International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-3, Issue-7, July 2017
ISSN: 2395-3470
www.ijseas.com

Optimal Solar Water Pumping System for Small Scale Irrigation : A Case Study on Economical Sizing for Dangila Area of Ethiopia

Muluken Zegeye*, V.Siva Ramakrishnan*, M.Premalatha**
*Faculty of Mechanical and Industrial Engineering, Bahir Dar University, Bahir Dar, Ethiopia
** Department of Energy Engineering, National Institute of Technology, Tiruchirappalli, India. vsmp1967@yahoo.com

Abstract

There is a great impact of diesel driven water pumping systems on irrigation, in remote areas around the world. However the gradual increase of fuel price worldwide has a serious effect on this system, that discourages the utilization of such technology. As an alternate, it is expected to deal with the economical solar water pumping system for small scale irrigation applications. This paper deals with the design of this PV water pumping, which provides the theoretical studies of photovoltaic and the analysis of electric power requirement for powering pumps for irrigation. The analysis employs determining the optimum tilt angle of solar panel which can collect the maximum solar energy, when irrigation demand could be higher based on seasonal variation. The irrigation requirement has been determined and the maximum power has been minimized so as to select the power which can satisfy all irrigation periods with reduced cost of PV system.

Keywords: *Photovoltaic water pumping, irrigation water requirement, Economic Analysis.*

1. Introduction

Energy is a critical foundation for economic growth and social progress. As economy advances and human society requires more energy, the lack of fossil energy and its effect on the environment has given rise to the ever-serious contradiction on, environmental protection and economic development. Renewable energy, with the availability of its renewability and minimum pollution will be the best choice to guarantee the future development of the world. As Ethiopia is one of the developing countries in the world, developing renewable energy is its inevitable choice for sustainable economic growth. Among the renewable energy sources, the photovoltaic energy has been widely utilized in low power applications in the world. A recent survey reveals that Ethiopia's solar power potential to be around 2 trillion MW hours, with the northern part of the country having the greatest potential. Since Ethiopia is not an oil producing country, it should achieve this target by strong industrial development. Agriculture in Ethiopia is dominated by rain-fed systems but low and unpredictable rainfall limits productivity and food security. Consequently, investment in small-scale irrigation has been identified as a key poverty reduction strategy. In its Growth and Transformation Plan (GTP), the government of Ethiopia discussed on, making use of groundwater for supporting the farming households in the adoption and use of private hand-dug wells and suitable water lifting technologies (WLTs). Since most rural areas are far from the electric service in Ethiopia, most hand dug wells, shallow wells and boreholes are fitted with hand pumps or diesel and petrol driven generators. Diesel/petrol pumps have many drawbacks such as high running and maintenance costs, unreliable supply of fuel, and poor availability of spare parts. CO_2 emissions can be greatly reduced through the application of these renewable energy technologies, which are already cost competitive with fossil fuels in many situations. In addition, the advantage of using water pumps, powered by PV system include low maintenance, ease of installation, reliability and matching between the power generated and the water usage needs. There are many studies that have been carried out for using photovoltaic water pumps worldwide, but this technology is still in its infancy stage in Ethiopia. They are mostly concentrated on efficiency improvement techniques and design based on peak hydraulic energy demand without considering the variation of solar energy and water requirement with time dynamically. Present study aims at, technical analysis and the economic feasibility of using PV system design for water pumping in Ethiopia particularly in Dangila area, for small scale irrigation applications. The study starts, for economical applications, by determining the optimum tilt angle for the solar panel during irrigation season and incorporates the relation between solar radiation, temperature, evapo-transpiration, effective precipitation, crop type & stages, hydrological condition, season of load condition and irrigation requirements.

2. Literature Review

2.1 Solar Energy: Solar radiation provides a huge amount of energy to the earth. The total amount of energy, which is irradiated from the sun to the earth's surface, equals approximately 10,000 times the annual global energy consumption. The sun radiates 174 trillion kWh of energy to the earth per hour. In other words, the earth receives 1.74×10^{17} watts of power from the sun [Danish Wind, 2011].

2.2 Solar Photovoltaic (PV) Cells:

Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into direct electricity by using semiconductors that exhibit the photovoltaic effect. In the past the PV cost was very high. For that reason, PV applications have been limited to remote locations not connected to utility lines. But with the declining prices in PV, the market of solar modules has been growing at 25 to 30% annually during the last year. A comparative study was performed in Namibia about the cost of solar water pumping and diesel over a range of heads of pump (10 to 200 m) and a range of daily flow rates (3 – 50 m^3/day). This analysis showed that solar pumps with a higher capital cost can compete with diesel pumps. Nowadays the efficiency of the best crystalline silicon cells has reached 24% for photovoltaic cells used in aerospace technology and about 14-18% overall efficiency for those used for industrial and domestic use.

2.3 Energy and Water Use in Irrigation:

In many developing countries, the inadequate supply of drinking and irrigation water is a severe problem. In rural areas with no access to grid power, national water authorities and private farmers have to rely on hand pumps and diesel-driven pumps, many of which are out of service due to technical defects or lack of fuel. As a rule, hand-operated pumps are the least-cost option for low consumption rates and low pumping heads. These pumps stand in competition with photovoltaic water pumps (PVP), which present themselves as a reliable and environmentally sound alternative means of water delivery.

2.4 Water Pumping System:

Powering of water pumping systems with (PV) generators has been an applied technology in many countries since 1977. A typical size of system with this type pump is at least 500W or larger. Surface pumps are more accessible for maintenance and less expensive than submersible pumps, but they are not well suited for suction and can only draw water from about 20 feet vertical.

2.5 Comparing Solar PV and Other Water Pumping Technologies:

Photo Voltaic are increasingly meeting the needs for water pumping systems in the range between the very small systems, where hand pumps dominate, and the large generator powered systems. Pump life can vary from 5 – 10 years. More than 20,000 PV-powered water pumps were installed in developing countries, notably India, Ethiopia, Thailand, Mali, the Philippines and Morocco. In determining whether to choose a wind or solar powered pumping system, there are more things to consider like: does the resource match the daily water requirement for each month? What are the maintenance requirements? What is the reliability and life cycle cost?

***2.6 Economical Sizing of Solar PV Water Pumping Systems for Small Scale Irrigation*:**

The usual way of optimizing of photovoltaic (PV) water pumping systems, which have been the issue of numerous papers, mainly dealt with improvement of effectiveness of various system components, as well as their better mutual adjustment, with the aim of total cost reduction of the PV pumping system. Hydraulic energy for PV pumping systems for irrigation is calculated based on required water quantity data and total head of water rise. Here the nominal electric power of PV generator is calculated based on the known monthly average daily demand for hydraulic energy and available monthly average daily solar irradiation in the critical month.

2.7 Irrigation in Ethiopia:

The agricultural sector is the leading sector in the Ethiopian economy, comprising 47.7% of the total GDP, as compared to 13.3% from industry and 39% from services. Though agriculture is the dominant sector, most of Ethiopia's cultivated land is under rain fed agriculture. Due to lack of water storage and large spatial and temporal variations in rainfall, there is not enough water for most farmers to produce more than one crop per year and hence there is a frequent crop failure due to dry spells and droughts which has resulted in a chronic food shortage currently facing the country.

3. Materials and Methods.

Analysis of Photovoltaic (PV) Energy for the Selected Site is shown in Figure 1

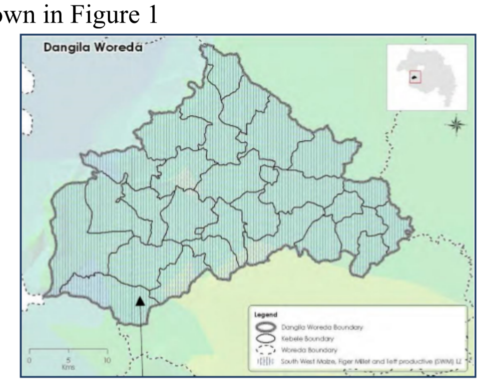

Figure 1: Dangila Woreda Map with rivers

3.1 Solar Energy in Dangila:

Dangila is located around 11.267ºN latitude and 36.883ºE longitude, and this geographical location encourages the use of solar PV for various energy productions. Dangila has a high solar energy potential, where average solar energy is between 5.12 KWh/m^2 per day in July to 7.0 KWh/m^2 per day in April, and the daily average of solar radiation intensity on horizontal surface is 6.1 KWh/m^2 per day while the average sunshine hours ranges from 4 hours in July to 8.96 hours in January and for the irrigation periods it is more than 7 hours.

3.2 Solar Radiation Data Collection:

The Ethiopian Meteorological Agency collects the sunshine hours for some areas of the country and therefore the solar radiation intensity is calculated from the average sunshine hours. The average monthly sunshine hour for Dangila area has been given in the Figure 2.

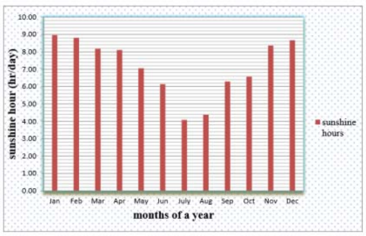

Figure 2: Monthly average sunshine hours for Dangila

3.3 Solar Hour Angle & Sunset Hour Angle:

The angular displacement of the sun east or west of the local meridian is the solar hour angle. It is equal to zero at s noon and varies by 15º per hour from solar noon. The solar hour angle corresponding to the time is given by:

$$\omega = (ST - 12)15^0$$

Solar radiation on a horizontal surface can be either of direct radiation or diffused radiation. When the sunset hour angle for the average day of the month is less than 81.4º, then equation would be:

$$\frac{\overline{H}_d}{\overline{H}} = 1.391 - 3.56\overline{K}_T + 4.189\overline{K}_T^2 - 2.137\overline{K}_T^3$$

When the sunset hour angle is greater than 81.4º, the monthly average diffuse radiation is given by,

$$\frac{\overline{H}_d}{\overline{H}} = 1.311 - 3.022\overline{K}_T + 3.427\overline{K}_T^2 - 1.821\overline{K}_T^3$$

3.4 PV Water Pumping Configuration:

In the proposed photovoltaic water pumping system, the solar panels are directly connected to a DC motor that drives the water pump. It need to be treated adequately throughout the entire operation period and the system is analyzed taking into account all changes that occur in relation to available capacity and needs. The climate determines the moisture and solar irradiation. The moisture and solar irradiation determine water requirements for irrigation. Land and geological features determine water storage capacity.

3.5 Irrigation method:

The PV pumping system would be applied conveniently to the surface irrigation, open channels methods and drip irrigation methods, due to power requirement and way of irrigating the crop. On the other hand surface irrigation method has been commonly functional in Ethiopia. Therefore, in this work Solar PV pumping system has been analyzed using this method of irrigation.

3.6 Irrigation and Nominal Electric Power Requirement

(a) Soil type and soil moisture:

If moisture from natural processes is inadequate, irrigation is demanded. As it is known Soil moisture is a result of natural processes (precipitation, infiltration, and evapo-transpiration) and characteristics of the soil. For Dangila the soil field capacity can be taken as 450mm of water

(b) Nominal electric power requirement of the PV generator:

Hydraulic energy expressed in kWh at the output of a pumping system for time period, as a function of flow rate requirement and total dynamic head can initially be expressed as follows:

$$E_{H(i)} = 0.00272 Q_{d(i)} H_{TE(i)}$$

The systematic approach to determining the required optimal nominal electric power of the PV generator, that it is directly dependent to the amount of water to be pumped, and indirectly related to the efficiency of the PV pumping system, amount of solar radiation on the plane of PV module per unit area as well as to the efficiency of irrigation method.

4. Results and Discussion.

4.1 Solar Panel Orientation and Inclination:

The irrigation requirement is maximized, when the difference between actual evapo-transpiration and effective precipitation is maximum. The irrigation requirement is maximized, during the months January and February.

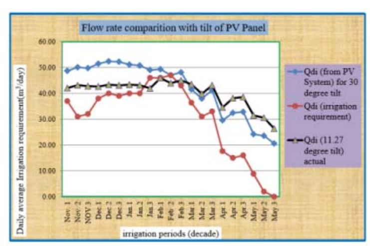

Figure 3: Comparison between daily irrigation water demand and the possible yield of water pumped .

Consequently, solar panel tilt angle has to be positioned to maximize the power during these months. The irrigation requirement after February is decreasing and also power output from the solar panel is decreasing.. On the other hand, the power output capacity increases from the solar panel tilted at 30º rather than tilting with latitude angle during the months of November and December. It is shown in Figure 3.

4.2 Hydraulic Power/ Water Flow Rate Requirement:

Irrigation water requirement has been analyzed by different and decadal average daily flow rate has been determined. The peak irrigation water demand is found on the month of February. From the optimal nominal electric power from the PV generator the possible water flow rate is evaluated. The peak nominal power can satisfy the overall demand during irrigation period. The irrigation requirement is shown in Figure 4.

4.3 Nominal Electric Power Requirement:

The optimal electric power required from the PV generator to satisfy the hydraulic energy for irrigation. This peak nominal electric power from PV generator has been found by minimizing the maximum electric power for the irrigation period and shown in the Table 1.

Table 1: Daily irrigation requirement and electric power demand from PV Generator.

Time stage(i)	$E_{T(i)}$ (KWh/m^2.day)	$R_{e(i)}$ (mm/decade)	$E_{tr(i)}$ (mm/decade)	$Q_{d(i)}$ (m^3/day)	P_{el} (Watt)
Nov. 1	7.38	2.6	40.32	37	457.48
Nov. 2	7.51	8.7	40.83	31	372.42
NOV.3	7.54	10	40.25	30	362.90
Dec.1	7.69	0.3	39.39	38	444.43
Dec.2	7.77	0	39.74	39	447.97
Dec.3	7.81	0	39.21	39	449.58
Jan.1	7.71	0	39.74	39	459.15
Jan.2	7.64	0	39.99	39	462.28
Jan.3	7.39	0	45.60	45	552.40
Feb.1	7.40	0	45.70	45	549.04
Feb .2	7.14	0	47.30	47	601.47
Feb.3	7.15	0	43.82	43	537.64
Mar.1	6.57	8.7	44.53	35	506.85
Mar.2	6.16	12	42.74	30	475.46
Mar.3	6.46	11.2	44.67	33	482.21
Apr.1	5.22	24	41.27	18	366.74
Apr.2	5.52	28.8	43.71	14	259.75
Apr.3	5.54	27.6	44.04	16	293.48
May.1	4.59	32	40.38	8	199.18
May.2	4.53	37.6	39.69	2	51.06
May.3	4.22	184	36.21	0	0.00

4.4 Cost Comparison

The amount of water demand for irrigation is comparatively large and most of the time in our country it is possible to use ponds, rivers and low head wells for such application.

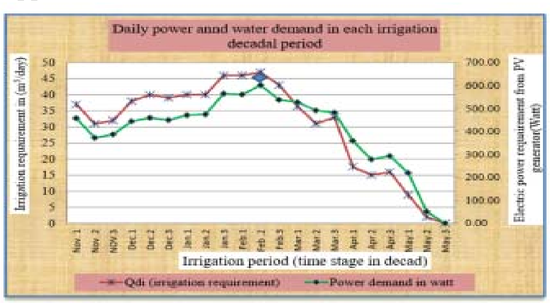

Figure 4: Average daily irrigation requirement and possible daily electric power demand from PV generator.

Economically, the two water pumping systems (PV and diesel) have been evaluated and compared based on LCC and unit cost of water pumped as shown in Figure 5. All of the cost comparisons show that solar PV water pumping system is more cost effective than diesel water pumping system. The life cycle cost of PV water pumping system for 20 years is found to be 38,880.43 Birr and for diesel water pumping system for the same 20 years is found to be 87,063.71 Birr. The price 1 m^3 of water from the PV generator costs 0.52ETB / m^3 and for that of diesel generator is 1.63 ETB/ m^3. The breakeven point between PV water pumping system and diesel pumping system is found to be less than four years . The fuel price and solar module cost is shown in Figure 6.

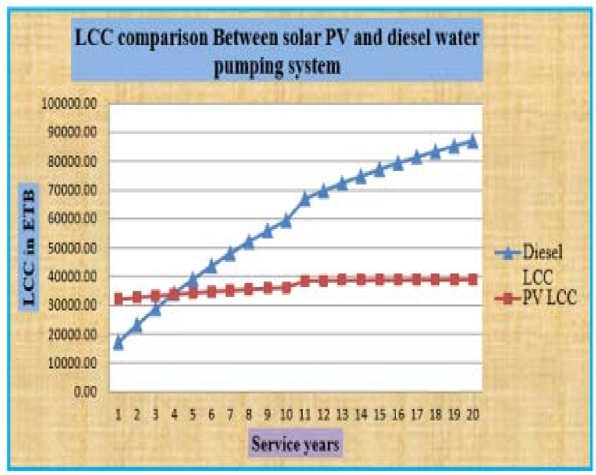

Figure 5: LCC years to breakeven for PV vs. Diesel generator water pumping system

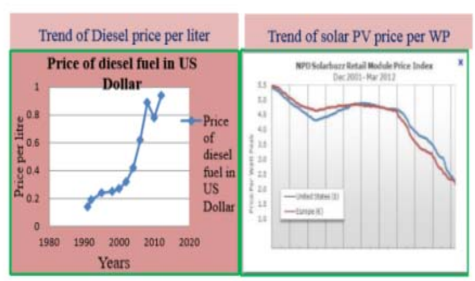

Figure 6: Trends of fuel price per liter and solar module price per watt

On the other hand as we can see from the graph the price of fuel rise from time to time where as the price of solar PV declines. For instance by substituting only currently available 26,000 pumps in Amhara region more than 48 million American dollar foreign currency can be saved annually.

5. Conclusions and Recommendations.

5.1 Conclusions: Generally, the optimization of the PV pumping system for irrigation is possible when for a certain optimal policy of irrigation water distribution i.e. for corresponding values of hydraulic energy, the certain nominal power of PV generator is found, which could meet all demands in the best possible way, throughout the entire observed period. This power could meet over all irrigation demand for all irrigation period up to one hectare irrigation area. Photovoltaic powered water pumping systems are attractive for small scale irrigation application with remote water sources and limited access to AC power. Even though diesel pumps have been in use for years for assisting agriculture, solar power has made significant steps towards becoming the system of choice for these circumstances. The technology for solar water pumping is exceeding all expectations, and will continue to be a viable choice for more and more users as its capabilities, reliability, and versatility increases while costs decrease with no environmental effect. As it is known now a days the price of fuel rise from time to time where as the price of solar PV declines. Furthermore fuel consumption is not reliable for irrigation application as it is not available easily on rural areas in addition to its environmental effect. On the other hand irrigation power requirements tend to coincide with the seasonal incoming solar radiation. Therefore, it is a time to shift to solar energy utilization for the sustainable growth. Furthermore, it is reliable that as water demand increase solar power also increases.

5.2 Recommendation: This study focuses only on the economical design of solar PV water pumping system and does not consider the efficiency improvement techniques. As a result, further research has to be conducted to improve efficiency of such solar PV water pumping system. The governmental and nongovernmental organizations have to participate on importing the technology and creating awareness about it. Therefore, financial access for loan has to be arranged so as to facilitate utilization of this technology which is more economical and environmental friendly.

6. References.

[1] Abu-Aligah, M. 2011. Design of Photovoltaic Water Pumping System and Compare it With Diesel Powered Pump. Jordan Journal of Mechanical and Industrial Engineering, Vol.5, No. 3.

[2] Awulachew, S.B., Merrey, D.J., Kamara, A. B., Koopen Van, B., De Vries, Penning F., and Boelle, E., 2005. Experiences and Opportunities for Promoting SmallScale/Micro Irrigation and Rainwater Harvesting for Food Security in Ethiopia: IWMI Working Paper 98, 2005.

[3] Daud, A. and Mahmoud, M., 2004. Solar Powered Induction Motor-Driven Water Pump Operating on a Desert Well: Simulation and Field Tests Science Direct. pp.701-714.

[4] Eker, B., 2005. Solar Powered Water Pumping Systems. Trakia Journal of Sciences, Vol. 3, No. 7.

[5] Foster, R., Cisneros, G., and Hanley, C.,. Life-Cycle Cost Analysis for Photovoltaic Water Pumping Systems in Mexico: 2nd World Conference on Photovoltaic Solar Energy Conversion. Vienna, Austria, July 6-10, 1998, p.5.

[6] Hamidat, A., Benyoucef, B., Hartani, T., 2003.Small-ScaleIrrigatedWith Photovoltaic Water Pumping System In Sahara Regions: Renewable Energy. Vol. 28,

[7] Odeh, I, Yohanis, Y.G., and Norton, B., 2006. Economic Viability of Photovoltaic Water Pumping Systems: Solar Energy. www.sciencedirect.com, pp. 850-860.

[8] Oko, COC, Nnamchi, SN, 2012. Optimum Collector Tilt Angles for Low Latitudes the Open Renewable. Energy Journal, vol.5, No. 7–14.

[9] Ramos J.S, Ramos Helena M,2009. Solar Powered Pumps to Supply Water for Rural Or Isolated Zones: A Case Study. science direct, pp.151-158.

[10] Von Aichberger, S., 2003. Pump Up the Volume: Market Survey on Solar Pumps. Photon International, pp. 50–57.

First Author. He is the Dean, Faculty of Mechanical and Industrial Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia. Obtained his B.Sc in Mechanical Engineering and M.Sc in Sustainable Energy Engineering, having wide experience in Teaching, Research and administration. His interest is in Solar Energy applicable for water lifting Applications.

Second Author: He is the full Professor in Thermal Engineering, Faculty of Mechanical and Industrial Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia. Obtained his B. E in Mechanical Engineering, M.E in Mechanical Engineering and PhD in Energy Engineering. Having Teaching, Research and Administrative experience spanning three decades.

Third Author: She is the Professor i/c Department of Energy Engineering, National Institute of Technology, Tiruchirappalli, India. Obtained her B.Tech in Chemical Engineering, M.Tech in Energy Engineering and PhD in Solar Energy Having Teaching, Research and Administrative experience spanning twenty five years