Sizing of Photovoltaic Submersible Borehole Water Pumping Systems at Imo State University Owerri

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***Abstract*—In this paper, sizing of photovoltaic submersible borehole water pumping systems at the Faculty of Engineering of Imo State University (IMSU) Owerri was carried out. The pumping system is located at a latitude of 5.508259 and a longitude of 7.042189. The meteorological data of the site was obtained from the NASA portal... Posit software was used to simulate the system and to determine its performance values. The daily water demand of the Faculty is estimated at 5600 liters per day which with 5 days of autonomy required a storage tank size of 28000 liters. The relevant mathematical expression, site and system parameters and simulation procedures are presented. The simulation results showed that in a whole year, only 3.3% of the required water is missing (not provided) and the missing water occurred only in the months of July to September which is the rainy season months for the case study site. In essence, the 3.3 % missing water will be supplied from the rainwater in those months. Furthermore, the overall system efficiency was 73.8 %. In all, about 14.8 % of the available energy was unused as the pump was switched off because the tank was full. The unused energy was actually used to power other electrical appliances in the Faculty. In essence, the water pump is designed to be a dispatchable load that can be connected to the solar power system when there is insufficient water in the tank. At other times, the solar power can be used to power other electrical appliances in the Faculty. The 5 days autonomy of the water pumping and storage system make it possible to schedule the water pumping system in every week to give room for powering other electrical appliance in the Faculty**

Keywords*— *Photovoltaic, submersible borehole pump, water pumping systems, days of autonomy, dispatchable load, solar power system
Introduction (Heading 1)

1. INTRODUCTION

Water supply has been a running challenge to many homes and institutions, especially in the various cities across Nigeria [1, 2, 3, 4, 5]. As such, many homes and institutions set up their own borehole water pumping systems. Despite such effort, irregular power supply from the national grid makes it difficult for these water boreholes systems to provide the much-needed water. Consequently, many residents and institutions rely on alternative power sources to energize the borehole water pumping systems [6, 7, 8, 9, 10, 11].

In this paper, the focus is on the solar photovoltaic submersible borehole water pumping systems at Imo State University (IMSU) Owerri. In a bid to satisfy the daily water demand for the Faculty, a solar-powered pumping system was proposed in the Faculty by the Electrical/Electronic Department who also conducted the feasibility study and the sizing and economic analysis. In this paper, the PVSyst software [12] simulated sizing of the proposed PV powered submersible borehole water pump is presented. The daily water demand was based on the daily water usage from the Faculty rain water collected in 8000 liters plastic tank kept in the Faculty.

The proposed borehole water pumping system is located at the Faculty of Engineering with a latitude of 5.508259 and a longitude of 7.042189. The solar power water pumping system is designed with 5 days autonomy. Adequate water storage tank is provided to store the 5 days water required in the Faculty. During the water-full idle period of the water pumping machine, the solar power system is used to power other electrical facilities in the Faculty. Hence, the rest of the paper presents the relevant data, mathematical models and simulation procedures for the sizing of the proposed submersible borehole water pumping systems.

II. THE METEOROLOGICAL DATA AT FACULTY OF ENGINEERING OF IMSU

The meteorological data of the water pump site is obtained from the NASA website [13] by supplying the latitude (5.508259) and the longitude (7.042189) of the site as well as the required meteorological parameters which include the monthly and the annual average of the daily global solar radiation on the horizontal plane and daily average temperature. The daily global solar radiation is directly downloaded into the PVSyst software [14 , 15] where it was converted to the daily Peak Sun Hour (PSH) as shown in Figure 1.

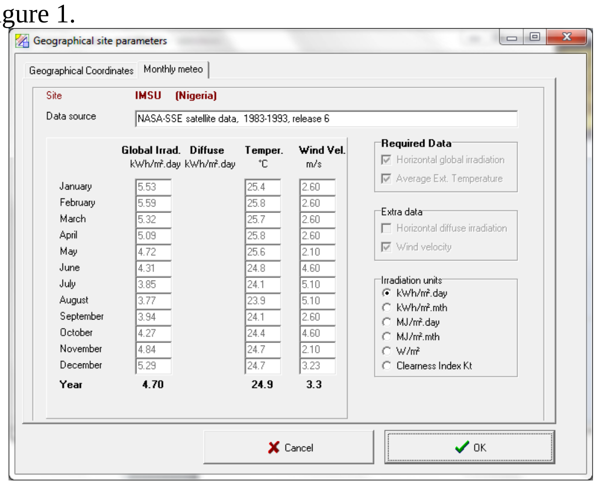

Figure 1 the daily Peak Sun Hour (PSH) and temperature IMSU Faculty of Engineering

With the help of the PVSyst software, the global radiation on the horizontal surface was transposed to an optimally tilted plane of the solar modules with an optimal tilt angle of 8° that gave a transposition factor of 1.01, as shown in Figure 2.

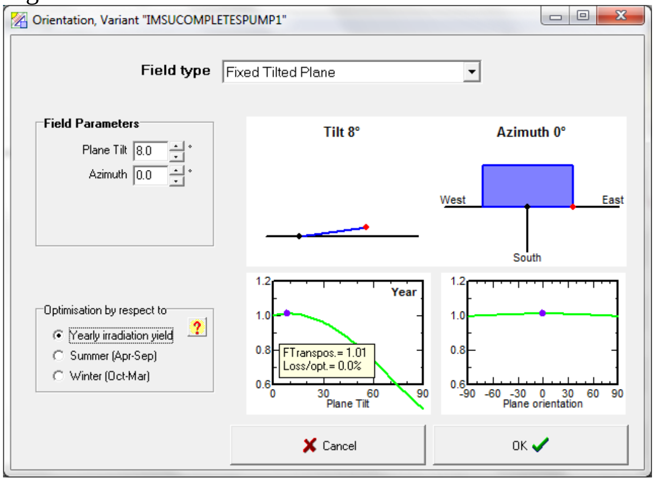

Figure 2 the optimal tilt angle of 8° with a transposition factor of 1.01 for the study site

III. THE PUMP SIZING EQUATIONS AND PARAMETER SPECIFICATIONS

The required pump hydraulic power, p_h in watt is given as;

$$p_h = \frac{\rho g H Q}{\eta} \quad (W) \qquad (1)$$

ρ Is the density of the water (kg/m^3)
g Is acceleration due to gravity? $m/s^2)$
H Is the total pumping head (m)?
Q Is the volumetric flow rate of water? $m^3/s)$
η Is the efficiency of the pump?

The total pumping head is;

$$H = H_G + H_S + H_D \qquad (2)$$

Where: $H_G$is outlet pipe height above the ground (m), H_S static head of the water level and

H_DIs the dynamic head

The required solar array power in watt is denoted as W_p where

$$W_p = \frac{p_h}{(S)(f_m)(f_t)} \qquad (3)$$

f_t Is the temperature derating factor, f_m is mismatch factor of the array, and S is solar irradiation in kWh/m^2 .

The Daily Water Demand and storage tank capacity: the daily water need is estimated to be 5600 liters per day (5.6 m^3) and the water pumping system is designed with 5 days of autonomy. Hence, the water storage tank volume is 5500 liters per day (5 days) =28000 liters = 28 m^3 per day. The water need and the tank capacity setting for the simulation in Posit are shown in Figure 3. According to Figure 3, the yearly (365 days) water need is 2044 m^3 which will require hydraulic energy of 373 kWh and an estimated PV array energy of 1260 kWh.

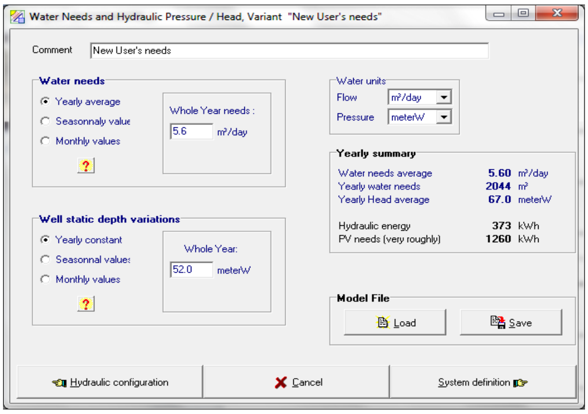

Figure 3 the water need and the tank capacity setting for the simulation in Posit

The storage tank, well parameters and the hydraulic circuit parameters: The storage tank, well parameters and the hydraulic circuit parameters of the pumping system are given in Table 1 and Figure 4 shows the Posit screenshot of the storage tank, well parameters and the hydraulic circuit parameters settings for the pumping system.

Table 1: The storage tank, well parameters and the hydraulic circuit parameters of the pumping system

Storage Tank Parameters	
Volume	28.8 m^3
Diameter	3.9m
Height (full level)	2.4m
Feeding altitude	15m
The Well Parameters	
Static level depth	52 m
Max. pumping depth	59 m
Pump depth	61 m
Well diameter	22 cm
The Hydraulic Circuit Parameters	
Pipes Type and diameter	PE20(3/4”)
Piping length	100 m
Number of elbows	2
Other friction losses	0.46
Water needs(yearly constant)	5.1

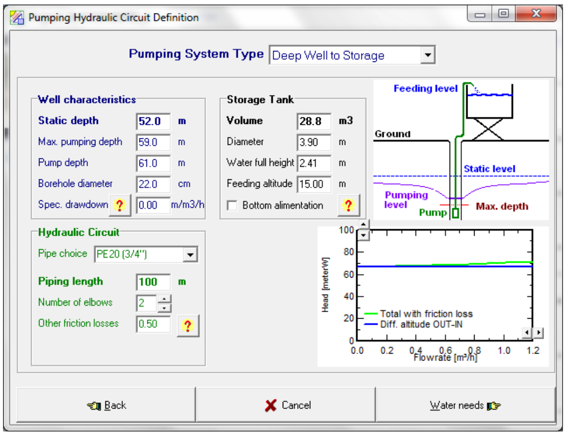

Figure 4: The Posit screenshot of the storage tank, well parameters and the hydraulic circuit parameters settings for the pumping system

The pump and PV array parameters: The selected pump and PV array parameters for the pumping system are shown in Table 2 and Figure 5. The system schematic diagram is given in Figure 6.

Table 2: The selected pump and PV array parameters for the pumping system

The Pump Parameters	
Model	Waterman OB
Manufacturer	ALL Power
Pump Technology	Membrane /Diaphragm
Motor	DC motor, Brushless
Power	216 W
Wellhead range	10-100 m
Number of pumps in series	1
Number of pumps in parallel	3
	Schott
The PV Array Parameters	
Manufacturer	Schott
Model	PS94SP100
PV module	Si-poly
Number of PV modules	10
Unit nominal power	100 WP
Array global nominal power	1800 WP
VMPP	38.3 V

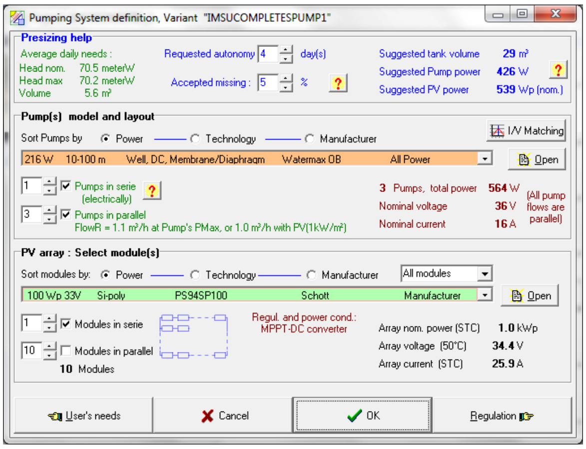

Figure 5: The selected pump and PV array parameters for the pumping system

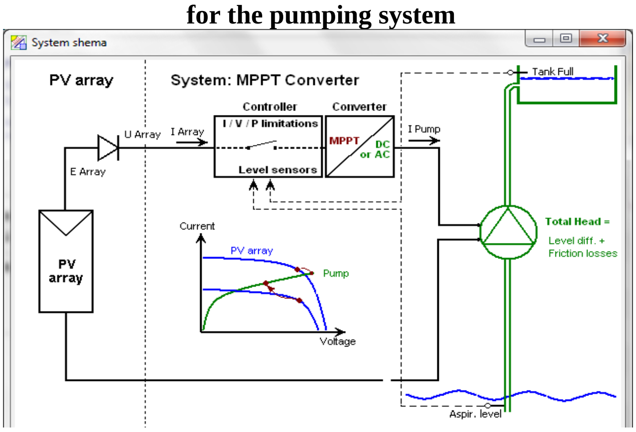

Figure 6 the System Schematic Diagram

IV. RESULTS AND DISCUSSIONS

The solar pumping system was simulated using Posit software. The main PVSyst result screenshot of Figure 7 shows that only 3.3% of the required water is missing (not provided) and the balance and main result of Figure 8 shows that the missing water (not supplied) occurred only in the months of July to September which are in the rainy season for the case study site. In essence, the 3.3 % missing water will be supplied from the rainwater in those months. Again, the overall system efficiency is 73.8 %.

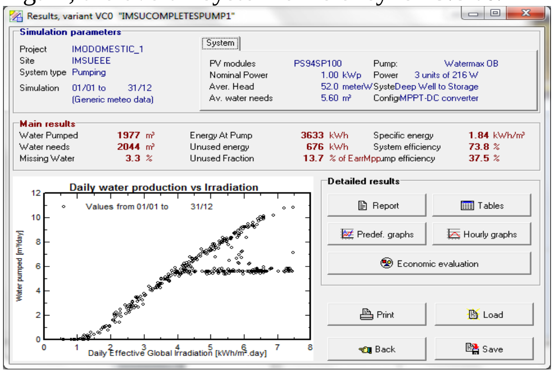

Figure 7 The Posit main results for the borehole pumping system

IMSUCOMPLETESPUMP1
Balances and main results

	GlobEff	EArrMPP	E PmpOp	ETkFull	H Pump	WPumped	W Used	W Miss
	kWh/m²	kWh	kWh	kWh	meterW	m³/day	m³/day	m³/day
January	175.4	142.0	92.96	35.71	70.01	6.015	5.600	0.000
February	163.2	130.8	75.91	42.53	69.77	5.335	5.600	0.000
March	160.7	130.6	92.15	25.49	69.58	5.836	5.600	0.000
April	144.9	118.2	85.12	20.24	69.40	5.600	5.600	0.000
May	136.1	110.9	85.70	10.98	69.29	5.419	5.600	0.000
June	119.1	97.1	80.57	2.01	69.19	5.206	5.591	0.009
July	110.6	90.7	74.29	0.00	69.21	4.644	4.967	0.633
August	110.3	90.4	73.02	0.00	69.12	4.457	4.113	1.487
September	113.5	93.3	79.65	0.00	69.07	5.090	5.254	0.346
October	129.7	106.5	90.82	0.96	69.40	5.742	5.498	0.102
November	147.0	119.1	86.34	19.70	69.76	5.696	5.600	0.000
December	169.2	137.2	92.57	30.25	69.99	5.954	5.600	0.000
Year	1679.7	1366.8	1009.11	187.86	69.48	5.417	5.382	0.218

Figure 8 The Posit balance and main result for the borehole pumping system

The system performance ratio is given in Figure 9. The annual average system performance ratio is 0.581 or 58.1 %. The lowest monthly system performance occurred in the month of February while the highest monthly system performance occurred in the months of September and October.

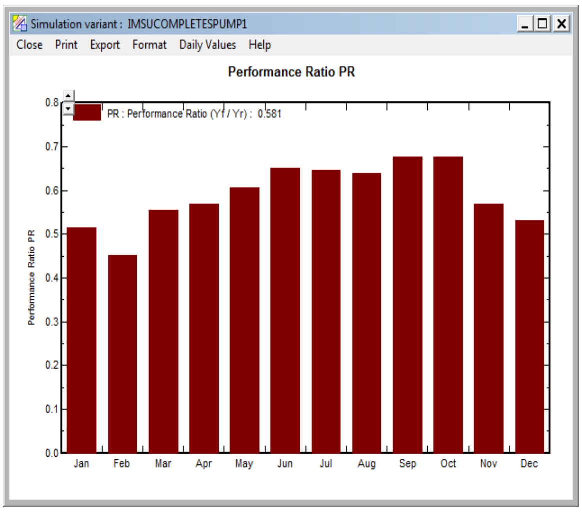

Figure 9 the system performance ratio

The system annual and monthly normalized production and loss factors chart is shown in Figure 10. According to Figure 10, about 14.8 % of the available energy is unused as the pump is switched off because the tank is full. The used energy is actually used to power other electrical appliances in the Faculty. When the tank is full or there is sufficient water in the water tank, the pump is switched off manually to allow the Faculty to use the same solar power system to power other appliances in the Faculty. In fact, with the 5 days autonomy built into the system, each the water tank is filled up, the water pump can be switched off for the next 4 days without the Faculty running out of water. Essentially, the water pumping system is a dispatchable load to the solar power system.

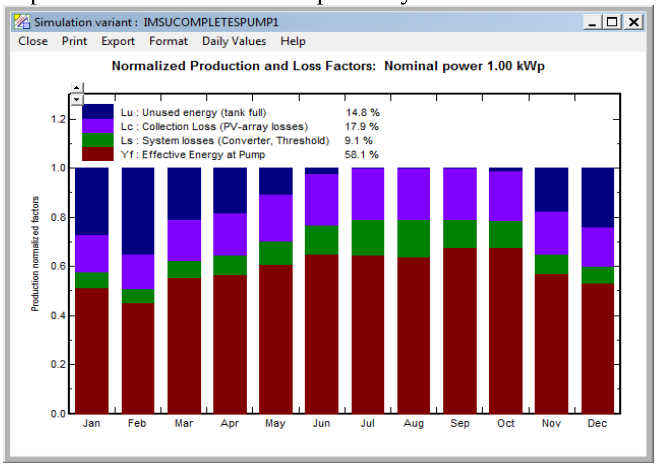

Figure 10 The system annual and monthly normalized production and loss factors chart

V. CONCLUSIONS

The sizing of a solar photovoltaic powered submersible borehole water pumping systems is presented for a Faculty in Imo State University. The solar PV water pumping system is meant to satisfy the water need of the Faculty and at the same time allow the solar power to be used to power other electrical appliances when the water tank is full or when there is sufficient water in the water storage tank and the pump is switched off. The relevant mathematical expression, site and system parameters and simulation procedures are presented. Particularly, the system was simulated using Posit software. In all, the Posit simulation results showed that over 96 % of the needed water will be supplied at all times. The remaining missing percentage of water needed will be supplied by the rainwater since the missing water occurred within the rainy season when the solar radiation is at its lowest value.

REFERENCES

1. Akpor, O. B., &Muchie, M. (2011). Challenges in meeting the MDGs: the Nigerian drinking water supply and distribution sector. *Journal of environmental science and technology*, *4*(5), 480-489.
2. Oni, A. O. (2009). *Arterial road network and commercial property values in Ikeja, Nigeria* (Doctoral dissertation, Covenant University).
3. Kiala, C., &Corkin, L. (2009). THE IMPACT OF CHINA-AFRICA INVESTMENT RELATIONS.
4. Effiong, Clement, Simeon Ozuomba, and Udeme John Edet. "Long-Term Peak Load Estimate and Forecast: A Case Study of Uyo Transmission Substation, Akwa Ibom State, Nigeria." *Science* 4.6 (2016): 85-89.
5. Markson, Idorenyin, Simeon Ozuomba, and Iniobong Edifon Abasi-Obot. "Sizing of Solar Water Pumping System for Irrigation of Oil Palm Plantation in Abia State." (2019).
6. Oniemola, P. K. (2015). Powering Nigeria through renewable electricity investments: legal framework for progressive realization. *Journal of Sustainable Development Law and Policy (The)*, *6*(1), 83-108.
7. Charles, A. (2014). How is 100% renewable energy possible for Nigeria.*Global Energy Network Institute (GENI), California*.
8. Umoette, Anyanime Tim, Simeon Ozuomba, and Nseobong I. Okpura. "Comparative Analysis of the Solar Potential of Offshore and Onshore Photovoltaic Power System." *Mathematical and Software Engineering* 3.1 (2017): 124-138.
9. Deele, Lemene B., Simeon Ozuomba, and Nseobong Okpura. "Design and Parametric Analysis of a Stand-Alone Solar-Hydro Power Plant with Pumped Water Storage Technology." *International Journal of Engineering & Technology* 4.1 (2019): 9-23.
10. Ozuomba, Simeon, E. A. O. Iniobong, and M. Idorenyin. "Impact of the Optimal Tilt Angle on the Solar Photovoltaic Array Size and Cost for a 100 kWh Solar Power System in Imo State." *International Journal of Sustainable Energy and Environmental Research* 8.1 (2019): 29-35
11. NASA (2018) POWER DATA ACCESS VIEWER online free tool. Available at:https://power.larc.nasa.gov/data-access-viewer/ Accessed on 19th November 2018
12. Sunday, Victor Etop, Ozuomba Simeon, and Umoren Mfonobong Anthony. "Multiple linear regression photovoltaic cell temperature model for PVSyst simulation software." *International Journal of Theoretical and Applied Mathematics* 2.2 (2017): 140.
13. Mermoud, A. (2012). Pvsyst: Software for the study and simulation of photovoltaic systems. *ISE, University of Geneva, www. pvsyst. com*.
14. Kandasamy, C. P., Prabu, P., &Niruba, K. (2013, December). Solar potential assessment using PVSYST software. In *Green Computing, Communication and Conservation of Energy (ICGCE), 2013 International Conference on* (pp. 667-672). IEEE.