ASSESSMENT OF RESOURCE POTENTIAL AND MODELING OF STAND-ALONE PV/WIND HYBRID SYSTEM FOR RURAL ELECTRIFICATION-A CASE STUDY IN AXUM DISTRICT

[1]Sisay Fitwi Abadi,
[1]Lecturer, Head of Electrical and Computer Engineering,
[1]Electrical and Computer Engineering,
[1]Adigrat University, Adigrat, Ethiopia

ABSTRACT: Ethiopia is one of the largest populated countries of the world, where more than 80% of the population is living without electricity. Being a developing country, the demand of electricity is increasing tremendously. Meanwhile, fossil fuel based electricity generation plants are lagging behind to supply the rising demand and the fossil fuel sources are very limited. Consequently, rural areas are dependent on local solutions for electricity supply. As an alternative, renewable energy based systems are becoming popular in Ethiopia, particularly solar, wind and hydro based systems, which are being set up in different sizes and configurations. This paper presents assessment of resource potential and modeling of renewable energy based hybrid system for the village of Kutur village, in the western area of Axum. It also compares the cost of the hybrid system against the cost required to electrify the village by extending the grid. The system is designed based on the resources available at the location. The sources considered in the analysis are solar PV, wind, diesel generator and battery backup system. HOMER simulation model has been developed for simulating the system with real weather data and nominal load profile. The cost of the system is determined based on the real market price of the components. Sensitivity analysis has also been carried out on the best suitable system to prove the system sustainability in the future. For sensitivity analysis, the change in load and change in rate of interest has been considered. Based on the factors such as initial cost, replacement cost, operating cost, total net present cost (TNPC), cost of energy (COE) and exhaust gas emission, the results show that PV-Wind-Battery based system is a feasible solution for the situation. The optimum system has the initial cost of 95,640 $, and operating cost of 2026 $/year, TNPC of 115,541 $ and COE of 0.125 $/kWh with no exhaust gas emission. Foremost, the emission is zero, which means it is green energy system. The hybrid energy system optimized by HOMER for this village is cost effective as compared to the cost required to electrifying the village. The breakeven grid extension distance is found to be 12.2kms, which implies that this hybrid energy system is cost-effective for areas greater than the breakeven distance.

Keywords - Hybrid power system, renewable energy, photovoltaic, wind, HOMER, Optimization, sensitivity analysis.

1. *INTRODUCTION*

The current potential capacity production of Ethiopia is more than 45000MW from hydro and more than 5000MW from geothermal. Additionally, the country has a potential to produce more than 10000MW of power from wind [1]. Despite the abundance of potential resources suitable for the energy sector development, the level of electricity production is improved to the current capacity of 2000MW after the completion of Tekeze, Gilgel Gibe II and Tana-Beles with a capacity of 300MW, 420MW and 460MW respectively. As a result, the overall access to electricity is increased to 35% from 13% which was some about 20 years ago [1].

The government has a plan to exploit energy from wind and geothermal to improve the access to electricity in to 50% in the coming five years. The Ethiopian Electric Power Corporation (EEPCo), a sole electric power producer and supplier in the country has a plan to increase the production in to 10,000MW in the near future including the other renewable energy resources especially wind [2]. Moreover, there is also a program to give electric access from solar to more than 150,000 households of remote rural areas of the country with sufficient solar radiation resource in the coming five years [2].
The electric supply system throughout the country is interconnected system (ICS). Hence, most of the remote rural areas which are located far off from the grid did not get electric access since the power to the grid is insufficient and is not cost effective to extend MV distribution line. Consequently, rural areas are dependent on local solutions for electricity supply. These areas have been using traditional biomass as source of energy for baking as well as cooking and oil for lighting purpose. However, the current price increase in imported oil and the negative effects of fossil fuels on the local and global environment motivates the search for other alternatives.
The rural areas of Axum are among the villages of Ethiopia which are facing similar problems due to the difficulty of giving electric access by extending the grid. But this can be minimized by looking for alternative resources which can be used as a stand-alone to give electric access to the community. Hence, solar and wind can be the first option since these resources are available for free.

Figure 1: living style of rural area communities

2. *RESOURCE ASSESSMENT AND LOAD ESTIMATION*

The solar data available in most towns of Ethiopia is sunshine duration, and the data for wind speed is measured at a height of 2m which is not recommended to use for assessing wind potential. To assess the availability of solar radiation as well as wind speed resource in Axum, data’s are taken from different sources including the National Metreological Service Agency of Ethiopia (NMSA). The data obtained from NMSA is then compared against the data from NASA and SWERA.

2.1 Assessment of solar radiation

The assessment of the potential for solar radiation of the selected area is done by taking data from different sources. These are NASA, SWERA and the National metrological service agency of Ethiopia as well as data assessed by Mulugeta and Drake for the regions of the country. At the first approach, the data taken from the national metrological service agency is analyzed using mathematical approach based on the sunshine duration collected on the past six consecutive years. The sunshine duration data taken from the National Metrological agency of Ethiopia, Mekele branch is converted in to solar radiation using Angstrom radiation-sunshine relation [3]. The measurements are taken for six consecutive years starting from 2006. As it can be seen on the table, the data's for years 2007, 2009 and 2010 are full, but for 2006, 2008 and 2011 measurements are taken partially; hence, the three years data are taken to convert in to solar radiation. Therefore, for calculating the radiation in KWh/m^2 from the sunshine duration using the Angstrom radiation-sunshine relation [4], the values for the regression coefficients ɑ and b are taken to be 0.30 and 0.50 respectively [3]. Finally, this result is compared with the data's taken from NASA and SWERA, and it is found that the annual average solar radiation obtained from NMSA (which is 6.21KWh/m^2) is nearly equal to the value taken from NASA (which is 6.15KWh/m^2). Consequently, 6.21KWh/m^2 is then taken as an input to the solar resource in modeling the hybrid system. The monthly average solar radiation of Axum for the data taken from NMSA and NASA is shown on Table 1 and Table 2 respectively.

Table 1: Solar radiation of Axum in KWh/m^2/day data from NMSA

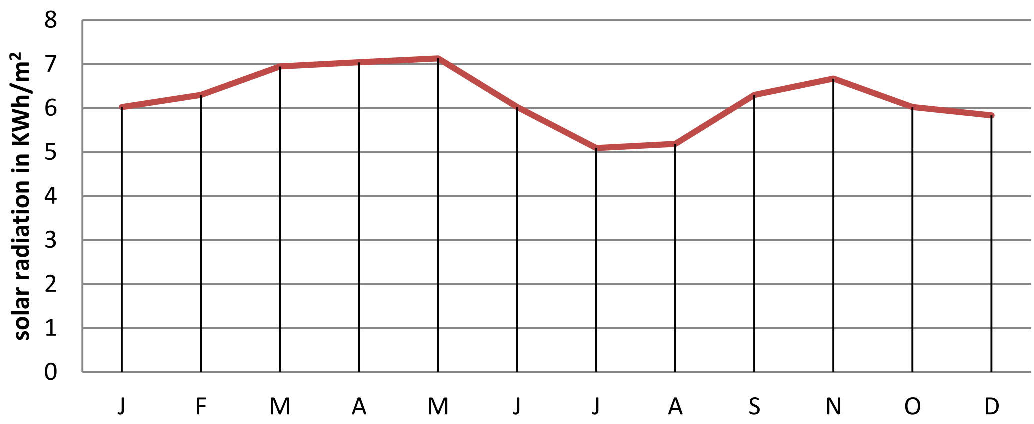
Year	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**N**	**O**	**D**
2007	6.11	6.39	7.22	6.94	7.22	6.11	5.28	5.56	6.39	6.67	6.11	5.83
2009	6.11	6.11	6.94	7.5	7.5	6.11	4.72	5.56	6.67	6.67	5.83	5.83
2010	5.83	6.39	6.67	6.67	6.67	5.83	5.28	4.44	5.83	6.67	6.11	5.83
Monthly average	**6.02**	**6.3**	**6.94**	**7.04**	**7.13**	**6.02**	**5.09**	**5.19**	**6.3**	**6.67**	**6.02**	**5.83**
Annual Average in KWh/m^2/day												6.21

From the results shown on Table 1 it can be seen that the solar radiation of the area is maximum in May which reaches a value of 7.13KWh/m^2/day, and is minimum in July (which has a value of 5.09KWh/m^2/day). Hence, it can be concluded that the area has good potential for using photovoltaic system for rural electrification.

Table.2: Solar radiation of Axum in KWh/m^2/day data from NASA

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22 year Average	5.76	6.2	6.59	6.92	6.74	6.49	5.8	5.58	6.25	6.23	5.88	5.51	6.15

Figure.2. monthly average solar radiation of Axum data from NMSA



2.2 Assessment of wind potential

To maintain the current economic growth of Ethiopia, it needs 38-fold increase in its electric supply by 2030; hence, new sources of energy are urgently needed [5]. Subsequently, the answer to this may lie in wind energy since strong and reliable winds of the country can generate a substantial amount of electricity at a reasonable cost - which can even be exported to neighboring countries. The areas which can provide the greatest potential for wind energy are the northern, central, eastern and southwestern part of the country [5]. Axum is also one of the districts found in the northern part of Ethiopia. Unlike to the solar radiation, the resource assessment for the wind potential is simply done by taking the data's from NASA. This is done because of the absence of full data for the wind speed in the national Metreological service agency of Ethiopia as well as in SWERA. Moreover, the annual average solar radiation obtained from NMSA is nearly equal to the data taken from NASA as it is shown on the solar radiation assessment. Therefore, the annual average wind speed for Axum which is located at latitude of 14° 07' N and longitude of 38° 43' E is found to be 4.28 m/s at a height of 10m. This value is used as input to the wind resource in modeling the hybrid system.

Table.3.The monthly average wind speed of Axum at 10m

Lat 14 Long 38.7	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual average
10 year average	4.45	4.48	4.46	4.26	3.64	4.92	5.42	5.00	4.08	3.13	3.56	4.01	4.28

2.3 Load Estimation

The load estimation which is the most important step in modeling the hybrid system is done for a single village found in Axum district. The name of the area is Awlio, and it is around 30kms away from the existing grid found nearby and 55kms from Adwa substation. Awlio kebele has 942 household families with a total population of 4274. One of the villages of this kebele (Kutur) has one primary school, kebele administration office, Tele, farmers training center (FTC) and one health center. The health center (HC) has midwives to help the mothers deliver babies. Moreover, they will offer support and advice to pregnant women. The load estimation for HC, FTC and kebele administration is done based on the Universal Electric

Access Program (UEAP) standard [6]. The population of this village accounts to around 13% of the total population of the kebele with about 120 households.

The deferrable load contains one water pump for all households as well as the service centers which deliver public service to the community. The type of water pump is HR-14 taken from the Lorenz PS600 series with 300W power rating and pumping capacity of 40 l/m (i.e.2400 l/h) [7]. The average daily water consumption of the community per household is 140 l including the water used for their cattle's. The total water consumption of the community is then 16800 l/day. Additionally, all the service centers are assumed to use a summed average of 4000 l/day. This indicates that the overall water needed by the village is 20800 l/day, and four water pumps of the over mentioned types are used to supply the water demand of the community. The water storage tank is assumed to have a capacity of storing water for four days (i.e.83200 l of water). The number of hours needed to supply the daily water consumption of the community is then obtained to be approximately 2.5hrs (which is $= \frac{20800}{(2400\times 4)}$). Hence, the daily deferrable load will be 3KWh/day and the corresponding electricity storage capacity is 10.8KWh which is 0.3x4x9 hour.

The primary load of Kutur village is calculated by considering lamps of 60W for lighting system with three lamps for each household, radio receiver of 20W, flour mill with rating of 15KW, TV and DVD with rating of 65 W and 20 W respectively, but the TV and DVD are assumed to be used by the model farmers of the community; and their number is assumed to be 10% of the total households of the village. The detailed primary load estimation is as shown on table 2.4. On the other hand, the load estimation for HC, FTC and Kebele administration as stated earlier is taken from UEAP (which is 3KW each) [6], because it is difficult to estimate their load based on the present status. The total power demand of the three service centers is therefore 9KW.

Table.4. Primary load estimation of Kutur village

Primary load	**Single household**	**No. of households**	**Total no. of equipment's**	**Size in W for one equipment**	**Total power in KW**	**Operating hrs per day**	**Energy in KWh**	**remark**
lighting lamps	3	120	360	60	21.6	6	129.6	
radio (tape recorder)	1	120	120	20	2.4	8	19.2	
TV	1	12	12	65	0.78	6	4.68	
DVD	1	12	12	20	0.24	4	0.96	
mill	1		1	15000	15	5	75	
health center					3	8	24	
FTC					3	8	24	
Kebele Adm.					3	8	24	
primary school	4	13	52	40	2.08	3	6.24	FL
Total					51.1		307.68	

3. *MODELING OF THE HYBRID SYSTEM AND COST ANALYSIS OF GRID EXTENSION*

3.1 Modeling of the hybrid system

As it is shown in the assessment of solar radiation, Axum has a monthly average solar radiation varying between a minimum value of 5.09KWh/m^2 and a maximum value of 7.13KWh/m^2 with annual average of 6.21KWh/m^2. Similarly, the monthly average wind speed of Axum varies between 3.13m/s and 5.42m/s at a height of 10m with annual average of 4.28m/s. These numbers indicate that the area has a potential for implementing PV-wind hybrid system to give electric access to the community of Kutur village of Awlio kebele found in Axum district. However, the investment cost of PV and wind turbine have always been the main barrier to the use of the hybrid system for small scale as well as large scale applications. But this time the cost of PV system as well as wind turbine is decreasing, while the price of oil is increasing in addition to the depletion of oil resource. This can encourage developing countries like Ethiopia which have good resources in both systems to use stand-alone hybrid system for supplying electric access to the remote rural areas. The current total investment cost of PV has reached 1100 $/kW, and for that of wind it has reduced to 880$/kW [9]. The current electricity grid coverage of Ethiopia is around 35%. Hence, the hybrid system can be competitive irrespective of its initial capital cost when considering the rapid increase in oil price. Moreover, it has negligible impact on global and local environment.

On the other hand, solar as well as wind power are becoming a serious candidate in electricity market due to increasing oil prices and substantial increase in manufacturing capacity of wind turbine and solar modules [10]. According to the green energy report conducted on Denmark, an estimated 23.9 GW of cells and 20 GW of modules were produced in 2010 by the solar PV industry [10]. Moreover, the total global capacity of wind power and solar photovoltaic power has reached 198 GW and 40 GW respectively [10]. But the PV-wind hybrid system may not be sufficient to supply energy on 24 hours for the whole years and therefore has to be supported by generator and batteries which can be used as a backup for supplying sustainable electricity using PV-wind hybrid system. The cost of generators varies between 200 $/kW and 228 $/kW [11].The main objective of this work is to assess resource potential of Axum and to model PV-Wind hybrid system with diesel and battery as a back up to electrify 120 households of Kutur village of Awlio kebele found in Axum district. Additionally, it will compare the initial capital cost of the hybrid system against the cost required for extending a grid.

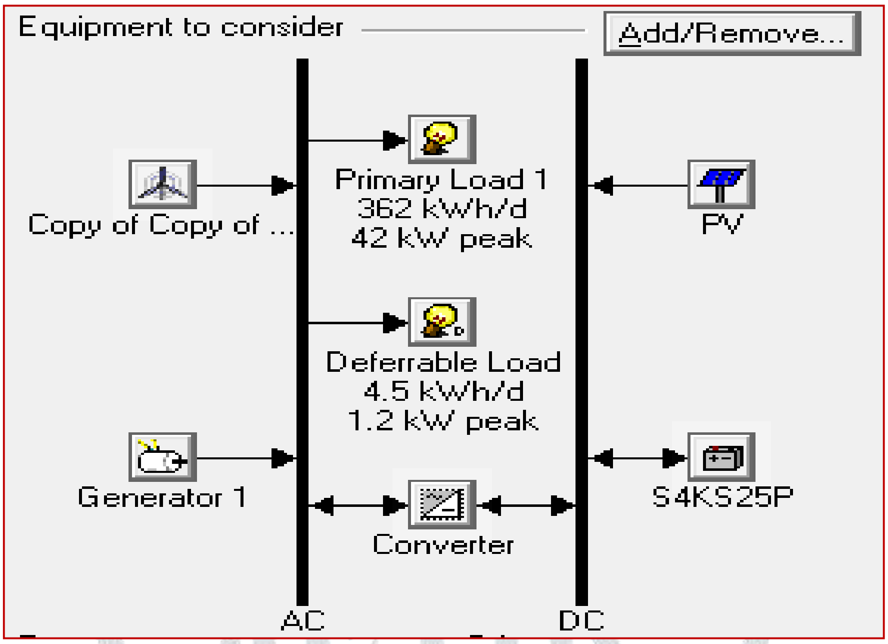


Figure.3. Model of the hybrid system (HOMER)

3.2 Cost analysis of grid extension

Power is transmitted to the end users through distribution lines. The mission of Universal Electric Access Program (UEAP) is delivering power to the consumers found in the remote rural areas of the country. This is mainly done by extending the national grid from a near-by substation or from an overhead medium voltage (MV) distribution line. The medium voltage levels that are most commonly used in MV line construction by the UEAP are 33KV, 19KV and 15KV. This time the UEAP is using the 33KV voltage level for electrifying the remote rural areas due to its advantage over the other options.

The main components of an overhead distribution line that can affect the cost of grid extension are:

- The line supports and their foundation
- Insulators
- Line accessories
- Conductors and overhead earth wires

The line supports can be made from wood (like local wood pole and South Africa pole), reinforced concrete pole and steel, but do u to its strength and availability UEAP is using concrete poles for MV distribution line to give electric access for selected rural areas.
This time the Universal Electric Access program is electrifying the rural areas by extending the grid found nearby them. The main tasks done during extension are surveying, excavation, pole erection, pole top configuration and stringing of conductors. For the MV distribution line construction All Aluminum Alloy Conductor with a size of $95mm^2$ is used for the 33 KV line. However, the number of the poles to be erected and the requirement of guy wire depends on the distance of the site from a nearby substation or MV distribution line, and geographical location of the selected sites. Moreover, different accessories are used depending on type of assemblies; and these can be classified as suspension, light angle 1, light angle 2, heavy angle, T-off, tension tower, and dead-end assemblies based on the angle deviation from a straight line.
Based on the theory mentioned earlier, the cost estimation for delivering electric access to Kutur village which is found in Axum is done. The distance of Kutur from an existing grid (i.e. Axum) is 26.5 km, and a

rough survey is conducted to select the type of assemblies to be used for MV distribution line construction. This village needs 1x200KVA rating transformers for supplying power to the people.

To give electric access to the 190 households, HC, FTC, flour mill, kebele administration and primary school of Kutur from the national grid found nearby, it needs extension of 30 km MV, 5.35 km LV distribution line and erection of one transformer with a rating of 200KVA. Hence, the cost is analyzed using an interlinked spread Microsoft excel sheet used by the UEAP; and the result obtained is as indicated on Table 5 The total cost as indicated on the table includes material, transportation and labor cost, and the investment cost is therefore 5,801,286.51 Ethiopian birr which is equivalent with 337,284.099 US dollar.

Tabe.5: Total cost needed for extending a grid to Kutur village of Awlio kebele found in Axum district

DESCRIPTION		**SALARY AND WAGE**	**ALLOWANCE**	**TRANSPORT**	**MATERIAL**	**TOTAL**
33KV LINE EXTENSION		555,518.52	678,967.08	339,100.20	2,773,182.82	4,346,768.62
0	X50KVA ERECTION	0.00	0.00	0.00	0.00	0.00
1	X200KVA ERECTION	2,589.10	3,164.46	3,371.28	88,721.63	97,846.47
0	X100KVA ERECTION	0.00	0.00	0.00	0.00	0.00
0	X25KVA ERECTION	0.00	0.00	0.00	0.00	0.00
1	X LOAD BREAK SWITCH	1,516.70	1,853.74	919.14	17,295.56	21,585.14
LV LINE EXTENSION		84,309.18	103,044.56	95,114.55	525,228.32	807,696.60
TOTAL		**643,933.50**	**787,029.84**	**438,505.17**	**3,404,428.32**	**5,273,896.83**
		INTEREST TO BE CAPITALIZED				
		OVER HEAD COST (10%)				527,389.68
		TOTAL COST				5,801,286.51
		RECHARGABLE/RECOVERABLE (*Contributions*)			AMOUNT	
		NET TOTAL				5,801,286.51

4. RESULTS AND DISCUSSION

HOMER is used for simulating the hybrid system containing PV-Wind, and diesel and storage battery as a backup. To get optimal combination of the hybrid components which could be implemented as a hybrid system model to give electric access to the community of Kutur village, the model was run repeatedly using different values for the most important variables. The software displays the result for the inputs either in overall form in which the top ranked system configurations are listed according to their net present cost or categorized form in which only the least cost system configuration is considered for each possible combinations. The variables listed on Table 6 are used as an input for simulating the hybrid set up using HOMER.

Table.6. Inputs to the software

Item	Size	Capital	Replacement	O & M cost	Sizes(KW) considered	quantities considered	lifetime
AC wind turbine (Fuhrlander 30)	30	26400	19800	528		0-3	25
AC Generator	33	6600	4200	0.24	0,33,66,99		30000h
PV	1	1100	1100	0	0-70		25
Battery(S4KS25P)	1900Ah	608	608	12.16		0-70	
Converter	1	600	600	0		0-70	15

Table.7. result in overall form

PV (kW)	FL30	GEN (kW)	S4KS25P	Converter (kW)	Dispatch strategy	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Ren Frac.	Capacity shortage	Diesel (L)	GEN (hrs)
50	1		30	30	CC	$95,640	2,026	$115,541	0.125	1	0.16		
50	1		30	30	LF	$95,640	2,026	$115,541	0.125	1	0.16		
50	1		40	20	CC	$95,720	2,233	$117,650	0.124	1	0.18		
50	1		40	20	LF	$95,720	2,233	$117,650	0.124	1	0.18		
40	1		40	30	CC	$95,120	2,377	$118,465	0.129	1	0.18		
40	1		40	30	LF	$95,120	2,377	$118,465	0.129	1	0.18		
40	1		50	20	CC	$95,200	2,587	$120,608	0.129	1	0.19		
40	1		50	20	LF	$95,200	2,587	$120,608	0.129	1	0.19		
70	1		20	30	CC	$102,760	1,872	$121,150	0.135	1	0.2		
70	1		20	30	LF	$102,760	1,872	$121,150	0.135	1	0.2		
80			50	30	CC	$101,200	2,203	$122,837	0.139	1	0.19		

Table 7 above shows a list of the possible combinations of system components in the overall form. The table has been generated based on inputs selected from the input summary table (Table 6): 0.5 $/l for diesel price, 0.6 for PV capital multiplier (3600 $/kW). The diesel price is the current price for diesel oil in the country. Interest rates are assumed to be 6.67% and project lifetime is 25 years. Looking at a few of the system setups listed the following interesting results are found. The most cost effective system, i.e., that with the lowest net present cost, is the PV/wind–battery–converter setup, where the generator operates using a cycle charging (CC) strategy (a dispatch strategy whereby the generator operates at full output power to serve the primary load and any surplus electrical production goes toward the lower-priority objectives). For this setup, the total net present cost (NPC) is $118,541, the cost of energy (COE) is 0.125 $/kWh, where the part of the non-renewable resources contribution is zero or 100% renewable. Of those compared, the second most cost effective system is the PV–wind–battery–converter setup, with the generator operating using a cycle charging (CC) strategy (a dispatch strategy whereby the generator operates at full output power to serve the primary load and any surplus electrical production goes toward the lower-priority objectives). For this setup the total net present cost (NPC) is $117,650, the cost of energy (COE) is 0.124 $/kWh. Again with this scenario, the part contribution of the non-renewable resources is zero, being 100% renewable. The average monthly electric production of this setup is given in Fig. 4.

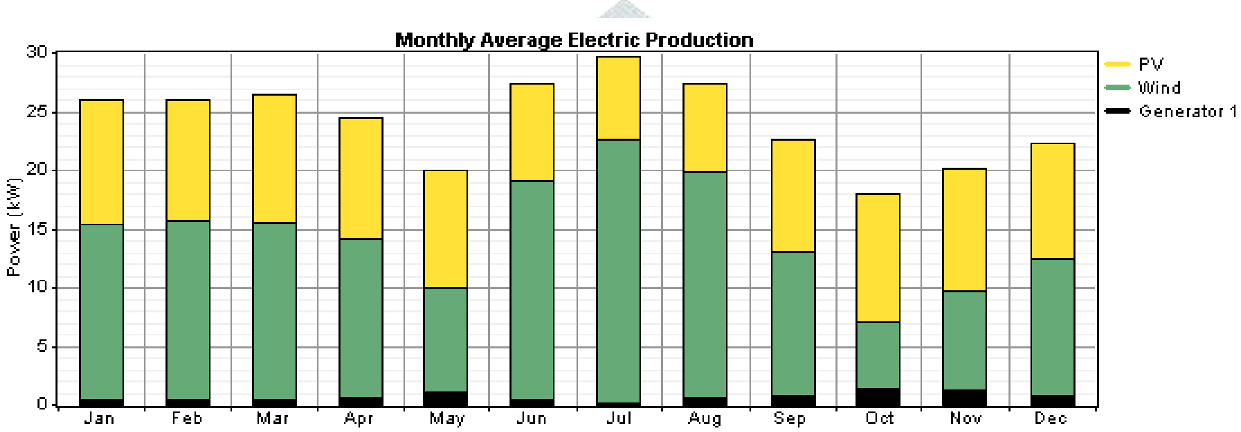


Figure.4. Contribution of the power units for a 98% utilization of renewable resources

Sensitivity analysis was also carried out and Figure 5 below shows the variation of diesel price against wind speed variation for a fixed average solar radiation of 6.28 kWh/m^2/day. In the Figure, the net present cost of the most cost-effective set-up for a particular set of PV and battery prices is also included. At lower wind speed (<3m/s), PV/battery system is cost effective and insensitive to wind speed variation. When the wind speed is slightly increased (3 to 5m/s), PV/wind/battery is cost effective at lower and higher PV module prices, respectively.

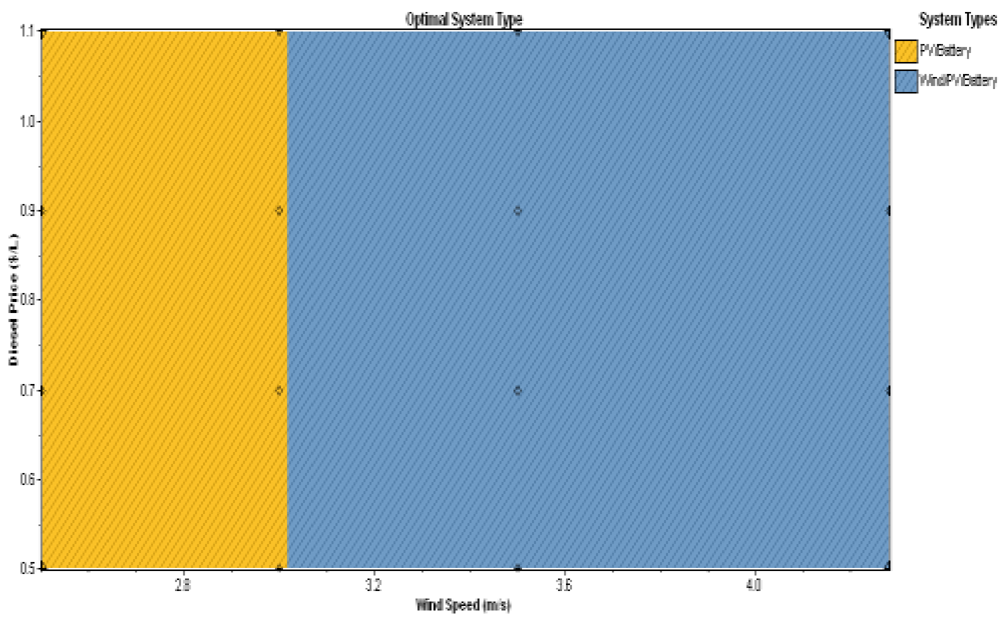


Figure.5: Sensitivity of PV cost to wind speed with some important NPCs labeled

HOMER software is also used to compare the investment cost of the hybrid system against the cost required for extending the grid. As a result, it is found that the hybrid system is cost effective for an area which is found at a distance greater than 12.2 km (which is the breakeven grid extension distance) from the existing grid found nearby.

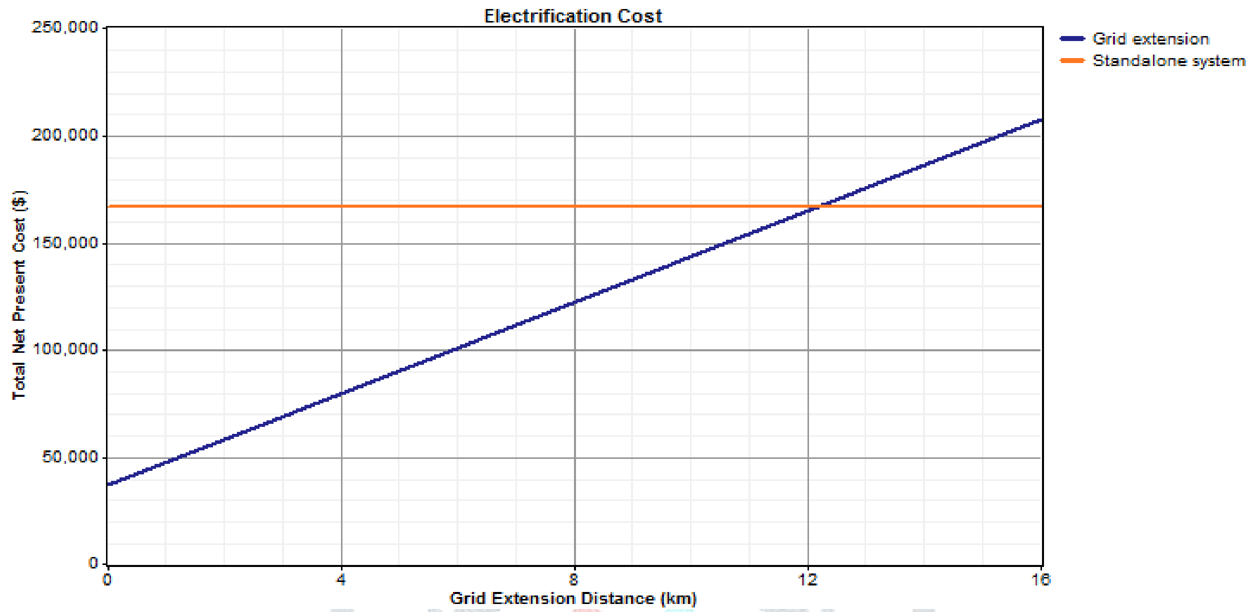


Figure.6: **Breakeven grid extension distance obtained using HOMER**

5. CONCLUSIONS

This paper has presented the assessment of resource potential and modeling of stand-alone pv/wind hybrid system for rural electrification in rural area of western Axum, where grid electricity is not present. The optimum design for the Kutur village consists of PV, Wind turbine and Battery system. The load is assumed based on regular rural lifestyle. The main parameters of analysis are per unit energy cost, initial cost, per year operating cost, and total net present cost of the system. The HOMER optimization is capable to clarify the viability of the system since the system has competitive energy costs with other possible configurations. The system is a non-polluting, reliable energy source with total net present cost $ 115,541, which cover the capital cost of $ 95,640, replacement cost of $ 98,360 and per year operating cost is $ 2026. The cost of energy is $ 0.125 /kWh, which is the lowest of all the possible configurations. Also, this system does not consume gas emission. Sensitivity analysis was also carried out and Figure 5 below shows the variation of diesel price against wind speed variation for a fixed average solar radiation of 6.28 kWh/m^2/day. In the Figure, the net present cost of the most cost-effective set-up for a particular set of PV and battery prices is also included. At lower wind speed (<3m/s), PV/battery system is cost effective and insensitive to wind speed variation. When the wind speed is slightly increased (3 to 5m/s), PV/wind/battery is cost effective at lower and higher PV module prices, respectively.

Finally, HOMER software is also used to compare the investment cost of the hybrid system against the cost required for extending the grid. As a result, it is found that the hybrid system is cost effective for an area which is found at a distance greater than 12.2 km (which is the breakeven grid extension distance) from the existing grid found nearby.

REFERENCE

[1] Invest in Ethiopia, Ethiopia trade and investment. *www.ethioembassy.org.uk/**trade_and_investment***. January 2012

[2] Ethiopian Television (ETV) news. http://www.erta.gov.et January 2012

[3] Frances Drake, Yacob Mulugetta. Assessment of solar and wind energy resources in Ethiopia. I. Solar energy. University of Leeds, Leeds LS2 9JT, U.K.

[4] Wind energy explained theory, design and application (J.F. Manwell, J.G. McGowan and A.L. Rogers University of Massachusetts, Amherst, USA, reprinted September 2002)

[5] Technical assessment of the use of a small-scale wind power system to meet the demand for electricity in a land aquafarm in Taiwan (Chi-ming Laia,*, Ta-hui Linb,1, 5 July 2005)

[6] Feasibility study for a standalone solar–wind-based hybrid energy system for application in Ethiopia, Getachew Bekele *, Björn Palm 1, December 2009

[7] Electric Power Distribution Network Design and Construction Training Manual, EEPCo.

[8] NASA Surface meteorology and Solar Energy, http://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi

[9] Hardy diesel generators. http://www.hardydiesel.com/diesel-generators-7-33-kw.html January 2012

[10] solar thermal process

[11]S. Diaf 1*, D. Diaf, M. Belhamel, M. Haddadi, A. Louche,2010"A methodology for optimal sizing of autonomous hybrid PV/wind system". France: Ajaccio

[12] Danish Wind Industry Association, (Jan., 2011), http://www.windpower.org/en/tour

[13] Luque, A. and Hegedus, S., (Ed) (2003) *Handbook of Photovoltaic Science and Engineering.* West Sussex, England: John Wiley & Sons Ltd.

[14] Bizuayehu T.(2011) "Improved Sustainable Power Supply for Dagahabur and Kebridahar Town of Somalia Region in Ethiopia", Reykjavik University Master's thesis ,January 2011

[15] Patel, M.R., (2006) *Wind and Solar Power Systems: Design, Analysis, and Operation.* 2nd Ed. Boca Raton: Taylor & Francis Group.

[16] Duffie, J.A. and Beckman, W.A., (2006) *Solar Engineering of Thermal Processes*. 3rd ed. New Jersey: John Wiley and Sons, Inc.

[16] Tzanakis, I., (2006) *"Combining Wind and Solar Energy to Meet Demands in the Built Environment": (Glasgow-Heraklion Crete Analysis).* MSc Thesis, University of Strathclyde.

[17] Twidell J. And Weir T, 2006, "Renewable Energy Resources", 2nd Edn, Taylor & Francis, London, 2006

[18] Aldo V., 2005, "Fundamentals of Renewable Energy processes", Elsevier Inc., 2005

[19] Patil, Mukind R., 1999, "Wind and Solar Power Systems", CRC pres LLC, USA,1999

[20] Japanese Embassy in Ethiopia, 2008 "Study on the Energy Sector in Ethiopia": *http://www.et.emb-japan.go.jp/electric_report_english.pdf*