Assessment of Standalone Photovoltaic Water Pump for a Remote School in Akwa Ibom State

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Abstract— **In this paper, assessment of a standalone photovoltaic water pump for a remote school in Mkpat Enin in Akwa Ibom State was presented. The assessment was conducted using PVSyst simulation software. Meteorological data for the school location was obtained from NASA portal. The daily water demand of 86 m^3 per day was determined using the school population and five (5) days storage capacity of 430 m^3 was provided. The results show that the missing water was 2.8 % and the system efficiency was 70.6 %. The month of February had a missing water of 9.539 m^3 per day which is about 11 % of the daily water demand. However, in respect of the climatic condition at the study site, the missing water in July can be supplied from the rainwater harvest since July is the peak of the rainy season in the study area. Also, the performance ratio or effective energy at the pump was 56.8%. The highest system efficiency is in the month of July while February and May had the lowest performance ratios. In all, the system will meet the water demand of the school if the school can use rainwater harvesting to make up for the missing water in the month of July and for the other months that had smaller missing water values.**

Keywords— Solar Power, Photovoltaic, Submersible Pump, Solar Radiation, Performance Ratio

I. INTRODUCTION

Remote locations in the developing countries suffer both shortage of clean water supply [1,2,3,4,5,6] and electricity supply from the national grid [7,8,9,10,11]. As such, people or organizations in the remote areas seek alternative sources of energy and water [12,13,14,15]. Among other sources, solar photovoltaic (PV) energy has become the most popular alternative source of energy apart from fossil fuel-based electric generator [16,17,18,19]. Also, in Nigeria, many people rely on borehole water to meet their daily water needs [20,21,22,23,24].

In this study, the daily water demand of a secondary school located in a remote location in Mkpat Enin in Akwa Ibom State Nigeria is considered. Then, a standalone PV powered deep well to storage water pumping system is proposed for the school. The ability of the proposed water pump to satisfy the water demand of the school is assessed using PVSyst software. The detailed simulation and assessment procedure are presented along with the discussion of the system performance parameters.

II. METHODOLOGY

A. The Description of the Case Study Site and the Simulation Datasets

The PV powered pump is for a school located in Mkpat Enin in Akwa Ibom state with geo-location coordinates of longitude : 7.766303 and latitude: 4.7024545. The school site has annual average Peak Sun Hour of 4.08 hours/day [25] and optimal tilt angle of 8°. Also, it has an average student population of 370 where about 140 of them are boarding students and the remaining 230 are day students. Also, there are 15 resident workers in the school staff quarter and 20 day workers that come for their homes outside the school premises. The school also has a restaurant that serves an average of 80 persons every day. The school population information and the daily water requirement data given in [26] were used to determine the daily water consumption of the school, as shown in Table 1. In all, the school population consumes about 22590 gallons of water per day which is equivalent to 85512.41 liters/day or 85.512 86 m^3/day $\approx 86\ m^3/\text{day}$.

Table 1 The Daily Water Consumption For The School

Water Consumer Type	Population	Water Consumed in gallons per day	Total Daily Water Consumed (gallons per day)
Boarding Students	140	100	14000
Day Students	230	25	5750
Resident School Staff	15	100	1500
Day School Staff	20	15	300
Restaurants (average number of persons served per day)	80	13	1040
Total	33		22590

The school water pump system is designed with five (5) days autonomy. Therefore, the water tank has a capacity that is five times the daily demand, and this givens 430 m^3. The following additional parameters are provided for the simulation in PVSyst:

i. ***The storage tank parameters***: The storage tank parameters used for the simulation are as follows: Volume: 430m^3; Diameter: 13.6 m; Height (full level): 2.89 m, Feeding altitude 17 m.

ii. ***The Well Parameters:*** The parameters are: Static head: 63 m; Maximum pumping depth: 70 m; pump depth: 73 m and well diameter 40cm.

iii. ***The hydraulic circuit parameters***: The parameters as Pipes Type and diameter: PE25 (1"); Pipe length 180 m; Number of elbows: 10; Other friction losses: 0.47 and the water demand is a yearly constant value of 86 m^3 per day.

B. The Simulation in PVSyst

The solar radiation data of the site was downloaded from the NASA portal into PVSyst software and the optimal tilt angle (8°) was selected using the PVSyst PV module orientation dialog box. The water demand data, the storage tank parameters, the well parameters and the hydraulic circuit parameters were also keyed into the PVSyst software. Based on the input data, the water pump and PV module were selected from the PVSyst database. Figure 1 shows the name and number of water pump and PV modules selected for the solar water pumping system.

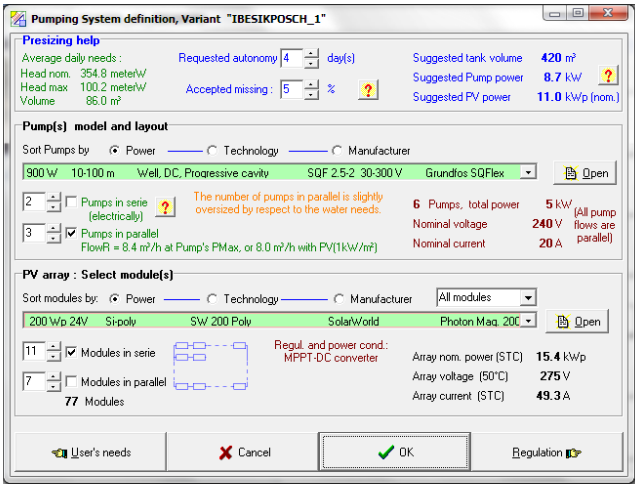

Figure 1 The selected water pump and PV modules

PVSyst automatically computed the yearly water need as 31390 m^3 along with the hydraulic energy (6843 kWh) and a rough estimate of the PV energy (23111 kWh) required to provide the hydraulic energy.

III. RESULTS AND DISCUSSION

The PVSyst simulation main result screenshot of Figure 2 shows that the missing water is 2.8 %. That means in a whole year only 2.8% of the needed water cannot be supplied due to low solar radiation and no water in the storage tank. Again, the result (Figure 2) shows that the system efficiency is 70.6 % which means that 29.4 % of the total power generated is lost due to the pump , PV and other system components efficiency or derating factors.

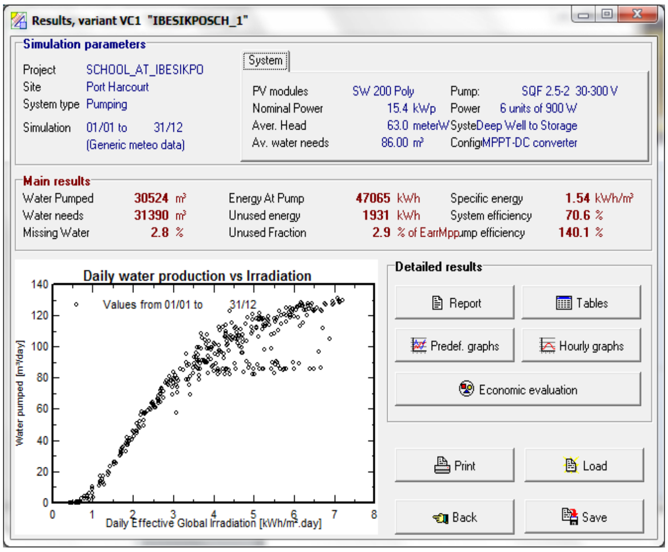

Figure 2 The PVSyst simulation main result screenshot of

Additionally, the PVSyst balance and main result screenshot is given in Table 2. The result shows that the highest missing water of 9.539 m^3 per day occurred in the month of July. The results in Table 3 shows that for the month of July, an average of 75.47 m^3per day was pumped , an average of 3.5 m^3per day was found in the storage and an average of 76.46 m^3per day was used by the school. This gave a shortfall or missing water of 86 -76.46 = 9.539 m^3 per day. In any case, for the case study site, the month of July is the peak period for rainfall. So, the missing water can be supplied from the rainwater harvested in the school.

Table 2 The PVSyst balance and main result

Simulation variant : IBESIKPOSCH_1

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IBESIKPOSCH_1
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	131.3	1676	1209	19.1	193.2	91.94	86.00	0.000
February	124.9	1558	963	105.1	196.5	81.24	86.00	0.000
March	136.0	1731	1184	43.8	195.2	90.21	86.00	0.000
April	127.2	1633	1105	90.1	189.3	86.12	86.00	0.000
May	127.0	1639	1011	195.6	188.7	76.00	86.00	0.000
June	106.6	1385	1039	0.0	188.1	80.88	79.07	6.935
July	100.5	1311	1035	0.0	172.7	75.47	76.46	9.539
August	100.7	1314	1019	0.0	174.5	74.34	76.57	9.432
September	113.5	1470	1081	0.0	187.1	83.84	79.73	6.266
October	119.9	1551	1115	0.0	191.1	84.12	84.47	1.533
November	121.6	1552	1113	0.0	195.7	87.57	85.39	0.614
December	132.8	1702	1199	82.5	197.0	91.70	86.00	0.000
Year	1441.8	18520	13074	536.3	189.1	83.63	83.12	2.877

Table 3 The Monthly Distribution of the water supply and missing water

Simulation variant : IBESIKPOSCH_1

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IBESIKPOSCH_1
Customised table

	E_PmpAv	TkF OFF	FlRate	WPumped	WStored	W Used	W Miss	Pump ON
	kWh	Hour	m³/h	m³/day	m³/day	m³/day	m³/day	Hour
January	1228	4	10.12	91.94	12.72	86.00	0.000	282
February	1068	21	10.25	81.24	9.32	86.00	0.000	222
March	1228	9	10.21	90.21	12.63	86.00	0.000	274
April	1195	18	9.83	86.12	13.16	86.00	0.000	263
May	1207	40	9.75	76.00	2.74	86.00	0.000	242
June	1039	0	9.78	80.88	4.64	79.07	6.935	248
July	1035	0	8.73	75.47	3.50	76.46	9.539	268
August	1019	0	8.80	74.34	1.27	76.57	9.432	262
September	1081	0	9.67	83.84	5.42	79.73	6.266	260
October	1115	0	9.88	84.12	4.90	84.47	1.533	264
November	1113	0	10.22	87.57	7.24	85.39	0.614	257
December	1282	16	10.35	91.70	12.70	86.00	0.000	275
Year	13610	109	9.80	83.63	1.08	83.12	2.877	3116

The screenshot of the system performance ratio is given in Figure 3 while the screenshot of the normalized production and loss factors is given in Figure 4. According to Figure 3 and Figure 4, the performance ratio or effective energy at the pump is 56.8%. The highest system efficiency is in the month of July while February and May had the lowest performance ratios. Analysis of the results in Table 3 shows that the month of July had ETkFull value of 0 while February and May had the highest value of ETkFull. This means that the water lost (not used and not stored) because the user need is met and the storage tank is full contributes to the system efficiency. Although July had the highest missing water value , it also recorded the highest system efficiency. The implication is that for higher system efficiency, oversizing of the system in order to satisfy the user demand in every month is not encouraged. Rather, a balance should be on reducing the missing water to a value below the critical point. In most cases, 5% missing water is recommended. For that case study school, the 9.539 m^3 per day is about 11 % of the daily water demand. However, the result is still acceptable since the month of July is the peak of the rainy season for the case study site; some of the water demand will be met by the rainwater harvest as well as reduced water usage due to lower temperature and higher humidity at such period.

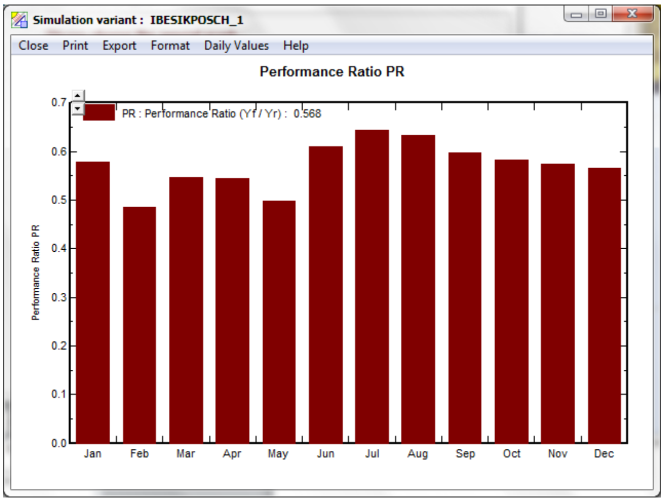

Figure 3 The screenshot of the system performance ratio

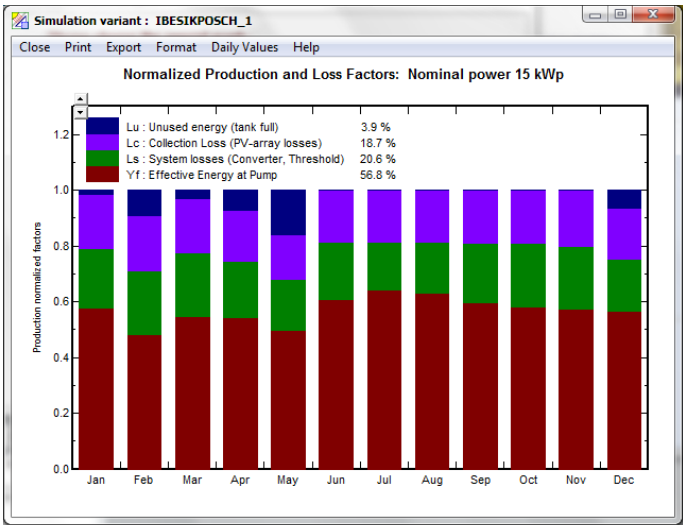

Figure 4 The screenshot of the normalized production and loss factors

IV CONCLUSION

Solar powered pump for a secondary school in Mkpat Enin, Akwa Ibom is presented. The system components are determined from the meteorological data, daily water demand data and the school population. The water source is a deep well and a submersible pump is used to store the water in a tank with 5 days of autonomy capacity for the school. The results show that the water demand of the school can be met with July as the critical month excess missing water based on the pumped water supply . However, in respect of the climatic condition at the study site, the missing water in July can be supplied from the rainwater harvest since July is the peak of the rainy season in the study area. In all, a good compromise is made in the selection of the system components, one targeted at meeting the daily water demand and two, maintaining high system efficiency .

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