Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

Energy Resource Potential Assessment for Solar Photovoltaic-Micro Hydro Hybrid Power Generation System.

(A case study for Jimma, Toli Kerso, Minko Village)

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***Abstract*— Renewable energy technologies offer clean, abundant energy gathered from self-renewing resources such as the sun, micro hydro, etc. Now days due to the ever increasing demand of electricity renewable energies becoming the best option for electrification especially for rural areas. This paper presents the resource assessment for the performance analysis and design of hybrid renewable energy combining micro-hydro and photo-voltaic system for the case study of Menko Toli Kersu kebele, Serbo Woreda. The solar energy resoyrce potential as well as the hydro resource potential including the solar insolation analysis and the flow duration studies are conducted for the case of Kersa rever and Minko Village are studied and the resurch results are presented, the result helps in the development of the solar PV-Hydro hybrid power generation system.**

Keywords—PV. Micro-hydro, Optimization flow; turbine; runner; flow rate, head, blades.

I. INTRODUCTION

The development of energy sector is a driving engine for promoting country's economy and the improvement of the living standard of the people. Access to modern energy, especially in rural, remote areas would help significantly to reduce poverty, to get better health care and education, to facilitate modern communication and information systems. Further, it will reduce city migration and depletion of fossil fuel resources and deforestation as well as pollutant gas emission to the environment. The development of renewable energy based on locally available resource should play a key role in this regard.

Ethiopia has a long tradition of using water driven mills. These mills are mainly used for grinding of grains in rural areas. More than 1000 of such mills were operational during the last century **[** HYPERLINK \l "Des125"[1], Most of them were abandoned without leaving any sustainable alternatives.

Ethiopia is one of the developing countries where more of the population live without access to electricity up to 2015 The World Bank International Development Association data indicated that only 35% of the total population have access to electricity [2]. Ethiopia has a huge renewable energy (micro-hydro power, solar, biomass and wind energy) potential that has not been used for rural electrification [3], the more noticeable benefits of usable electric power include; improved health care, improved communication system, a higher standard of living and economic stability. Unfortunately, many of the rural areas of Ethiopia haven't benefited from these uses of electricity in the same proportion as the more populated urban areas of the country. A major limitation to the development of many rural communities has been the lack of this usable electricity. Due to the remote location and the low population densities of the rural communities the traditional means of providing power have proven too expensive, undependable, difficult to maintain, and economically unjustifiable. Consequently, many of these communities remain without electricity and may never receive grid power from the utility [4].

The Small town of Menko Toli a village is one of those rural areas which have no access to electricity. The community requires electricity for house equipment like TV, Radio player, lighting and other. A hybrid PV and micro Hydro power generation system is proposed to supply electricity to a model community of more than 2,500 people and 630 households in the base year 2014, The hybrid power generation system (HPGS) is a system aimed at the production and utilization of electrical energy coming from more than one source, provides that at least one of them is renewable such as a system often includes some kinds of storage in order to satisfy the demand during the periods in which the renewable sources are not available and to decrease the time shift between the peak load and the maximum power produced. Power conditioning unit and controller to convert and control one form of energy to another [5].

The hybrid renewable for different regions and locations, climatic conditions, including solar irradiance, temperature and so forth, are always changing, in order to efficiently and economically utilize renewable energy resources of solar and micro hydro energy applications, the optimum much design sizing is very important for solar and micro hydro power generation systems with battery banks. The sizing optimization method can help to guarantee the lowest investment with reasonable and full use of the PV system and micro hydro system and battery bank, so that the system can work at optimum conditions with optimal configuration in terms of optimization techniques of hybrid PV and micro hydro systems

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

sizing have been reported in the literature using the HOMER optimization software. A stand-alone off grid solar and micro hydropower system consists of a charging system, battery storage system, a power conversion system [6].

Most of rural areas of Ethiopia are not yet electrified even though, 85% the country's population spread in this region. Ethiopian communities believe that electrification is the only duty of the Ethiopia electric power corporation [1], electrifying these remote areas by extending a grid system is very challenging and costly. Moreover, power from EEPCO is not sufficient to supply both rural and urban needs of electrification. Therefore, other sources of electrical power have to be identified so that the electric demand of the people is satisfied. This study will assess the electric demand of Menko Toli, Serbo Woreda, and identify potential renewable energy alternatives that best suits the area. Currently on this site there is micro-hydro with generating capacity of 15kw of power, even though, the demand of the population is beyond this capacity. Therefore, the ever increasing load demand of the Menko Toli villagers will stress upon the generators and dramatically decrease the life span of the project because of efficiency problem.

In this research a comparative assessment of the solar energy potential and hydro power potential for rural electrification for selected site in Ethiopia is analyzed.

II. SOLAR ENERGY RESOURCE POTENTIAL

Solar energy is the primary sources for all forms of energy. Solar energy measurement was taken from the average density of solar radiation incident on the earth's surface. Ethiopia has an excellent solar energy resource, with monthly global radiations ranging from5000-7500 MW/m^2. But this value varies through time from a minimum of 5.55kWh/m^2 in February and March and with the location from 4.25 kWh/m^2 in extreme western low lands to 6.25 kWh/m^2 in north east

In this work all solar energy resource data collected in many of the meteorological stations (NMSA),NASA and SWERA throughout the country is the average daily sunshine hours. The available sunshine hour data from the National Meteorological Agency of Ethiopia (Jimma branch) was used to estimate the solar radiation energy of the Serbo Werda Meko Toli . Table.1 shows the five years average daily sunshine hours in each month for the site under study.

Table 1 Average monthly sunshine hours of Menko Toli

Yr.	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Sep	Oct	Nov	De
09	7.7	7.5	8.2	7.1	6.7	4.9	3.9	3.7	4.5	8.1	8.4	9.1
10	7.7	7.5	8.2	7.1	6.7	4.9	3.9	3.7	4.5	8.1	8.4	9.3
11	7.7	7.7	8.1	7.5	7.6	6.3	4.0	4.4	5.2	6.3	7.1	8.0
12	6.4	7.5	7.5	7.2	7.5	7.7	4.7	4.6	5.0	6.4	8.8	5.6
13	8.2	5.1	7.0	6.4	5.6	5.9	3.4	3.8	5.3	7.7	7.3	6.6
Av. Sh	7.6	7.1	7.8	7.1	6.8	6.0	4.0	4.1	4.9	7.3	8.0	7.7

The monthly average daily numbers of hours of bright sunshine for Menko Toli Site are the same because they have the same sunshine hour data from NMSA with Shrink as nearby station.

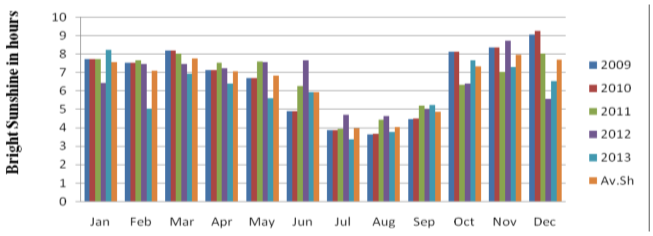

Fig.- 1 Monthly average daily numbers of hours of bright sunshine for Menko Toli Sites

The monthly average daily hours of bright sunshine from NMSA with Shrink as nearby station for each year and four years average data from 2009 up to 2013

A. *Estimation of the irradiance on the surface of the PV array*

The simple model used to estimate monthly average daily global solar radiation on horizontal surface is the modified form of the Angstrom-type equation. Solar irradiation is the amount of available solar energy on the ground surface over a specified time, expressed as kWh/m^2 or MJ/m^2. The sum of direct and diffuse solar irradiation is called global irradiation. Solar irradiation is important factor for design and operation of solar energy system because it can estimate the cost of building photovoltaic system, especially solar cells which are sold based on the area [8].

$$H = H_O\left(\left(a + b\left(\frac{n}{N}\right)\right)\right) \quad (1)$$

The extraterrestrial radiation is calculated by,

$$H_o = \frac{24\times 360\times G_{SC}}{\pi}\left(1+0.033\times\cos\left(\frac{360nd}{365}\right)\right)\times \left(\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta\right) \quad (2)$$

The maximum possible daily hours of bright sunshine, is given by,

$$N = \cos^{-1}(-\tan\phi\tan\delta) \quad (3)$$

The sunset hour angle in degrees is calculated by [9]

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \quad (4)$$

For, n is the day of the year. January first n=1to 365 days [8].
the declination angle (δ)

$$\delta = 23.45^0 \sin\left[360^0\left(\frac{284+n}{365}\right)\right] \quad (5)$$

The regression coefficients "a" and "b" are expected to improve by adding the effect of elevation, sunshine duration, and latitude together. Thus the regression coefficients "a" and "b" in terms of the latitude, elevation and percentage of possible sunshine for any location around the World (for 5°< Φ <54°) are correlated by Gopinathan with equation below

$$a = -0.309 + 0.539\cos\phi - 0.0693h + 0.29(n/N)$$
$$b = 1.529 - 1.027\cos\phi + 0.0926h - 0.359(n/N)$$

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Where: h is the elevation of the location above sea level in km. For this study the data taken from site measurement with GPS and NASA gives as:

Elevation=1844, h=1.844km, and ϕ =7^{0}44.44'

Where $1kmh/m^2 / day = 3.6MJ / m^2$

the average numbers of hours of sunshine were obtained from daily measurements covering a period of 5years From Table 2.1, the overall average clear index $\frac{n}{N}$ was computed and substituted into equation 2.6 and 2.7 to obtained the values of the regression coefficients a and b as 0.26 and 0.48 respectively. The values of a and b were substituted into equation 1 which gives the model for computing the estimated global solar radiation shown in Table 2.3,. It is indicated that our model is suitable for the estimation of monthly average daily global radiation, from monthly average daily sunshine hours in the Menko Toli. For this

Table.2 average days for months and the declination angle

Month	n_d for i^{td}ay of the month	For the average day of the month		
		Date	day of year (n_d)	declination (δ)
January	i	17	17	-20.9
February	31+i	16	47	-13.0
March	59+i	16	75	-2.4
April	90+i	15	105	9.4
May	120+i	15	135	18.8
June	151+i	11	162	23.1
July	181+i	17	198	21.2
August	212+i	16	228	13.5
September	243+i	15	258	2.2
October	273+i	15	288	-9.6
November	304+i	14	318	-18.9
December	334+i	10	344	-23.0

Table 3 Solar radiations analyzed from sunshine duration data for the site

Month	n_d	δ(°)	ωs (°)	N (hours)	n (hours)	$\frac{n}{N}$	a	b	H_o(kwh/ m²/d)	H(kWh/ m²/d)
January	17	-20.9	87.14	11.62	7.58	0.65	0.29	0.45	9.21	5.40
February	47	-13.0	88.27	11.77	7.10	0.60	0.27	0.46	9.85	5.38
March	75	-2.4	89.69	11.96	7.77	0.65	0.28	0.45	10.34	6.00
April	105	9.4	91.24	12.16	7.09	0.58	0.27	0.47	10.47	5.68
May	135	18.8	92.55	12.34	6.83	0.55	0.26	0.48	10.25	5.37
June	162	23.1	93.19	12.45	5.96	0.48	0.24	0.51	10.06	4.89
July	198	21.2	92.91	12.39	4.00	0.32	0.20	0.56	10.10	3.93
August	228	13.5	91.79	12.24	4.05	0.33	0.20	0.56	10.33	4.00
September	258	2.2	90.29	12.04	4.90	0.41	0.22	0.53	10.34	4.52
October	288	-9.6	88.73	11.83	7.33	0.62	0.28	0.46	9.93	5.61
November	318	-18.9	87.43	11.66	7.98	0.68	0.30	0.43	9.36	5.55
December	344	-23.0	86.82	11.58	7.70	0.66	0.29	0.44	8.98	5.21
Annual Average							0.26	0.48	9.99	5.13

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Table 4 Monthly average daily solar radiations from NMSA, NASA & SWERA

Date of month	Kersa Menko Toli		
	NMSA	NASA	SWERA
January	5.40	5.86	6.00
February	5.38	6.27	6.01
March	6.00	6.26	5.45
April	5.68	6.01	4.86
May	5.37	5.81	4.71
June	4.89	5.24	4.05
July	3.93	4.61	3.26
August	4.00	4.86	3.39
September	4.52	5.55	4.27
October	5.61	5.93	5.04
November	5.55	6.09	5.75
December	5.21	5.97	6.26
Annual Average	5.13	5.70	4.92

thesis the NMSA value of monthly average daily solar radiations, when compared with NASA and SWERA (Solar and Wind Energy Resource Assessment), shows no big difference According to NMSA data, the area has average annual solar radiation potential of 5.13kWh/m^2/d, and 6.56 kWh/m^2/d as per the information in Solar and Wind Energy Resource Assessment, and 5.7 kWh/m^2/d in NASA's data center.

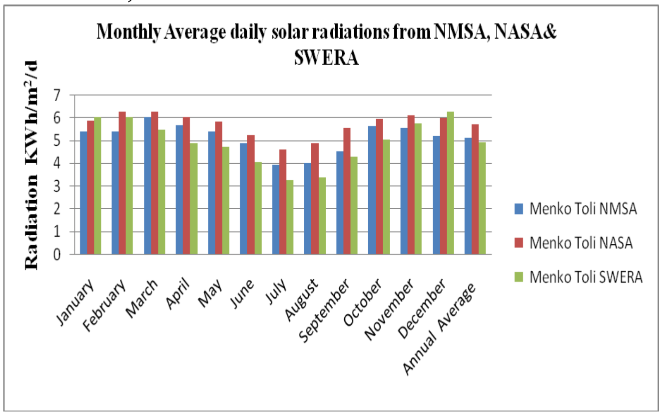

Fig.-2 Monthly Average daily solar radiations from NMSA, NASA& SWERA

Fig.-3 shows that in the overall average years (2009 - 2013), there were two maxima (major and minor) and two corresponding minima (major and minor). The major maximum occurred between February-April during the dry season and the minor maximum occurred between November-January. In the rainy season (May-October), we have the major minima in the months of July-August. The peak month, March,. Fig.-4 also indicates the trend of global solar irradiation at Menko Toli, with high values during the dry season. While minimum irradiation is obtained during the rainy season, as the rain bearing clouds pervade the sky. Finally, in Fig.-5 the monthly variation of global solar radiation and sunshine duration have same trends where the maximum values each mentioned parameter were observed in March and the minimum in July.

III. Basic Theory and Resource Potential of Micro Hydropower

Hydropower is a renewable, non-polluting and environmentally benign source of energy. Hydropower is based on simple concepts. Moving water turns a turbine, the turbine spins a generator, and electricity is produced. Many other components may be in a system, but it all begins with the energy in the moving water. The use of water falling through a height has been utilized as a source of energy since a long time. It is perhaps the oldest renewable energy technique known to the mankind for mechanical energy conversion as well as electricity generation. In the ancient times waterwheels were used extensively, but it was only at the beginning of the 19th Century with the invention of the hydro turbines that the use of hydropower got popularized.

Hydropower plants range in size from large power plants that supply many consumers including industrial and commercial load to small and micro plants that provide electricity for small numbers of houses or villages. Generally, there are three different sizes that hydropower plants are based upon. Though different countries have different criteria to classify hydro power plants, a general classification of hydro power plants is as follows [10].

Table 5-Classification of hydro power plants

Type	Capacity
Large- hydro	More than 100 MW and usually feeding into a large electricity grid
Medium-hydro	15 – 100 MW - usually feeding a grid
Small-hydro	1 - 15 MW - usually feeding into a grid
Mini-hydro	Above 100 kW, but below 1 MW; either stand alone schemes or more often feeding into the grid
Micro-hydro	From 5kW up to 100 kW; usually provided power for a small community or rural industry in remote areas away from the grid
Pico-hydro	From a few hundred watts up to 5kW

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A. Hydrological data analysis

The hydrological study undertaken for the mini hydropower project was aimed at the determination of design discharges (minimum and maximum) for a given set of return periods that were consequently utilized for design of new structures and hydropower schemes. In undertaking the hydrological study and analysis the following operations are carried out. the hydrology and hydraulic study is to determine the Economical sizes of hydraulic structures which safely evacuate design flood of without causing significant damage to the structures, river banks and adjoining settlements. Moreover the minimum flow on the river and water availability for 90% dependability.

The physical size of the whole system, especially the electro-mechanical equipments, are sized and selected by harmonizing the power demand at the end use devices with the power generated due to major site parameters that are the Head (H) and the Flow (Q) of the Kersa Micro hydropower scheme. Installed capacity of Menko Toil Micro hydropower plant Based on the main hydraulic data gathered from the site the output power of the turbine is calculated with the

Location	Area (Km^2)
At Giligel Gibe	2966
At Kersa	152

following basic formula. Turbine output power (P_{tur}, kW).

$$P_{tur} = \rho \times g \times H \times Q \times \eta \quad (6)$$

Therefore, assuming 65 % efficiency for locally manufactured cross-flow turbine, the net head, H =11 m and water flow rate, Q=0.2 m^3/s, gravity 9.81 m/s^2 the power output (P in kW), for Menko Toli site will be 14.03 kW however the installing generator is 15kw, the diversion of turbine used 30% of the main river of Kersa .

B Study of watershed characteristics of Kersa River

To obtain information on the Kersa River for mini hydropower catchments and data on relief, geomorphology, soil type, land cover and catchment parameter topographic maps, land use and land cover maps, soil and geomorphology maps, national atlas of Ethiopia as well as site visit inspection and assessment information were used. To study the watershed characteristics of the Kersa River extensive study has been done including field inventories using topographic maps. Data regarding catchment areas, i.e. watershed size and shape, stream slope, stream length and land slope were determined from topographic map, satellite data DEM 30mx30m resolution and metadata satellite imagery 15mx15m grid. [11].

C. . Catchment area delineation

The catchment area of the Keras River is delineated from DEM data and topographic map. The sizes the catchment area determined using Arc Map 10 GIS software. (See drawing catchment area).

D. Flow duration analysis

Flow duration analysis is needed to determine the installed capacity of a hydropower project. The flow duration curve in this project is the most important because this project is planned as run of river type. Flow duration curve in Kerssa river basin was calculated by using daily run off data at Intake. The flow duration curve in Kerssa River was calculated by using data at the outlet site at Gilgel Gibe Area ratio method is used to compute the flood flow at the site of interest for this study. A peaking factor of 0.05 is employed. The estimated flow duration curve the 90% dependable discharge at Intake site [11].

E. Flow rate of the site

For the case of Menko Toli, there is gauging station. Especially for the design of all the components of MHP (Micro-hydro power) it is need to have a rainfall, water flow rate data. There is one river flow gauging station at Gilgel Gibe I River having a catchments area of 2966km^2. Kersa River it have smallest catchments of 152km^2 feeding site at Gilgel Gibe I gauging station

Table 6-Flow duration data

Flow duration curve at Gilgel Gibe I		Flow duration curve at Menko toli	
% Time	Flow (m^3/s)	% Time	Flow (m^3/s)
0	59.44	0	3.03
5	58.64	5	2.99
10	51.54	10	2.62
20	51.17	20	2.61
30	46.4	30	2.36
40	40.59	40	2.07
50	36.4	50	1.86
60	30.9	60	1.57
70	30.15	70	1.53
80	27.88	80	1.42
90	26.52	90	1.35
95	25.78	95	1.31
100	22.27	100	1.13

Thus to estimate the stream flow of ungauged sites empirical method of estimation is used rather than statistical model and rainfall-runoff model for this study. Stream flow estimation for ungauged catchments by transposing gauged stream flow data from an analogue catchment is a widely use technique requiring the rescaling of the flow regime to the ungauged target catchment. These techniques all take the following form [11].

$$QX_T = k\left(\frac{A_T}{A_A}\right)QX_A \quad (7)$$

Table 7 The value of k as a function of land use, topography, and soil type for use in rational method

Land use and topography	Soil Types		
	Sandy loam	Clay and silt loam	Tight clay
Cultivated land			
i) Flat	0.30	0.50	0.60
ii) Rolling	0.4	0.60	0.70
iii) Hilling	0.52	0.70	0.82
Pasture land			
i) Flat	0.10	0.30	0.40
ii) Rollin	0.16	0.36	0.55
iii) Hilling	0.22	0.42	0.60
Forest land			
i) Flat	0.10	0.30	0.40
ii) Hilling	0.30	0.50	0.60
Populated land			
i) Flat	0.40	0.55	0.65
ii) Rolling	0.50	0.65	0.80

Menko Toli site is where the logs indicated that for the pit located on the right side 1 m deep composed of reddish-brown clayey and black soils with high clay content. The other pit located on the left side 60cm deep composed of black soils with high clay content. During excavation the water came out easily based of this the so type of Menko Toil has been clay.

Table 8 Average monthly water flow rate at Gilgel Gibe I River

Month	1997	1998	1999	Average
January	17.40	76.12	26.97	40.163
February	7.76	38.96	14.21	20.31
March	6.43	43.58	19.56	23.19
April	44.26	30.32	15.68	30.086
May	70.17	55.16	44.39	56.54
June	181.61	78.13	92.15	117.30
July	187.00	226.85	213.17	209.01
August	279.18	458.64	291.11	342.98
September	185.68	257.03	154.38	199.03
October	122.77	226.38	194.37	181.173
November	324.73	88.51	67.40	160.213
December	143.09	39.91	29.49	70.83
Annual	121.15	134.97	96.91	121.15

Table 9 Average monthly flow rate at Menko Toli

Month	Flow rate of Gillgle Gibe I m3/s	Flow rate of Menko Toil m3/s
January	40.163	0.370
February	20.31	0.190
March	23.19	0.214
April	30.086	0.277
May	56.54	0.521
June	117.30	1.082
July	209.01	1.928
August	342.98	3.164
September	199.03	1.836
October	181.173	1.671
November	160.213	1.478
December	70.83	0.838
Annual	121.15	1.131

From the above results, constructing hybrid power generation system in Toli- kersu kebele is feasible.

IV. NOMENCLATURE

P_{tur} Turbine output power in kW
ρ Density of water (1000kg/m^3)
g Gravity (9.81 m/s^2)
Q Flow rate (m^3/s)
ω_s Sunset hour angle in degrees
η Turbine Efficiency
N Maximum possible daily hours of bright sunshine
n Number of days of the year
H Monthly average daily radiation on horizontal surface. (MJ/m^2).
H_o Monthly avg daily extraterrestrial radiation on a horizontal surface (MJ/m^2).
δ Declination angle (°)
QX_T Flow in the target unguaged catchment T
QX_A Flow in the catch. A
A_T Catchment area for the unguaged catchment T
A_A Catchment area for the analogue catchment A
k Scaling constant or function

V. CONCLUSION

The average solar insolation result found for Minko Village was 5.13kWh/m^2/d, the minimum water flow found from the flow duration study for the dry season, December was found to be 0.838m^3/sec, and the net head in the study area was found 10.5m. Having this values dictates the possibility of constructing an economically feasible Solar Photovoltaic Micro Hydro Hybrid Power Generation System in the village

IV. ACKNOWLEDGMENT

My acknowledgment goes to Jimma University/Jimma Institute of Technology Research office for supporting this work in terms of finance, and i also would like to thank, Dr.-Ing Getachew Shunki, and Mr. Dawit Leykun, who kept me highly motivated to undertake every activity of the research project.

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