DESIGN OF PHOTO-VOLTAIC ARRAY AND BATTERY BANK SIZES FOR A SOLAR-POWERED INTELLIGENT DRIP IRRIGATION SYSTEM IN MOKWA

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ABSTRACT
The finite nature of fossil fuel, its high cost, environmental unfriendliness as well as the world politics is creating a shift towards renewable energy sources, solar energy inclusive. This research paper presents the design of a photo-voltaic array and battery bank capacity for a solar-powered intelligent drip irrigation system in Mokwa, Nigeria. The system was designed to serve an experimental field where eggplants and tomatoes are to be grown. Main items in the Internet of Things (IoT) include an irrigation pump, solenoid valves, soil moisture and temperature sensing devices, micro-controllers on arduino boards and a gateway. Result obtained revealed that load by the Pump, Arduino boards and the Solenoid valves were 1072.8 Whr, 1440 Whr and 483.84 Whr, respectively. The total load on the entire system was determined to be 2996.64 Whr/day. Based on the designed load, a total of 3 photo-voltaic arrays (solar panels) of 200 W rating and 2 deep cycle batteries of 249.72 Ah capacity were found suitable. It is therefore recommended that the design specifications be strictly followed during installations.

KEYWORDS: Battery bank, Charge controller, Drip irrigation, Micro-controller and Photo-voltaic cell

INTRODUCTION

According to the reports of the United States Department of Interior Bureau of Reclamation of the Lower Colorado Region (DIBR, 2012), two major intelligent irrigation system controllers are identified: weather-based systems and soil water-based systems. These types of controllers use a closed loop control system, which means that feedback is received from the irrigated system and the irrigation is scheduled according to the information relating to site conditions such as soil moisture and the weather condition at a given time. Instead of a human being doing the application, a microcontroller does. Microcontroller is an integrated chip that performs a controlling function (Moreira *et al.,* 2012). It is a one-chip microcomputer used to control a wide range of electrical and mechanical appliances. In recent time, some microcontrollers in use are programmable, thus increasing the number of applications they can be used (Rasyid *et al.,* 2015).

Electricity is the major source of power in the farm most especially in the advanced countries of the world that have steady power. According to Narayanamoorthy (2004), lack of steady power is a serious challenge of large-scale irrigation farming in developing countries, and this creates a forum for a more efficient alternative power sources, less costly and environmentally friendly. One of these energy sources is the utilization of solar irradiation for the generation of electricity in order to power the irrigation pumps and the microcontrollers in the case of the automated system. However, because of the intermittency and non-constant nature of solar irradiance, which is heavily dependent on the time of the day and season, there is the need for some types of energy storage which could be fulfilled using a battery.

According to Prasad *et al.* (2015), a typical photovoltaic (PV) system for generating, storing and supplying power to an irrigation system consists of a PV array, a controller, an inverter, a battery storage, and control switches. Even though they have their disadvantages, the main advantages of solar power system include their environmental friendliness, low maintenance cost, long life, no fuel requirement (so no operational cost), and easy installation. Doan (2017) stressed that for optimization of PV power system, a specific PV and number of PV panels, fixed tilt and azimuth angle of the PV panel, and times of operation must be put into considerations. In another submission, which is in line with Swanson's Law, it is estimated that the cost of PV panels reduces by 20% for every doubling of PV panels sold. At this current rate, costs reduce by 50% every 10 years (Reichelstein and Yorsten, 2013).

Irrigation farmers in the study area are used to water pumps that utilizes either petrol or diesel. Apart from their scarcity, the price of petrol and diesel is never fixed. This research paper therefore concentrated on designing a photo-voltaic array and battery bank sizes for a solar-powered intelligent drip irrigation system in Mokwa. Considering the low maintenance cost of solar energy, compared with the unbearable cost of fossil fuel, the uncertainty in its availability in future, its environmental unfriendliness, high power consumption of pumping machines for irrigation, as well as world politics, it was deemed necessary that the solar-powered system is embraced. These therefore necessitate the present study.

METHODOLOGY

The Study Area

The research took place in the Orchard of the Niger State College of Agriculture Mokwa. Mokwa Local Government Area of Niger State is an agrarian domain, occupying a strategic land area with maximum potential for all year round crop cultivation and rearing of animals. These potentials had been observed long before now, and that led to the citing of a good number of agricultural institutions, owned by the government at all levels, as well as some non-governmental agencies (i.e., Ahmadu Bello University Farms, National Cereal Research Institute, International Institute of Tropical Agriculture, Golden Penny Farms, Ultra-Modern Abattoir, Cattle Ranch etc). The long southern border of the local government area is formed by the Niger River from Lake Jebba in the west beyond the confluence of the Kaduna River in the east (Fig. 1).

Fig. 1: Map of Nigeria showing the location of the Study Area

Geographically, it is on the north and east hemisphere, stationed on Latitude 9° 17' 41.35" N and Longitude 5° 03' 14.83" E., politically it is a local government area in the Zone A senatorial district. The study area falls under the Southern Guinea Savanna (i.e. comprising short grasses and scattered trees) of the tropical climate vegetation belt of Nigeria, having two (2) distinct seasons (rainy and dry seasons). Rainfall commences mostly in the months of April-May and terminates around October-November, with an average annual rainfall amount of 1229 mm, with the highest amount (260 mm) mostly in September, and the least amount (0.1mm) in January. The average maximum and minimum monthly temperatures are 34 and 27 °C respectively, with the average daily sunshine hours of 7.0. It has a total land area of approximately 4,338km^2 (1,675 sq mi) and an estimated human population of 244, 937 (NPC, 2006), predominantly Nupe speaking people.

Study Materials

As an intelligent system, it involved the Internet of Things (IoTs) in order for irrigation to be accomplished without human intervention. Materials to be used in this research include a pumping machine, two solenoid valves, two soil moisture and temperature sensors, three micro-controllers on Arduino boards and a gateway between the farm free cloud. The water source for the system are two PVC tanks; one overhead on a 3 meters high platform and the other on the surface.

Method

The field was first subdivided into two (2) sections and a reconnaissance survey was conducted to determine the slope of the land, this is in order to determine the appropriate direction or position for placing the major pipes and the minor ones as specified in Egharevba (2009). Soil samples were collected from the field using a soil auger at the two (2) different points, placed in polythene bags, labeled appropriately and taken to the laboratory for analysis. Preliminary tests conducted included soil water infiltration test, soil textural class, wetted perimeter test and soil chemical properties.

On the photo-voltaic array and energy bank design, the total load on the individual units of the system, such as the irrigation pump, Arduino board and sensors were first determined as described in Geofrey *et al.* (2015) and Al-Shamani *et al.* (2017).

1. Considering the solenoid valves, Arduino boards and sensors with different voltages and current specifications, their individual power was determined as:

$$P = IV \quad (1)$$

Where, P, I and V are the power rating in Watt (W), current in Ampere (A) and voltage in Volt (V), respectively.

However, in situations where the specifications are in current and resistances, the power ratings were determined as:

$$P = I^2R \quad (2)$$

Where, R is the resistance in ohms (Ω), while other parameters are as earlier defined.

2. Pumping Machine: The power of the pumping machine was determined using equation 3 (Punmia *et al.*, 2005):

$$P_e = 9.81\frac{QH}{\eta} \quad (3)$$

Where, P_e is power required by the pump in Watt (W), Q is quantity or volume of water that must be lifted by the pump in a given time, and H is the total dynamic head.

3. Daily wattage: This was determined based on the time (in hours) of usage of each item. The wattages were determined by multiplying the individual power ratings obtained with their actual time of usage. The micro-controller on the arduino boards is the brain box of the entire system, and are expected to work for 24 hours daily. Since the system is a closed loop, weather based and on-demand, the solenoid valves are also expected to work for 24 hours daily. Since it takes the pump at most 2 hours to refill the tank when empty, therefore, it works for 2 hours each day.

4. Total Load: Total load on the system was determined as in Geofrey *et al.* (2015) using equation 4:

$$L_T = L_P + L_A + L_S \quad (4)$$

Where, L_T is the total load on the system, L_P is the load by the pump, L_A is the load by the Arduino boards and L_S is the load by the solenoid valves.

5. Estimating Photo-voltaic Array Sizing: The total PV energy was determined by multiplying the total load connected by a

factor of 1.3 in accordance with the solar energy best practices (Dhanne *et al.*, 2014). The total wattage of PV capacity was determined by dividing the total PV energy by the illumination per day, which is 7 hours daily. The total number of panels required was determined by dividing total PV wattage by PV rating. However, the PVs are assumed to be of 250W rating.

6. Estimating Battery Bank Size: The power or battery bank size was determined using equation 5:

$$B_c = \frac{T_L * D_a}{B_L * D_d * NB_V} \quad (5)$$

Where;

B_c is the battery bank capacity in (Ah), T_L is the total load on the system in (Whr), D_a is the periods of autonomy in (hours), B_L is the battery losses (%), D_d is the depth of discharge in (%), and NB_V is the nominal battery voltage in (V).

7. Estimating charge controller size: The charge controller sizing was determined by first dividing the total PV wattage by its voltages and multiplying by the total number of PV arrays in parallel (Emmanuel, 2009), as presented in equation 6.

$$CC_S = \frac{P_{Wt}}{P_V} * NP_p \quad (6)$$

Where,

CC_S is charge controller size in (A), P_{Wt} is panel wattage rating in (W), P_V is panel voltage rating in (V), and NP_p is number of panels connected in parallel.

For this design, the panels rating was assumed to be 250W, 24V and all panels are expected to be connected in parallel. All results obtained are noted, tabulated and analyzed accordingly.

RESULTS AND DISCUSSION

The preliminary soil test indicates that samples obtained from points A and B, as well as their composite (X) are loamy sand soils. Dry bulk densities of the three (3) samples were determined as 1.48 gcm^{-3}, 1.51 gcm^{-3} and 1.46 gcm^{-3}, respectively. The gravimetric moisture content of 1g of the composite sample at saturation was 0.39gg^{-1} and by implication, every 1g of the soil sample has a void of 0.39% to be occupied by air or water when dry and wet, respectively. This was in line with the findings of Palada *et al.* (2011), that all soils culturally have an average of 55% solid composition and 45% space for either air in dry states or water when saturated.

The result of the infiltration rate indicates an infinitesimal intake rate in both points A and B, even as the test was carried out in late December, which was barely two months after the stoppage of rainfall. This also authenticates the result of the soil classification test which confirmed the soil to be loamy sand. The rates of infiltration in the two (2) points are as low as 0.75cm/min and 1.0cm/min as shown in Figs. 2a and 2b. This low infiltration rate gives an idea of the selection of drippers with very low discharge that fits the soil water intake rate, in order to avoid waste of water due to overflow. The chart also indicates that after 45 minutes, the water intake was almost zero. That is, there was stagnancy in water movement into the soil after this time, and any further application will just amount to wastage.

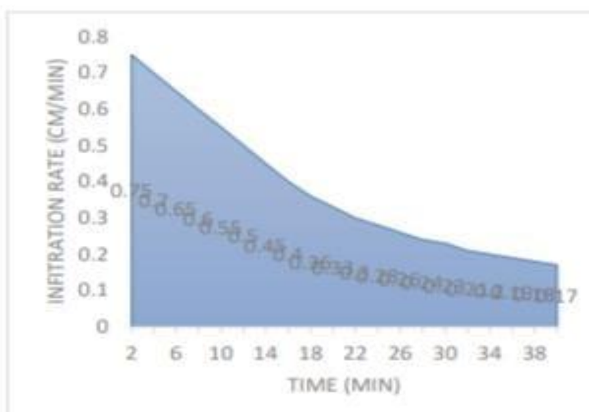

Fig. 2a: Plot of infiltration rate (cm/min) at point A

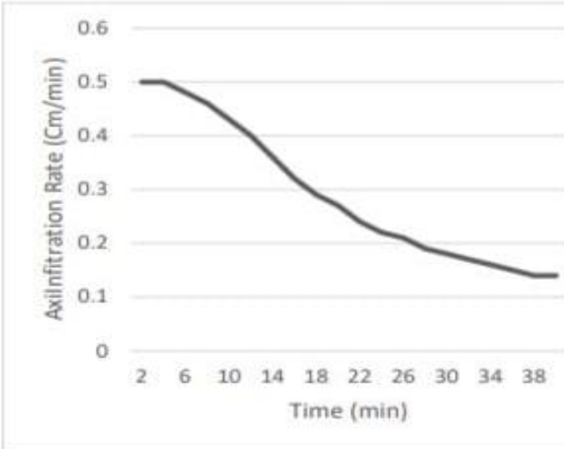

Fig. 2b: Plot of infiltration rate (cm/min) at point B

The soil pH was found to be 6.9, which is just slightly (about 0.1) above the required pH (between 5.5 and 6.8) for effective growth and development of tomato and eggplant as in Naika *et al.* (2005). Also, the concentration of available phosphorus was determined to be $10.3mgg^{-1}$; while concentrations of sodium, potassium, magnesium and calcium are 0.16, 0.13, 2.3 and 4.0 $cmolkg^{-1}$ respectively. The average wetted perimeter and wetted depth are 37cm and 26cm respectively, this result also confirmed the fact that the soil in the area is a loamy sand, as horizontal movements of water into such soils in a given time interval are always more than the vertical movements, thus making the wetted area to form a spherical shape (Michael and Ojha, 2006).

Table 1 presents the result of the types and number of hardware considered for the design, their power rating and total load on the entire system. The power requirement of the system was determined based on the total load of the system hardware (Geofrey *et al.*, 2015). The load by the pump, the Arduino boards and the solenoid valves are 1072.8Whr, 1440Whr and 483.84Whr, respectively. The total load on the entire system was determined to be 2996.64Whr/day.

Table 2 presents the PV arrays, battery banks, charge controller and their capacities. The total PV energy needed was determined as 2996.64Whr/day, the total PV wattage needed is 428.09W after dividing total energy with seven (7) hours of illumination per day, and the numbers of PV panels needed are determined to be 2.14 at a rating of 200W. Based on the solar energy best practices as contained in Al-Shamani *et al.* (2017), a total of 3 panels is selected. The battery bank size was determined as 249.72Ah, and the number of batteries needed to power the entire system was 1.25 (approximately 2 batteries of 200Ah size). Based on this result, the two (2) batteries needed were of the rating 249.72Ah, 12V in order to properly take care of the 12 hours of days of autonomy. More so, since the panels are rated 200W, 12V, all the 3 panels must be connected in parallel, this will make the expected current passing through as 16.67A. Based on these specifications, therefore, the size of the solar charge controller required for this research work was determined as 62.50A.

Table 1: Hardware considered in the design, their power rating and total load

Items	Quantity	Power rating (W)	Total power rating (W)	Time of Usage (hrs)	Energy Required (Whr)	Total Load (Whr/day)
Arduino Board	06	10	60	24	1440	
Pump	01	44.7	44.7	24	1072.8	
Solenoid Valves	4	5.04	20.16	24	483.84	
Total Load						**2996.64 Whr/day**

Table 2: Solar power requirements, quantity and their sizes

Items	Rating	Quantity	PV energy	PV-wattage	Capacity/Current
Solar Panel	200W	3	2996.64 Whr/day	428.09W	16.67A
Battery Bank	12V	2			244.82Ah
Charge Cont.		1			62.50A

CONCLUSION

The research paper concentrated on the design of a photovoltaic (PV) array and energy bank (battery) capacity for a solar-powered intelligent drip irrigation system in Mokwa, to serve a garden of eggplants and tomatoes. Preliminary soil test revealed useful information concerning the soil, such as the soil water infiltration value, wetted perimeter, as well as some soil physical and chemical compositions. The number of photovoltaic arrays and energy bank (batteries) designed for effective system functioning is 3 and 2 respectively. The PV arrays are designed to be 200W and have an energy bank (battery) capacity of 244.82Ah. In order to achieve a long-lasting power supply; a charge controller of 62.50A was also designed. It is therefore recommended that the actual number of Photovoltaic arrays and battery banks designed, as well as their capacities be strictly abided by during the installations to avoid malfunction after the setup.

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