International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869 (O) 2454-4698 (P), Volume-3, Issue-7, July 2015

Design and Optimization of Solar PV and Wind energy Hybrid System for off-grid application in remote Tigray Region, Ethiopia

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***Abstract*— One of the major worldwide concerns of the utilities is to reduce the emissions from traditional power plants by using renewable energy and high cost of supplying electricity to remote areas. Hybrid power systems can provide a good solution for such problems because it can integrate renewable energy along with the traditional power plants. In Tigray region, Ethiopia a remote village called Sassu which is about 7 km south of Adigrat town was selected as a case study in order to investigate the ability to use a hybrid power system to provide the village with its needs of electricity. The simulation of this hybrid power system was done using HOMER software. Based on the available energy resource around the site Wind/PV/DSl/Battery configuration have net present cost value of $88,498.00 and cost of electricity (COE) about 0.65 ($/kWh) for oil price of $ 0.4/L.**

***Index Terms*— Hybrid System, HOMER software, off-grid.**

I. INTRODUCTION

In 21st century renewable energy becomes the focus area for sustainable energy supply and climate resilience economic development. Providing reliable energy for rural community is the main challenge of many developing countries. Ethiopia is of the country endowed with renewable energy sources such as solar, wind, hydro geothermal and others. The annual average global radiation of the country is 5.2 kWh/m^2/day and minimum is 4.5kWh/m^2/day in July and maximum of 5.55kWh/m^2/day in February a March [1]. There is also huge potential of wind resources in north east and central and eastern port of Ethiopia. But 69 % [2] of Ethiopia population does not have accesses to electricity. The difficult is mainly because of lack of finance, the people are scarcely populated, away from grid, poor policy or not choosing appropriate technology. Renewable energies such as wind and solar are highly variable, weather condition dependent. Integrating two or more renewable energy sources with each other of with fossil fuel will offer better performance, flexibility of planning and environmental benefits. Hybrid systems also give the opportunity for expanding the generating capacity in order to cope with the increasing demand in the future Remote areas provide a big challenge to electric power utilities[5]. Hybrid power systems provide an excellent solution to this problem as one can use the natural sources available in the area. Figure 1 shows the typical configuration of wind-PV hybrid system, which includes wind and solar conversion system, storage and emergency generator [3].

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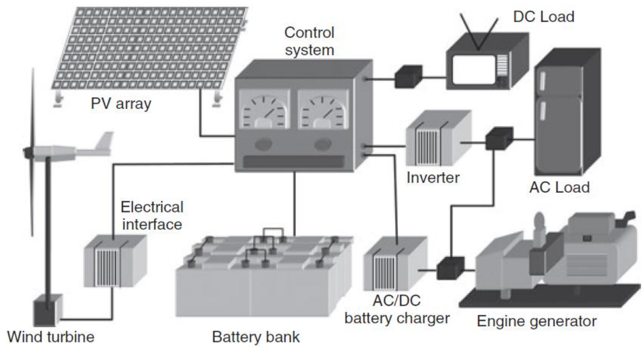

Figure 1 Diagram of PV–wind–engine generator hybrid system

II. SIMULATION OF HYBRID POWER SYSTEM

In order to design a mini-grid hybrid power system, one has to be provided with information for the selected location. Typical information’s required are; the load profile that should be met by the system, solar radiation for PV generation, wind speed for the wind power generation, initial cost for each component (diesel, renewable energy generators, battery, converter), cost of diesel fuel, annual interest rate, project lifetime, etc. Then using these data one can perform the simulation to obtain the best hybrid power system configuration.

HOMER is a computer software used to model, analyze and visualize off-grid and grid-connected power systems [7]. It simulates the operation of a system by making energy balance calculations every hour for each of the 8,760 hours in a year. It finds the least cost combination of components that meet the specified electrical and thermal loads. HOMER simulates thousands of system configurations, optimizes for life cycle cost, and generates results of sensitivity analyses for most situations [6].

III. SITE DESCRIPTION

The site under investigation is located at 14°16’ N 39°27’ E with an elevation of 2457 meters above sea level and with a time Zone of Africa/Addis-Ababa UTC/ GMT+03. The village was selected as a case study in order to investigate the ability to use a hybrid power system to provide the village with its needs of electricity. The main activities of people in the village are agriculture &and animal husbandry.

IV. WORK METHODOLOGY

HOMER software is used to model and optimize the village energy demand with their locally available resources and select the most appropriate technology option with a minimal NPC as a bench mark for preference. The block diagram shown in Fig 2 below is the overall procedures employed for micro-power system analysis at any particular site of interest.

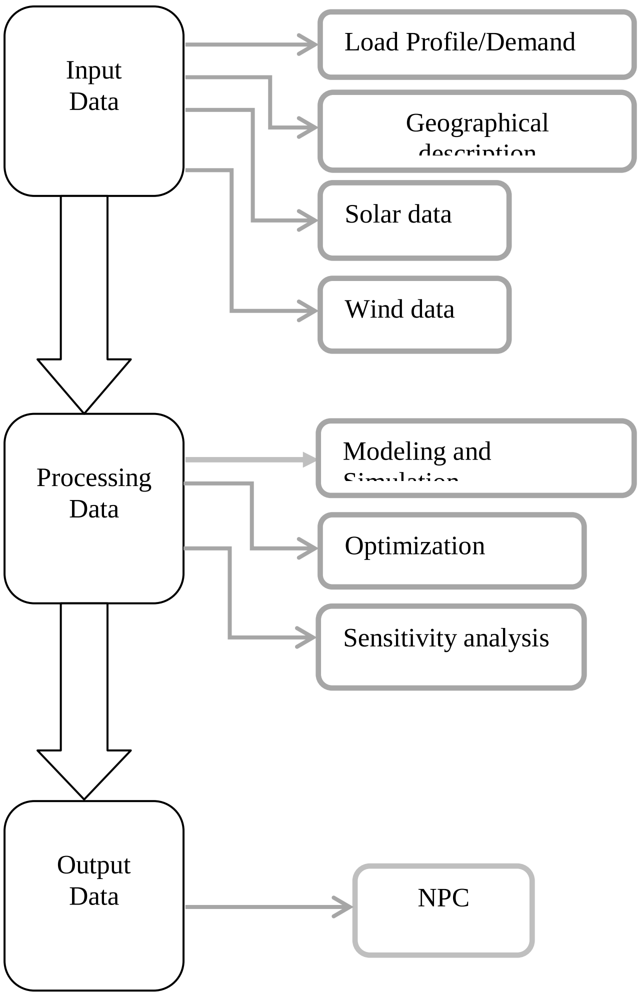

Figure 2: Summarized flow chart of modeling and simulation of hybrid power system using HOMER

The design process starts with the estimation load requirement and available energy resource estimation, and then followed by modeling and analyzing and finally presentation of the output.

V. LOAD PROFILE

The shown in Fig 3 below the load requirement varies throughout the day. The maximum demand occurs during day time because and the minimum load occurs at 3 PM night onward to 7 AM morning. The reason behind high demand in day time is energy intensive activity such as tea machine, electric milling machine and other activities. The load requirement throughout the year assumed to be similar. The random variability factors; day-to-day variability and time-step-to-time-step variability, which are used to account the deviation load from average daily and hourly value respectively were introduce in homer. These values are assumed as 8% and 10% respectively. The homer simulation result shows the daily average, peak and scaled energy demand are 12.8kWh/day, 25.6 kWh / day and 35kWh/day respectively.

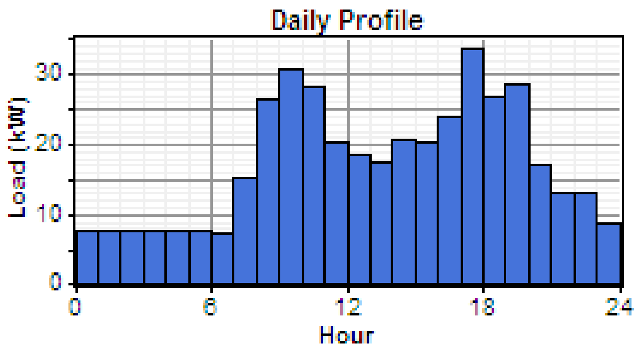

Figure 3 Hourly load profile

VI. SOLAR DATA

The solar radiation and wind speed data for the site were obtained from the National Aeronautics and Space Administrative (NASA) surface meteorology website. The selected site has a higher and lower daily solar radiation on with a value of 6.8 3 kWh/m^2/day and 5.3 kWh/m^2/day in April and august respectively. The scaled annual solar radiation of the site was estimate by HOMER was 5.94 kWh/m^2/day.

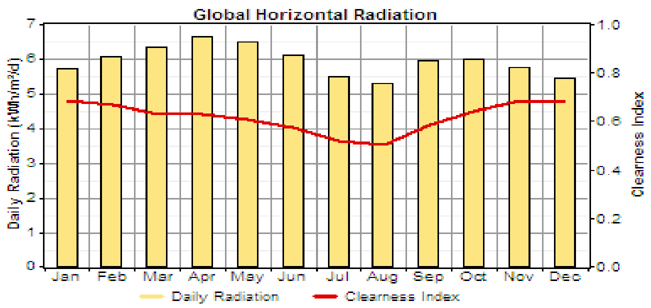

Figure 4: Global Horizontal Radiation

VII. WIND DATA

Since the energy for solar is stochastic and not sufficient enough to provide the demand, wind turbine is used as supplementary. The selected site has a higher and lower monthly wind speed with a value of 5.7 m/s and 5.3 m/s in July and October respectively a.g.l.

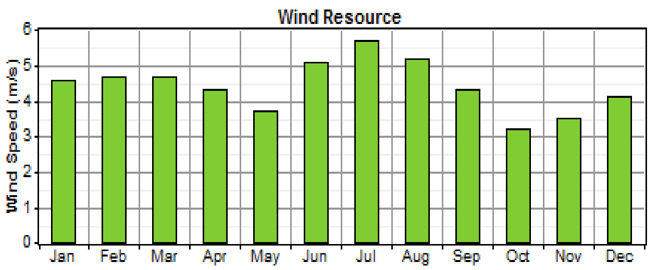

Figure 5 Wind resource

There are important parameters such as Weibull *k* which is a measure of long term distribution of wind speed over the year, auto correlation factor which is measure of the hour-to-hour randomness of the wind and diurnal pattern strength speed, which indicates how strong the wind in hours of the day[4]. The values of parameter used in this work are 2, 0.85 and 0.2 for Weibull parameter (k), the auto correlation factor, and the diurnal pattern strength respectively.

VIII. HYBRID ENERGY SYSTEM COMPONENTS

Figure 6 and table 1 shows the proposed comments of the hybrid system, which consists, diesel generator, PV, wind turbine, battery bank and converter.

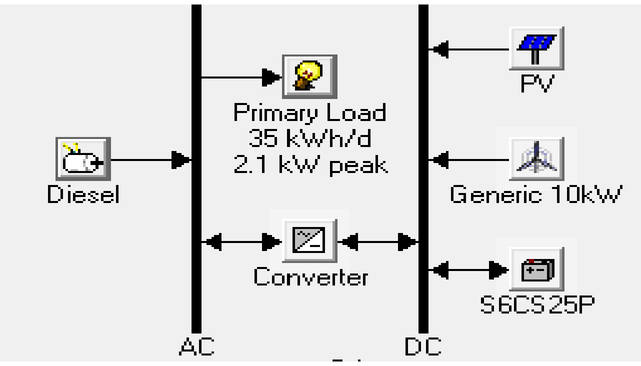

Figure 6 Schematic of the hybrid PV-wind energy system

Table 1The specification of each system components

Component and its description	Specification data
Diesel generators	
Size	12kW
Capital cost	$9500.00
Replacement cost	$ 8250.00
Operating and maintenance cost	$ 0.300/h
PV	
Capital cost/replacement cost	$5500.00/kW
Life time	25years
Operating and maintenance cost	$50.00
Wind Turbine	
Size	10 kW
Capital cost/replacement cost	$15000.00
Operating and maintenance cost	$100
Life time	15 years
Battery	
Nominal voltage	6V
Nominal capacity	1156Ah
Capital cost/replacement cost	$1200.00
Operating and maintenance cost	$100.00
Inverter	
Size	10kW
Capital cost\ Replacement cost	$12500.00
Operating and maintenance cost	$100.00
Efficiency	95%

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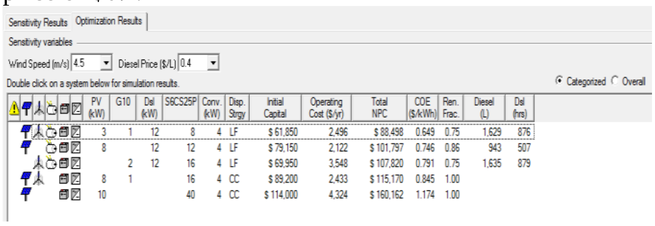
IX. RESULTS AND DISCUSSION

The simulation was done on the assumption that the projection period of 25 years with 8% annual real interest rate. The search spaces are 0 kW to 10kW for PV, 0 to 6kW for wind turbine, 0kw to 80 kW for inverter and 0kW to 40 kW for battery storage. HOMER simulation result is categorized into sensitivity results and optimization results. The sensitivity helps us to explore the impact of change in factors such as resource, fuel price and different system configuration. For this hybrid system two variables (Wind speed and fuel price) are considered. The optimization results can be displayed as either categorized or total to show different system configuration based on their economic and technical merit.

X. OPTIMIZATION RESULTS

The optimized result for the selected village around Adigrat with three power resources (Solar, wind and diesel) is presented in the Table 2 below. The first best combination (case 1) is 12 kW diesel generators, 3kW solar PV, 8 battery and 4kW inverter and which have net present cost value and cost of electricity (COE) of $88,498.00 and 0.65 ($/kWh) respectively for one year for fuel price of $0.4/L.

Table 2 Categorized different hybrid configuration for a fuel price of $0.4/L



Sensitivity Results | Optimization Results

Sensitivity variables

Wind Speed (m/s) 4.5 Diesel Price ($/L) 0.4

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

PV (kW)	G10	Dsl (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Dsl (hrs)
3	1	12	8	4	LF	$ 61,850	2,496	$ 88,498	0.649	0.75	1,629	876
8		12	12	4	LF	$ 79,150	2,122	$ 101,797	0.746	0.86	943	507
	2	12	16	4	LF	$ 69,950	3,548	$ 107,820	0.791	0.75	1,635	879
8	1		16	4	CC	$ 89,200	2,433	$ 115,170	0.845	1.00		
10			40	4	CC	$ 114,000	4,324	$ 160,162	1.174	1.00		

The simulation was done by assuming 75% minimum renewable energy fraction share. The total electricity production per year for two best scenarios is shown in Fig. 7a and Fig. Wind takes the largest share which accounts 55 % of total electricity production, while 33% from PV and the remaining from diesel and excess electricity is 4,913kWh (24%) per year. The second option (Case 2) is the combination of solar and diesel which uses 8kW PV and 12kW diesel, 12 batteries, and 4 inverters and has NPV of $101,797.00 and 0.75$/kWh COE for one year for fuel price of $0.4/L. This combination produces about 17,973 kWh per year; 16,148 kWh per year from PV, 1,825 kWh per year from diesel and the excess electricity is about 2,105kWh per year (11.7 %). The share of renewable energy in case 1 is about 75% and in second option about 86%.

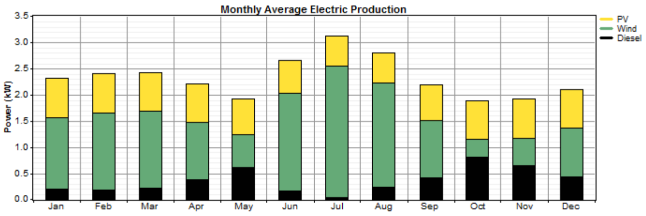


Figure 7a Monthly average Electric productions for case 1

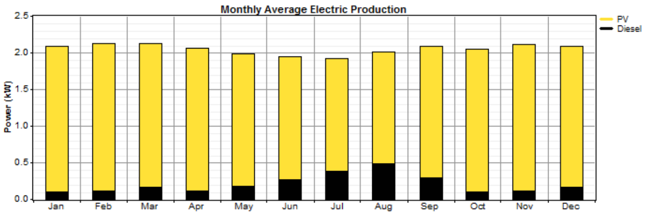


Figure 7b Monthly average Electric productions for case 2

Fig 8a and 8b are used to show the net present cost of case 1 and case 2 respectively. From Fig 8a it was observed that PV contributes $18,101.00, battery $17,574.00, inverter $5,952.00, Diesel Generator $ 21,071.00 and the remaining $6,000.00 others of the total annual cost.

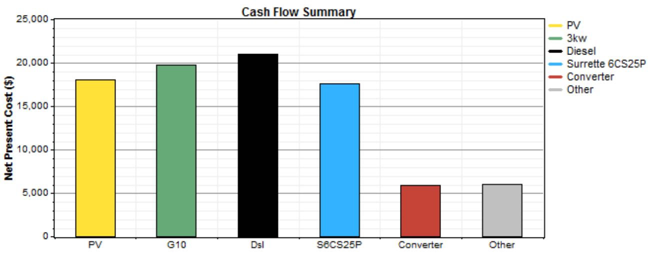


Figure 8a Cash flow for case 1

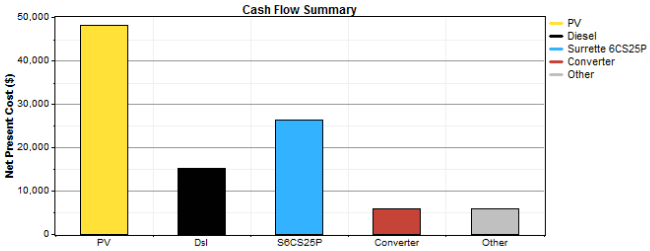


Figure 8a Cash flow for case 2

For case 2 as shown in Fig 2 PV takes the largest proportion of the cost about $48, 270.00, battery about $26,362.00, Diesel generator about $15,213.00 and the remaining by other components.

XI. Sensitivity Results

Fig 9 below is sensitivity analysis result for Wind/Dsl/Battery and Wind/PV/DSl/Battery configuration on which PV production is superimposed. For wind speed greater than 5.71 m/s the NPV Wind/Dsl/Battery system has smallest NPV regardless of the fuel price. In the cause of Wind/PV/DSl/Battery configuration NPV is much higher Wind/Dsl/Battery system even at lower fuel price. At fuel price around 0.45/L and wind speed around 5.8 m/s, the two systems have nearly similar NPV.

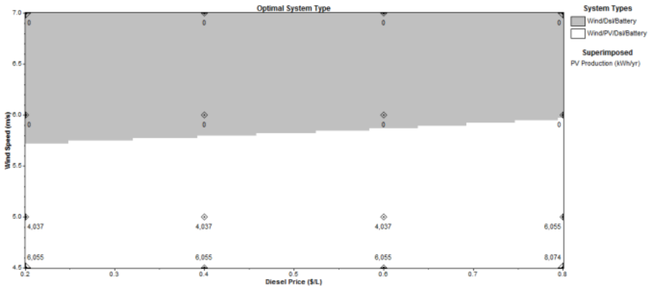


Figure 9 Optimum system types with different oil priceand wind speed

XII. Conciluslion

To reduce the emissions from traditional power plants, by using renewable energy, and to decrease the high cost of supplying electricity to remote areas from grid, hybrid systems are of considerable importance. Hybrid systems are one of the most promising applications of renewable energy technologies in remote areas, where the cost of grid extension is high. Applications of hybrid systems range from small power supplies for remote households providing electricity for lighting or water pumping and water supply to village electrification for remote communities.

HOMER Software used to analyze and simulate the possible alternatives to decide for the best choice for selected site. A village in Sassu (near to Adigrat, Ethiopia) was selected for the study described in this paper. The load profile of the village as well as the solar and wind speed data were used as the inputs to the software. Different scenarios and conditions were considered to cover possible states of the system in the village. Three possible resources (diesel, wind and solar) were considered for design and simulation. The best three categorized optimal cases are the PV/wind /diesel/battery, pv/diesel /battery and diesel /wind/battery with NPV $101,797.00, $88,498.00, and $107,820.00 respectively. Therefore, PV/wind /diesel hybrid system is one best alternative energy supply system for remote Tigray Region, Ethiopia

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