International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869 (O) 2454-4698 (P), Volume-3, Issue-10, October 2015

Photovoltaic-Diesel Hybrid Power system for Rural Electrification in Ethiopia - Way forward for sustainable development [Case Study for Guaguata Village]

Desta Goytom, Muluwork Kahsay

***Abstract* - The focus of this paper is to design and model an optimal hybrid power system from the technical and economic view to meet the load requirements of rural sites which are detached from main national electric grid by taking Guaguata kebele near to Bahirdar, Ethiopia.**

Rural villages in Ethiopia utilize bio mass as main energy sources for cooking uses. However, due to hardship to women and its contribution to the rapid deforestations of the country, biomass sources need to be replaced by other renewable resources. On the other hand, though substantial effort has put to improve agricultural productivity, there exists shortage of food products in the country which cause quality of life to be poor. Irrigation and mechanized agriculture are believed to be the main solution for such extended problems in the rural communities. Utilization of fossil fuel for irrigation purpose is not advisable as Ethiopia depends on fuel imports from untrustworthy foreigners.

For a large community with families clustered around a small area, provision of power from the main grid is an excellent and the best alternative. Unfortunately, in rural areas , where the houses are scattered over a large area the proposition of power generation and distribution using the above mentioned techniques consume a lot of resources ; Consequently becomes unaffordable and expensive. This paper attempts to fill the gap PV-based hybrid system, using solar / diesel generator, is an alternative to deal with this barrier and supply electricity to rural areas that is far from the grid. Qualitative and quantitative analysis methods were employed in the research.

During collection of the solar intensity potential row data of the site: National metrological service agency (NMSA), NASA satellite and universal instrument pyranmometer were used. The quadratic and the linear Angstrom regression equations have been used to calculate the monthly average values of solar radiation from the sunshine hour. The results have been compared to internationally accepted NASA satellite data derived from software called homer from National Renewable Energy Laboratory using Mean Square Error (MSE) method which is based on the arithmetic mean value. In this study the linear Angstrom Equation has been the best fit with Mean Square Error compared to quadratic Angstrom equation derived data. Linear Angstrom equation derived data and homer synthesized data are used to reasonable anticipate the solar insolation of the unmeasured months of the year.

Beside it has also been calculated the electrical load demand of the community in reasonably way.

After input data collection and analysis; based on analytical computer simulation method, the hybrid power systems have been designed and modelled The results showed that diesel integrated photovoltaic systems are cost effective in many areas are distant from utility grid where is power supply from conventional sources is impractical or costly.

Furthermore, practicing the PV-hybrid system in the rural sites can alleviate the poverty by improving productivity, health and narrows the living style difference between of urban and rural; meets the goal to the Earth summit of June 2012, which says, countries need to increase the amount of renewable energy consumption throughout the world to 15 percent of total electricity consumption by 2020.

***Index Terms*— rural electrification, homer, hybrid photovoltaic, pyranmometer.**

Desta Goytom, School of Mechanical Engineering, Jimma University/ institute of Technology, Jimma, Ethiopia, Mobile No. +251911530887

Dr. Muluwork Kahsay, School of Mechanical Engineering, BahirDar University/ institute of Technology, BahirDar, Ethiopia, Mobile No. : +251-911- 793-94

I. INTRODUCTION

Ethiopia is one of the largest and the second populace country in Africa with a total land area of 1.126 million square kilometers and a total population of about 80 million. It has a demographic annual growth rate of 3.6%. Out of the total population, 85% lives in the rural area while 15% in urban and semi-urban settlements. The country is still among the least developed for which about 45 % of the population live below poverty line. Agricultural export **[2]** is critical to the economy and accounts for 47% of the GDP. Thus the rural population plays a central role in the country's economy.

Because of the crucial role it plays in economic and social development energy has been accorded special consideration in any country's transformation and growth development.

There is a strong link between energy and Development. Those countries with high consumption of energy are all highly developed. The reason is that all economic and social development undertakings need and use energy.

Different research works **[3, 4, 5- 21]** have been performed by different researchers in the area of energy resources. Because renewable energy resources do not cause environmental pollution and climate change (as is the case with oil and coal it is believed they would be the main energy sources of 21st century if both developed and underdeveloped worlds have given due attention to their development and exploitation.

Ethiopia is blessed with hydroelectric, solar, wind and geothermal renewable energy resources. Unfortunately, however, the sad fact is that there isn't any renewable energy resource that has been developed other than big hydroelectric power plants. Recently of the renewable energy resources available only geothermal and wind energy resources are under practice. But still having all potential, however, there is no project dedicated to the extensive development of renewable energy resources except for the sole pilot project undertaken by the Ethiopian Rural Energy Development and promotion Center **(EREDPC) [1].**

The Ethiopian Electric Power Corporation (**EEPCO**), the sole electric power producer in the country, currently generates around 2000 MW where it comes from two different power supply systems, namely, the Inter-connected system (**ICS)** and Self Contained System (**SCS**). ICS is mainly supplied from hydro-power plants as well as geothermal (steam). Whereas, SCS consist of mini hydro-power plants and a number of isolated diesel generating units widely spread all over the country. It is expected to reach the total power generation nearly to 3000 MW after the completion of the started hydropower plants. When we are looking for alternative resources, renewable energy may offer an ideal source of electricity for the remote areas which are far from national grid line. Application of renewable energy technologies for rural electrification is increasing in recent years, but is not very extensive. Nowadays as an option for providing power, solar photovoltaic (PV) is gaining popularity, though its high initial cost is a major barrier for its prevalent use.

In Ethiopia the appropriate energy mix should be accorded serious attention considering the current drought and the power shortage we have been facing now and then in the past years. The fact in Ethiopia, that 94 % of the country's electric power generation relies on water resources is a clear indicator of the serious crisis the country would have faced had protracted drought set in. consequently, of the electric power plants we have ,some of them must use solar energy resources other than water.

The main intention of this paper is to show an optimal photovoltaic–diesel hybrid power system model from the technical and economic view to meet the load requirements of rural sites which are detached from main national electric grid by taking Guaguata kebele as a case study base.
The worth of hybrid photovoltaic–diesel system has been evaluated with regards to its size, operational requirements, cost, etc. Throughout this study National Renewable Energy Laboratory's (NREL) and micro power optimization model software has been used to perform the techno-economic feasibility of hybrid photovoltaic–diesel power systems.

II. METHODOLOGY AND DATA ANALYSIS

Yinsa is one of rural village which is found in near to Bahirdar City. It is 10km far away from Bahirdar.
Its area is estimated to be 5640 m^2 and a village community of nearly 1395 families, which encompass 6975 people in total. The geographical location of village is similar to Bahirdar, having a latitude, altitude and elevation 11.36°N, 37.23°E and 1920 m above sea level respectively. The average daily temperature of the village is 27°C minimum and 32°C maximum. The village has also three sub-kebeles such as Yinsa, Achaber and Guaguata. Among these kebeles, Guaguata keble has been taken as model kebele to study photovoltaic hybrid power system as per their electric power demand of the population.
The Guaguata's community is about 201 households, which take in 1206 people in total. This kebele contains one church and one elementary school. The community is primarily using kerosene, candle and dry cells for lighting.

Fig 1. Pictorial representation of village

In this study, it has been taken sunshine hour data for determination of solar energy using empirical formulae for the selected site, from National Metrological Service Agency (NMSA) for analytical calculation use. The monthly average values of solar radiation have been determined from the sunshine hour using the quadratic as well as the linear Angstrom equation. Furthermore, a direct measurement of solar radiation was provided on the selected site using Fig 2 pyranometer apparatus.

Fig 2. Pictorial representations of DL2e Data Logger and pyranmometer

After doing so the result of the given site has been compared to internationally accepted data derived from software called Homer from National Renewable Energy Laboratory (NREL) and with direct measurement of solar radiation using pyranometer. The data shown in Table 1 is the daily radiation that has been obtained using homer by inputting the altitude and latitude of the studied site.
The monthly average values of solar radiation from the sunshine hour using the quadratic as well as the linear Angstrom equation and from homer has been depicted in Table 2 **[22].**

Table 1. Daily average solar irradiation results using homer

Months	**Daily average solar radiation,** kWh/m^2/day
January	5.955

February	6.227
March	6.626
April	6.676
May	6.248
June	5.667
July	5.054
August	5.253
September	5.884
October	5.964
November	5.989
December	5.697

Table 2. Daily Average solar radiation Results (kWh/m^2)

Months	H quadratic	H linear	H homer
Jan.	5.687034	5.807357	5.955
Feb.	6.209316	6.276168	6.227
Mar.	6.647054	6.517721	6.626
Apr.	6.855869	6.655825	6.676
May	6.693218	6.428526	6.248
Jun.	6.12089	5.926369	5.667
Jul	4.812395	5.268394	5.054
Agu.	4.855791	5.307589	5.253
Sep.	5.983745	5.811412	5.884
Oct.	6.254316	6.07525	5.964
Nov.	5.803053	5.88717	5.989
Dec.	5.510778	5.69765	5.697

The daily average solar insolation results data using pyranometer, linear regression and homer has shown in the Fig 3 below.

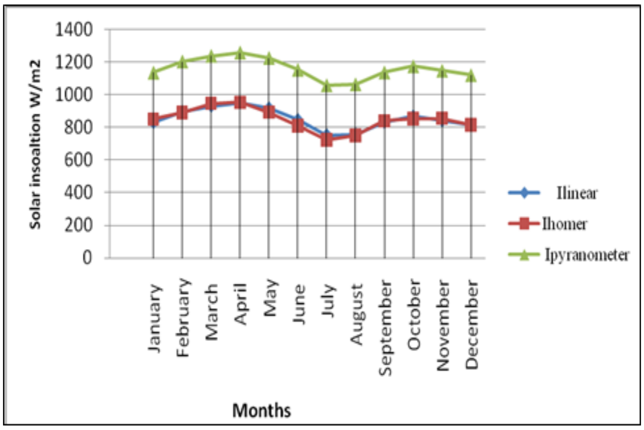

Fig.3. Daily average solar insolation results data using pyranometer, linear Regression and homer

Once it has been determined the solar radiation data of the given site, in the next step to estimate the electrical load demand of the community which is the most significant steps in the design of a hybrid system. The two types of loads (*primary and deferrable*) have been treated. Primary load that must be met immediately, whereas deferrable load is the load that must be met within a certain time frame (although the exact timing is not important).

Used data to forecast the accurate load demand of the community are: *the number of household living in the village, the total irrigated area in hectare, the minimum and maximum suction head of the site, the type of crop growing on the site, the daily consumptive water requirement of crops per hectare and the daily consumptive power requirement of energy in the village.*

The type and power rating of the electric appliances that are supposed to be used by the community are given in Table 3. These data help to estimate all the power required by the household and institution in the site.

Table 3. Typical wattage requirements for electric appliance

Types of electric appliance	Power ratting in Watt
Compact fluorescent	14 watt
Radio receiver/Caste player	15 watt
14” color television	50 watt

The energy demand requirement of the households in the given village is different depending on their current economic status. Therefore, the community is classified in to three categories according to their energy demand size as is shown the Table 4. Table 5 shows the daily energy demand of the institutions in the studied site.

Table 4. Household Energy Demand Size of Guaguata Keble

Electrical Appliances	No. of house holds	Use Hours per day	System size [Watt]	Daily power use of household [Wh/day]
2 bulb + Radio\ Caste player	101	5 hr	43	21,715
3 bulb + Radio \Caste player	70	5 hr	57	19,950
4 bulb + Radio\ Caste player +14" color TV	30	5 hr	121	18,150
Total	**201**		**221**	**59,815**

Table 5. Institutions’ Energy Demand Size in Guaguata Keble

Institutions	No. of institutions	Watt	Use hours per day	Daily Energy Use (Wh/day)
Church	1	120	4hrs	480
School	1	220	4hrs	660
Total	**2**	**340**		**1140**

Hence, on a daily and hourly basis 30 % of power level has been added to the calculated load in order to randomize the load profile and make it more realistic by considering the future population increment and load demand increment. Therefore, total daily energy consumption for the community of families increases to *87.04l5 kWh*. And the annual peak load will be *29 kW*.

The following section describes the various inputs utilized in the HOMER model. The specifics for all the equipment considered for each power system schematic is listed and the resources of fuel supply and solar data are given which have been analyzed previously.

In the optimization process, Table 6, various sizes of power inverters, PV modules, diesel generators, and batteries were included in the search space of the program.

Table 6. Technical data of PV, diesel units, batteries and inverters

PV-Diesel Components	**Data**
PV	
Capital cost	4000 $/kW (maximum)
Model	Kyocera KD210GX-LPU 210 watt
Length x Width x Depth	59.1in x 39in x 1.8in
Weight	39.7lbs
Life time	25
Diesel Generator units:	
Diesel type	Model BCJD 40-60SP
Maximum (Standby)power Output	40 kW
Continuous (Prime) power Output	36kW
Full load fuel consumption	11.1 Lit /h
Minimum load fuel consumption	6 Lit /h
Batteries	
Type of batteries	Surette 6CS25P
Nominal voltage (V)	6V
Nominal capacity	1156Ah
State of charge (SOC)	40%
Nominal energy capacity of each batter (V*Ah/1000)	6.94kWh
Inverters	
Inverter type	Sunny Island 5048U
Capital cost	715$/kW
Efficiency/power consumption	95.00%

After all the inputs utilized in the HOMER model for the Guaguata kebele, the complete HOMER's graphic user interface that specify the total load requirements and all components of micro power system such as diesel generator, PV, converter and battery has been depicted by the following schematic diagrams Fig 4.

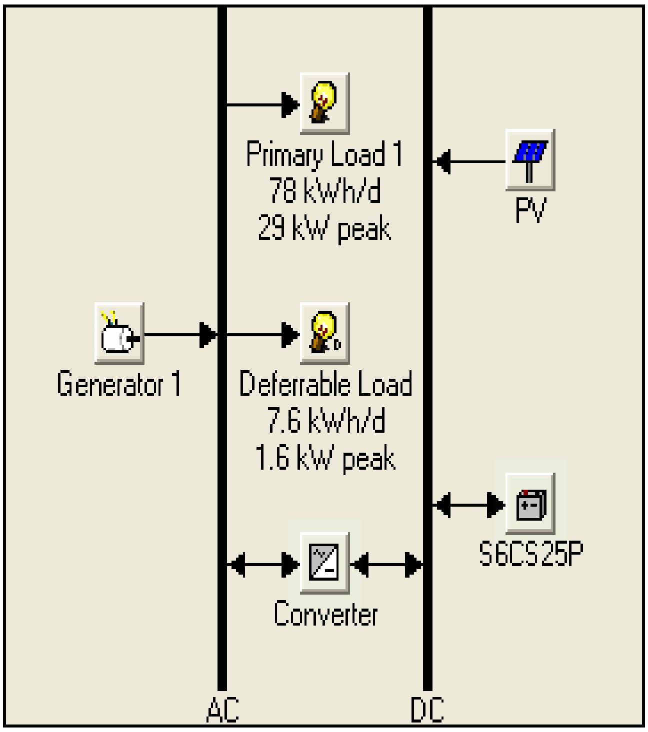

Fig.4 HOMER diagram for the hybrid PV Generator Battery converter set up

III. RESULTS AND DISCUSTIONS

This model was run repeatedly using different values for the most important variables and as a result a list of optimal combinations of PV, generator, converter, and battery are provided, which could be implemented as a hybrid system setup that fulfill the given requirement . The results are displayed in either of two forms; an overall form in which the top-ranked system configurations are listed according to their net present cost and in a categorized form; where only the least-cost system configuration is considered for each possible system type. Table 7 shows a list of the possible combinations of system components in the overall form. And, Table 8 shows a list of the possible combinations of system components in a categorized form.

The following tables (7 and 8) have been generated based on inputs selected from the input summary Table 6: 0.781$/lit for diesel price, cost of PV is 4 $/W. The diesel price is the current price for diesel oil in the country. Interest rates are assumed to be 6.0 % and project lifetime is 25 years. With regard to the generator, selected from locally available capacities, 32 kW and 36kW, the 32 kW generators has been found to be the most cost effective. As the list is long, part of it has been cut retaining only those of greatest interest.

Table 7. Overall optimization results according to net present cost (NPC).

PV kW	Gen kW	Bat. No.	Conv. kW	Display strategy	Initial capital $	Total NPC $	COE $/kWh	Ren. Frac t.	Diesel Lit.	Gen hr.
0	32	-	-	CC	8,825	143,490	0.359	0.00	12,505	1825
1	32	-	1	CC	13,541	143,535	0.359	0.08	12,012	1825
1	32	-	2	CC	14,257	144,486	0.362	0.08	12,011	1825
2	32	-	1	LF	17,541	145,039	0.363	0.16	11,762	1825
2	32	-	2	LF	18,257	145,373	0.364	0.16	11,700	1825
1	32	-	4	CC	15,689	146,405	0.367	0.08	12,011	1825
2	32	-	1	CC	17,541	146,453	0.367	0.15	11,904	1825
2	32	-	2	CC	18,257	146,748	0.367	0.15	11,837	1825
2	32	-	4	LF	19,689	147,281	0.369	0.16	11,699	1825
2	32	4	1	LF	21,141	147,333	0.369	0.16	11,437	1825
2	32	4	2	LF	21,857	147,864	0.370	0.16	11,394	1824
2	32	-	4	CC	19,689	148,656	0.372	0.15	11,836	1825
3	32	-	1	LF	21,541	149,039	0.373	0.22	11,762	1825
1	32	4	1	CC	17,141	149,079	0.373	0.08	12,012	1825
3	32	-	2	LF	22,257	149,228	0.374	0.22	11,685	1825
1	32	-	7	CC	17,837	149,282	0.374	0.08	12,011	1825
3	32	4	2	LF	25,857	149,696	0.375	0.23	11,177	1825
2	32	4	4	LF	23,289	149,776	0.375	0.16	11,394	1825
1	32	4	2	CC	17,857	149,976	0.375	0.08	12,007	1825

The most cost effective system, i.e., that with the lowest net present cost, is the stand alone generator 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 $143,490, the cost of energy (COE) is 0.359 $/kW h, there is no contribution from renewable resources, the amount of diesel oil used annually is 12,505 litter and the generator operates for 1825 hr/year. The advantage of this solution is that the net present cost is the lowest, but renewable resources in no way contribute to the energy supply. Of those compared, the second most cost effective system is the PV-generator-converter setup, with the generator operating with 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 $143,648, the cost of energy (COE) is 0.360 $/kW h, the amount of diesel oil used annually is 12,024 lit and the generator operates for 1825 hr during the year. Again with this scenario, the part contributed by renewable resources is rather small, being only 8%.

Table 8. Optimization results, in a categorized form, ranked according to the NPC of each system type.

PV kW	Gen kW	Bat. No.	Conv. kW	Display Strategy	Initial capital $	Total NPC $	COE $/kWh	Ren. Fract.	Diesel Lit.	Gen hr.
-	32	-	-	CC	8,825	143,490	0.359	0.00	12,505	1825
1	32	-	1	CC	13,541	143,648	0.360	0.08	12,024	1825
2	32	2	1	LF	19,341	145,456	0.364	0.16	11,526	1825
-	32	2	1	CC	11,341	147,280	0.369	0.00	12,510	1826
5	32	8	4	LF	38,889	158,010	0.396	0.36	10,462	1823
15	32	40	23	LF	121,293	163,679	0.410	0.92	1,684	328
19	-	50	28	CC	141,048	176,852	0.443	1.00	-	-

Further down in the list, there is a system comprising a PV-generator-battery-converter setup. For this setup the proportion from renewable sources is increased from 8% to 36%, with only a minor increase of 9.61 % in the cost.

As we can see, the net present cost (NPC) is $158,751 and the COE is 0.397 $/kW h. Here on this setup all the electrical energy demand has been supplied and there is no unmet load and shortage of electrical energy as it shown on the Table 9. However, the contribution made by renewable resources is not quite much.

Table 9. Relationship between of electrical energy consumption and supply

Load	Consumption (kWh/yr)	Fraction
AC primary load	28,470	91%
Deferrable load	2,774	9%
Total	31,244	100%

Quantity	Value	Units
Excess electricity	3,366	kWh/yr
Unmet load	0.0000248	kWh/yr
Capacity shortage	0.00	kWh/yr
Renewable fraction	0.358	

Again further down in the list, there is also PV-generator-battery-converter setup. For this setup the proportion from renewable sources is increased from 36% to 92% with only a minor increase of 6.58 % in the cost. At this setup also, all the electrical energy demand has been supplied and there is no unmet load and shortage of electrical energy similar to the above set up.

This could be a good alternative for implementation as the contribution made by renewable resources is quite significant. The cost summary of PV-generator-battery-converter setup with having 92% renewable fraction has depicted in Fig 5 and Table 10.

Report – MODELING
92% Renewable fraction

Diesel Price:	0.781 $/L
PV Capital Cost Multiplier:	1
PV Replacement Cost Multiplier:	1

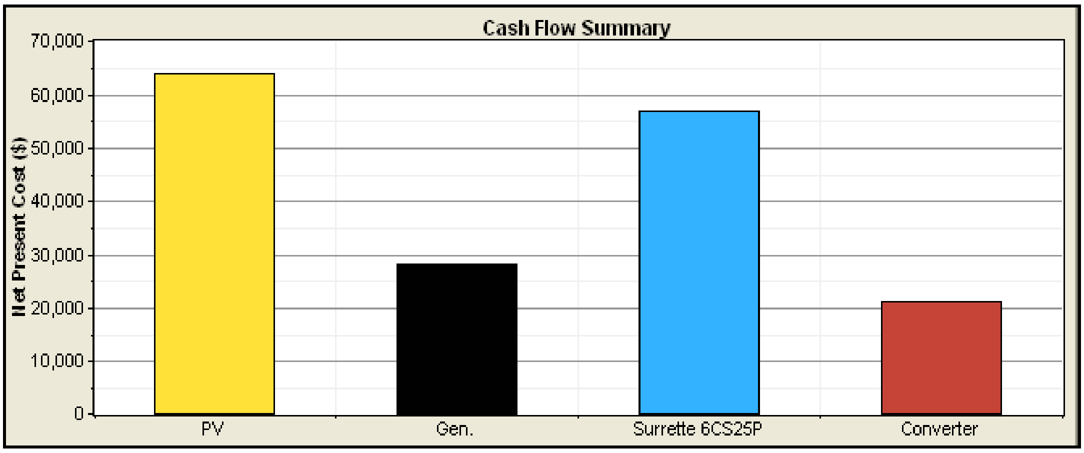

Fig 5. Cost summary for a 92% utilization of renewable resource

Table 10. Net present cost of the system setup

Components	Component Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	64,000	0	0	0	0	64,000
Generator	18,825	0	1,659	18,434	-911	28,008
Surrette 6CS25P	36,900	16,929	7,862	0	-4,860	56,830
Converter	15,752	6,573	0	0	-1,223	21,101
System	125,477	23,501	9,521	18,434	-6,994	169,939

SENSITIVE ANALYSIS

Sensitivity analysis has also been carried out; the main objective this analysis is to deal with uncertainty which will be created by the input variables variation in the future. For instance the price of PV and diesel has been taken here. The current maximum PV price is assumed to be $4000/kW and the minimum $1200/ kW, assuming a future fall in price. And the current price of diesel oil in the country is 0.781 $/lit and assuming that the price will increase to 1$/lit in future. Therefore, Table 11 bellow illustrates the respective sensitivities of the PV capital cost multiplier to the price of diesel.

Table 11. Sensitivity of PV cost to diesel price for feasible optimal system types

Diesel $/Lit	PV Cap. Multi.	PV kW	Gen. kW	Batt. No.	Conv. kW	Disp. Strgy.	Initial Cap. $	Total NPC	COE $/kWh	Ren. Frac.	Diesel lit.	Gen. hr.
0.781	1.00	-	32	-	-	CC	8,825	143,490	0.359	0.00	12,505	1,825
0.781	0.80	1	32	-	1	CC	12,741	142,848	0.358	0.08	12,024	1,825
0.781	0.50	19	32	41	24	LF	100,909	135,636	0.340	0.97	924	185
0.781	0.30	20	32	40	24	LF	86,009	119,707	0.300	0.97	875	176
1.000	1.00	17	32	43	24	LF	132,709	173,997	0.436	0.95	1,141	225
1.000	0.80	17	32	43	24	LF	119,109	160,397	0.402	0.95	1,141	225
1.000	0.50	20	-	50	30	CC	106,480	138,080	0.346	1.00	-	-
1.000	0.30	20	-	50	30	CC	90,480	122,080	0.306	1.00	-	-

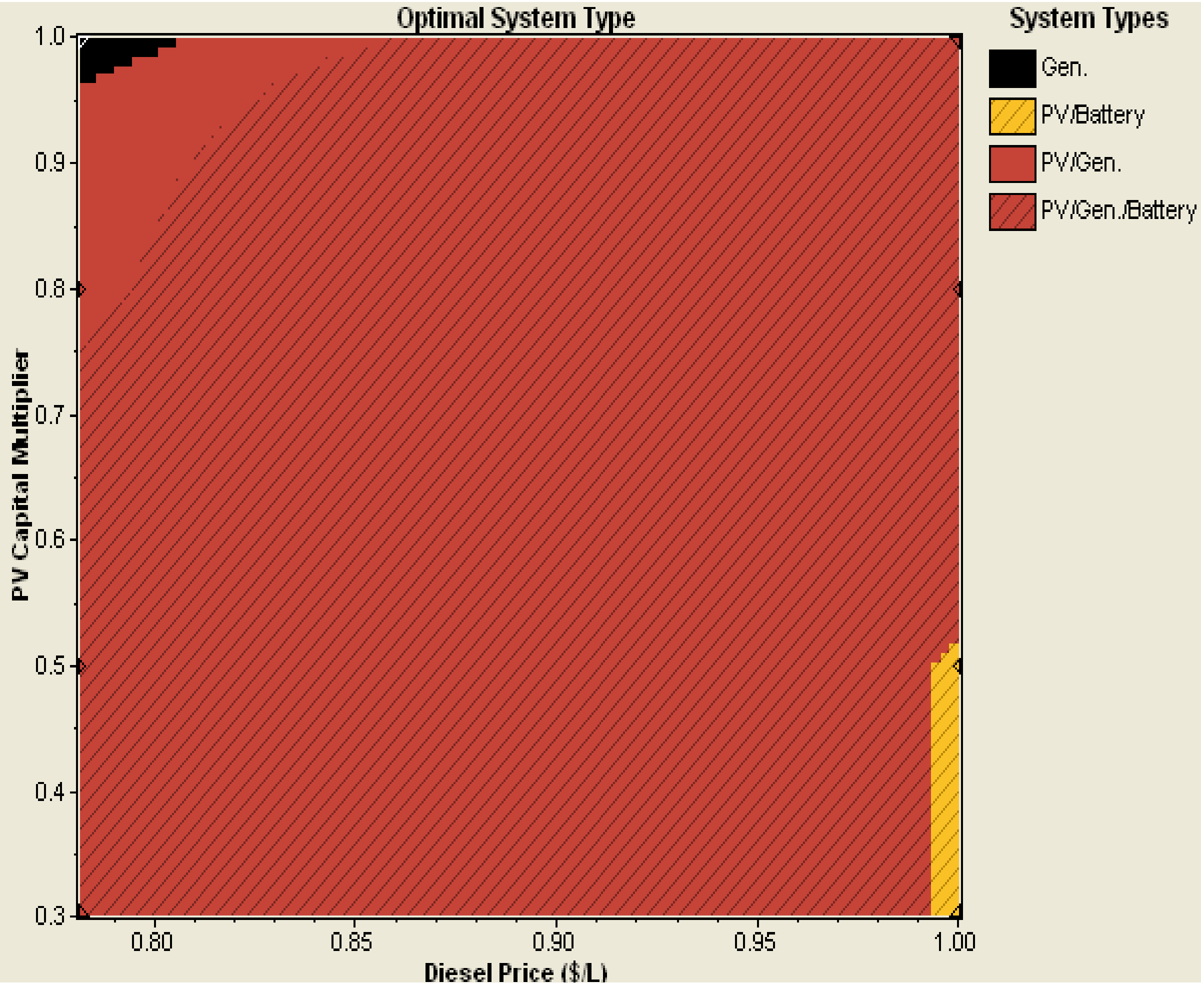

Fig. 6. Sensitivity of PV cost to diesel price for feasible optimal system types

A figure 7 shows the amount of CO_2 emission releases to the environment for different kind of energy system. When the energy system contains much renewable fraction (i.e. the black colour on the figure), it is clearly seen that the amount CO_2 emission released to our environment is decreasing zero level. On the other hand, when energy system contains less or no renewable energy (i.e. red, orange, and pink colours on the figure), the amount CO_2 emission release into the atmosphere is increasing to high level.

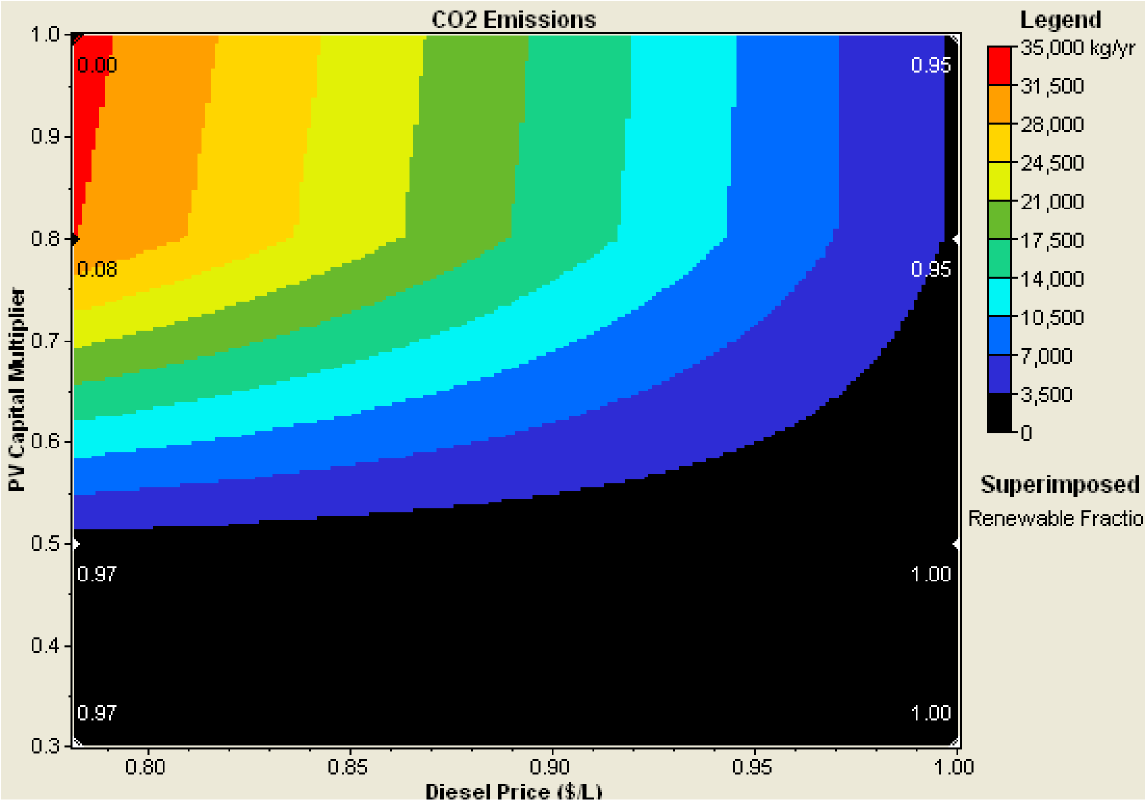

Fig.7. Sensitivity of PV cost to diesel price for CO2 emission superimposed with renewable fraction

Summarizing, based on the data given in Table 6, the simulation was run and the results show numerous possibilities for implementable setups with different levels of renewable resource utilization. Table 12 shows the better optimal energy systems that possible to be implemented from numerous possibilities of setups that obtained by homer simulation process.

Table 12. Summary of the optimal power systems model

Model Type	Initial Capital	Total NPC	Payback Period Years	COE $/kWh	Renew fraction	Fuel Lit.	Unmet load %	Emission level of pollutant CO_2 Kg/yr
Standalone Diesel Generator	8,825	143,490	23	0.359	0	12,505	0	32,928
PV-generator-battery-converter -1	38,889	158,751	9	0.396	0.36	10,462	0	27,745
PV-generator-battery-converter -2	121,293	163,679	8	0.410	0.92	1,684	0	4,862
Standalone PV System	141,048	176,852	7	0.443	1.00	0	0	0

As can be seen in the table above, the most cost effective system is the standalone diesel generator setup, with a total net present cost of $143,490; however, this setup does not include a contribution from renewable resources. Other attractive setups from the list are those with a 36%, 92% and 100% utilization of renewable resources. For the setup with a 36% utilization the net present cost is $158,751 and the levelized cost is 0.396 $/kW h. This is only an 8% increase in cost but it achieves a 36 % use of renewable. For this system there is no unmet demand, no shortage of capacity and excess electricity generation of only 9.6%.

For the setup with 92 % utilization of renewable resources the net present cost is $163,679 and the levelized cost of energy is 0.410 $/kW h. The cost increase over the 36% utilization is minor increase of 9.61 %. Again with this system, there is no unmet demand, no shortage of capacity and only 12.5% excess electricity.

For the setup with 100 % utilization of renewable resources the net present cost is $176,852 and the levelized cost of energy is 0.443$/kW h. The cost increase over the 92 % utilization is minor increase by about 8%. Again here with this system, there is no unmet demand, no shortage of capacity and 17.68 % excess electricity.

Considering the emission levels of pollutants such as CO2, CO, SO2, and NOx, the last two systems produce more than less half that of the earlier option. In addition, in view of the payback period of the systems models which encompass the renewable energy have fast payback period comparing to the stand alone diesel system.

As can be observed, the net present cost has to be balanced against the desire to move towards the use of renewable energy. The benefit of such a move cannot be easily expressed in terms of cost. However, the price for diesel oil is increasing over time, while that of PV and the other system components is expected to fall. Under such circumstances, and considering the minor difference in cost suggested by this analysis, it seems realistic to defend the choice of an option which includes much renewable energy source.

PHOTOVOLTAIC-DIESEL HYBRID POWER SYSTEM LAYOUT

Therefore the researchers has recommended the single-phase, two-wire line configuration on basis of our country's nominal voltage (i.e. 220V for domestic customers) and its benefits in the case of light loaded.

In addition, the mounting structure of PV arrays has also been suggested by the researcher to be made locally using angle iron metals which is equivalent to the depth of the PV panel. The depth of PV panel that has been chosen is 44.1mm. Therefore the angle iron specification that to be used here is 6m×0.050m×0.050m so that it can hold PV array in appropriate way. The orientation angle of the mounting structure should be the same to the latitude of the given site. Figure 8 shows as one option of single-phase line PV-hybrid power system installation for cluster villagers.

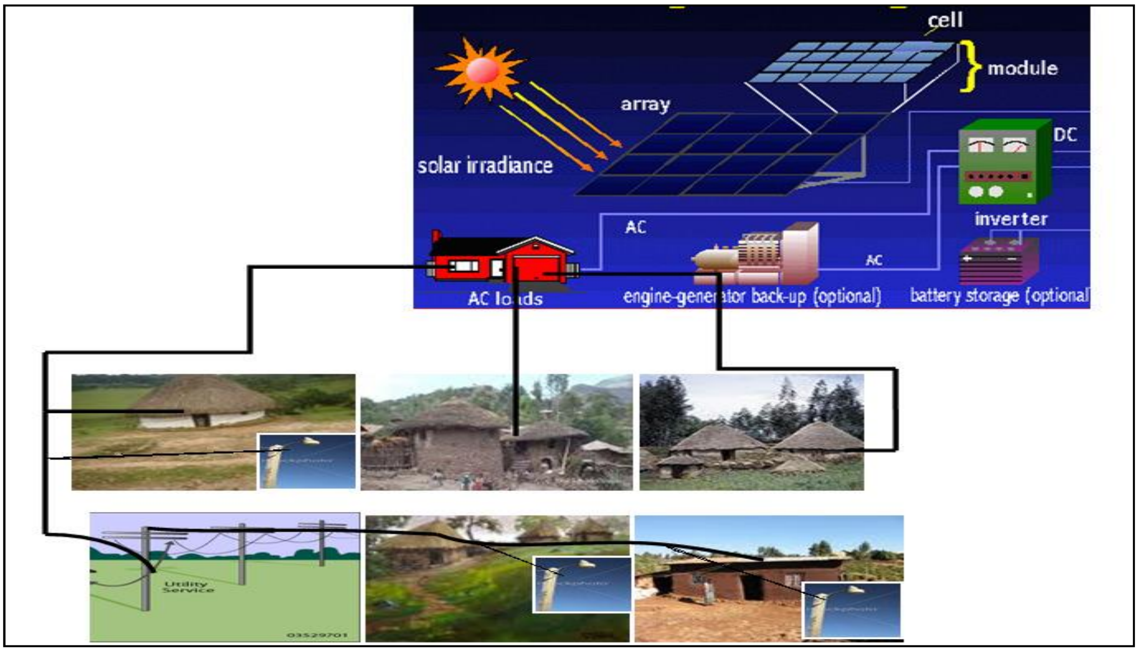

Fig 8. Schematic representation of single-phase line configuration of PV-diesel hybrid Power system

The second installation option that serves for dispersed villagers whose houses are a little far from power house has depicted in Fig 9.

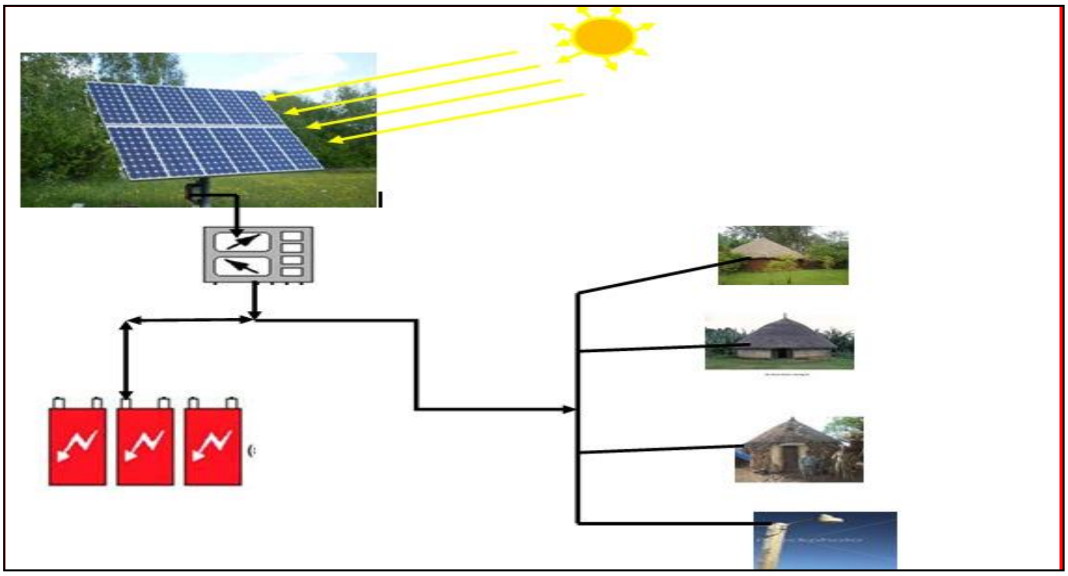

Fig 7. Schematic representation of PV installation for Gojo houses far from power house

IV. CONCLUSIONS AND POLICY IMPLICATIONS

Policy Implications:

A number of implications can therefore be extracted from these research findings thus the government needs to revisit its energy policy to devise an appropriate policy frame work that addresses the problem faced by the energy sector.

1) Out of 85% of the rural population, only 1% has access to electricity. Their isolated settlements and low income makes it unrealistic for the grid extension to reach them in the near future. Thus, the villagers have to rely on kerosene and traditional fuel wood biomass to meet their energy demand, both for cooking and lighting. This unsustainable use of energy has for long been damaging to the environment and the human life. Utilization of pv-diesel based hybrid system and related other small scale energy sources tackle the problem.

2) In view of the fact that the government alone cannot afford electrifying rural areas of Ethiopia where 85% of the total population reside, maximum effort must be exerted to transform the prevailing attitude towards the private investors, help and facilitate the private sector participation in rural off grid electricity supply in all possible ways beyond designing of energy policies

3) The quest for safe, secure and sustainable energy poses one of the most critical challenges of our age. We have an addiction to fossil fuels, and it's not sustainable. The developed /underdeveloped world gets high percent of its energy from fossil fuels... And this is unsustainable for two reasons. First, easily-accessible fossil fuels will at some point run out, so we'll eventually have to get our energy from someplace else. Second, burning fossil fuels is having a measurable and very probably dangerous effect on the climate. Avoiding dangerous climate change motivates an immediate change from our current use of fossil fuels. Utilization of PV-Diesel based hybrid power system supports well the Government legacy towards green economy.

4) If the effort is extended in sustainable basis over and above helps to reduce the destruction of forests also prevents health problems respiratory infections associated with exposure to smoke from fuel /wood.

5) Applying the PV-diesel based hybrid system saves time irrigation pumps on gathering fuel wood cow dung and grain grinding an also for fetching water and similar activities, secures the environment by cutting the waste of fossil fuel, provides light, electricity, could be used for running drinking and irrigation pumps, operating cottage industries and equipment in the health and education institutions in the rural areas.

6) In countries like Ethiopia where a great major of the population live in the rural areas, it is only by constructing small scale power plant that one could provide electricity to every house hold or village. For this purpose, none is better suited renewable energy resources. It is possible for e.g. to provide areas with electricity power using solar lanterns. Similarly it is possible to use solar water pumps for the supply of potable water for humans and animals and also for irrigation. It is also possible to use solar stoves for cooking food, and solar water heater that can be mounted on roof tops for heating water. Having all this potential however there is no project dedicated to the development of renewable energy resources except EREDPC. For which the government should accord more attention in the future strengthening the recent legacy of the country towards the renewable energy. Ethiopia requires its Energy training center so our Government should designed an effective mechanism towards small scale power growth parallel with the ongoing hydropower sector.

V. CONCLUDING REMARKS:

The present work has been devoted to study PV-diesel hybrid powers system for rural electrification detached from the national main grid where supply of power from grid is impractical or extremely costly.

The major conclusions that can be drawn from this work as follow:

1) The hybrid PV-diesel power system offers several benefits such as: utilization rate of PV generation is high; load can be satisfied in the optimal way; accelerate rural access to electricity, diesel efficiency can be maximized; diesel maintenance can be minimized; reliable power supply; and a reduction in the capacities of PV, diesel and battery (while matching the peak loads) can occur. This is in addition to an improvement in the quality of life for many that are living in remote areas.

2) Also investments in mobilization of PV systems may stimulate/gear up the local economy (in a long-run) by exploitation of available local resources. The present work shows that the potential of solar energy cannot be overlooked.

3) More importantly, with use of this hybrid system, about more than 5183 kg /year of carbon emissions can be avoided entering into the local atmosphere. So it has great contribution in reduction of environmentally polluting emissions gases.

4) The findings of this investigation can be employed as a frame-of-reference in designing of hybrid PV-diesel-battery systems and other possible hybrid power systems for other locations having similar climatic and load conditions.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the collaboration of officers in the Yinsa village and National Metrological Service Agency (NMSA) in providing of essential data for the site.

Last but not least, the authors also acknowledge all the authors of references that have been given in this work.

REFERENCES

[1] Solar and Wind energy Utilization and Project Development Scenarios, Country Background information, Ethiopian Rural EnergyDevelopment and Promotion Center, October 2007

[2] Zelalem Alemu Habtemariam**,** Renewable Energy Support Policy Options for Sustainable Development: Using the Analytic Hierarchy Process: The case of Rural Ethiopia. Delft University of technology, 2006.

[3] Nayar CV, Phillips SJ, James WL, Pryor TL, Remmer D. Novel Wind/diesel/Battery Hbrid Energy System. Solar Energy 1993; 51(1):65–78.

[4] Elhadidy MA, Performance Evaluation of Hybrid **(**Wind/solar/diesel) Power systems. Renewable Energy **2002**; 26(3):401–13.

[5] Hansen U., Technological Options for Power Generation. The Energy Journal 1998; 19(2):63–87.

[6] WEC, 2004 Survey of Energy Resources, 20 ed. 2004: World Energy Council.

[7] GEC, Solar Photovoltaic Power Generation: EnvironmentalTechnology Database in 21st century, Osaka, Japan; 2004.
[8] Infield DG, Wind Diesel Design and the role of short term flywheel Energy Storage. Renewable Energy **1994**; 5(1–4):618–25.
[9] Wichert B. PV-diesel hybrid energy systems for remote **area** power generation a review of current practice and future developments. Renewable and Sustainable Energy Reviews 1997; 1(3):209–2.
[10] Dufo-Lopez R, Bernal-Agustin JL, Design and control **strategies** of PV-diesel systems using genetic **algorithms**. Solar Energy 2005 79(1):33–46.
[11] Fortunato B, Mummolo G, Cavallera G. Economic optimization of a wind power for isolated locations plant. Solar Energy 1997; 60(6):347–58.
[12] Raja IA, Abro RS. , Solar and wind energy potential and utilization in Pakistan. Renewable Energy 1994; **5**(1–4):583–6.
[13] NH, Overview of wind/diesel systems. Renewable Energy 1994; 5(1–4):595–617.
[14] Lundsager P, Bindner H. A simple, Robust & Reliable Wind Diesel Concept for Remote Power Supply, Renewable Energy 1994;5(1–4):626–30.
[15] Yu H, Pan J, Xiang A. A, multi-Function **Grid**-Connected PV system with Reactive Power Compensation for the grid. Solar Energy 2005; 79(1):101–6.
[16] Traca A, et al, Source Reliability in a Combined Wind-Solar-Hydro System. IEEE Trans Power Apparat System 1983; 102(6 (June)): 1515–20.
[17] Chowdhury BH, Saifur R. Analysis of **Interrelationships** between Photovoltaic Power and Battery Storage for Eutility Load Management IEEE Trans Power System 1988; 3(3):900–7.
[18] Frances Drake and Yacob Mulugetta, Assessment of Solar and Wind Energy Resources in **Ethiopia**. Solar Energy, School of Geography University of Leeds, and Leeds LS2 9JT, U.K. May 1996.
[19] Bekele Baissa, The Energy Dimension in food security Proceedings of the food security conference, 2003, UNCC, Addis Ababa, August 2003.
[20] Muluwork Kahsay, Techno -Economic Analysis of Solar Thermal Energy Systems. Proceedings of the **EEA** 2011, IX International Conference on the Ethiopian Economics AddisAbaba, 2012(3):199-211.
[21] Desta Goytom., Feasibility Study on PV-Diesel Hybrid Power System for Rural Electrification: Guaguata Village, MSc Thesis Work: Bahir Dar , Institute of Technology, 2010.
[22] Frances Drake and Yacob Mulugetta., Assessment of Solar and Wind Energy Resources in Ethiopia. I. Solar Energy, School of Geography, University of Leeds, and Leeds LS2 9JT, U.K. May 1996.

Desta Goytom Tewolde

Academic Background

B.SC. in Mechanical Engineering at Addis Ababa University Technology Faculty, Ethiopia, from November 2001 to August 2006

M.Sc. in Mechanical Engineering (***Thermal Engineering Stream***) at Bahirdar University Bahirdar Institute of Technology, Ethiopia, from April 2008 to June 2010.

Work Experiences

Jan 2013 – Present: Thermal Engineering Acting Chair holder at Jimma University, Jimma Institute of Technology, Ethiopia.

Nov. 2011- Present: Lecturer at Jimma University, Jimma Institute of Technology, Ethiopia.

Oct. 2010 - Oct. 2011: Lecturer at DebreBirhan University, Ethiopia.

Sept. 2009 - June 2010: Part Time Teacher at preparatory school parallel with my M.Sc. Study.

Sept. 2007- May 2008: Trainee and Senior Engineer in Edible Oil and Meat Processing Factories Erection.

March 2007-Sept. 2007: Junior Mechanical Engineer in Maintenance and Servicing of Earth Moving Machineries in Private Construction Company

Dr. Muluwork Kahsay (PhD),

Title: Ass. Professor and Chairman

Institution: Bahirdar Institute of Technology

Bahirdar University