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Hybrid renewable energy design for rural electrification in Ethiopia

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Abstract

This paper presents the development of an effective approach of design, simulation and analysis of stand-alone hybrid renewable energy resources for typical rural village in remote area situated in SNNPR region of Ethiopia. It emphasizes the renewable hybrid power system to obtain a reliable autonomous system with the optimization of components size and Levelized Cost of Energy. The main power of the hybrid system comes from the photovoltaic panel batteries / inverter system, while the diesel generator is used as backup units. The optimization software used for this paper is HOMER. HOMER is design software that determines the optimal architecture and control strategy of the hybrid system. Critical decision variables like the size of the PV array, size and number of battery string, inverter, size of diesel Generator, dispatch strategy, are given weight in the optimization process. Wind speed and solar radiation data have been taken from NASA's meteorological department. A remote village with energy consumption of 279 kWh/day and 64 kW peak power demand was considered. The simulation results indicate that the proposed hybrid system would be a feasible solution for distributed generation of electric power for stand-alone applications at remote village with 200 households with average of five family members per household. An innovative approach of determining rural electric load for remote village which does not have electric access has been proposed

Key words- Hybrid system, HOMER, Photovoltaic, Diesel Generator

I. Introduction

Reliable access to electricity is a basic precondition for improving people’s lives in rural areas, for enhanced healthcare, education, and for growth within local economies as well as to meet millennium development goal in 2015. At present, more than 80% people in Ethiopia do not have access to electricity in their homes. Almost all of these people live in rural areas; most have scant prospects of gaining access to electricity in the near future. The Ethiopian Government tried to connect this rural location by using national grid extension for the last two decades. However, still the current electricity access is below 50% and the real connection is less than 14% [1]. In this scenario the rural people who have very low load demand with dispersed settlement will not get electricity in the near future

Energy is a key component of any poverty eradication and sustainable development strategy and is critical to the achievement of the millennium development goals. Better access to sustainable energy service for rural people in Ethiopia is prerequisite for the sufficient supply of lighting, communication systems, and the development of income generating activities as well as the improvement of the public health situation. Today it is widely accepted that Renewable energy system (RES) have a large potential to contribute to the strengthening and development of national sustainable energy infrastructures in many countries in the world by securing better energy independence through the mobilization of domestic renewable energy resources especially in rural areas[2].

One of the main problems of standalone system such as solar as well as wind energy is the fluctuation of energy supply, resulting in intermittent delivery of power and causing problems if supply continuity is required. This can be avoided by the use of standalone hybrid systems. A hybrid power system can be define as a combination of different, but complementary energy generation system based on renewable energy or mixed (RES- with a backup of Liquefied Petroleum Gas (LPG)/diesel/gasoline gen_set). Hybrid systems capture the best features of each energy resource and can provide “grid-quality” electricity, with a power range of one kilowatt to several hundred kilowatts. They can be developed as new integrated designs within small electricity distribution systems (mini-grids) and can also be retrofitted in diesel based power systems. Hybrid systems can provide a steady community-level electricity service, such as village electrification, offering also the possibility to be upgraded through grid connection in the future. Proposed Hybrid power systems in this paper typically rely on renewable energy to generate 95% of the total supply. The large share of renewable makes this system almost independent and lowers the energy prices over the long- term, and the diesel generator set is used as a backup to assist in periods of high loads or low renewable power availability. The battery backup size is lower due to back up system and suffers less stress than in a 100% renewable power system, prolonging battery lifetime significantly and reducing replacement costs.

II. Methodology

The simulated hybrid renewable energy system comprises of wind turbine, Photovoltaic (PV) array with power converter, battery and Diesel generator. The battery is added into the system as a backup unit and act as a storage system. This system is designed specifically for an off grid system at remote area to supply power 24/7 bases. The system is designed by considering remote village called Dembile which, is located around 80km from Arbaminch town, in Bonke woreda in SNNPR region of Ethiopia. The solar and wind resource data of the remote site was taken from online data of NASA Methodological department [11]. The field surveys has been conducted to get daily load profile and energy usage pattern of the village. Since the village does not have Electricity access, the daily load profile of electrified village with the same socio economic condition with the selected village has been taken for simulation. The HOMER software is used to determine the optimal sizing and operational strategy for a hybrid renewable energy system based on three principal tasks which are simulations, optimization and sensitivity analysis. The following subsection discusses on the three principal tasks of the HOMER software.

A. HOMER: SIMULATION

HOMER simulates the operation of the system based on the components chosen by the designer. In this process, HOMER will perform the energy balance calculation based on the system configuration consisting several numbers and sizes of component. In this case study, PV array system, wind turbine, diesel generator with battery and converter are the components chosen for the analysis. It then determines the best feasible system configuration which can adequately serve the electric demand. HOMER simulates the system based on the estimation of installing cost, replacement cost, operation and maintenance cost, fuel and interest rate.

B. HOMER: OPTIMIZATION

The optimization process is done after simulating the entire possible solutions of hybrid renewable energy system configuration. HOMER display a list of configurations sorted based on the Total Net Present Cost (TNPC). It can be used to compare different types of system configuration from the lowest to the highest TNPC. However, the system configuration based TNPC is varied depending to the sensitivity variables that have been chosen by the designer.

C. HOMER: SENSITIVITY ANALYSIS

The HOMER software will repeat the optimization process for every selection of sensitivity variables for the hybrid renewable energy system. The sensitivity variables are such as the global solar, wind speed and the price of diesel fuel. Then, the list of various configurations of hybrid renewable energy will be tabulated from the lowest to the highest TNPC. The optimal solution of hybrid renewable energy system is referring to the lowest TNPC.

III. System Configuration

The typical wind-solar hybrid power generation systems include PV system, WT system, battery units, diesel generator, related electric devices and loads. Wind-solar hybrid power generation systems can be divided into three classes according to bus bar forms, including pure AC bus bar system, pure DC bus bar system and hybrid AC-DC bus bar system. The three classes systems have different features. The detail explanation of each configuration found in [19]-[27]. In this paper AC-DC configuration is used due to its advantage compared to other configurations

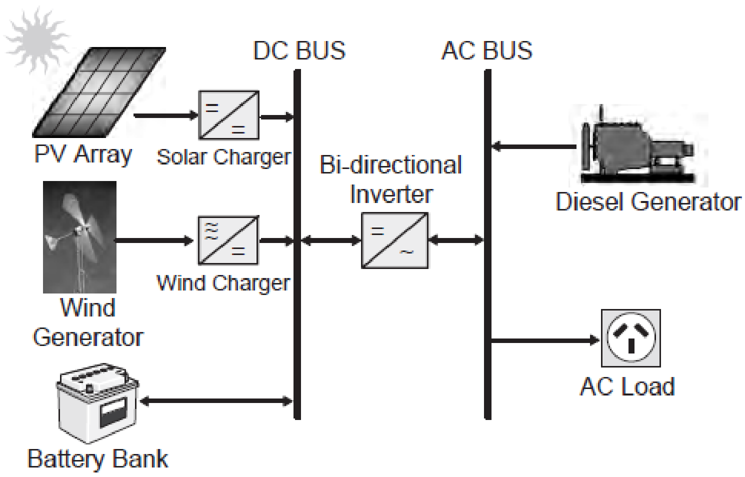

Fig.1 AC-DC Hybrid configuration

AC -DC configuration has superior performance over the other type of hybrid system. In this scheme the renewable energy source and the diesel generator supply a portion of the load demand directly, resulting in higher overall system efficiency. The diesel generator and the inverter can operate in stand alone or parallel mode. This offers some combination of the source for meeting the load. When the load is low, either the diesel generator or the battery can supply the load. However, during peak load both sources are operated in parallel mode. Due to this parallel operation the initial capacity of diesel generator and inverter can be reduced. In this scheme a controller is needed to supervise the operation of the system, selecting the most appropriate mode of operation to supply a certain load without power interruption.

IV. System Description and Simulation

From the design point of view, the optimization of the size of hybrid plants is very important, and leads to a good ratio between cost and performances. Before the system sizing, load profile and available renewable resource of the site should be evaluated. The load profile for hybrid system was created from result of survey of electrified village with the same socio economic status of the selected case study village. The daily load and hourly load was calculated by using spreadsheet program EXCEL. The case study village is consisting of residential houses, public institution (one school and one health centre), small commercial centre (shop, barber shop, and one grinding mill) and water pumps for potable drinking water. The lifetime estimated for this project is 25 years in simulation while the real interest rate is fixed at 10% which is common in many developing countries

A. Electrical load information

As seen from the survey of some rural villages in Ethiopia the electrical load demand is very low dominated by lighting load. In this study, 200 rural household with average family size of 5, public and commercial centers are considered.

Around three water pumps are assumed to deliver the water need. One pump used for school, health clinic and a milling house; and the remaining two for house use. The selected type of water pump has a capacity of 150W power rating, with a pumping capacity 20 liter/minute. The required amount of water needed per family is ~100 liter/day, for cattle ~25 liter /day, for school, health center, shopping center and milling house~2000 liter/day. The above assumption is based on country average consumption of water per person and per cattle, i.e. the average consumption is 20 liter/person/day and 25liter/cattle/day. Since in the village we assumed 200 households with average of five member per family and three cattle per households, the total consumption of water per day is around 36m^3/day. Three water pumps with capacity of 20 l/min can provide more than 36m^3/day if it runs for 10 hour per day. A water tank of capacity 43 meter cube is considered and at full load the pumps draw 0.75kW of electrical power and pumps 3.6m^3 per hour. The peak deferrable load is 0.75kW, which is the rated power of the pump. It would take 12 hour for the pumps at full power to fill the tank. So the storage capacity is 12 hour times 0.75kW, which is 9kWh. It would take for the pumps 10 hour at full power to meet the daily requirement of water for the village. So the average deferrable load is 10 hour per day times 0.75kW, which is 7.5kwh/day. By referring the load profile given in Fig.2 and Fig.10, 279kWh/day is the average estimation of daily energy consumption of primary load which has 64 kW peak and 4.2 kWh/day for deferrable load with 750 watt peak. Three water pumps which have capacity of 20 l/min have been selected as deferrable load in the simulation. In order to analyze uncertainty in the future, load sensitivity analysis has been done by 10% and 20% increment of the load. The monthly load demand of this village is shown in Fig. 3. It is observed that the annual peak load of 64 kW has occurred in March, Jun, July and December. The daily peak load occurred from 6:00 up to 13:00

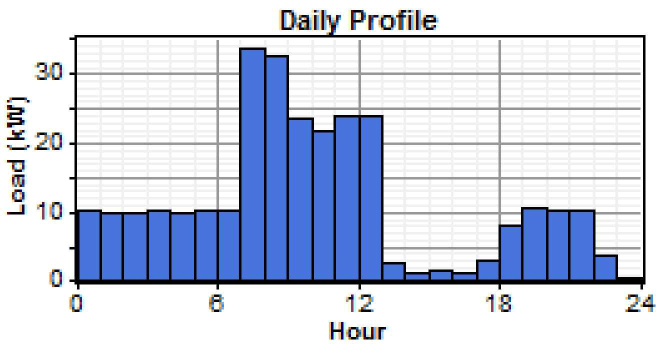

Fig.2 Daily load curve of the village

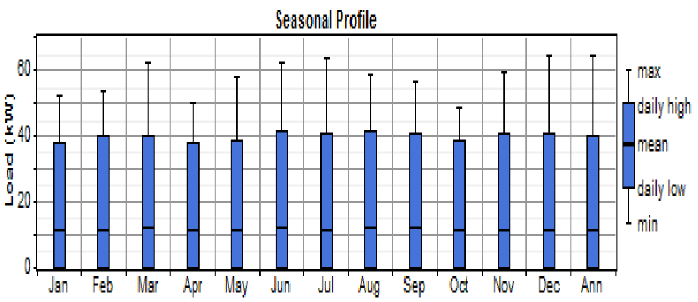

Fig.3 Monthly load variation of the village

Generally there is significant seasonal load variation in towns due to change of equipment used in home such as heating and cooling devices which consumes significant amount of Energy. However, the seasonal load variation in the proposed rural village is insignificant since the electrical equipment used in the village assumed the same throughout the year.

Table1. Load profile of the Village

Residential load						
Type	**No of house hold**	**Appliance type**	**Ratting (W)**	**No. of Appliance**	**Run time h/day**	**kWh**
High class House Hold	10	CFL lamp	15	4	5	0.3
		Tape Recorder	50	1	10	0.5
		Television	250	1	8	2
		Total kWh/day /high class house hold				**2.8kwh/day**
Middle class House Hold	100	CFL lamp	15	3	4	0.18
		Tape recorder	50	1	10	0.5
		Total kWh/day /middle class house hold				**0.68kWh/day**
Low class House Hold	90	CFL lamp	15	1	4	0.6kwh
		Total kWh/day /low class house hold				**0.6kWh/day**
Public and commercial load						
School	1	CFL lamp	15	15	5	1.125
		Tape recorder	75	1	8	0.6
		Television	250	1	6	1.5
		Computer	700	3	7	14.7
		Refrigerator	200	1	8	1.6
		Others	250	1	6	1.5
Total kWh/day						**21.025 kWh/day**
Health Center	1	CFL lamp	15	8	8	0.96
		Tape recorder	50	1	6	0.3
		Television	250	1	14	3.5
		Lab. equipment	1000	1	12	12
		Refrigerator	200	1	8	1.6
		others	250	1	6	1.5
Total kWh/day						**19.86 kWh/day**
Commercial Load		CFL lamp	15	15	8	1.8
		Tape recorder	75	5	8	3
		Television	250	4	6	6
		Razor	20	8	12	0.48
		Grinding mill machine	12000	1	14	168
		others	250		6	1.5
Total kWh/day						**180.78kWh/day**

HOMER software needs hourly load as input for simulation. In order to get the hourly load of the village the above loads are distributed in EXCEL spreadsheet program from the knowledge of load usage time, which is gained from the Electrified village of the same socio economic condition. For instance lighting loads are switched on from 18:00-23:00, grinding mills are operated during daytime and the entertainment devices usually switched on when required.

B. Photovoltaic (PV) economic information and solar resource

The size of a PV array system in the optimum system is 78 kWp. While the total capital cost is $218,400 and the replacement cost is $0 since the project life time is the same as PV array life time, which is 25 year. The fixed PV panels will have a rated power of 175 Wp per unit, with output voltage of 24V D.C.; the number of PV panels is even since the D.C. bus bar voltage is 48V D.C. The design accounts for the decrease in PV efficiency panels with the ambient temperature. The solar radiation data is taken from NASA meteorological department database. The array slope angle is set to 15 degree and the array azimuth is 0 degree which is referring to the South direction. The lifetime for this PV array system is 25 years with a de-rating factor of 90% and ground reflectance is 20%. Fig.4 shows the average monthly solar radiation data of the village where maximum radiation occur in the month February and the minimum radiation available in the month of July, which is the raining season of the region. Fig.5 shows the average daily solar radiation where the maximum occur around noon 12:00. It is seen from the data that the site has tremendous solar resource potential with average radiation of 6kWh/m^2/ day. This is the reason that 95% of electrical energy come from Photovoltaic array while the rest 5% diesel generator in optimum system.

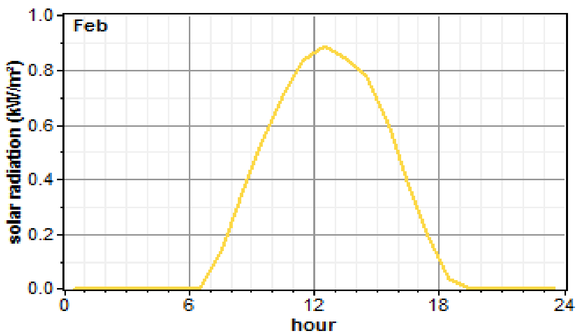

Fig.4 Monthly average solar radiation of the site

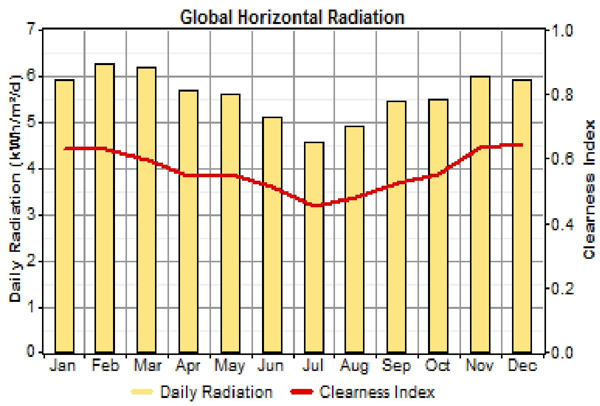

Fig.5 Hourly solar radiation curve of the sit

Wind turbine will use the force from air current flowing across the Earth’s surface which is called surface wind. The wind power is defining from the wind velocity and area of the wind flow:

$$P=0.5\rho AV^3 \ldots\ldots\ldots\ldots\ldots(1)$$

Where
P: the power in the wind (watts)

ρ: Air density (1.225 kg/m^3)
A: the cross-sectional area through which the wind passes (m^2)
V: wind speed normal to A (m/s)

From Equation (1) the power in the wind increases as the cube of wind speed. This means, for example that doubling the wind speed increases the power by eightfold and small variation in wind speed produces wide variation in wind turbine power output. A is obviously just $A = (\pi/4)\ D^2$, where D is the diameter of the blade so wind power is proportional to the square of the blade diameter. Doubling the diameter increases the power available by a factor of four. That simple observation helps explain the economies of scale that go with larger wind turbines. The cost of a turbine increases roughly in proportion to blade diameter, but power is proportional to diameter squared, so bigger machines have proven to be more cost effective. The wind speed of selected village is very low and it ranges from 3m/s to 4.5 m/s with monthly average of 3.91m/s.

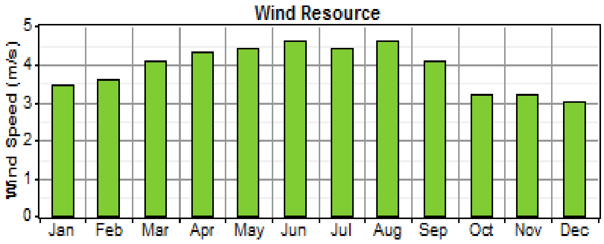

Fig.6 Average monthly wind speed over the year

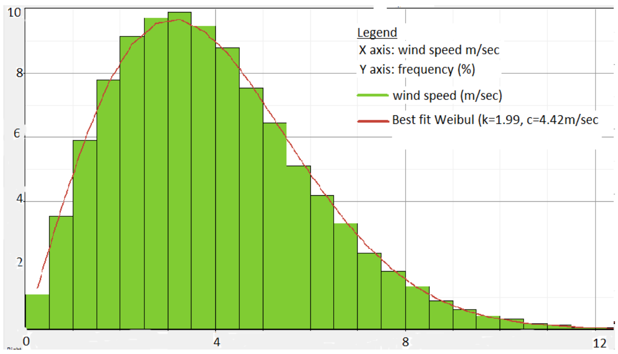

Fig.7 Weibull probability distribution function of wind speed

The wind speed over a year is presented in a weibull distribution form in the Fig.7. The autocorrelation factor of 0.85 is measured based on the hour to hour randomness of the wind speed. The diurnal pattern strength of 0.25 represents as the strength of a wind speed. The technical information of wind turbine used in simulation is shown in Table 2.

Table 2. Wind turbine technical information

parameters	*Value information*
manufacturer	Bergey windpower, type BWC Excel-R/48
Rated power	7.5kW
output	DC,48V
Cut in speed	3m/s
Cut out speed	25m/s
Hub height	50 m

C. Diesel Generator

The diesel power plant of 5 kW is used in optimal configuration. The diesel price with four discrete values of 1$/L, 1.2$/L and 1.5$/L are used for the sensitivity variables. At present, the diesel price is about 1$/L in Ethiopia. The lower heating value is 43.62MJ/kg, density of the fuel is 820kg/m3 and carbon content is 88% and sulphur content is 0.33%.The diesel generator forced to operate from 6:00 to 14:00 and from 18;00 to 20:00 for optimum system to supply nighttime load and to avoid frequent startup of generator which reduce its life.

D. Battery

The type of battery that used for the system is Surrette 6CS25p model with the rating of 6V, 1156Ah, 6.94kWh with lifetime throughput 9645kWh. The cost for one battery is $900 with the replacement cost of $800. The battery stack is containing several numbers of batteries and the battery string contains 8 batteries in series with bus voltage of 48v. Total of 96 batteries are used in optimal system. The quantities of batteries string considered in simulation are 8, 10, 11,12,13,14 and 16 strings.

Table 3.Technical data and study of assumptions of component

PV Array	**DC**
Capital cost	$4000
Replacement cost	$3000
O& M cost	$0
Efficiency	15%
Lifetime	25
Tracking system	No traking
Wind Generator	**DC**
Technology	BWC –Excel R/48

power	7.5 kW DC,48V
Hub Height	50m
Capital cost	$30000
Replacement cost	$25000
O& M cost	$50
Lifetime	10 year
Diesel Generator	**AC**
Capital cost	500$/kW
Replacement cost	400$/kW
O& M cost	0.015$/hour
Lifetime	25000hr
Battery	**DC**
Technology	Surrette 6CS25
Capacity	6.94kWh
Nominal Capacity	1156Ah
Voltage	6V
Min. state of charege	60%
Capital cost	$900
Replacement cost	$800
O& M cost	10$/year
Efficiency	80%
Lifetime	10year
Converter	**AC/DC/AC**
Capacity	30kW
Capital cost	$700
Replacement cost	$700
O& M cost	50$/year
Efficiency	90%
Lifetime	10 year
System Data	
Project life time	25 year
Operating strategy	Load following
Spinning reserve	10
Set point SOC	60%
Maximum annual capacity shortage	20%
Daily noise of load	15%
Hourly noise of load	30%

F. Power converter

A power electronic converter is used to maintain the flow of energy between ac and dc components. The optimal size of power converter used in this system is 32 kW. The capital cost, replacement costs and maintenance for this equipment for 1kw is $700, $700 and 50 $/ year respectively. Seven different sizes of converter which are 15kW, 20.kW, 30kW, 32kW, 35kW, 40.kW and 45 kW are considered in the simulation of hybrid renewable energy system. The lifetime for one unit of converter is 10 years with the efficiency of 95%.

Technical data and cost of components used in the design of hybrid system is taken from the web site of corresponding manufacturers and suppliers [3]-[21]-[26] and summarized in Table3.

V. Operation Principle of Standalone Hybrid System

The operation principle of proposed hybrid system is based on dispatch strategy and energy management unit. Wind turbines and PV arrays which are the basic load suppliers, will charge the battery bank when there is an excess power remaining after meeting the load demand. Since output power of PV module is in DC mode, they must be converted to the AC power by using an inverter so that it can be utilized to meet the AC load demand. If PV module and wind turbines cannot meet the demand, the battery bank will not be charged, but will be discharged to supply the demand. The allocation of resource based on load condition is called dispatch strategy. The dispatch strategy for a hybrid energy system is a control algorithm for the interaction among various system components. The control strategy determines the energy flows from the various sources like diesel generator and different types of renewable generators, towards the user loads, and dump load, including the charging and discharging of the energy storage systems, on a time scale of minutes to hours, in such a way as to optimize system performance in terms of operating cost.

HOMER can model two dispatch strategies, cycle charging and load following. Which is optimal depends on many factors, including the sizes of the generators and battery bank, the price of fuel, the O&M cost of the generators, the amount of renewable power in the system, and the character of the renewable resources. Under the load following strategy, whenever a generator is needed it produces only enough power to meet the demand. Load following tends to be optimal in systems with a lot of renewable power, when the renewable power output sometimes exceeds the load. Under cyclic charging strategy whenever the generator has to operate, it operate at full capacity with surplus power going to charge the battery bank.

VI. Result and Discussion

The proposed hybrid renewable energy system for the village is shown in Fig.10. It consists of primary load of 279kWh/day, with peak load of 64kW and deferrable load of 7.5kWh/day with peak load of 750W. Deferrable load is electrical load that must be met within some time period, but the exact timing is not important. Loads are normally classified as deferrable because they have some storage associated with them. Therefore, in this simulation three water pump with rating of 150W each used as deferrable load. The software considered this deferrable load as critical load when the water tank is empty. The HOMER software identifies the best possible configuration for the hybrid renewable energy system. For an example, the optimal sizing and operational strategy for a hybrid renewable energy system may sometime consider all of the equipment or without considering one part of the equipment. Thus, combination of the equipment is depending on the optimization procedure and sensitivity variables.

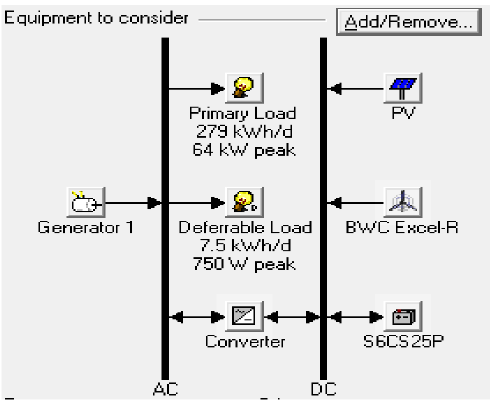

Fig.8 Hybrid power system configuration

A. Optimization of hybrid renewable energy system without considering sensitivity variables

HOMER performs the optimization process in order to determine the best solution in terms of component size and Total Net present cost of hybrid renewable energy system based on several combinations of equipment. Hence, multiple possible combinations of equipment could be obtained for the hybrid renewable energy system due to different size of PV array system, number of wind turbines, size of generator, number of batteries and size of dc-ac converter. In the optimization process it simulates every combination system configuration in the search space. The feasible one will be displayed at optimization result sorted based on the Total Net Present Cost (TNPC).

The combination of system components is arranged from most effective cost to the least effective cost. The optimization results of hybrid renewable energy system are obtained for every selection of the base case i.e. fuel price 1$/L, primary load 279 kWh/Day, real interest of 10% and PV cost and replacement multiplier of 1 .Table 4 shows a list of optimization results for the hybrid renewable energy system without considering the sensitivity variables. In Table 4 the results represent different combination of components which are wind turbine, PV array system, battery and converter as optimum combination. The total net present cost for optimum combination is $412,720 and cost of energy (COE) is 0.538$/kWh with total renewable fraction of 89%. However, sensitivity variables should be taken into account in order to obtain a rational result of hybrid renewable energy system. The primary load, diesel fuel price, PV capital and replacement cost and annual Real interest rate are the sensitivity variables considered for the optimal design of this system.

B. Hybrid Renewable Energy System Considering Sensitivity Variables

Sensitive variables are very essential to consider uncertainty of input variables such as wind speed, solar radiation, load variation, etc. in the future. In this simulation the following sensitivity variables are used. Primary load 279,300 and 350 kWh/day ,Real interest rate 6 ,8 and 10%, Photovoltaic capital cost multiplier 1 and 0.7, Diesel fuel price 1$/L, 1.2$/L and 1.5$/L.

HOMER displays primary load of 350 kWh/day, fuel price of 1.5$/L, PV capital and replacement cost of 0.7 and Annual Real interest rate of 8% for sensitivity variable in Table 5. It is then used in the optimization process to obtain the best configuration of hybrid renewable energy system consisting of diesel generator, PV array system, battery storage and/or power converter with total net present cost of $443,627 and cost of energy $0.401/kWh. In this case study, the system consisting of diesel generator, PV array, battery storage and power converter yields to the most economical cost with the minimum TNPC of Energy. The second cost effective system from categorized simulation result is wind-PV system. As seen from wind speed profile of the village, the monthly wind speed is very low and the output from wind turbine is insignificant. The energy obtained from different components of hybrid renewable energy system is shown in Fig.11. The PV array produced 146,066kWh/yr that is 95% of the total energy served. The remaining 5% of total energy is served by the diesel generator, which is 6,896kWh/yr. This system produced 13.8% of excessive energy.

The optimization result based on every combination of sensitivity variables is depicted in graphical form as shown in table5. The results show that every sensitivity variable gives different TNPC value of hybrid renewable energy system. It is worth mentioning that the sensitivity variables comprise of primary load, fuel price, PV capital and replacement cost multiplier and annual real interest rate. Table 5 shows that the TNPC of PV-Generator battery hybrid system become economically feasible when the primary load is varied from 279kWh/day to 350kWh /day and annual real interest rate 10%. The system is also economical even if the diesel fuel price increase from the current 1$/L to 1.5$/L, which is actual expecting due to soaring oil price

As it is observed from simulation PV/gen/battery system is still optimum for wide variation of load and diesel fuel price. Therefore, the optimum system for the case study village is PV/gen/battery system with converter with minimum COE of $0.401/kWh.

Table 4. Optimization result without considering sensitivity variable

Sensitivity Results | Optimization Results

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

PV (kW)	XLR	gen (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	gen (hrs)	Batt. Lf. (yr)
50		5	104	25	CC	$ 313,600	10,920	$ 412,720	0.538	0.89	0.19	4,266	2,647	12.0
60		5	88	25	LF	$ 339,200	8,349	$ 414,984	0.530	0.94	0.17	2,510	1,560	12.0
60		5	88	30	LF	$ 342,700	8,391	$ 418,869	0.536	0.95	0.18	2,152	1,322	12.0
50		5	104	30	CC	$ 317,100	11,357	$ 420,189	0.547	0.89	0.19	4,263	2,661	12.0
60		5	88	32	LF	$ 344,100	8,458	$ 420,873	0.539	0.95	0.18	2,054	1,257	12.0
65		5	64	25	CC	$ 337,600	9,241	$ 421,481	0.556	0.92	0.20	4,138	2,842	12.0
50		5	112	25	CC	$ 320,800	11,166	$ 422,158	0.544	0.89	0.18	4,207	2,582	12.0
50		5	104	32	CC	$ 318,500	11,469	$ 422,608	0.551	0.89	0.19	4,206	2,627	12.0
60		5	96	15	CC	$ 339,400	9,279	$ 423,627	0.557	0.91	0.20	3,871	2,342	12.0
60		5	96	25	LF	$ 346,400	8,573	$ 424,218	0.532	0.94	0.16	2,425	1,511	12.0
60		5	88	35	LF	$ 346,200	8,612	$ 424,375	0.544	0.95	0.18	1,957	1,186	12.0
50		5	104	35	CC	$ 320,600	11,655	$ 426,394	0.557	0.89	0.19	4,136	2,581	12.0
70		5	64	25	LF	$ 357,600	7,622	$ 426,790	0.559	0.95	0.20	2,714	1,682	12.0
50	1	5	96	15	CC	$ 329,400	10,779	$ 427,242	0.563	0.90	0.20	3,951	2,376	12.0
60		5	96	30	LF	$ 349,900	8,589	$ 427,867	0.537	0.95	0.16	2,043	1,268	12.0
65		5	64	30	CC	$ 341,100	9,595	$ 428,196	0.561	0.92	0.20	4,053	2,847	12.0
60		5	88	25	CC	$ 339,200	9,847	$ 428,585	0.535	0.92	0.16	3,848	2,526	12.0
50	1	5	96	25	LF	$ 336,400	10,167	$ 428,685	0.554	0.93	0.18	2,590	1,604	12.0
60		5	104	15	LF	$ 346,600	9,159	$ 429,734	0.564	0.92	0.20	3,477	2,097	12.0

Table 5. Optimization result with sensitivity variables

Sensitivity Results | Optimization Results

Sensitivity variables

Primary Load (kWh/d) 350 | Diesel Price ($/L) 1.5 | PV Capital Multiplier 0.7 | Interest Rate (%) 8

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

PV (kW)	XLR	gen (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	gen (hrs)	Batt. Lf. (yr)
78		5	96	32	LF	$ 329,700	10,930	$ 446,374	0.401	0.95	0.20	2,599	1,583	12.0
71	1	5	96	30	LF	$ 338,700	12,491	$ 472,036	0.423	0.95	0.20	2,757	1,685	12.0

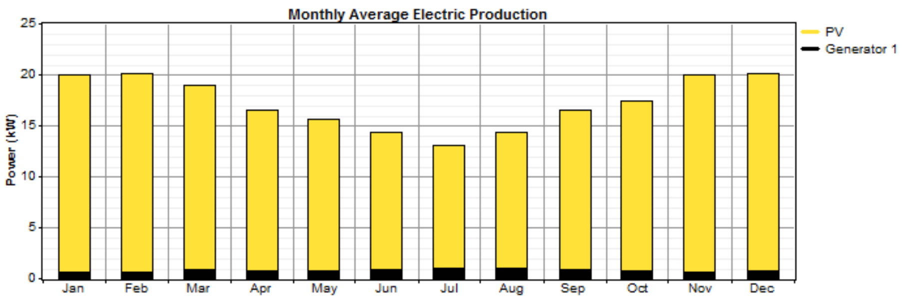

Fig9. Monthly average Electrical energy production of hybrid energy system

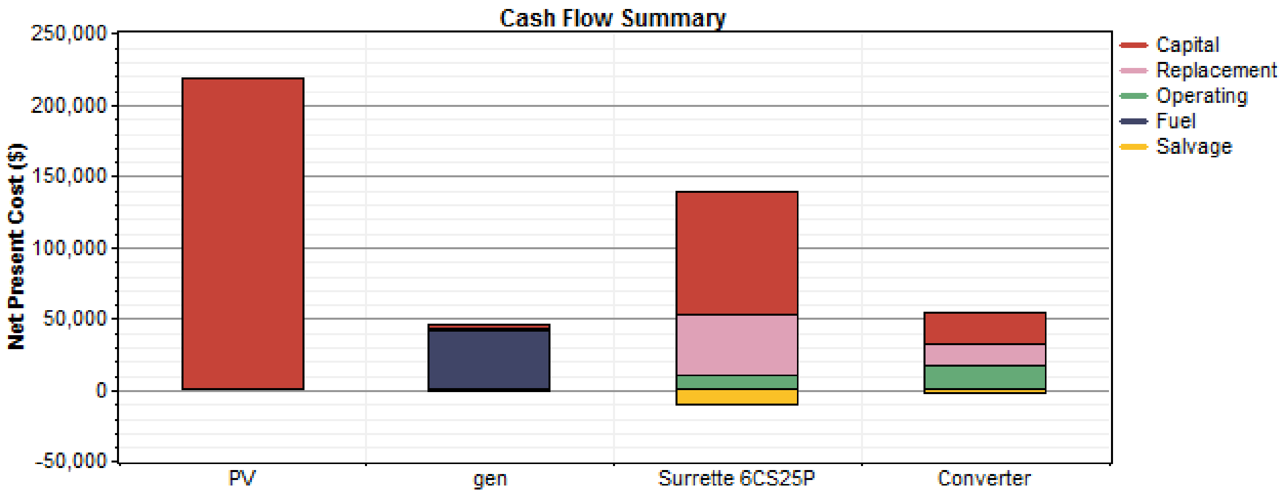

Fig.10 cost summery by component

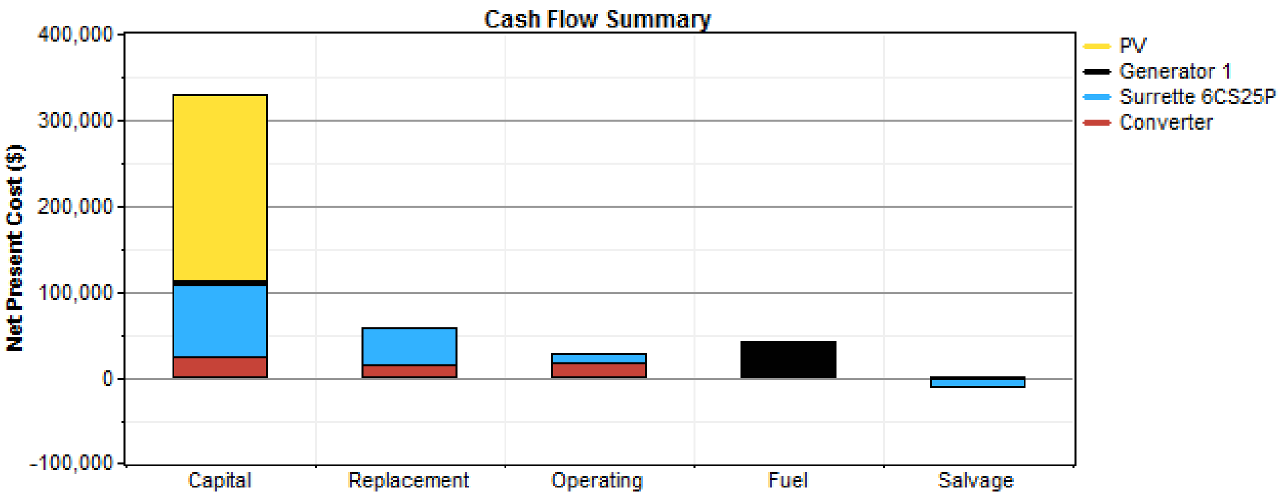

Fig.11 Cost summery by cost type

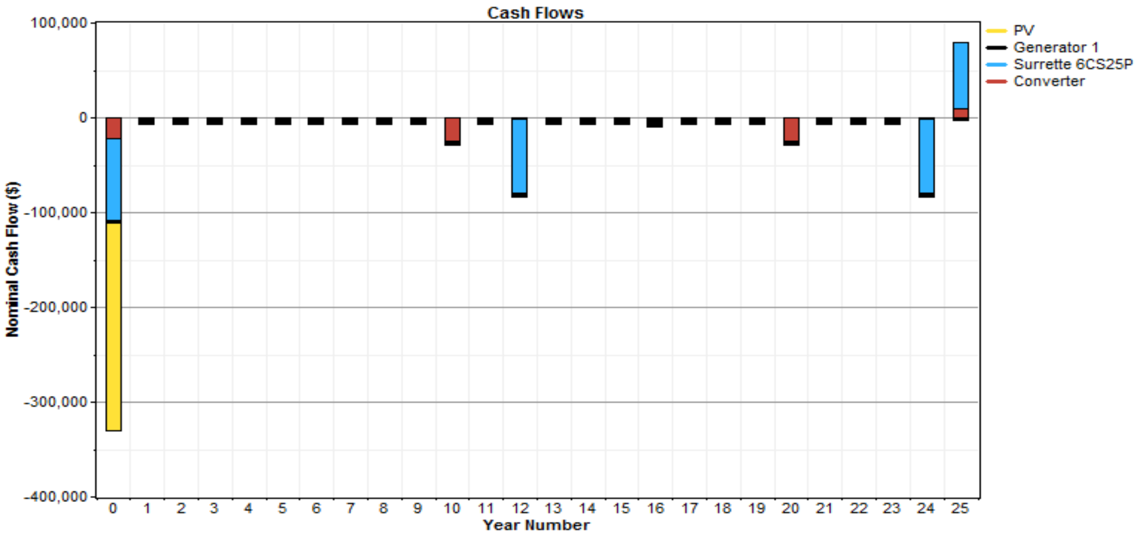

Fig 12 .Cash flow summery

VII. CONCLUSIONS

Reaching the non electrified rural population is currently not possible through the extension of the grid in Ethiopia, since the connection cost is not economically feasible due to dispersed rural settlement and low load factor. Further, the increases in oil prices and the unbearable impact of this energy source on the users and on the environment, are slowly removing conventional energy solution such as fuel gen_set based systems, from the rural development agenda. Grid extension and off grid hybrid solutions are complement each other rather than compete. Off-grid hybrid stand alone renewable energy are economically viable in lieu of grid extension in areas where there is low load factor, low population densities and difficult geographic terrain to be crossed

Despite their significant benefits to the environment and great long-term potential for sustainable energy development, hybrid power systems are currently in an economic disadvantage position because of their high installation costs compared with traditional electric generation as seen from Fig.13. In the majority of cases, the incentives from federal and state governments and local utilities are necessary to make a hybrid system economically viable, which, in turn, makes the incentive policies so critical to the widespread deployment of such systems.

From simulation result, the combination of PV array, diesel generator, battery storage and converter brings to the optimal configuration of hybrid renewable energy system applicable to be used as an off-grid system for selected village of 200 house hold in southern region of Ethiopia with cost of energy $0.401/kWh. Since the solar resource potential of the site is high 95% of the energy is produced from solar array and 5% from diesel generator. The energy storage system and inverter should be replaced two times during project period. However, the last time replacement of the battery occurred in 24th year from 25 year of total project life time salvage value of around $90,000 left at the end of project period. As seen from the simulation result the designed system can provide 24 hour electricity for the village without interruption.

The cost of energy (COE) of the optimal system is higher than the current grid price of electricity, which is highly subsidized by the government. In this simulation we did not consider any subsidy from the government.

However, if we consider the Economic and social values that stand alone hybrid system brings to community this system is still feasible in comparison with grid extension to remote site, which is far away from access to grid line and its is more reliable with high quality of Electricity when compared to stand alone PV system.

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