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Feasibility Study of Wind and Solar Powered Pumped Hydro Energy Storage System for Isolated Grid Application in Amhara Region

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Abstract

The stored water can then be used for hydroelectric power generation to cover the power demand of the model village. The advantage of this technology is that it can becomes commercial very quickly, making it a useful tool to balance the varying electricity demand from consumers or unplanned outages of other power plants. The most suitable location for the upper reservoir and head measurement for decisive power production are carried out at the selected location of the existing dam. consequently the total energy output from the proposed pumped storage system is calculated which is892.71kw.at the same timethe total energy demand of the model village have been analyzed in such a way that, is the data can be used by homer s/w to determining the scaled peak load of the village under study. The total energy demand of the model village under investigation reaches to 739 kW hence pumped storage system is commissioned over koga dam for small isolated power production. From the analysis of the potential of wind energy the results show that maximum power of 112.6 kW. However; the solar energy potential of the region can be classified as excellent as the daily average solar radiation is about 5.4kwh/m^2/day which is reasonable for power production. The power required for the pump to lift 1.14m^3/s of water to height of 12.5 m of the proposed reservoir needs 139.79 kW of power from both wind and solar.

Keywords: Pumped storage system, energy demand, Amhara region, Ethiopia, Model village, power output

INTRODUCTION

According to the International Energy Agency, Ethiopian electricity production is almost exclusively based on hydropower, oil, gas, and biomass and solar to some extent. However, the potentials for large-scale hydropower has been almost exhausted over the past and in the pursuit of meeting emission reduction goals without compromising the security of energy supply, the Ethiopian government has been promoting other renewable energy sources such as hydro, wind and solar power. All are particularly attractive for Ethiopian, as it enjoys high wind speeds, large rivers and high solar energy potential.

A process, also known as hydroelectric storage, for converting large quantities of electrical energy to potential energy by pumping water to a higher elevation, where it can be stored indefinitely and then released to pass through hydraulic turbines and generate electrical energy . An indirect process is necessary because electrical energy cannot be stored effectively in large quantities. Storage is desirable, as the consumption of electricity is highly variable between day and night, between weekday and weekend, as well as among seasons. Consequently, much of the generating equipment needed to meet the greatest daytime load is unused or lightly loaded at night or on weekends. During those times the excess capability can be used to generate energy for pumping, hence the necessity for storage.

Several studies over the past few years have further looked into technologies to realize such benefits and pumped-storage wind-hydro plants, which use reservoirs to store water previously pumped up with wind power, have been found to be profitable under particular circumstances in the regions where high potential of wind energy is available in the site. As an alternative solar energy available will be the other source of energy to pump water in coordination with wind power.

REVIEW OF LITERATURE

Wind energy is one of the oldest sources of energy used by humankind, comparable only to the use of animal force and biomass [Wagner and Mathur, 2009]. Some 5000 years ago wind was used to sail ships in the Nile River. Many civilizations used wind power for transportation and other purposes: The Europeans used it to accomplish some mechanical works such as grind grains and pump water in the 1700s and 1800s.

The first wind turbine used to generate electricity was installed in U.S in 1890 [Patel, 2006]. However, for much of the twentieth century there was small interest in using wind energy other than for battery charging for distant dwellings. These low-power systems were quickly replaced once the electricity grid became available.

The sudden increases in the price of oil in 1973 stimulated a number of research, development and demonstrations of wind turbines and other alternative energy technologies in different countries [Rivera, 2008].

The first demonstration projects using 2 MW wind turbines with a rotor diameter of 74 meters were installed before the turn of the century. 2 MW turbines are now commercially available and 4 to 5 MW wind turbines are currently under development [Ackermann et al., 2002].

Dimitris Al. Katsaprakakis, Pr. Dimitris G. Christakis, (1994) propose a power production system for the island of Astypalaia. Their proposed system aimed at the wind energy penetration maximization and the imported fossil fuels minimization, consumed in the electricity production. The proposed system consists of wind parks, a pumped storage system (PSS) and thermoelectric machines. Their whole project was evaluated mainly from an investment point of view. The investment includes only the wind parks, the PSS and the relevant infrastructure (roads construction, utility network, etc.).

METHODOLOGY

The Koga irrigation and watershed management project is constructed under on the Koga River, which originates on the Wezem Mountain at an altitude of about 3200 m. The Koga River is a tributary of the Gilgel Abbay in the headwaters of the Blue Nile catchment, which flows into Lake Tana. The river is 64km long, joining the Gilgel Abbay River downstream of the town of Wetet Abbay, at an altitude of 1985m. The Koga dam is located between 11° 10' and 11° 32'north, and 37° 04' to 37° 17'east. The catchment area at the Koga dam site is $170km^2$, of which about half is used extensively for subsistence agriculture.

It was designed to achieve through the development of irrigation most notably for the 7000ha irrigation project (Nile basin Authority 2012), and is also used for flood mitigation. The dam is located to the south of Bahir Dar which will be provided with water from a reservoir created by an earth fill dam across the river Koga. Additionally the dam regularizes the irrigation flows as well as to supply water for a number of remote areas those looking water during dry season. The plan of the project is to develop an irrigation scheme utilizing water stored in the reservoir. It involves the construction of a 21.5 m high, 1860 m long dam with a storage capacity of 83.1 million cubic meters, across the Koga River near Kudmi village.

Figure 1. Site Identified For Construction of Pumped Hydro Energy Storage and the Topography

MATERIALS. Collection of materials that are needed for measuring and data recording devices to carry out the task is fundamental. The main materials that required for the work are tape measure (30m), Stadia rod (strait stick), rope and GPS (GARMIN 72H) for allocating the topography map of the proposed system.

METHODS

Site investigation and measuring the available head which is essential for power calculation and for other tasks. In order to estimate the surface areas and volumes of reservoirs fieldwork was carried out in Kudmi District, where the reservoirs area surveyed in the south and south eastern part of the Koga dam according to the suitability of the topography. The data obtained from the field work has been put in to ArcGIS software to indicate the contour created for the reservoir area during field work and for determining the size of the new reservoir.

Analysis of demand load of electric power consumption of the model village under study based on the data obtained from investigation and putting to HOMER software to indicate the total energy consumption of the model village and applying the power obtained from pumped storage system up on the model village to assure the degree of feasibility that how much power is covered by the proposed pumped storage system. For primary case the wind speed data has been measured from the site for representative days; whereas for the corresponding solar radiation the sunshine hour data for one year is collected from the National Metrological Services Agency (NMSA) or Amhara metrological service bureau, NASA and SWERA.

Analyzing Data obtained for solar resources based on Modified Angstrom Linear Regression Equation. Determining and explaining the renewable energy resources output obtained from both wind and solar from the data collected and various procedures has been followed to obtain the available wind energy potential required. Computing the energy obtained from wind and solar with the power required for pump.

Endogenous Energy Sources in Ethiopia

There are various sources of energy which can be used for domestic purposes that can be classified as geothermal, biomass, wind, solar and many others. Energy supply in Ethiopia is mainly based on biomass resources. Out of the 698.84 Terra-joules of energy utilized in 1994, the share of biomass resources was 95.1 percent. The contribution of energy from petroleum and electricity was only 4.3 and 0.6 percent, respectively. Studies made at various time indicate that the country has an estimated 30 to 50 billion m^3 of natural gas, 1000 Megawatts of geothermal power and an unknown but substantial quantity of coal and other energy sources such as oil shale.

As regards alternative sources of energy, the country has an estimated potential for generating 2.3 Terra Watt hours of solar energy and 4.8 million Terra Calories of wind energy per annum. In 1999, total energy consumption in the country amounted to 723 Meta-joules. Generally the country promotes a substantial amount of energy for domestic use and for exporting to the neighboring countries (EEPCo 2000).

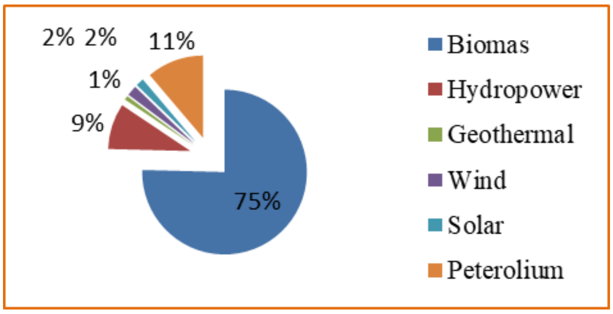

Figure 2. Energy Share for Endogenous Energy Sources In Ethiopia from 1980-1999

Hydropower Energy Actual Situation and Further Construction Plans In Ethiopia

Ethiopia considers itself the powerhouse of Africa due to its high hydropower potential. Only a fraction of this potential has been harnessed so far. In 2009 less than 10% of Ethiopians had access to electricity and the country was plagued by power outages. Three hydropower plants with a combined capacity of 1.18 GW were commissioned in 2009 and 2010 alone, more than doubling the previous installed capacity of the country.

The largest hydroelectric plant in Ethiopia, Beles, began initial operation in May 2010. Contracts for five more large dams have been signed. Once completed, which is expected to be around 2015, these dams would increase the installed capacity by more than 11 GW from less than 1 GW in 2008.

The construction of more large dams is foreseen in a Master Plan that aims to bring capacity to 15 GW. Power demand in Ethiopia is constrained by poverty, and the country thus plans to export power to Sudan, Kenya, Djibouti and even Yemen and Egypt [EEPCo]. The benefits of the dams are not only limited to hydropower. Many dams are multi-purpose dams that are also designed to provide water for irrigation and flood control. However, hydropower is expected to be the main benefit of the dams.As mentioned above, nine hydropower plants are in operation, which are providing about 650MW, 85% of the total energy supply.). (Planning Power system, 2008) The main ICS, which serves the major towns and industrial centers, has a total installed capacity of 1559.3 MW. This installed capacity is contributed by hydropower installations having a total installed capacity of 1390.6 MW and thermal stations of about 168.7 MW.

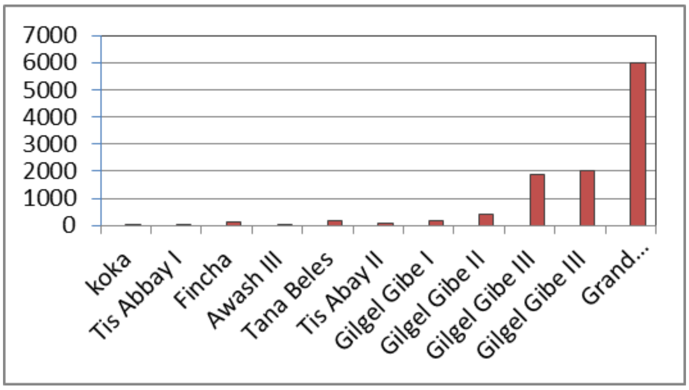

Figure 3. Summary of Existing and future construction Hydropower Plants in Ethiopia

Pump Hydro Storage Systems in the World:

In recent years, in addition to the worldwide revived interests in developing conventional PHS projects, many developers are also proposing new approaches. Japan pioneers in utilizing seawater PHS. The Okinawa seawater PHS station, which has commenced operation in 1999, is the world's first seawater PHS system. A similar seawater project has been proposed in Ireland. Researchers had proposed the possibility of utilizing an underground cavern as the lower reservoir for a PHS project since the 1970s. The commercial interests in developing underground PHS have surged in recent years in the United States. Several developers have received preliminary permits to study the feasibility of building underground PHS facilities at their identified sites . There are also projects in the United States proposed to use groundwater and recycled wastewater for PHS .

Many existing PHS facilities were built many decades ago and therefore were equipped with outdated and inefficient technology. There is a significant potential in increasing PHS capacity simply by renovating and upgrading the existing PHS facilities. In addition, many existing conventional hydropower stations could be re-engineered to add pump-back units and become combined PHS stations. Although PHS may be an essential enabling technology for de-carbonizing electricity, the political will to mitigate carbon dioxide or to remove regulatory barriers for PHS is far from certain. The price of natural gas is also a key determinant in the future of PHS. Because PHS is essentially a peak-load technology, which competes directly with gas-fired power, low natural gas price would render PHS uncompetitive.

The vision of de-carbonizing electricity and how PHS fits into that vision will like vary from country to country. PHS is the only widely adopted utility-scale electricity storage technology. As of 2009, there are hundreds of PHS stations operating with total capacity of 127 GW worldwide [10]. Japan currently has the largest PHS capacity in the world. Table 1 shows the installed PHS capacities in major countries.

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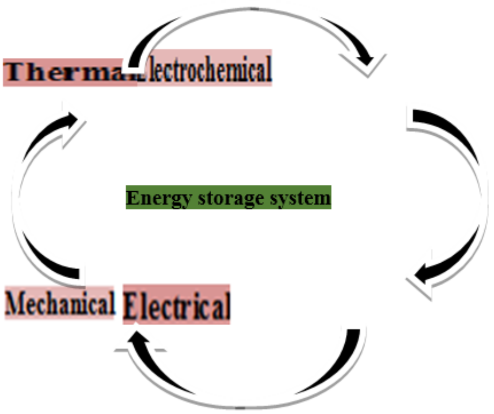
Table 1. Installed PHS capacities in the world.

Country	Installed PHS Capacity (MW)
Japan	25,183
USA	21,886
China	15,643
Italy	7,544
Spain	5,347
Germany	5,223
France	4,303
Australia	3,580

Mechanical energy storage systems



Compressed air energy storage (CAES)

Compressed air (compressed gas) energy storage is a technology known and used since the 19th century for different industrial applications including mobile ones. Air is used as storage medium due to its availability. Electricity is used to compress air and store it in either an underground structure or an above-ground system of vessels or pipes. When needed the compressed air is mixed with natural gas, burned and expanded in a modified gas turbine.

Typical underground storage options are caverns, aquifers or abandoned mines. If the heat released during compression is dissipated by cooling and not stored, the air must be reheated prior to expansion in the turbine. This process is called diabetic CAES and results in low round trip efficiencies of less than 50 %. The advantage of CAES is its large capacity; disadvantages are low round-trip efficiency and geographic limitation of locations.

Flywheel energy storage (FES)

In flywheel energy storage rotational energy is stored in an accelerated rotor, a massive rotating cylinder. The main components of a flywheel are the rotating body or cylinder (comprised of a rim attached to a shaft) in a compartment, the bearings and the transmission device (motor/generator mounted onto the stator.

The energy is maintained in the flywheel by keeping the rotating body at a constant speed. An increase in the speed results in a higher amount of energy stored. To accelerate the flywheel electricity is supplied by a transmission device. If the flywheel's rotational speed is reduced electricity may be extracted from the system by the same transmission device. Flywheels of the first generation, which have been available since about 1970, use a large steel rotating body on mechanical bearings.

Advanced FES systems have rotors made of high-strength carbon filaments, suspended by magnetic bearings, and spinning at speeds from 20 000 to over 50 000 rpm in a vacuum enclosure. The main features of flywheels are the excellent cycle stability and a long life, little maintenance, high power density and the use of environmentally inert material. However, flywheels have a high level of self-discharge due to air resistance and bearing losses and suffer from low current efficiency. Today flywheels are commercially deployed for power quality in industrial and UPS applications, mainly in a hybrid configuration. Efforts are being made to optimize flywheels for long-duration operation (up to several hours) as power storage devices for use in vehicles and power plants.

Pumped Hydro Energy Storage System

Some areas of the world have used geographic features to store large quantities of water in elevated reservoirs, using excess electricity at times of low demand to pump water up to the reservoirs, then letting the water fall through turbine generators to retrieve the energy when demand peaks. By 1933 reversible pump-turbines with motor-generators were available. Adjustable speed machines are now being used to improve efficiency.

Pumped storage hydro power is available at almost any scale with discharge times ranging from several hours to a few days. Their efficiency is in the 70% to 85% range. For instance, pumping water up and down to store wind turbine energy brings efficiency around 20%, meaning that 80% of the electricity originally produced by the turbine is lost: clearly not mature.

There is over 90 GW of pumped storage in operation worldwide, which is about 3% of global generation capacity. Pumped storage plants are characterized by long construction times and high capital expenditure. Pumped storage is the most widespread energy storage system in use on power networks. Its main applications are for energy management, frequency control and provision of reserve.

Until recently, PHES units have always used fresh water as the storage medium. However, in 1999 a PHES facility using seawater as the storage medium was constructed. A typical PHES facility has 300 m of hydraulic head (the vertical distance between the upper and lower reservoir). The power capacity (kW) is a function of the flow rate and the hydraulic head, although the energy stored (kWh) is a function of the reservoir volume and hydraulic head.

Site Observation and Head Measurement

In the extent of head measurement there will be the variation in head measured at each location. As the measurement of head is conducted by ordinary method of leveling the topography between the lower elevation and upper elevation is varied abundantly hence the highest elevation is selected. In the same manner the measurement is conducted to the same direction of the reservoir to be surveyed.

In addition to this table 2 summarizes head measurement of each selected site based on the suitability of the topography.

Table 2. Head measurement results at the selected sites and their corresponding reservoir type

Method	Site (reference to the existing dam)	Head (m) for 50m interval	Reservoir type
Leaving	North	10-12.5	upper
	South East	4-7	upper
GPS	North	1990-2200	upper
	South East	2000-2300	upper

Head measurement is carried out at 50m interval for both reservoir in north and south east part of the existing Dam. As from the table 6.1 shows the reservoir found from both direction is upper reservoir. In northern part the elevation ranges from 10m to 12.5m as the highest point where as for the south eastern part it extents 4m to 7m range. The result obtained from GPS indicates much higher difference in both locations. Whereas the leveling method provides slight difference and head measured by leveling method is more applied in this research.

Reservoir Surveys and Storage Capacities

Whatever may be the use of a reservoir, it's most important function is to store water and to release it later when it is required. It acts much like a battery, storing power in the form of water when demands are low and producing maximum power during daily and seasonal peak periods. The storage capacity of a reservoir is, therefore, its most important characteristics. The available storage capacity of a reservoir depends upon the topography of the site and the height of the topography found in that area. To determine the available storage capacity of a reservoir up to a certain level of water, site surveys are usually conducted. For accurate determination of the capacity, a topographic survey of the reservoir area is usually conducted, and a contour map of the area is prepared. The storage capacity and the water spread area at different elevations can be determined from the contour map.

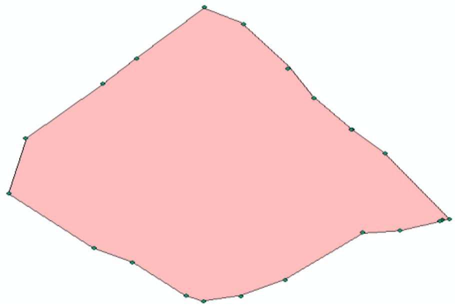


Figure 4: Schematic diagram to show shape and contour determination of a reservoir (north of the dam).

The dimensions of the reservoirs were surveyed by shape and size of surface area were determined by walking around each location with handheld GPS with (error of <5m) to locate (x, y and z) coordinates values or interpolated coordinates at specified points, taking large number of points along the shoreline. Random points, at least 20m apart were made during measurements to allow creation of contours from which surface area was derived See Figure 4.

In determining the volume of the reservoir indicating the relation between the areas derived from Arc GIS with incremental head is the most essential parameter. The reservoir capacity is directly proportional to the area and the differential depth of the location under investigation. At any given elevation, the increment of storage in the reservoir at that elevation will be *Ady*.

Then the total storage below the maximum level to any will be given by the equation,

$$v = \int_0^y A dy \tag{1}$$

Where *A* is area of the reservoir and *dy* is a differential depth or height. The relation for the above terminology is expressed in terms of elevation and area at maximum pool level. The volume of the reservoir guarantee the power produced continuously up to the minimum pool level sufficiently.

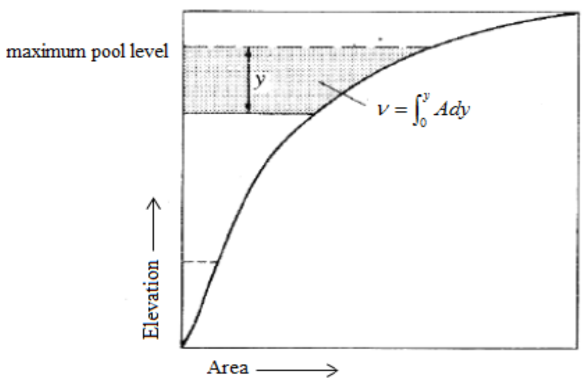


Figure 6. 2 Elevation and area relationship for volume determination.

The maximum pool level indicates the upper water level for the reservoir and its operating condition at the maximum of water found in the reservoir. As stated from above two storage reservoirs are surveyed based on the topographic suitability and their available head found. In this thesis project reservoir measured at high head is more suitable for decisive power production. From the above equation 7.1 the capacity of the reservoir is merely calculated with the help of the incremental elevation *(dy)* obtained from field work and area of the reservoir created by the contour. Hence the volume of the reservoir for the selected topography will become;

$$v = \int_0^y Ady$$

$$v = 708{,}607.5\,\mathrm{m}^3$$

Hence the most essential parameter is the reservoir volume that determines the capacity of the power produced in the plant.

Power from the Proposed Pumped Storage System

It was desired to examine the total power obtained from the measured elevation from the site and the corresponding assessed reservoir area in order to examine the potential of the system in satisfying the power demand of the selected places. The elemental power components of the total discharge passing through the turbine gives the theoretical power of the plant as:

$$P = \rho g Q H \qquad (2)$$

The actual power output from the plant extracted by the hydropower unit is the rate of doing work and can be represented mathematically as follows:

$$P = \rho g Q H \eta_t \qquad (3)$$

Where ρ the density of the water, g gravitational acceleration, Q is the discharge from the reservoir *H* is the total head obtained from measurement of the site (12.5m) and ($\eta_t = 80$ at 100 rpm) is efficiency of turbine. The value of discharge *Q* can be found by the relation of head. Since the head is available the corresponding flow via the turbine is possible to be determined. The flow through the turbine is not similar to the flow in the pump: hence the flow through the turbine is assumed as 9.1 m^3/s which is similar to the flow in the main canal (Q = 9.1m^3/s).

$$P = 1000kg/m^3 * 9.81m/s * 9.1m^3/s * 12.5m * 0.80$$
$$P = 892.71kW$$

The electricity production from this extra water is estimated to be 7,827,102.7 kWh/y this maximum power obtained from the proposed system is resulted from the pumped storage system not from wind and solar. The power extracted from the pumped storage system exceeds than the total amount of the energy required for the model village. That is power for the model village is 739 kW and the power extracted from the site is 892.71kW; therefor this would certainly meet the total need of electricity of the village in present situation of the inhabitants in the village.

Estimation of Household Electricity Demand for A Model Village.

In this section of the study, as a part of the feasibility study of isolated wind and solar powered pumped energy storage system for small rural villages in Amhara region, estimation of load has been performed. As it is clearly seen in the title itself, the domain of the study is a small rural village situated in Amhara region in Mecha woreda. As a result the daily energy demand of the village, the peak hours of the village where peak load is necessary, the peak load, and the seasonal variation of load is required for the village under investigation.

In order to roughly estimate the total daily total energy demand to the village, all the energy would be summed up. Table 3 shows the energy demand of each institution and the number that those institutions are found in the village. As it is clearly seen in the table, the large amount of the energy is allocated to the residents' purpose. In actual case the load of the energy demand of the village is not real; instead it would be calculated by HOMER by considering the entire peak hour factor. Therefore the amount given here is not used for design purpose instead used for rough estimation and for checking the deviation of the final value.

Table 3: Rough Estimation of Total Daily Average Energy Demand of Hamusit Village

Name of institutes need energy	No of institutes	Energy demand (kWh/d)	Total energy demand (kWh/d)
House holds	450	25kW	5400
Shops, Cafeterias, Barbers	13	Given as total	116
Government offices	1	12.2	12
Milling house	6	783	783
Clinics and Veterinary centers	1 each	30	30
Schools	3	98	110
Total			6450

The Peak Load, Base Load and Deferrable Load for Model Village.

Peak load or peak demand are terms used in energy demand calculation describing a period in which electrical power is expected to be provided for a sustained period at a significantly higher than average supply level. Peak demand fluctuations may occur on daily, monthly, seasonal and yearly cycles. For anelectric utility company, the actual point of peak demand is a single half hour or hourly period which represents the highest point of customer consumption of electricity. While base load is the minimum amount of power that a utility or distribution company must make available to its customers, or the amount of power required to meet minimum demands based on reasonable expectations of customer requirements.

Base load values typically vary from hour to hour in most commercial and industrial areas. Moreover, in power generation it is well known that the load needed by customers vary in seasonal bases and in this study, these kinds of loads that are variable through seasons and described as deferrable load.

The first group, which is designated as Primary Load 1, consists of all the residential appliances which are employed constantly through the years without seasonal variation. In this division, all the appliances that work in the residence which are stated in Table 3 are considered, as well in the process of calculating the peak load, their time of application has been indicated in Fig 5&6.

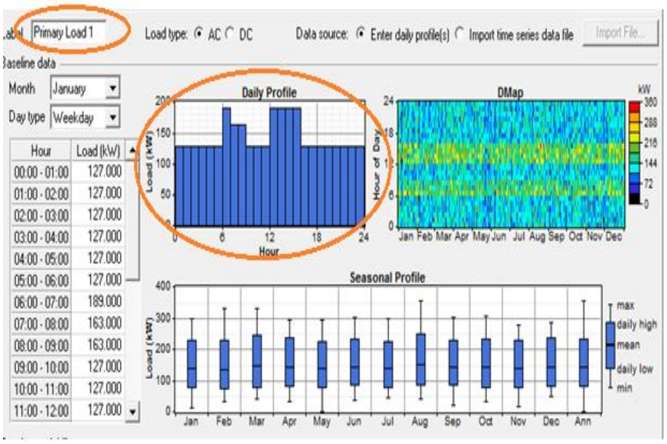


Figure 5: Load Input Window of HOMER by Taking Primary Load 1 as Sample

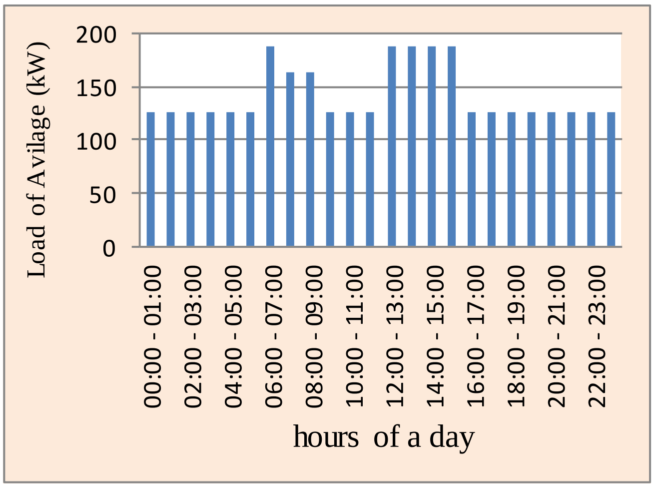


Figure 6: Power Curve With Respect To Result of Peak Hour Calculation.

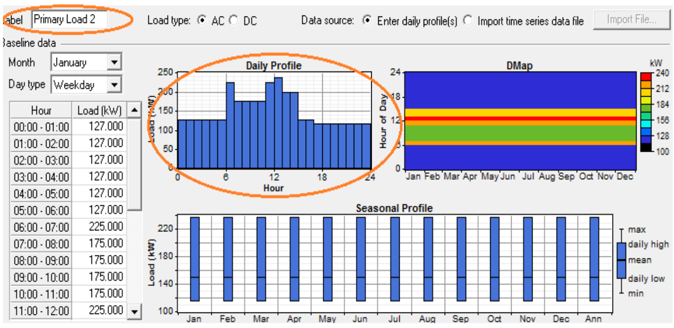


Figure 7: Load Input Window of HOMER by taking Primary Load 2 as Sample

Regarding the deferrable load, different assumptions have been made based on pre knowledge of the real situation of the country as well as daily observation. The assumptions basically deal with different scenarios to the need of air conditioning systems in Ethiopia in the four seasons. The assumptions are stated below;

1. January, February, and March are hot seasons that needs considerable amount of power for ventilation, it has been assumed a total of 3 hrs ceiling fans to work in Houses, school, and offices.
2. April, May and June are the hottest season that needs high amount of power for ventilation, it has been assumed that working time for ceiling fans to be 7hrs in Houses, school and offices, the assumption is made 7hrs by assuming 2 hrs in the morning and 5 hrs in the afternoon use of the fan.
3. July, August and September are somehow cold seasons that need less power for ventilation. Only 0.5 hr of ventilation is assumed for this season. Accordingly the result stated in Figure 6.6 has been obtained which shows the variation of the seasonal power curve.
4. October, November and December are cold seasons that need intermediate power for ventilation in some buildings, it has been assumed a total ventilation hours to be 1 hr.

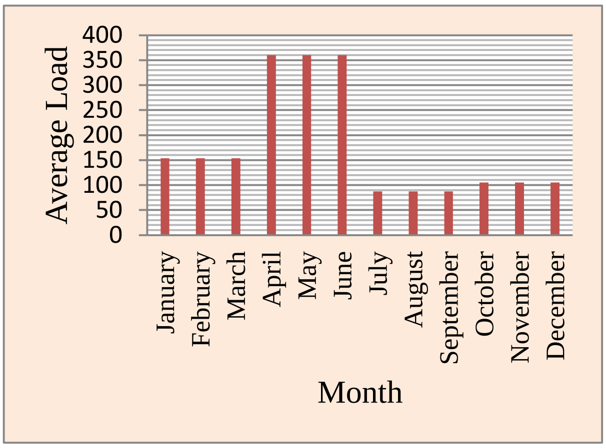


Figure 8: Deferrable Load of Air Conditioning System for Hamusit Village

Accordingly the result stated in Figure 6.5 has been obtained which shows the variation of the seasonal power curve. As it is clearly seen in the figure, the highest load demand is attained in the hot season, which implies the load of the air conditioning system is basically a cooling system which is true estimation in case of Ethiopia. The maximum value of monthly energy attained reaches to 360 kWh/d during the hot seasons and the minimum energy required at rainy seasons which is 85 kWh/d.

Peak Load and Daily Energy Demand of Hamusit Village from HOMER.

So as to give the study more viable and accurate the data obtained is feed to HOMER Therefore, it is so crucial for HOMER to be fed with the peak load and the energy demand on daily basis to find the anticipated energy demand of the village under investigation. In order to elaborate slightly how those input data are fed and how the results are obtained an illustrative figure has been given in Appendix 4. Finally after feeding HOMER all the necessary data that has been calculated in the above paragraphs,

Table 4 would be obtained which would in turn be a crucial output for interpreting the total energy demand of the village.

Table 4: Scaled Peak Load and Scaled Annual Average Energy of Hamusit Village

Category	Scaled Peak load (kW)	Scaled Annual Average Energy (kWh/day)
Primary Load 1	354	3611
Primary Load 2	237	3401
Deferrable Load	148	177
Total	739	7189

As it is clearly seen in from Table 4; the total scaled peak load of the village is 739 kW and the Scaled Annual Average Energy is 7189 kWh/day which is the overall total power required for the village. This total peak load involves primary load 1, primary load 2 and deferrable load. The Maximum power is consumed by residential appliances which are categorized as primary load 1 which work all over the time. Also the scaled peak load required for residential buildings that is primary load 2 is 237kW and for deferrable lad the scaled peak load is 148kW.

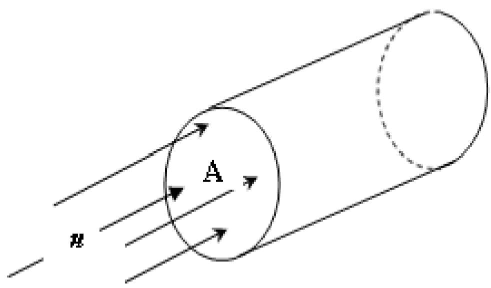
Energy for Pumping.

The principle of operation of wind turbines are based on an aerodynamic lifting. The wind strikes the blades and uses both the drag force (Horizontal) force and the lifting (perpendicular) force. The lifting force acts as the main driving power of the rotor of the wind turbine because it is a multiple of the drag force. The lifting force of the air flow is captured by the rotor blade and causes the necessary driving torque for the wind turbine (Ackermann, 2005).

The wind turbine captures the wind's kinetic energy of air mass by a rotor consisting of two or more blades which is mechanically coupled to an electrical generator. Most of the time the turbine is mounted on a tall tower to enhance the energy capture. The sites with steady high wind produce more energy over the year [Patel, 2006].

Energy Output from wind.

The calculation procedures for determining the power available in the wind can be found in many standard text books on wind power. The following basic relationships can be used, for calculating, the power output from wind. The energy the wind transfers to the rotor of a wind turbine is proportional to the density of the air, the rotor area and the cube of the wind speed. Increasing these factors will increase the power available from wind (G.D.RAI 2001). Equation 4 shows the relationship between these parameters but all this parameters is included on the power curve of any wind turbines.



The wind power developed and transferred to the rotor of the wind turbine will be:

$$P = \frac{1}{2}\rho A u^3 \tag{4}$$

Where:

P - Power in the wind (Watt)

ρ - Density of the air (at normal atmospheric pressure and at 15° Celsius air ways' some 1.225 Kilograms per cubic meter)

A - Rotor Area

u - The wind speed (m/s)

It is to be noted that the mean wind speed should not be simply inserted into Equation 4, as this will give an erroneous result because of the fact that the mean of the cubes of wind velocities will almost always be greater than the cube of the mean wind speed (G.D.RAI 2001).

The most accurate estimate for wind power density is that given by Equation 5.

$$\frac{P}{A} = \frac{1}{2} * \frac{1}{n} * \sum_{j=1}^{n} \left(\rho_j * u_j^3\right) \tag{5}$$

Where n is the number of wind speed readings and ρ_j and $u_j$are the j[th] readings of the air density and wind speed. For a known pressure and temperature the air density can be expressed as:

$$\rho = \frac{P_r}{RT} \tag{6}$$

Where $p_r$is air pressure (Pa) and R is the specific gas constant (287 Jkg-1 K-1) and T is air temperature in ^{0}K. For the available temperature data:

$$\rho = \frac{P_O}{RT} \exp\left(-\frac{gz}{RT}\right) \tag{7}$$

Where Po is standard sea level atmospheric pressure (101,325 Pa), g is the gravitational constant (9.8 m/s^2); and z is the location elevation (m) above sea level [Oklahoma Wind power, 2008]. If pressure and temperature data is not available, the following correlation may be used for estimating the density [Oklahoma Wind power, 2008]:

$$\rho = 1.225 - \left(1.194 * 10^{-4}\right) * Z \tag{8}$$

In the effort considering the effect of air temperature in the overall power production is absolutely essential; therefor air temperature at 26m above the surface in taken for the analysis and calculation of air density. The power of an air mass captured by the wind turbine can be calculated in kilo watts as follows:

$$P_{availabel} = COP \frac{\rho A u^3}{2} \tag{9}$$

In equation 9 (G.D RAI 2001), COP is an overall measure of performance under rated conditions,ρ is the density of the air (air is 1.225 kg/m^3), A is the area swept by the blades (m^2) and V is the speed of the wind (m/s). As shown in equation 6.6, the output power is also related to the area intercepting the wind, that is, the area swept by the wind turbines rotor. For the horizontal axis turbine, the rotor swept area is the area of a circle.

For maximum power production corresponding with the wind speed available Vestas V80 is selected with blade length of 32m. The selection of wind turbine blade radius for calculating swept area A is based on the mean wind power in which the average wind power is produced at its maximum or rated wind speed and the larger swept area the higher power is produced. From this assumption the swept area A is calculated as:

$$A = \pi r^2 \tag{10}$$

Where r is blade length. Relatively small increases in blade length or in rotor diameter produce a correspondingly bigger increase in the swept area.

As the data collected from filed work and other sources the monthly average mean wind speed is calculated; hence we can calculate power output from Equation 9.

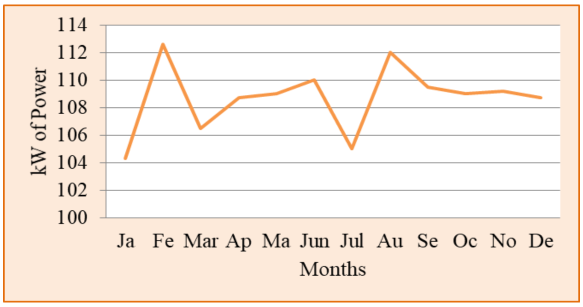


Figure 10: Power output obtained from wind for one year at 26m elevation

The above figure 10 indicates that the average power output for one year. The calculated value is based on the average wind speed obtained for the months of the year. The power output fluctuates between 112.6 kW and 104.3 kW. From the above figure 10 wind power obtained provides maximum output power of 112.6 kW at the month of February and August and minimum power of 104.3 kW found at January and July with deliberate variation. The power at this condition provides allowable energy for pumping which is remarkable and acceptable.

CONCLUSION

1. This study aimed to identify the possible site for pumped storage system and allocating the energy demand of the model village and comparing with the power output from the proposed site to state the degree of feasibility. Also it aimed to ass's power required for the pump from wind and solar.
2. The diurnal variation analysis of monthly solar potential the April month gives the maximum monthly energy output. It is found that the month of December produces the lowest solar radiation.
3. The monthly minimum and maximum energy output obtained from solar is 5.4kWh/d and 7kWh/d respectively which is recommended for power production, since energy from wind and solar is used for supplying power for driving pump. At the same time power output from wind of the study area have been determined as a result of the data analysis; and it was found that the site is endowed with wind energy potential which adequately able to generate electricity with the average capacity of 108.5 kW and highly reliable for supplying power for the pump.
4. The technical point of view the total scaled peak load of the model village is about 739kW and the total power output from the proposed pumped storage system is about 892.71kW and the system is feasible in satisfying the energy demand of the model village in present situation and life style of the inhabitants.

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