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Optimal solar power for control of smart irrigation system

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Abstract. Irrigation is very vital to food security but deployment of effective irrigation requires solar energy especially in the rural areas with no grid power**.** In this work, the optimal power required in the solar photovoltaic (PV) and the battery of a solar powered system (at any instance) for effective operation of a smart irrigation facility in Elizade University Ilara Mokin, Nigeria is determined. The system uses current and voltage sensors placed at the solar photovoltaic (PV) and the battery sections to perform real-time measurements on irrigation solenoid valves. Acquired current and voltage sensor values are passed to a microcontroller, readable in the computer serial monitor and later used to compute the required power in both PV and battery sections. The developed solar power system was implemented on a pilot farm with irrigation facilities consisting of sensors (moisture content, water level) and actuators (three solenoid valves). Tests were performed under the load-on condition. Results obtained reveal a maximum power threshold of 72.68 W for the solar PV and 14 W for the battery when three solenoid valves were loaded or operated at the same time and a minimum value of 31.55 W for the solar PV and 1.9 W for the battery when one valve is operated. The power thresholds obtained would be useful for configuring the smart irrigation system controller to ensure adequate delivery of water to crops as well as prolong the lifespan of the developed solar powered system.

1. Introduction

Water availability is a major constraint to the practice of agriculture especially in sub-Saharan Africa. This is because there is the need for adequate water supply in order to guarantee good yield from agricultural crops. In an attempt to supplement the water available from rainfall, farmers engage in irrigation practices. In most of the places where irrigation is practiced, farmers depend on manual methods using watering cans which is time wasting, energy sapping and very inefficient [1]. When automated irrigation is used, farmers make use of pumps to draw water from nearby rivers, wells or bore holes in order to wet their crops. Apart from the fact that this method is not economical, the generators also release carbon monoxide into the atmosphere which increase the level of greenhouse gases in the atmosphere leading to global warming. Many of the farms are located in the rural areas with bad roads making accessibility very difficult [2].

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As a result of the bad roads, the transportation of diesel or petrol to these remote locations becomes irregular and as such irrigation processes using generators become irregular thus resulting in poor crop yields. There have been attempts by researchers to develop smart irrigation systems in which sensors such as moisture content sensors are deployed in the farm to measure the moisture content of the soil and transferring such parameters to the controller which use the data acquired from the sensors to energies irrigation pumps and valves that release water to crops [1, 3]. Some have even gone to the extent of being able to monitor the environmental condition of the farm such as atmospheric temperature and humidity, level of water in the reservoir, soil moisture content through a web interface or an Android application on their mobile phone [2, 3]. As good as these improvements are, they cannot be implemented without adequate power especially when the farms are in the rural communities without the grid power. Most rural communities in Africa lack grid connected power and where they exist, they are very inadequate and unreliable. For example, in a country like Nigeria, with a population of about 220 million people and the maximum power generation is about 4500 Megawatt. This means that more than 90% of the populace in the rural areas would be without grid connected power and where they exist, they are very unreliable. The irony of the matter is that a large percentage of food produced in Nigeria is from these rural areas with inadequate or non-existing power source.

Solar energy is playing an important role in compensating for the deficit in electrical energy all over the world [4]. There is now a paradigm shift from fossil fuel to renewable sources such as solar, wind, water and the likes due to more energy demand, depletion of the conventional energy sources such as coal, petroleum and their non-environmentally friendliness [4, 5]. In [6], PV system was described as the best solution for remote agriculture. In order to solve the challenge of providing solar power for irrigation system, some researchers have made a good attempt. The authors in [7] developed a solar powered irrigation system using a 2 horse power water pump with 60 W solar panels. In an attempt to minimize power and water usage, moisture content sensors are used to detect the amount of water already present in the soil so as to determine the amount to be supplied by the irrigation system. This goes a long way to determine how long the power from the solar system will be utilized. In an attempt to improve the efficiency of solar photovoltaic (PV) used to power irrigation system, the authors in [8] developed a system in which the solar PV array is mounted on an automatic tracking device connected to a direct current (DC) motor.

The PV is made to rotate using the DC motor as the sun moves from sunrise to sunset. This was to allow maximum concentration of sunlight on the panel throughout the day for optimal performance. The authors in [6] designed and implemented power for an agricultural system using solar power. The system had two parts namely the solar and automatic irrigation part. The former makes use of the solar PV, charge controller, battery and so on to provide power for the system while the latter used soil moisture sensor, temperature and humidity sensor to detects the values of soil moisture, temperature & humidity at different points in the field and pass these parameters to the microcontroller [6]. The microcontroller compares measured values with the pre-set threshold values and instructs the water pumps to release water for crop use. In [7], the authors developed a solar power system for an irrigation system. The problem of water and power wastage were addressed by using a drip irrigation approach that ensures that only the water quantity required by a particular crop is delivered directly to the root of that crop.

This way, the water is highly optimized and so the period of irrigation as well as solar power required is greatly minimized. In [5], a grid-interfaced solar photovoltaic power generating system was proposed. From a single phase grid feeder, grid current is obtained using a current sensor and passed to a microcontroller. This current serves as a reference. The intention is to detect zero crossing and auxiliary power supply to the microcontroller. During peak hours when voltage fluctuation problems occur in the transmission line, at this condition the load get damaged. To avoid this, battery is connected parallel to the solar panel [5]. The authors in [5] used a microcontroller to determine voltage fluctuation during peak periods, while in [8], a microcontroller is also employed to track sunshine by rotating a motor. The PV system parameters of interest can be monitored using relevant sensors in which the acquired data is logged by a microcontroller. This technique has been well reported in literature [9-10].

The authors in [10] developed a low cost wireless monitoring system for a single solar panel. The system constantly measures current, voltage and temperature of the solar panel. All the required sensors (voltage and current sensor, as well as, thermocouple) were placed together with Raspberry pi zero in a modular box and externally connected to the solar panel. The acquired data (voltage, current and temperature) were transferred to a Raspberry pi zero which sends the data into a cloud server database via wireless link. Users can monitor the acquired data via a webpage [10]. In [11], a cost effective data acquisition system (DAQ) based on Laboratory Virtual Instrument Engineering Workbench (Lab-VIEW) was developed. The developed system was employed for continuously collecting and displaying the electrical output parameters of a stand-alone PV system. The proprietary data acquisition and electronics circuit card from National Instrument (DAQ card NI USB-6009 8 inputs) was used to acquire the PV current and voltage. A computer running Lab-VIEW software was coupled to the DAQ card with a universal serial bus (USB) interface cable which displays the measured PV current and voltage. In addition, the solar irradiance could be estimated directly via measuring PV panel short circuit current instead of using expensive commercial instruments [11].

In this research, an Atmega 328 microcontroller on Arduino board will be interfaced with a solar system providing power for a smart irrigation system in order to determine the amount of power generated at the solar PV and the battery at any instant in order to optimize power usage by the irrigation system for the purpose of system efficiency and quality service delivery. The rest of the paper is arranged as follows. Section 2 is the methodology, section 3 is the result, 4 is discussion, while section 5 focuses on the conclusion.

2. Methodology

In this research, solar power is designed and implemented for a smart irrigation system. Power sensors (current and voltage sensors) are employed to measure the power generated by the solar photovoltaic (PV) and the power delivered by the battery at any instant in order to optimize the power supplied to the irrigation system, Figure 1 is the block diagram of the proposed system. The methodology adopted is grouped into the load assessment of the solar system components, data acquisition using power sensors and power optimization for the smart irrigation system.

2.1 Load assessment

Table 1 contains the list of the components of the irrigation system and the details of their wattage, power demand and required energy. From Table 1, the sum of energy (watt-hour) demand by the system is given as 678.75 Watt-hour. Given a 100 W solar PV, 12V, 200Ah deep cycle battery:

Total Watt-hours/day to be supplied by solar panels = 678.75×1.3 = 882.37 Watt-hour (1)

In equation 1, 1.3 represents component loses. The peak sun hour for Ilara Mokin, Nigeria with longitude7.3497° N and latitude 5.1067° E is five (5) hours [12].

Watt peak rating of the solar panel is then $\frac{882.37\ (\text{Watt}-\text{hour})}{5\ \text{hour}} = 176.47\ \text{W}$ (2)

Number of 100 W panels required = $\frac{176.47\ \text{W}}{100\ \text{W}} = 1.7647 \approx \text{select } 2\ \times 100\ \text{Watts PV}$ (3)

Battery size (Ah) = $\frac{678.75\ (\text{Watt.hour})}{0.85\times0.6\times12\text{V}} \times 1 = 110.9\ \text{Ah}$ (4)

(This is the Ah required for 1 day without power)

Number of 200Ah batteries, 12 V required will be = $\frac{110.9\ \text{Ah}}{200\ \text{Ah}} = 0.55\ \approx 1\ \text{battery}$ (5)

The specification of a 100 W PV module is given below

The total short circuit current (for PV modules connected in parallel) =1×4.74 A = 4.74 A (6)

For standard practice, charge controller current rating (normal charge controllers) = 1.3×4.74 A = 6.162 A≈ 10 A (7)

Voltage rating of the charge controller = 41.4 V input / 12 V output (8)

Table 2 is a summary of the components required for the solar power supply and their quantity and rating.

2.2 Data acquisition using power sensors

2.2.1 ACS 712 Current Sensor Module

In order to measure the current in the solar PV and the battery, two ACS712 current sensors are used. The sensors can detect alternating current (AC) or direct current (DC) easily to the maximum value of 30A with an input voltage of 5 V from the microcontroller. The output for both the solar current and the battery current were connected to the analogue pins of the microcontroller analog input pins A4 and A6 respectively as shown in Figure 2.

Table 1. Power ratings of the different components used for the irrigation system

Components	**Power (W)**	**Power factor**	**Power demand (VA)**	**Hour**	**Energy (Watt-hour)**
3 Solenoid valves	15	0.8	18.75	5	93.75
1 Relays	3	1	3	5	15
3 DC pumps(3)	66	0.8	82.5	5	412.5
1 DHT22 sensor	1.5	1	1.5	5	7.5
1 Power pack	24	1	24	5	120
1 Arduino Mega	5	1	5	5	25
1 Card reader	1	1	1	5	5
Total	115.5		135.75		678.75

2.2.2 Voltage Sensor

The solar system makes use of voltage divider circuit as its voltage sensor in which the output voltage determines the voltage value for the solar PV and the battery. One voltage sensor is connected to the solar PV while another is connected to the battery. The voltage values measured from PV and battery are connected to analog pins A3 and A5 of the microcontroller respectively as shown in Figure 2. In this work, equations 9 to 11 represents the voltage divider used and the power computations. The block diagram is illustrated in Figure 1 while the circuit connection is shown in Figure 2. In order to choose the value of R1 and R2, we assume that the voltage going into the microcontroller at pins A3 and A5 is 4.5 volts (less than 5 volts threshold for the microcontroller). The open circuit PV voltage is 44 volts. So using the voltage divider equations 9 and 10, R1 is chosen to be 10 kΩ while R2 is 1kΩ in each of the cases for both PV and the battery. V_{inPV} is the input voltage from PV while the input voltage from battery to microcontroller is V_{inPV}. Equations 11 and 12 give the PV and battery power respectively.

$$V_{outPV} = V_{inPV} * \frac{R_2}{R_1+R_2} \tag{9}$$

$$V_{outB} = V_{inB} * \frac{R_2}{R_1+R_2} \tag{10}$$

To obtain solar and battery power, equations 11 and 12 are used.

$$P_{PV} = I_{PV} * V_{outPV} \tag{11}$$

$$P_B = I_B * V_{outB} \tag{12}$$

Where: I_{PV} = Solar PV current, V_{outPV} = Solar PV voltage, P_{PV} = Solar PV power, I_B = Battery current, V_{outB} = Battery voltage, P_B = Battery power.

2.3 Power optimization for the irrigation system

The optimization parameters were obtained from tests carried out on smart irrigation facilities at the Botanical garden in Elizade University, Nigeria as shown in Figures 4 and 5. Figure 3a shows a scaffold supporting an overhead reservoir and a solar PV, a yellow metal casing for safe-guarding the solar energy components and a pilot farm where drip irrigation is implemented. Figure 3b shows the solar components in the metal casing consisting of a Maximum Power Point Tracking (MPPT) charge controller, deep cycle battery, irrigation control unit where the microcontroller and the power sensors are housed. MPPT charge controllers has advantage of extracting maximum energy from the sun by selecting optimal current and voltage to deliver maximum power to load. Also contained in the metal casing are three solenoid valves which act as actuators through which water is drawn to the three ridges representing different crops sections within the farm.

2.3.1 Load-ON Measurement of the PV Power

In this case, the solenoid valves (loads) were connected one after the other and used to draw water to the irrigation site for about two minutes in each case, until it stabilizes and readings of the PV and battery voltages and currents were recorded. This exercise was carried out about three times after which the average current and voltage were obtained. Figure 4 shows the data obtained from the PV experiment while Figure 5 is the battery power measurement.

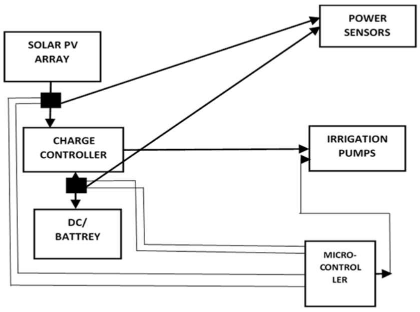


Figure 1. Block diagram of optimized solar powered irrigation system

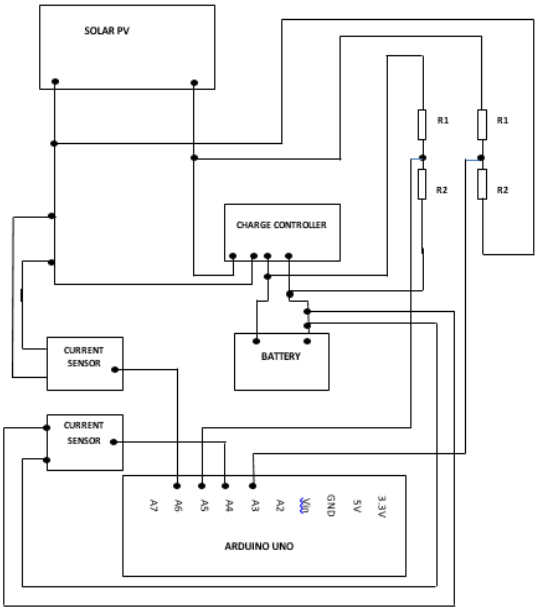


Figure 2. Schematic diagram of optimized solar system

Table 2. Components for the solar power supply

Components	Quantity	Ratting
Number of solar panels	2	100 W
Charge controller	1	10 A minimum
Battery	1	200Ah / 12V
Inverter	0	1 kVA

Figure 3a. Smart irrigation pilot farm

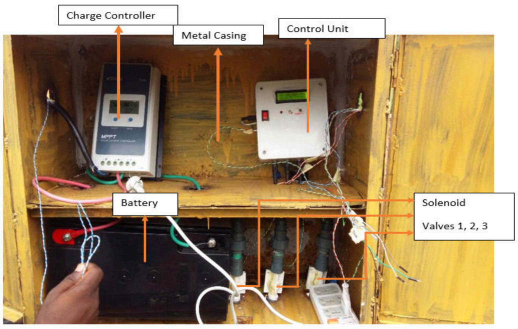


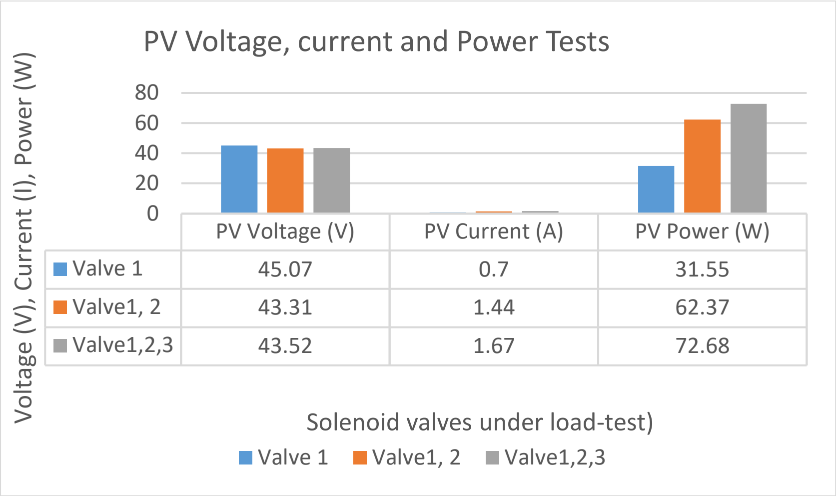
Figure 3b. solar power components for the smart irrigation system

3. Results and Discussion

Power threshold of 72.7 W and 14.0 W were obtained for the photovoltaic (PV) and battery respectively when three valves were used with the irrigation system; while minimum threshold of 31.6 W and 1.9 W were obtained for the PV and battery when one valve was used. When two valves were used, the readings obtained were 62.37W for the PV and 5.79 W for the battery. This is shown in Figures 4, 5 and Table 3.

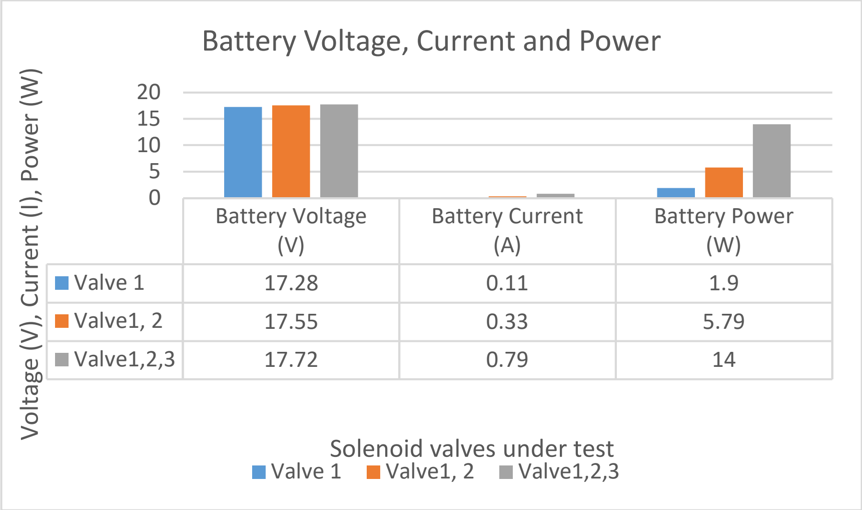
Table 3. On – Load Measurement of the PV and Battery Power

Load	PV Voltage (V)	PV Current (A)	PV Power (W)	Battery Voltage (V)	Battery Current (A)	Battery Power (W)
Valve 1	45.07	0.7	31.55	17.28	0.11	1.90
Valve1, 2	43.31	1.44	62.37	17.55	0.33	5.79
Valve1,2,3	43.52	1.67	72.68	17.72	0.79	14.00



	PV Voltage (V)	PV Current (A)	PV Power (W)
■ Valve 1	45.07	0.7	31.55
■ Valve1, 2	43.31	1.44	62.37
■ Valve1,2,3	43.52	1.67	72.68

Figure 4. Power delivered by the PV when connected with irrigation valves



	Battery Voltage (V)	Battery Current (A)	Battery Power (W)
■ Valve 1	17.28	0.11	1.9
■ Valve1, 2	17.55	0.33	5.79
■ Valve1,2,3	17.72	0.79	14

Figure 5. Power delivered by battery when connected with irrigation valves.

The power thresholds obtained from the load-on tests of the solar PV and battery were used in programming the microcontroller as well as optimization of solar power for the irrigation system. This is illustrated in Table 5. For irrigation to take place, the system checks for the level of power in the PV and battery using the obtained thresholds as benchmark, determines the power level (peak, medium, low, very low) and takes a decision on how many irrigation valves would be used at a time. This is in an attempt to manage the available power. For example, in case 1, the PV power is greater than or equal to the obtained thresholds of 72.68 W and battery power is greater or equal to 14.00 W, then the system is considered to be at a peak level and so valves 1, 2 and 3 can operate without much harm to the solar system. In case 4, the PV and battery power are below the obtained thresholds, the power level is considered very low and no valve is allowed to operate so that the battery is not over-drained. In case 2, this is a scenario in which the PV power is high but the battery is low (below its operating threshold). Two valves are used in this case. It is believed that the 2 valves cannot constitute too much stress on the battery since the solar power is available both to power the valves and to charge the low battery. In case 3, the PV power is low while the battery power is high. The system considers the power level as low and deploys one valve for irrigation. This is to prevent the battery from being power-stressed as it delivers its reserved power when the PV is not having enough power (peak sun hour) to charge it. Figure 6 is the flowchart of the developed algorithm.

Table 4. Simulated power for optimization of the irrigation system

Irrigation cases	PV threshold (W)	Battery threshold (W)	PV	Battery	Power level	Irrigation Valves action
1	>= 72.68	> = 14.00	High	High	Peak	3 valves on
2	>= 62.37 < 72.68	> = 1.90<5.79	High	Low	Medium	2 valves on
3	>= 31.55 < 62.37	> = 5.79< 14.00	Low	High	Low	1 valves on
4	< 31.55	< 1.90	Low	Low	Very low	0 valve on

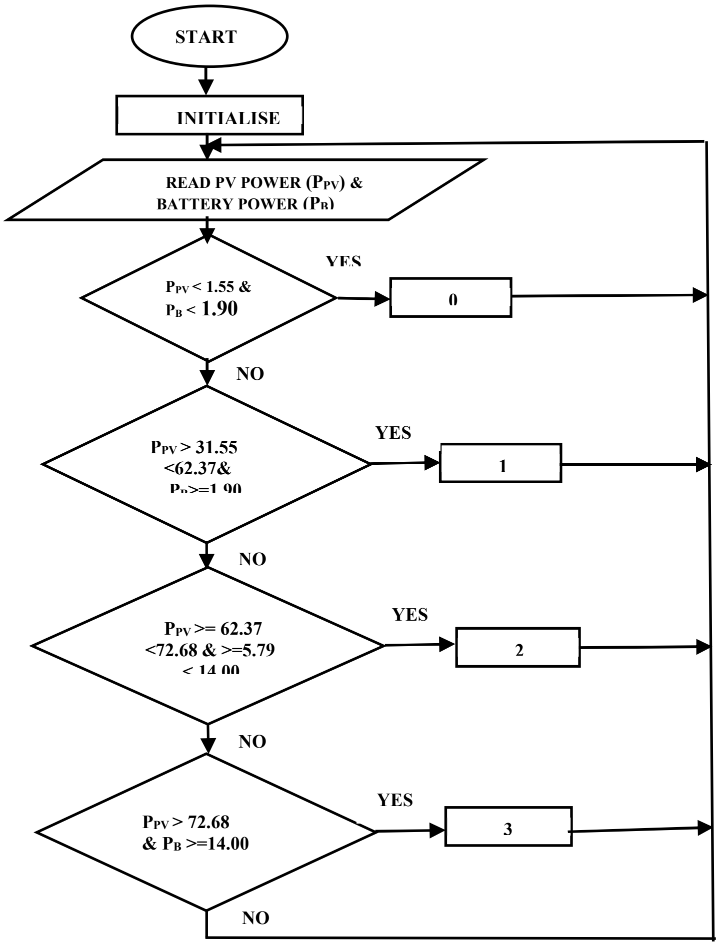


Figure 6. Solar power optimization flowchart for an irrigation system

4. Conclusion

In this work, the solar power optimization for a smart irrigation system is achieved. The maximum power threshold of valves under various load-on conditions were also determined and used for evaluating solar power levels (peak, medium, low and very low) in order to decide which valves were required for irrigation. The developed optimization algorithm is capable to operate the irrigation solenoid valves once the established thresholds are exceeded. It also has the capability to prevent the solar battery from being over-used or drained. Apart from ensuring adequate water supply to crops, the developed algorithm will encourage efficiency and longevity of the solar powered irrigation. Future work would be the development of an Android application to monitor system performance by receiving notifications to remotely operate the irrigation pumps and solenoid valves once the established thresholds are exceeded.

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