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An assessment of solar-powered soybean farm basin irrigation water supply system

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***Abstract*—In this paper, an assessment of solar-powered soybean farm basin irrigation water supply system was presented. The one-hectare Soybean farm is located at Ishieke in Ebonyin state with geo-coordinates of 6.406476, 8.087187. The basin irrigation system is used to water the farm from a stored water pumped from a borehole using a solar-powered submersible water pump. The daily irrigation water demand is determined, solar radiation data are obtained from NASA and PVSyst software is used to simulate the solar-powered water pumping system. The results show that the pump system has a system efficiency of 76.5 % , with the specific energy yield of 0,89 kWh/ m^2. The effective energy at the pump is only 61.2 % of the input energy from the PV array. This amounts to a performance ratio of 0.612. Also, the system has an annual missing water value of 0.5 % . Also, all the annual missing water occurred in August , September and October , with August being the highest at a value of 7.746 $\mathrm{m}^2/\mathrm{day}$ which is about 8.5 % of missing daily water demand. Fortunately, August is the period of heavy rain in the case study area and the very-low-solar-radiation situations, in most cases, corresponds to occasions when there is heavy rainfall in a day. As such, the missing water in August will be compensated by the open air rainwater catmint on the Soybean farm. In all, the water supply from the pump is adequate for the Soybean farm irrigation.**

***Keywords*—Soybean, Basin Irrigation, Solar Energy, Performance Ratio, Missing Water, Rainwater Catchment**

I Introduction

In recent years, more Nigerians are venturing into agriculture in response to the call for diversification of the national economy [1,2,3,4,5,6,7]. Among other crops, Soybean has attracted the attention of the teaming Nigerian farmers in view of its nutritional value and its wide adoption in the food mix of many Nigerian homes. Nowadays, Soybean milk is popular and Soybean extracts and juice are being prepared and sold by an increasing number of people [8,9,10,11,12,13,14]. Also, there has been sensitization by health experts in recent years on ways people can use Soybean to enhance their diet and expand their food diversity.

In view of these efforts and increasing demand, more people are venturing into Soybean farming so as to take advantage of the surging local demand. One major problem encountered by the farmers is the provision of adequate water for irrigating their farms, especially during the dry seasons when there is very limited water supply from rainwater [15,16,17,18]. Moreover, these farms are always in remote locations, away from the national electric grid. As such, alternative energy is required to power the irrigation water supply system for the farm. In this paper, a solar-powered water pump for supplying the basin irrigation [20,21,22] water to a one-hectare Soybean farm is presented. The study provides the necessary mathematical calculations to determine the daily water demand for the basin irrigation of the Soybean farm. Then PVSyst software [23] is used to simulate the solar pumping system and particularly to select the appropriate water pump and PV module that will be used for the water supply. The overall solar water pumping system is further assessed to ensure that the system will be able to meet the daily water demand of the farm irrespective of the temporal variations in the solar radiation and rainfall. Furthermore, the critical months with shortfalls in the water supply are further examined to check whether the open-air rainwater catchment on the farm at those months will be adequate to supply the missing water.

II Methodology

The soybean farm is located at Ishieke in Ebonyin state with geo-coordinates of 6.406476, 8.087187. It is a one (1) hectare farm irrigated using the basin irrigation method. In order to determine the solar photovoltaic modules and water pump that will be used for the farm irrigation water supply, some key parameters are required. Let V denote the total volume of water required for one complete irrigation cycle of the farm, where V is in m^3; let h denote the irrigation water depth requirement for the plant, where h is in mm and A denote the total area irrigated in one complete irrigation cycle of the farm, where A is in ha $= 10000\ \mathrm{m}^3$, then, for basin irrigation V is given as [24,25,26];

$$V = (A)\frac{h}{1000} \qquad (1)$$

Also, let A_{pd} denote the area irrigated in one day of irrigation of the farm, where A_{pd} is in ha; let V_{pd} denote the daily volume of water required for one day irrigation of the farm, where V_{pd} is in m^3/day; let n denote the number of day for one complete irrigation cycle, where n is in days; let q denote the discharge or flow rate where q is in m^3/hr or litre/sec and let t denote the duration of irrigation per day where t is in hour or second , then;

$$q = \frac{V}{(t)n} \qquad (2)$$

$$V_{pd} = q(t) \qquad (3)$$

$$A_{pd} = \left(\frac{1000}{h}\right)V_{pd} \qquad (4)$$

In order to realize its yield potential, a soybean crop needs 20 inches (50.8 mm) to 25 inches (63.5 mm) of water throughout the season [27] and it also can accommodate 7 to 10 day irrigation cycle [28]. Then, for 1 ha of farm A = 1 =10000 m^3, the water required when h = 63.5 mm is given as; $V = (10000)\frac{63.5}{1000} = 635\ m^3/ha.$

Based on the meteorological data from the NASA portal, the Soybean farm location has minimum monthly average daylight hours of 11.8 hours per day and the annual average daylight hours of 12.1 hours per day. As regards solar radiation expressed in Peak Sunshine Hours (PSH), the minimum monthly average PSH is 3.8 hours and the annual average PSH is 4.7 hours. In respect of the average daylight hours, 10 hours per day irrigation time (t) is selected for the farm. Also, seven (7) days irrigation cycle (that is, n =7) is selected, then the pump discharge rate for the farm is; $q = \frac{V}{(t)n} = \frac{635}{(10)7} = 9.075\ m^3/hr = \frac{9.075}{3600}m^3/s = 0.002521\ m^3/s$. The required daily water volume is ; $V_{pd} = q(t)V_{pd} = 9.075(10) = 90.75\ m^3/day$. The area irrigated in one day of irrigation is; $A_{pd} = \left(\frac{1000}{h}\right)V_{pd} = \left(\frac{1000}{63.5}\right)90.75 = 1429\ m^2/day.$

The water is obtained from a deep well and the water is pumped from the well using a submersible water pump and the water is stored in a storage tank for the irrigation purpose. The storage tank capacity is found from the daily water demand and days of autonomy of the water supply, which in this case is 5 days. So, the storage tank capacity is 5 times the daily water demand of 90.75 m^3/day which gives 454 m^3. The storage tank diameter is about 14.6 m with a height of 2.71 m and feeding height of 11 m. The borehole has a static head of 31 m, maximum pumping depth of 34 m, pump depth of 39 m and borehole diameter of 36cm. The selected pipe is PE25 (1") with a total pipe length of 210 m, a total of 8 elbows and other friction losses of 0.47. A yearly fixed water demand value of 90.8 m^3 per day is selected. The simulation is carried out in PVSyst software and the results are presented and discussed in the preceding section.

III **Results and discussions**

The results from the PVSyst show that based on the daily water demand of 90.75 m^3/day and the hydraulic circuit input parameters, the yearly water demand is 33142m3, the hydraulic power required is 3793 kWh and the electrical energy required from the PV array is 12819 kWh. The selected pump and PV module are shown in Figure 1. Figure 1 shows that the selected pump is a 590 watt Watermax PC DC pump manufactured by AllPower . A total of six of such pump are required . Similarly, the selected PV module is the 150 watt 19V DS-A2-150 monocrystalline silicon PV module manufactured by Photon Mag. 2008. About 48 of the PV modules are needed to provide about 7.2 kWp power used to drive the water pump.

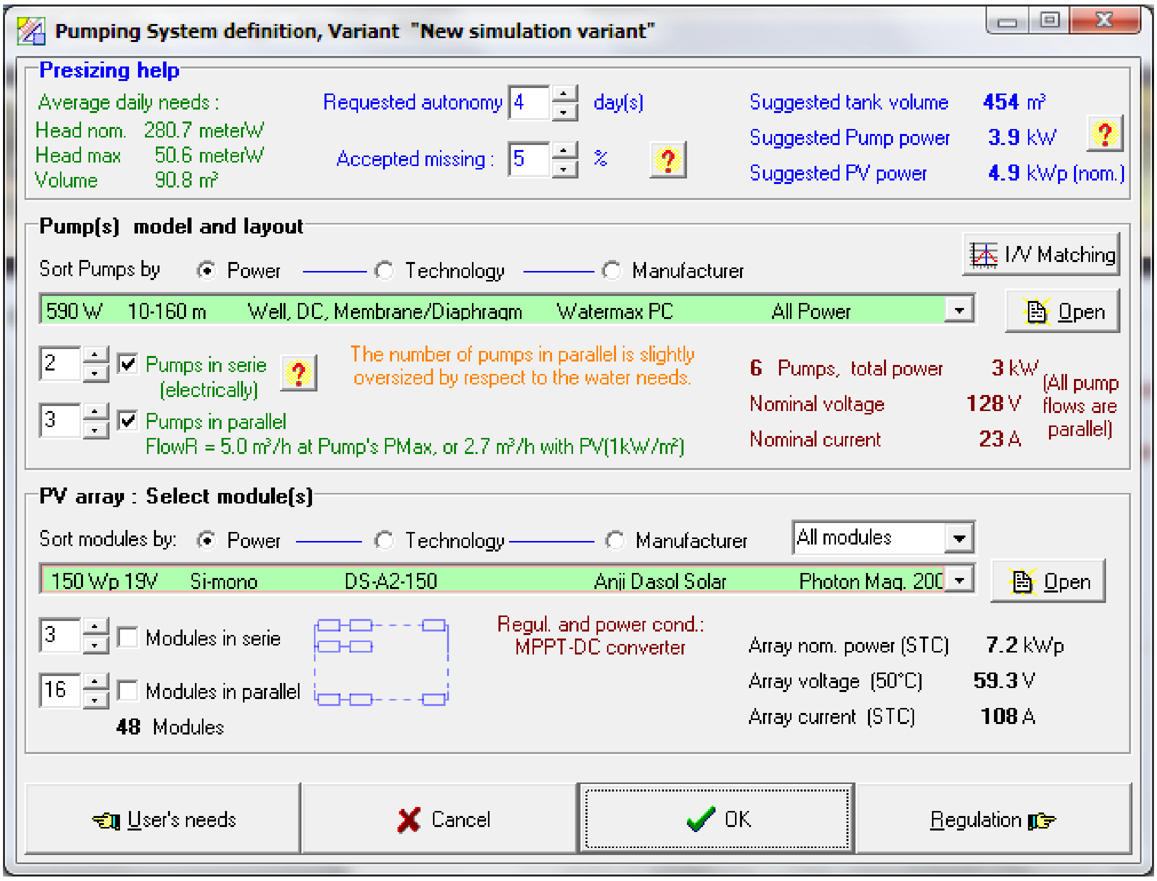

Figure 1. The selected pump and PV module

The PVSyst main result output form presented in Figure 2 shows that the pump system has a system efficiency of 76.5 % , with the specific energy yield of 0,89 kWh/ m^2. Also, the system has an annual missing water value of 0.5 % . The PVSyst balances and main result table presented in Table 1 shows that all the annual missing water occurred in August , September and October , with August being the highest at a value of 7.746 m^2/day which is about 8.5 % of missing daily water demand. Figure 3 shows that the missing water in the month of August occurred on 7th of August and on 13th of August when there was little or no stored water and the available solar radiation was too small to provide enough to pump sufficient water for the daily demand. Fortunately, August is in the period of heavy rain in the case study area and the very-low-solar-radiation situations, in most cases, corresponds to occasions when there is heavy rainfall in a day. As such, the missing water in August will be compensated by the open air rainwater catmint on the Soybean farm. Furthermore, the normalized production and loss factors in Figure 4 showed that the effective energy at the pump is only 61.2 % of the input energy from the PV array. This amounts to a performance ratio of 0.612. Also, Figure 4 showed that while every other month had excess water production indicated by the unused energy (tank full) value, the months of June, August, September and October do not have unused energy. In all, the water supply from the pump is adequate for the Soybean farm irrigation.

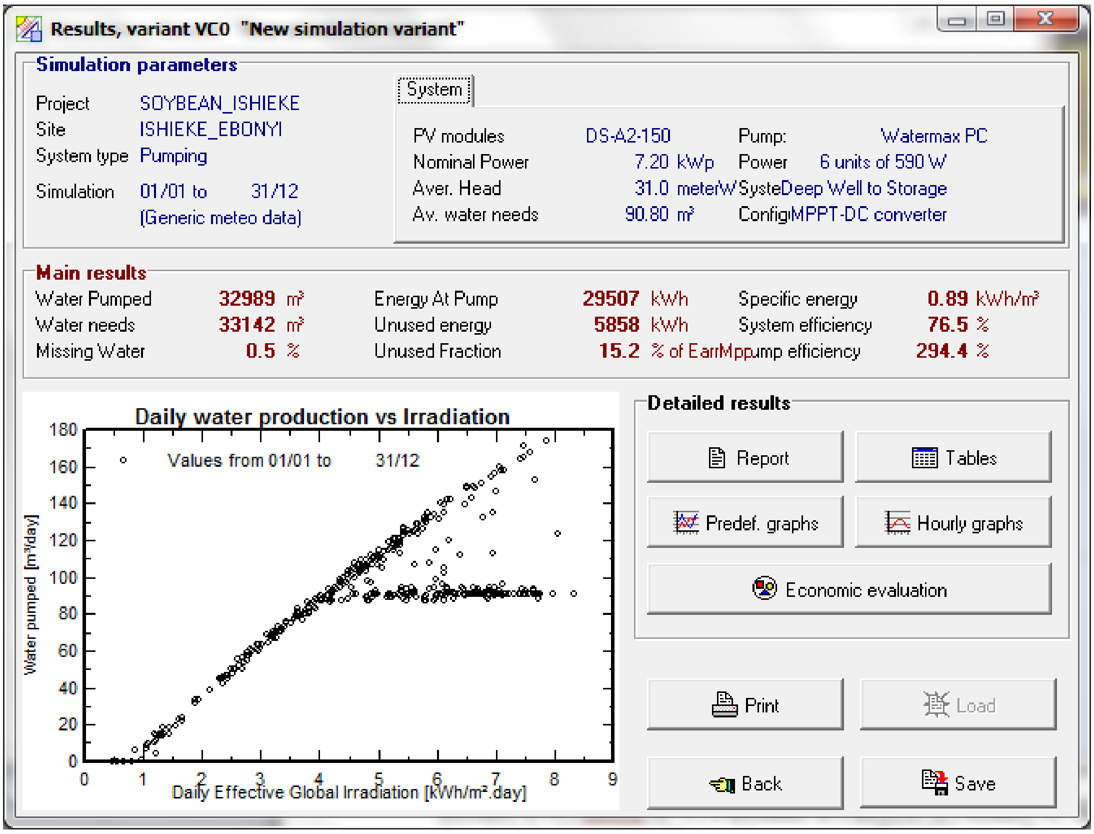

Figure 2 The PVSyst main result output form

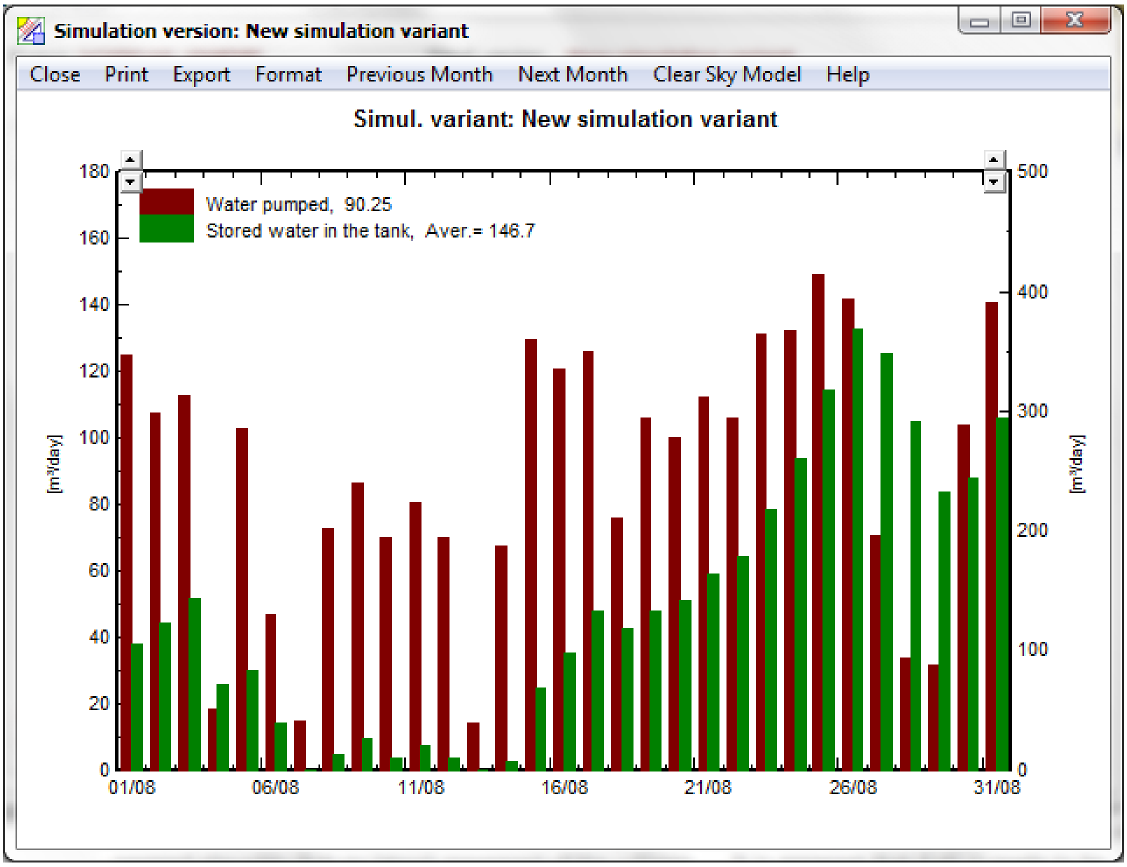

Figure 3 The Bar chart of Pumped water and stored water for the month of August

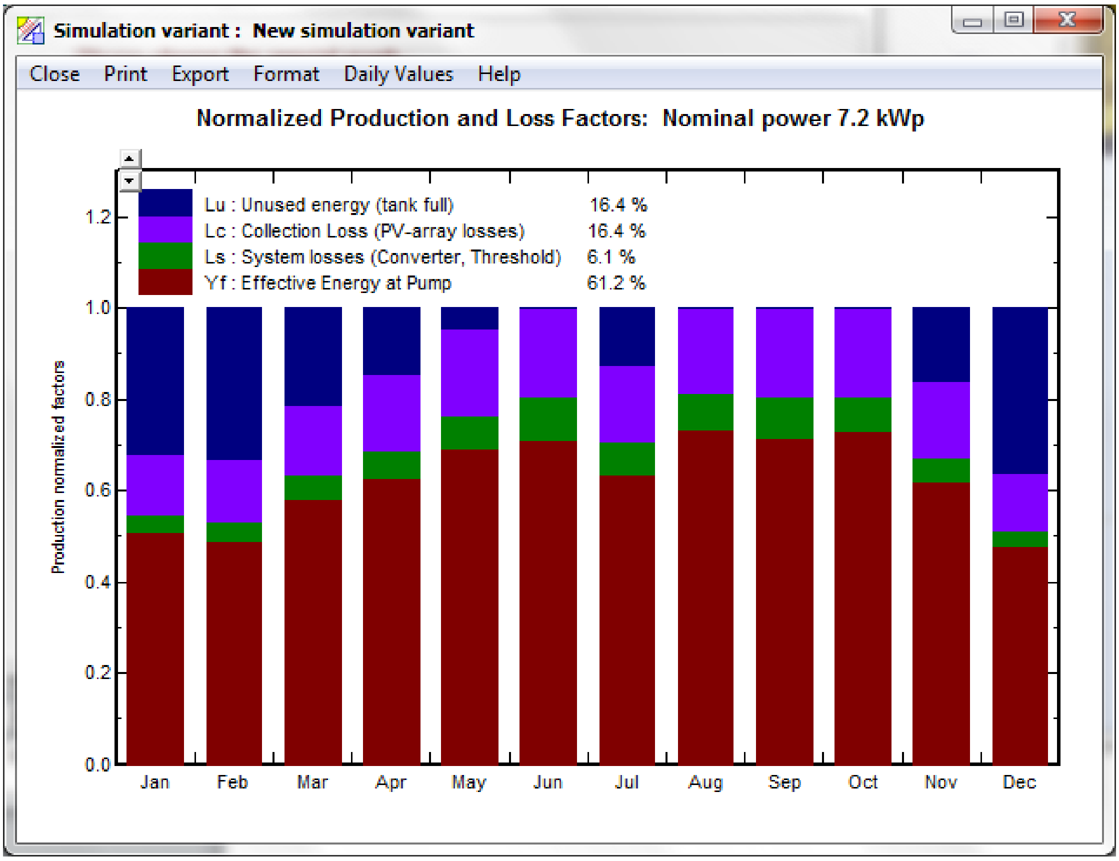

Figure 4 The Normalized production and loss factors

Simulation variant : New simulation variant

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New simulation variant

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	197.2	1158	743.8	344.9	253.4	97.39	90.80	0.000
February	172.7	1007	627.0	312.2	241.9	90.80	90.80	0.000
March	161.8	961	697.1	189.6	211.4	90.78	90.80	0.000
April	144.8	865	677.9	116.1	187.6	90.77	90.80	0.000
May	136.1	815	701.8	34.5	179.2	90.72	90.80	0.000
June	119.4	719	634.7	0.0	172.9	84.55	90.80	0.000
July	139.4	840	659.5	100.7	195.7	85.36	90.80	0.000
August	128.0	776	699.1	0.0	174.4	90.25	83.05	7.746
September	113.3	682	605.5	0.0	167.5	80.48	87.20	3.597
October	131.5	792	716.0	0.0	184.6	92.79	90.52	0.283
November	160.7	951	739.8	142.0	220.3	99.61	90.80	0.000
December	196.6	1153	694.2	387.3	256.8	90.92	90.80	0.000
Year	1801.5	10716	8196.5	1627.2	201.3	90.38	89.82	0.978

IV Conclusion

Assessment of PV-powered water pump for basin irrigation water supply in a Soybean farm is presented. The focus is the determination of the expected daily water required for the irrigation of the Soybean farm and also to use PVSyst software to select appropriate water pump and PV array that will enable the needed water to be pumped from a borehole to a storage tank. The relevant mathematical expressions for the daily water demand of the irrigation system are presented along with the relevant parameters for PVSyst-assisted sizing of the water pump and PV module. After the simulated sizing of the water pump in PVSyst, the simulation results were further analyzed to ensure that the selected water pump and PV array will effectively meet the daily water demand for the irrigation of the Soybean farm. Also, where missing water occurred, the value of the missing water was further examined in conjunction with the rainfall pattern of the study site so as to know if the missing water can still be met through the open air rainwater capture at the farm site. In all, the annual missing water is very negligible, which shows that the water supply from the solar powered pump is effective in meeting the overall irrigation water need of the farm.

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