International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

DESIGN OF AN AGRICULTURAL PLATFORM POWERED BY SOLAR PHOTOVOLTAIC ELECTRICAL ENERGY AT GANDO IN TOGO

KOMBATE Yao[1], HOVA Hoavo*[1], DJAGLO Anani-Koffi-Ayèlété[1] & LY Ibrahima[2]
[1]Laboratoire Matériaux, Energies Renouvelables et Environnement (LaMERE), Département de Physique, Faculté des Sciences et Techniques, Université de Kara, Togo
[2]Département génie électromécanique, Ecole Polytechnique de Thiès, Sénégal

DOI: 10.5281/zenodo.3828859

ABSTRACT

This article presents the sizing and economic analysis of a photovoltaic solar pumping system for an agricultural plateform in Gando in northern Togo. For the design of photovoltaic solar pumping system, hydraulic parameters (water flow and total head) are essential for the design of the system. For this purpose, a simple analytical method is developed for the design of photovoltaic solar pumping system. The developed model was used to determine the peak power of the PV generator and the power of the possible solar pump for a daily 70 cubic meter water flow. Considering the investment cost of photovoltaic solar pumping system, an analysis of the cost of pumping water from a well of 30 m total head was performed. We see that the cost of the cubic meter is US $0.12 against US $0.42 per cubic meter for pumping system using the electrical network.

KEYWORDS: photovoltaic solar pumping system, sizing, total head, water flow, cost of cubic meter of water.

1. INTRODUCTION

Energy and water are the two major needs of the world that must be addressed to ensure the subsistence of human beings on this planet. All countries need to diversify the means of production of energy and at the same time safeguarding the protection of the environment. Access to electricity and water are the main challenges to the sustainable development of a country. In Togo, the rate of access to drinking water increased from 30 % in 2005 to 60 % in 2019, 55 % in rural areas. The government is committed to provide drinking water to 80 % until 2022 against 60 % today[1].

For mechanized agriculture, electric power is an important factor. In Togo, the distribution of final consumption of electrical energy between the different sectors of economic activity shows almost no consumption of petroleum products and electricity in agriculture. This is an indicator of low mechanization in the agricultural sector in Togo (agricultural machinery) and low use of processing technologies and conservation of agricultural products (agriculture, forestry, fisheries and livestock)[2].Especially in Gando, a semi-urban area, primarily agricultural workforce (agriculture and livestock), is experiencing a shortage of drinking water and irrigation difficulties vegetable crops against-season.

The photo voltaic solar pumping system can meet the demand for drinking water and irrigation of vegetable crops. The advantage of solar PV pumping systems using solar energy to pump water is that they can be installed in remonte locations, farms and forests that are not connected to the power grid. To this is added its abundance and the absence of environmental and noise pollution.

When sizing the PV solar pumping system, hydraulic parameters such as water flow and total head are required to calculate the peak power of the PV generator, hydraulic power system and the electrical power of the solar pump. However, climate data such as temperature and solar radiation significantly influence the PV solar pumping systems in actual operating conditions. Several theoretical and experimental studies were performed on the PV solar pumping systems currently installed throughout the world, especially in remote areas where access to electricity is difficult to supply drinking water and for crop irrigation [3], [4], [5], [6], [7], [8]. Various models have been developed for this purpose to simulate and size PV generators [9], [10], [11] and to study the effect of

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

climate data on electrical and hydraulic parameters of the PV solar pumping systems. These studies show that total head affects the performance of PV solar pumping systems and the efficiency of the PV solar pumping system is obtained for a deep total head [12], [13]. The water flow increases with increasing pump power for different total head heights according the non-linear model [14], [15]. Economic studies have also shown that the pumping systems are long-term economically viable and does not emit greenhouse gases [3], [5], [6], [8].

This paper presents and discusses the sizing of the solar PV pumping system of an agricultural plateform (drinking water, market gardening and watering). The effect of solar radiation on the peak power of the PV generator and the effect of the total head on the power of the pump are simulated and analyzed in Matlab. An economic analysis of the PV solar pumping system as an alternative to the pumping system using the electricity network is carried out.

2. MATERIALS AND METHODS

A solar PV pumping system over the sun is divided into four essential components [14], [16], namely : the PV generator that directly converts the sunlight into electrical energy in the form of direct current, the power conditioning system (if applicable), the load (electric motor coupled to a solar pump) and the storage system and water supply, which supplies water to the distribution point.

The analytical method is used for the sizing of the solar PV pumping system of an agricultural plateform. This consists in calculating the peak power of the PV generator and choosing the corresponding solar pump that meets the required service under the reference conditions defined by three values : the minimum monthly average solar radiation received by the PV generator, the hourly water flow and the total head. An economic analysis is finally studied to calculate the cost of the cubic meter of water.

Location of the platform site. Gando is the capital city of the prefecture of South-Oti in Savanna region. With an area of 4,300 ha () and an estimated population of 8,965 inhabitants (Recensement Général de la population du Togo-2010, actualisation partielle de 2014), Gando is characterized socially by a predominantly agricultural workforce. In this locality, agriculture remains an activity that ensures more jobs. It is subsistence agriculture. Livestock is the most important secondary activity. Gando is located at latitude 10.4 degrees north, longitude 0.5 degrees East and at an altitude of 175 m. The worst month is August with an average monthly solar radiation of 4.56 .

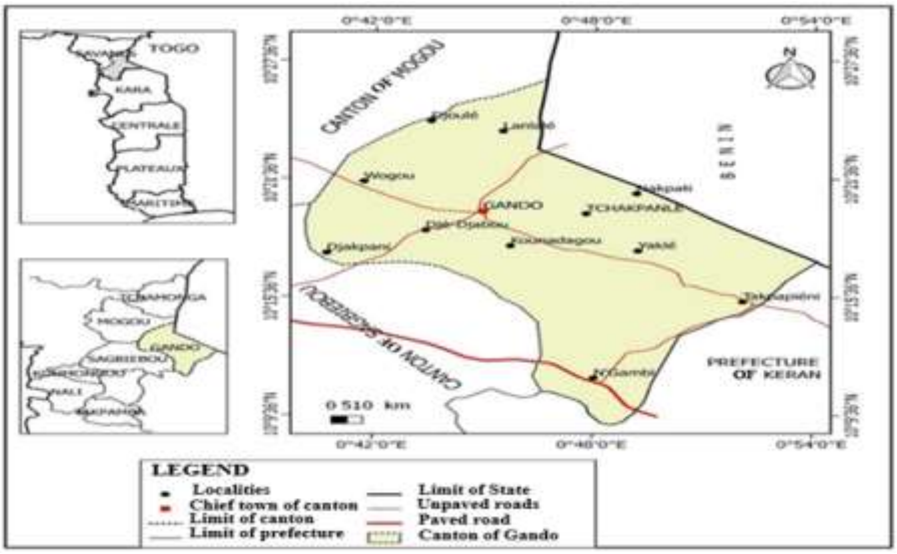

Figure 1. Location of the platform site

Water needs. The PV solar pumping system to be designed will be used to irrigate vegetable crops (market gardening), water livestock for 100 heads and provide drinking water to 300 inhabitants of a locality close to the

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

platform. Water needs that are considered necessary for the rural areas of poor countries are about 20 liters per person and 30 liters per head of cattle [14], [16]. Thus, the need for drinking water and livestock watering are estimated at 9 per day and the maximum need for water for vegetable crops of 61 per day per hectare was obtained in April from the software CROPWAT 8.0. The water requirements of the platform (drinking + market gardening + watering) are shown in Table 1 below.

Table 1. Water requirements of the platform

Types of water requirements	Volume of water ($m^3.day^{-1}$)
Market gardening	61
Drinking	6
Watering	3
Total requirements	70

Total head. The total head (H_T) is the sum of the static head (H_s), of the height of the water storage tank (H_t), the drawdown head (H_d), the difference between the static and the dynamic level of water (H_d) and the equivalent head (H_{fl}) caused by friction losses of the water in the pipe.

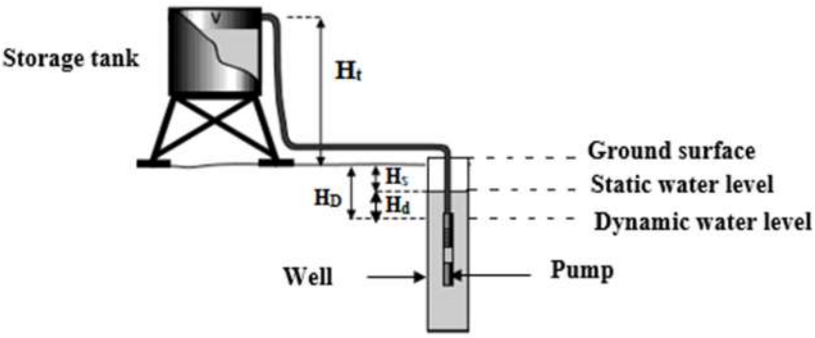

Figure 2. Hydraulic data of a solar pumping system

From Figure 2, the total head is calculated by the following equation[16] :

$$H_T = H_t + H_D + H_{fl} = H_t + H_s + H_d + H_{fl} \quad \text{(i)}$$

Sizing the solar pump. The power required for pumping water is determined by the equation (ii) [4], [5] :

$$P_{hyd} = g \times \rho \times Q \times H_T \quad \text{(ii)}$$

where:P_{hyd} is the hydraulic power (W), g is the intensity of the earth's gravitational field (9.81 $m.s^{-2}$), ρ is the volume mase water (1000 $kg.m^{-3}$), Q is the flow of water necessary for pumping ($m^3.s^{-1}$), H_T is the total head (m).

The electrical power needed solar motor-pump is calculated by equation (iii) :

$$P_e = \frac{P_{hyd}}{\eta_{MP}} = \frac{\rho \times g}{\eta_{MP}} \times Q \times H_T \quad \text{(iii)}$$

whereη_{MP} is the efficiency of the solar motor-pump.

The model expresses the electrical power to the motor-pump directly as a function of the total head for different water flows. The choice of a solar motor-pump is based on the flow of water that can be pumped from the drilling, the total head and has electric power.

Sizing the PV generator. The peak power of the PV generator is calculated by the formula (iv) [4] :

$$P_p = G_r \eta_r \frac{\rho \times g \times Q \times H_T}{3600 \times \eta_{pv} \times \eta_{MP} \times G_\beta} \quad \text{(iv)}$$

where:P_p is the peak power of the PV generator (watt peak, Wp), η_r is the performance of the PV generator at the reference temperature ($T_r = 25°C$), G_r is the irradianceat the referencetemperature ($G_r = 1000\ \mathrm{W.m^{-2}}$), G_β

is the incident solar radiation on the plane of the PV generator to the inclination β ($W\mathrm{h.m^{-2}.day^{-1}}$), $\eta_{pv} = f_m[1-\alpha(T_c - T_r)]\eta_r$ is the efficiency of the PV generator in operating conditions with$f_m = \frac{P_{max}}{V_{oc}I_{sc}} = \frac{V_m I_m}{V_{oc}I_{sc}}$: form factor,α : temperature coefficient of the PV modules, T_c : temperature of the PV modules, it depends on the irradiance of the ambient temperature and the wind speed (40° C), Q is the flow rate of water ($\mathrm{m^3.day^{-1}}$), H_T is the total head (m).

Replacing the expression of η_{pv} in relation (iv), we obtain equation (v) below :

$$P_p = \frac{G_r \times \rho \times g}{3600 \times f_m[1-\alpha(T_c - T_r)]\eta_{MP}} \times \frac{Q \times H_T}{G_\beta} \quad \text{(v)}$$

By setting $C_p = \frac{G_r \times \rho \times g}{3600 \times f_m[1-\alpha(T_c - T_r)]\eta_{MP}}$, the relation (v) becomes :

$$P_p = C_p \times \frac{Q \times H_T}{G_\beta} \quad \text{(vi)}$$

The model expresses the peak power of the PV generator directly as a function of the solar radiation for different total heads. Given the availability of the incident solar radiation, the total head and the daily water flow, equation (vi) determines the peak power of the PV generator.

Economic analysis. For the economic analysis the following equation is used to find Present Value of Cost (PVC) for the PV pumping system [8] :

$$PVC = IC + (MO \times PWF) - S\left(\frac{1}{1+r}\right)^n \quad \text{(vii)}$$

where :IC is the initial cost of the PV pumping system including, civil works, transportation, installation and the cables connection, MO is the maintenance and operation cost (5 % of initialcost), PWF is the present worth factor, S is the scrap value (10 % of the initial cost), r is the discount rate (10 %), n is the life of time the PV pumping system (20 years).
The discount factor PWFisobtainedby using equation (viii) :

$$PWF = \frac{(1+r)^n - 1}{r(1+r)^n} \quad \text{(viii)}$$

The cost per cubic meter is obtained using equation (ix) below:

$$Cost/m^3 = \frac{PVC}{AWR \times PWF} \quad \text{(ix)}$$

whereAWR is the annual water requirements, which can be calculated using the followingequation :

$$AWR = Q \times 365 \quad \text{(v)}$$

where$Q$ is the flow of water necessary for pumping ($\mathrm{m^3.day^{-1}}$).

3. RESULTS AND DISCUSSION

Sizing the photovoltaic pumping system. The input data of the design of photo voltaic solar pumping system are listed in Table 2.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Table 2. Input parameters of the pumping system PV

Parameters	Values
G_r	1000 $W.m^{-2}$
g	9.81 $m.s^{-2}$
ρ	1000 $kg.m^{-3}$
η_p	45 %
η_{pv}	14 %
f_m	0.9
T_r	25 °C
T_c	40 °C
f_m	0.90
α	0.005 /°C

The results simulation of relations (iii) and (vi) in the Matlab environment are represented respectively by the curbes of figures 3 and 4.

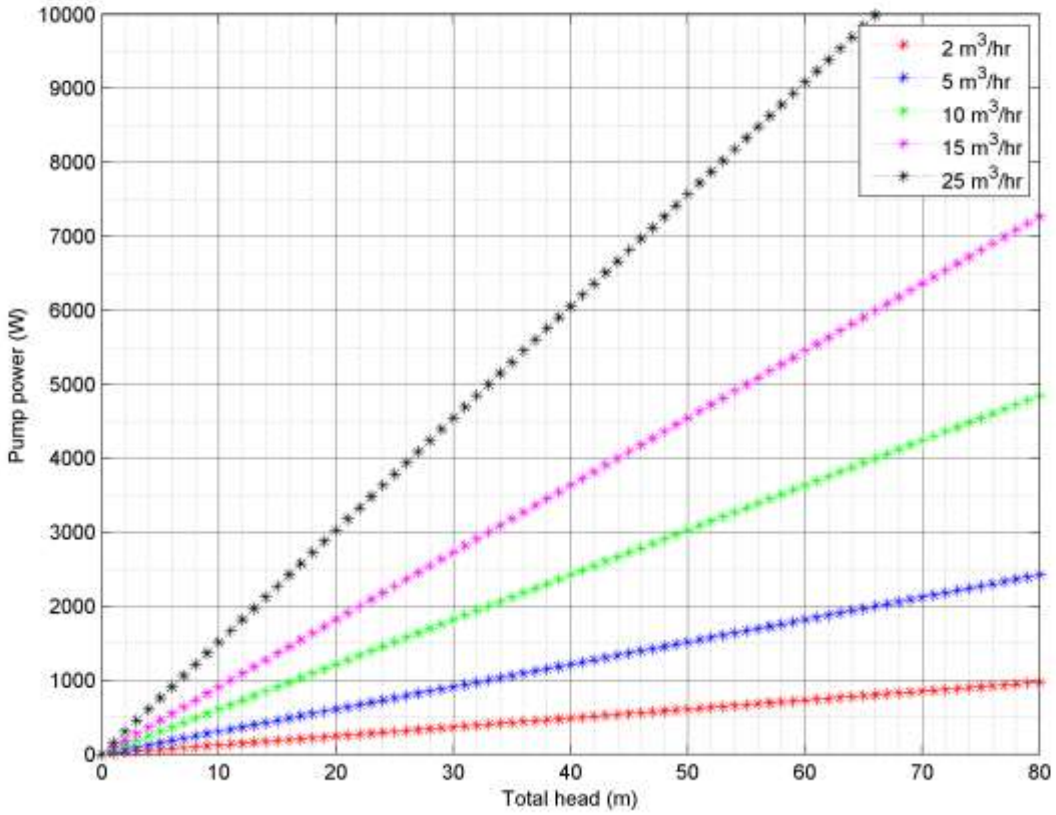

Figure 3. Network power curves of the pump according to total head

The simulation results in figure 3 show that the power of the solar pump increases with the total head and the hourly flow.

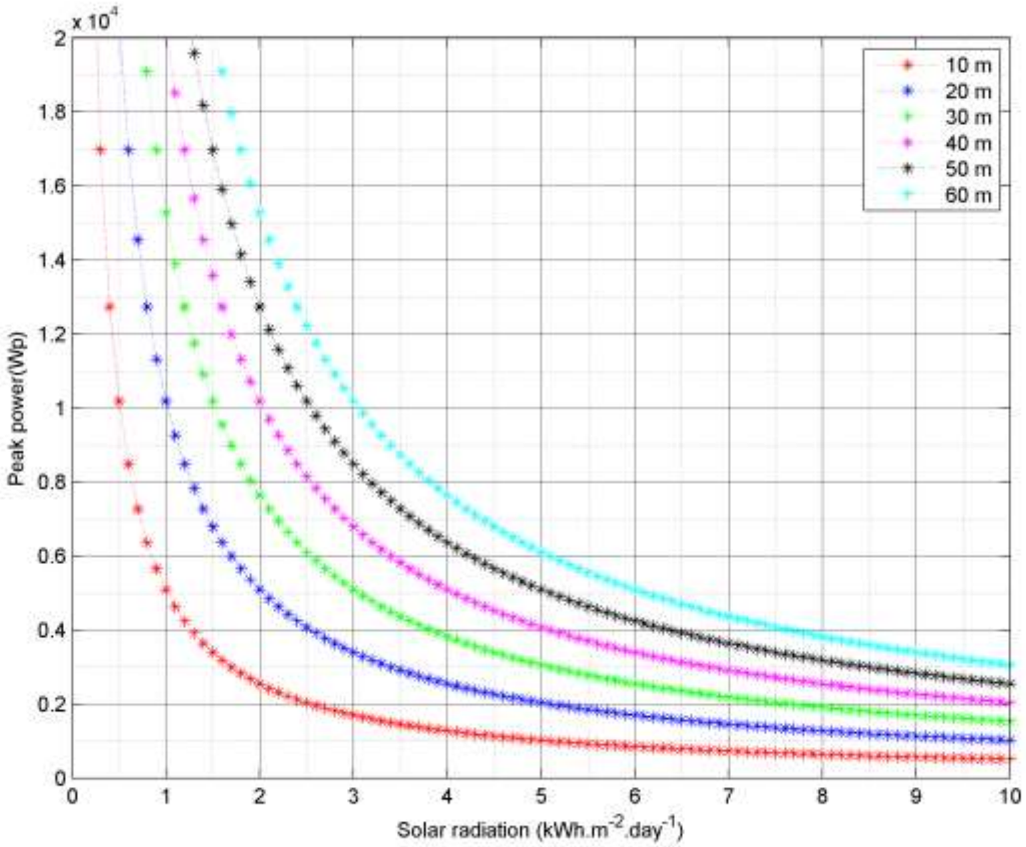

Figure 4. Network of power curves as a function of solar radiation

The simulation results in figure 4 show the effect of solar radiation on the peak power of the PV generator. Indeed, when solar radiation increases, the peak power of the PV generator decreases but increases with increasing total head.

The choice of configuration for the design of the platform will depend on Gando's water table. The deeperitis, the higher the total head ; consequently, the size of the PV generator and power of the solar pump are high. So whatever the total head values, the dail flow of 70 m^{3}from the plate form remains the same. Finally to reduce the size of the system, it is advantageous to choose a total head of low value.

For a daily flow of 70 m^3, a total head of 30 m and an average monthly solar radiation of 4.56 $\mathrm{kWh.m^{-2}.day^{-1}}$, the load profile of the agricultural platform gives an electrical energy equal to 12.72 $\mathrm{kWh.day^{-1}}$. Thus, the sizing results show a peak power of the PV generator equal to 3.35 kWp, a power of the solar pump of 2.8 kW and a converter of 3 kVA (48 Vdc et 220 Vac).

Economic analysis. The necessary economic indicators for system viability study are listed in Table 3.

Table 3. Economic Indicators

Life of time the PV pumping system (n)	20 years
Daily water requirements (Q)	70 m^3
Annual water requirements (AWR)	25,550 m^3
Initial cost (IC)	18,340.25 $
Presentworth factor (PWF)	8.513

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Scrap value (S)	1,834.025 $
Maintenance and operation cost (MO)	917.013 $
Present Value of Cost (PVC)	25,874.68 $
Cost per cubicmeter	0.12 $/m^3

The initial cost of the PV pumping system including, civil works, transportation, installation and the cables connection is US $18,340.25. The cost of a cubicmeter of PV solarpumping system designedis US $0.12, compared to the pumping system of the Togolese Water Company (Togolaise des Eaux, TdE) using the electrical network, the cost of whichis US $0.42 per cubicmeter and US $0.83 per cubicmeterat the rate of US $0.041 for two 25 liter cans for the sale of water in standpipes.

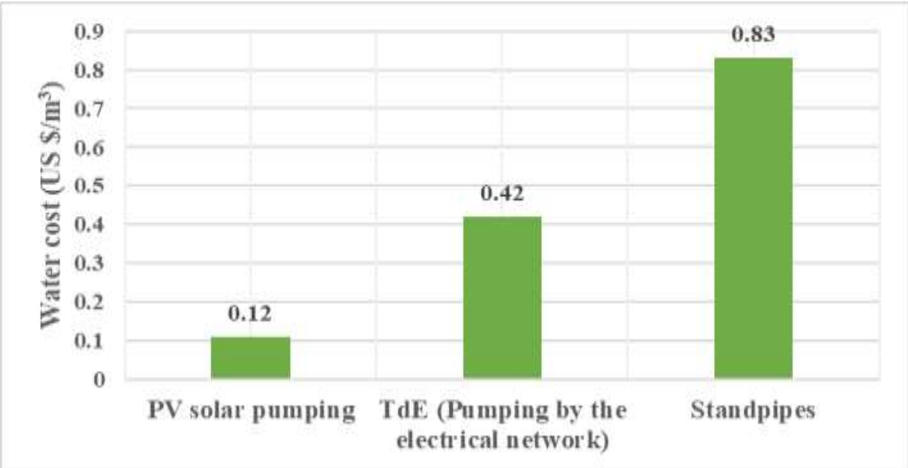

Figure 5. Costs of different pumping systems

4. CONCLUSION

In this study, design and economic analysis of water pumping system on solar photovoltaics were presented. The simulation results obtained with Matlab show that the proposed method makes it easy to get an idea of the total head range for a peak power of the generator and the water flow set to avoid under-sized and oversized PV pumping system. However, compared to the simulation model, this design method does not take into account the size of the tank, the calculation of hydraulic losses and configuration of the PV generator. To this end, a new design method is feasible to take account of said parameters. In the case of the designed platform where the daily flow of 70 m^3 , the discounted cost of the cubic meter obtained is US $0.12 per cubic meter. The PV solar pumping system is a simple option, economically and technically viable and efficient for remote areas. The result of this work should encourage the government for wide installation of PV pumping system to clean and healthy.

REFERENCES

[1] Ministère de l'Eau, de L'Equipement rural et de l'Hydraulique Villageoise, publié le 07 févier 2019.
[2] Energie Durable pour Tous, Evaluation rapide et analyse des Gaps, juin 2012.
[3] L.C. J. SiIveira, A. H. Pereira, A. B. Moreira, C. R. Schmidlin Jr, P.C.M. Carvalho and T. N. Cavalcante Neto, "Study of technical and financial viability of PV powered water-pumping systems in the Federal University of Ceará,''2004 IEEWPES Transmission & Distribution Conference& Exposition : Latin America.
[4] T. Khatib, "Design of Photovoltaic Water Pumping Systems at Minimum Cost for Palestine : A Review,'' Journal of Applied Sciences 10 (22) : 2773-2784, 2010 ISSN 1812-5654.
[5] A. Z. Sahin and S. Rehman, "Economical Feasibility of Utilizing Photovoltaics for Water Pumping in Saudi Arabia,'' International Journal of Photoenergy Volume 2012, Article ID 542416, 9 pages

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

doi:10.1155/2012/542416.

[6] S. Lal, P. Kumar and R. Rajora, "Techno-economic analysis of solar photo voltaic based submersible water pumping system for rural areas of an Indian state Rajasthan'', Science Journal of Energy Engineering, 2013 1(1).

[7] Campana, P., Li, H., Zhang, J., Liu, J. and Yan, J. (2015), "Economic optimization of photovoltaic water pumping systems for irrigation,'' Energy Conversion and Management, 95: 32-41 http://dx.doi.org/10.1016/j.enconman.2015.01.066.

[8] A. Al-Badi and H. Yousef, "Design of Photovoltaic Water Pumping System as an Alternative to Grid Network in Oman,'' International Conference on Renewable Energies and Power Quality (ICREPQ'16) Madrid (Spain), 4th to 6th May, 2016.

[9] L. Narvarte, E. Lorenzo and E. Caamaño, ''PV pumping analytical design and characteristics of boreholes,'' Solar Energy Institution, ETSI Telecommunication, Ciudad University s/n, 28040, 32p, 2011.

[10] A. Amevi, F. X. Fifatin and R. Awuah-Baffour, "Analytical Method of ZizingP hotovoltaic Water Pumping System,'' Conference on Adaptive Science &Technology (ICAST),2012 IEEE 4th International.

[11] M. Benghanem, K.O. Daffallah, S.N. Alamri and A.A. Joraid, "Effect of pumping head on solar water pumping system,'' Energy Convers Manage 2014, 77:334-9.

[12] K. A. Tiwari, R. V. Kalamkar, "Effects of total head and solar radiation on the performance of solar water pumping system,'' Renewable Energy 2017, https:// doi.org/10.1016/j.renene.2017.11.004.

[13] Abdellahi Ba et al., "Performance optimization of the PV pumping system,'' Procedia Manufacturing 22 (2018) 788-795.

[14] M. G. Thomas, "Water Pumping-The Solar Alternative, Photovoltaic Systems Design,'' Assistance Center, Sandia National Laboratories, NM 87185, Albuquerque, 58 p., 1987.

[15] A. Mohammedi, D.Rekioua and N. Mezzai, "Experimental Study of a PV Water Pumping System,'' J. Electrical Systems 9-2 (2013) : 212-222.

[16] J. Royer, T. Djiako, E. Schiller and B. S. Sy, "Le pompage photovoltaïque : Manuel de cours à l'intention des ingénieurs et des techniciens,'' IEPF/Université d'Ottawa/EIER/CREPA, Canada 1998..