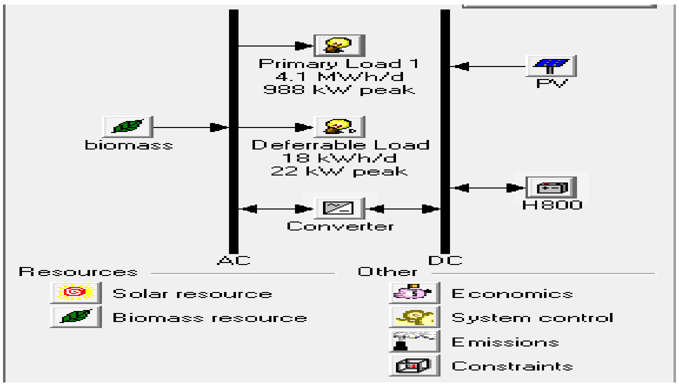


Fig3. 1 Model of the System

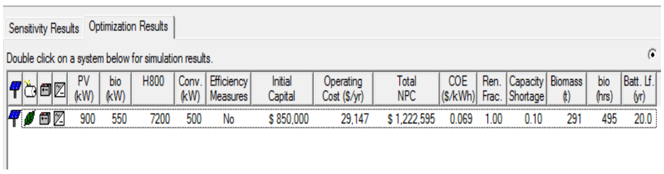


Fig3. 2 System Optimization Output

4. RESULT ANALYSIS

The architecture of the model consists of photovoltaic system, biomass energy, battery storage, and converter and loads (primary and deferrable). The total primary load and deferrable load of the village is 4.1MWh/day and 18KWH/d. after the system is optimized using homer software the size each of each component is specified. Accordingly PV 900kw, battery 7200 strings of capacity 800 Ah biomass generators 550kw and converter 500kw are selected using optimization software. The electrical power generated using the two systems are shown on fig 4.1.

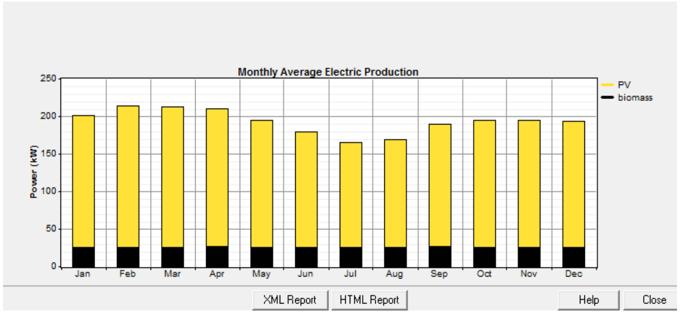


Fig4. 1 Monthly Average Electric Power Production

4.1 Cost analysis

It is pertinent that economic analysis should be made while attempting to optimize the size of integrated hybrid PV-Wind generation systems favoring an affordable unit price of power produced. In the United States, direct combustion is the most common method of producing heat from biomass. Small-scale biomass electric plants have installed costs of $3,000 to $4,000 per kW, and a levelized cost of energy of $0.8 to $0.15 per kilowatt hour. [5] [7] [9] [11].The unit price of each component is shown in table 6.1

Table4. 1 Per-unit Costs of the System Components

Item	PV	Battery	Inverter	Biomass
Costs	$5/W	$1.705/Ah	$0.831/W	$3000/kw

Source: international journal of engineering and technology vol.2(10),2010, 5231-5237

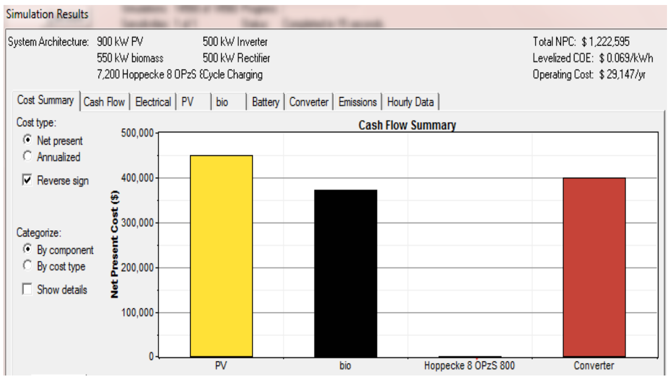


Fig4. 2 overall cost of the system

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusions

A hybrid power generation system which comprises of PV arrays and wind biomass with battery banks has been discussed in this paper to achieve a cost effective system configuration which is supposed to supply electricity to model community of 190 households to improve the life of people in the rural area of Café Jalela where electricity from the main grid has not reached yet.

The results obtained from the software give numerous alternatives of feasible hybrid systems with different levels of renewable resources penetration which their choice is restricted by changing the net present cost of each set up. The COE of the feasible setups in this study, which is around $ 0.069$/KWh, are high compared to the current global electricity tariff and the tariff in the country (<5 cents/kWh). However, considering the shortage of electricity in the country (<30% 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 a standalone hybrid system in protecting the environment from degradation, the improvement of life of people living in rural area, development of clean energy, the future situation regarding fossil fuel sources, and its contribution to the reduction of pollutant emissions into the environment should be taken in to account.

Taking these issues into account the free solar and wind energy of the country should be utilized to improve the quality of life of the communities living in rural areas

5.2 Recommendation

As far as environmental issue is concerned using renewable energy resources is the best alternative. Ethiopia has a huge potential of renewable energy resources which can be used for rural electrification through the off-grid system. There are, however, many challenges like low purchasing power of the rural community, unfavorable conditions towards the utilization of renewable energies, absence of awareness how to use these resources, etc. Thus, the researcher of this work recommends that the government, non-governmental organizations and the private sectors should make combined efforts to overcome these challenges by using more flexible approaches to improve the current poor status of rural electrification in Ethiopia.

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