

Development and Performance Evaluation of a Solar Powered Spraying Machine

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ABSTRACT

This work developed and evaluated a decoupled solar powered spraying machine. The work involves the decoupling of existing designs (to reduce weight and bulkiness) and the introduction of a lithium iron phosphate (LiFePO₄) battery (as against lead acid battery). The main parts of the solar powered sprayer are solar panel (50W), control switch, charge controller (20A), 12 V direct current (DC) operated pump, LiFePO₄ battery (12.8V, 6 Ah), battery management system (BMS), press switch button and sprayer tank (15 liters) with nozzle. A charging station that includes the solar panel, control switch, charge controller and a plug attached to a cable was developed as a unit. The plug is expected to be inserted into a socket attached to the battery pack for charging. The battery pack, electric pump, press switch button and sprayer tank with nozzle were assembled together as another unit which can be attached and detached from the charging station based on the required task. It is attached when charging is needed or it is to be used to power home devices and detached when it is to be used for spraying. The system was later tested for performance evaluation. The results of the tests showed that a fully charged battery was able to dispense 223 liters of water with an energy consumption of 68 Wh. The average energy used per liter was 0.305 Wh. The results also showed that, the sprayer (with a fully charged battery) can work for up to six hours (non-stop) before the battery is completely drained. One major advantage of this set up is that, if the farmer is not spraying, the developed device can be used to light up homes and charge small devices such as phones, MP3, internet router and so on.

1. INTRODUCTION

A spraying machine is a device used to distribute liquid or powder material onto a surface for purposes determined by the user. It typically consists of a pump, a spray gun, and a nozzle, and they are used for different applications including automotive, construction, and agriculture. Agricultural Sprayers are the equipment used for applying liquid substances to plants. These substances could be herbicides or pesticides. Based on the specification, size, and crop requirements, sprayers are of different types like, hand-operated sprayers, low-pressure sprayers, high-pressure sprayer, air carrier sprayers and foggers (Mittal *et al.*, 2016). Besides, sprayers are used to supply water for irrigation. They are one of the essential tools required for

crop production. Sprayers are convenient to use than conventional watering can (Chand *et al.*, 2011) for irrigation.

Agricultural practices in developing countries are so laborious that farmers control weeds on their farm land by cutting down the unwanted plants using cutlasses and hoes. This had been the practices since the olden days and even in subsistence scale farming of nowadays. The use of cutlasses and hoes had caused injuries that sometimes lead to deformity and even short life span to some farmers. Modern practices of farming have made the work easier and even faster. Some hectares of land can be worked on within short period of time by using machines such as spraying machine, tractor, planter and harvester (Mallan *et al.*, 2021; Lawal *et al.*, 2019; Kumar and Parihar, 2018; Zilpilwar *et al.*, 2018; Malatesh *et al.*, 2017). The earlier spraying machine was manual type in which one hand is used to lift the handle up and down (i.e., up-stroke and down-stroke of the lever) in order to build up pressure on the liquid (herbicide or pesticide) inside the tank so that the liquid can come out through the nozzle (Awulu and Sohoshan, 2019).

The most popularly used sprayer in this part of the world is the knapsack type. This type of sprayer is manually operated, which makes its usage to be stressful to the operator as it requires jacking up and down a lever for pressure build up. Recently, a hybrid knapsack sprayer was introduced into the market to combat the stress attached to the manually operated one. It is hybrid because it can be manually and electrically operated. It has an inbuilt 12 V lead acid rechargeable battery to power an inbuilt electrical pump for spraying (Zilpilwar *et al.*, 2021; Awulu and Sohoshan, 2019; Maulana *et al.*, 2018). A major setback to this type of sprayer is that, it requires the availability of electricity (either from grid or fuel generator) to charge the battery after it drains. This makes it unsuitable to many rural farmers in developing countries who are not connected to the grid and also find it difficult to look for fuel stations that are also far from them. Some farmers who are connected to grid might suffer epileptic power supply. Another setback is the lead-acid battery used, it cannot be discharged heavily and has low charge-discharge cycle, making it to have short lifespan.

To combat the above-mentioned setbacks, some researchers have developed solar powered sprayers of different configuration. The developed sprayer has solar panel, charge controller, rechargeable lead acid battery and electrical pump, all coupled together. Some designed the coupled system to be backed-up while in use (Basavaraj *et al.*, 2020; Ingle *et al.*, 2020; Kumawat *et al.*, 2018; Sinha *et al.*, 2018; Yallappa *et al.*, 2016) while others provided wheels to move the system around due to its bulkiness (Dhananjay *et al.*, 2022; Sahu and Kumar, 2018; Krishna *et al.*, 2017). It is important to note that, carrying a sprayer on ones back with solar panel and controller will make it to be heavy and bulky (Zilpilwar *et al.*, 2021). On the other hand, not all farm terrain can support easy wheeling of the sprayer, hence, pushing it about may be stressful and require excessive efforts. In order to overcome the challenges posed by the developed solar sprayers, this study developed and evaluated a solar sprayer that decouples the solar panel and controller from the sprayer. With this decoupling, the heaviness and bulkiness of the system has been catered for. Also, a lithium iron phosphate (LiFePO₄) battery was used as storage. This battery technology can be discharged heavily and has a high charge-discharge cycle, which makes it to have long lifespan. It is also important to note that, while other study dwell more on one-time mechanical evaluation of the sprayer, this work performed important mechanical and electrical evaluations of the developed sprayer from full-charge to low cut-off battery voltage.

2. METHODOLOGY

Electrical connections were made according to the wiring diagram in Figure 1. The components parts are readily available in market. The 50 W solar panel charges the 6 Ah battery through the 20 A charge controller to protect the battery from overcharging. It should be noted that the 50 W panel was selected to charge the battery fast. With an approximate average sun time of two hours, the battery is expected to be fully charged. A switch was placed in between the solar panel and the controller to disconnect panel from

the controller whenever the sprayer is taken out for use (according to best practices, panel should not be connected to the controller if battery has not been connected). This switch also connects the solar panel to the controller during charging of sprayer's battery. The charging current from the controller is delivered to the battery through battery management system (BMS). The BMS is an electronic device that ensures the healthiness of a LiFePO_4 battery pack. The 12 V DC operated pump is connected to the terminals of the battery through a press button switch to allow for easy make and break of the system. The suction part of the DC operated pump is inserted into the knapsack tank, while the discharge part is connected to the nozzle. The rechargeable 12.8 V LiFePO_4 battery was selected to power the pump due to its small size, light weight, chargeability and energy density. The 12.8 V LiFePO_4 battery which was made from four pieces of 3.2 V, 6 Ah cells and BMS is shown in Figure 2.

The charging socket is provided to connect and disconnect the sprayer from the charge controller. Connecting to the charge controller through the charging socket also allows the usage of the sprayer's battery for domestic purposes. The developed sprayer is shown in Figure 3. The charging station which consists of a charge controller (connected to solar panel) is permanently fixed to a point, while the knapsack sprayer can be connected and disconnected to the station through the charging cable. The image of the detached sprayer is shown in Figure 4. The press button switch is used to energize the pump for spraying. Figure 5 demonstrates how to use the developed sprayer after the battery is partially or fully charged. The press button switch is held in the left hand and the nozzle handle is held with the right hand. It is so easy to operate by just pressing the switch button to create the necessary pressure needed for spraying. It should be noted that the mechanical parts of the sprayer was not removed but was temporarily disable.

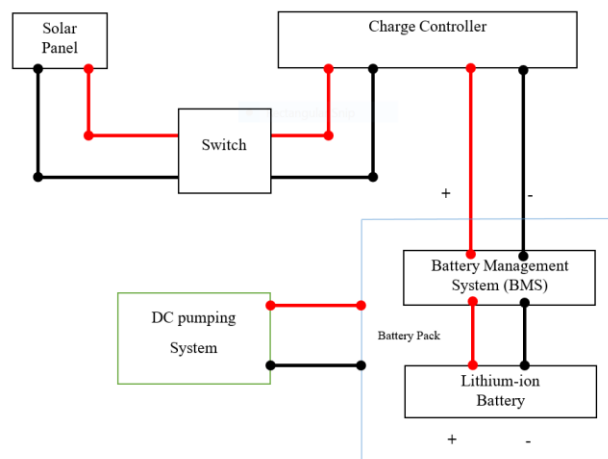


Figure 1: Wiring Diagram of the Solar Powered Sprayer System

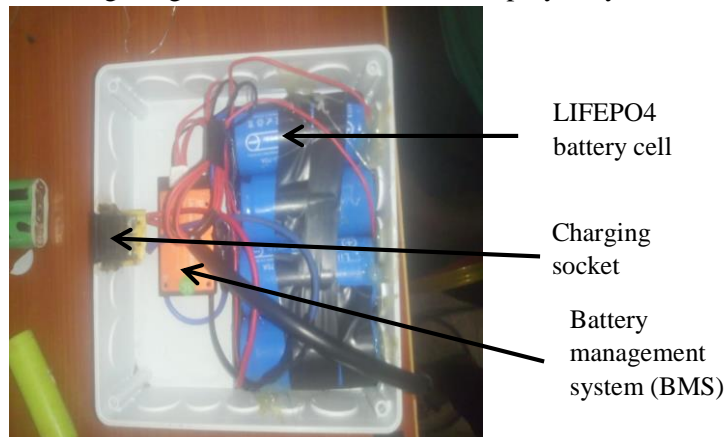


Figure 2: Internal Components of the Battery Casing

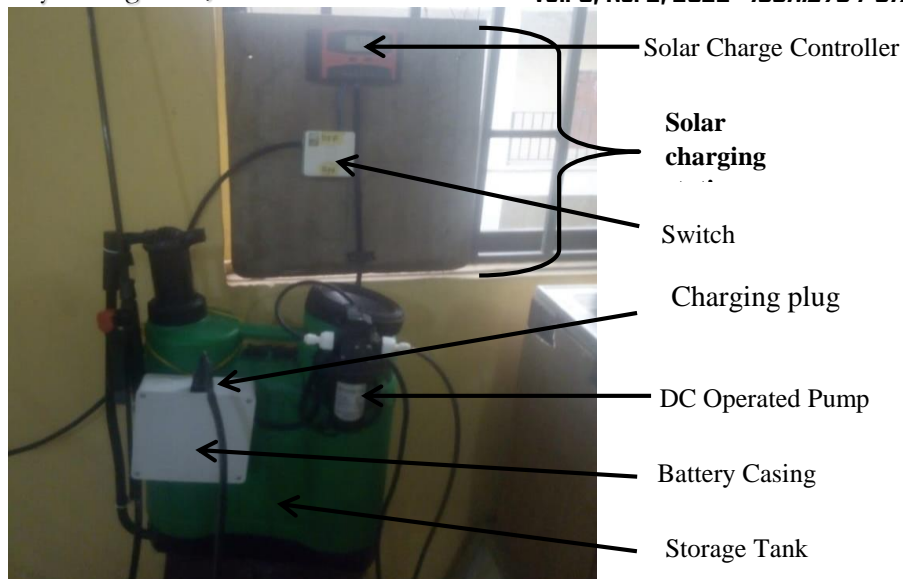


Figure 3: Developed Solar Powered Spraying Machine

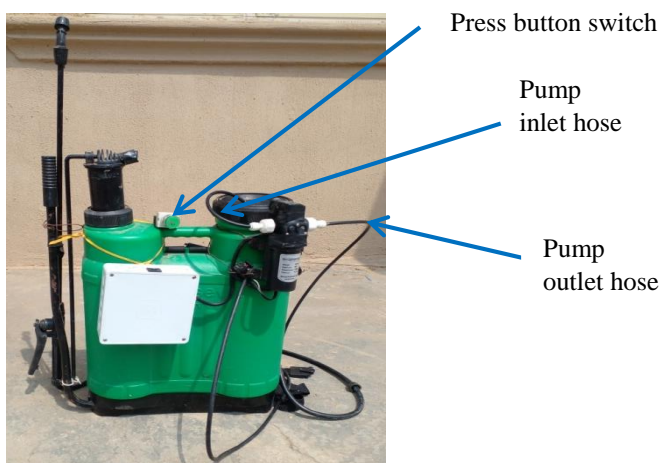


Figure 4: Decoupled Solar Powered Spraying Machine



Figure 5: Sprayer in Use

3. RESULTS AND DISCUSSION

To evaluate the sprayer, the battery was fully charged to a voltage of 13.04 V. The capacity of the liquid storage tank used in this project is 15 liters. As earlier stated, a press switch button is used to energize the DC pump to build up the pressure inside the pump, then the nozzle helped released the liquid to the point of application. This is a smarter way of energizing the system as against the mechanical means of activation. Water was the chosen liquid used to test this device. The liquid in the storage tank was continuously filled and dispensed until battery low voltage level was reached (i.e. when the pump no longer works). It is important to note that, the nozzle used for the evaluation has one hole for dispensing. This testing was carried out from full open circuit battery voltage (OCBV) of 13.04 V until low battery mark of the BMS was reached. The OCBV at BMS cut-off was 11.97 V. Different electrical and mechanical properties were noted during the testing. Multi-meter (which has the ability to measure voltage, current, power and energy) was used to monitor the electrical properties while the flow rate was determined after noting the time taken to dispense specific volume of water. The electrical properties that were monitored included voltage, power and energy. The mechanical property monitored was the discharge rate of the system. The weight of the knapsack spraying machine was measured to be 3.4 kg before the modification and 4.3 kg after the attachment of the DC pump and battery pack. There was only an addition of 0.9 kg. The total weight of the water-filled sprayer was obtained to be 19.7 kg.

After the test, 14 tanks (of 15 liters each) and 13 liters of water were dispensed before the battery reached low cut off point. The total volume of water dispensed was 223 liters. Various parameters monitored during the tests are presented in Table 1. It was discovered that, throughout the evaluation, the steady-state power consumed by the electrical pump ranges from 9.8 W to 13.9 W. It could be seen from the Table 1 that the voltage difference after dispensing each tank is minimal and at some points constant as further shown in Figure 6. There was no difference in voltage after dispensing tanks 8 and 9. The voltage difference increased abnormally as the battery approached its low level as shown in Figure 7. A plot of the energy usage before and after dispensing the tank's water is shown in Figure 8 and the actual energy consumed to dispense each tank is shown in Figure 9. Figures 8 and 9 show that the energy used to dispense 223 liters of water is 68 Wh and the average energy used per tank (for the 14 fully dispensed tanks) is 4.64 Wh while the average energy used to dispense a liter is 0.305 Wh ($68 \text{ Wh} \div 223 \text{ liters}$). Returning this amount of energy back into the battery (i.e. charging the battery) through the 50 W panel with an assumption of 80% panel efficiency will take an average sun time of 1 hour, 42 minutes ($68 \text{ Wh} \div (50 \text{ W} \times 0.8)$). This is an indication that, the battery can be fully charged after being discharged.

Table 1: Recorded Parameters of Developed Sprayer during Evaluation

Tank	OCBV (V)		Drop in OCBV (V)	Energy (Wh)		Energy used (Wh)	Volume dispensed (liter)	Time taken to dispense (min)	Discharge rate (liter/min)
	Initial	Final		Initial	Final				
1	13.04	12.98	0.06	0	5	5	15	17	0.88
2	12.98	12.94	0.04	5	9	4	15	18	0.83
3	12.94	12.90	0.04	9	13	4	15	20	0.75
4	12.90	12.86	0.04	13	18	5	15	23	0.65
5	12.86	12.84	0.02	18	23	5	15	23	0.65
6	12.84	12.82	0.02	23	28	5	15	23	0.65
7	12.82	12.79	0.03	28	32	4	15	24	0.65
8	12.79	12.79	0.00	32	36	4	15	24	0.63
9	12.79	12.79	0.00	36	41	5	15	25	0.60
10	12.79	12.76	0.03	41	45	4	15	27	0.56
11	12.76	12.72	0.04	45	51	6	15	28	0.54
12	12.72	12.65	0.07	51	55	4	15	28	0.54
13	12.65	12.57	0.08	55	60	5	15	28	0.54
14	12.57	12.40	0.17	60	65	5	15	30	0.50
15	12.40	11.91	0.49	65	68	3	13	28	0.46

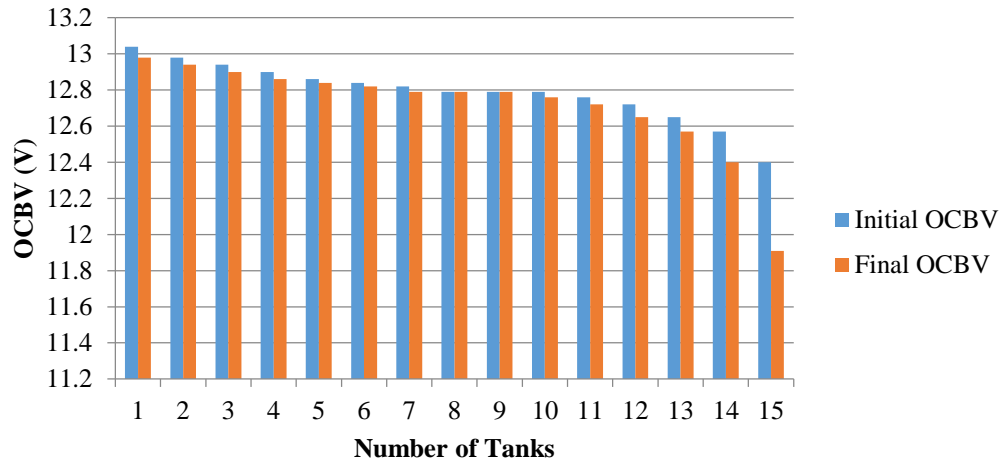


Figure 6: Initial and Final Open Circuit Battery Voltage (OCBV)

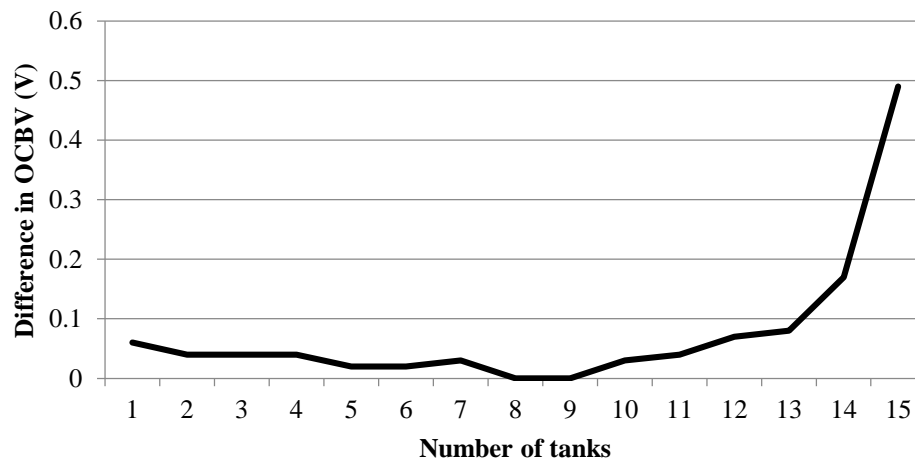


Figure 7: Difference in Open Circuit Battery Voltage after Dispensing Each Tank

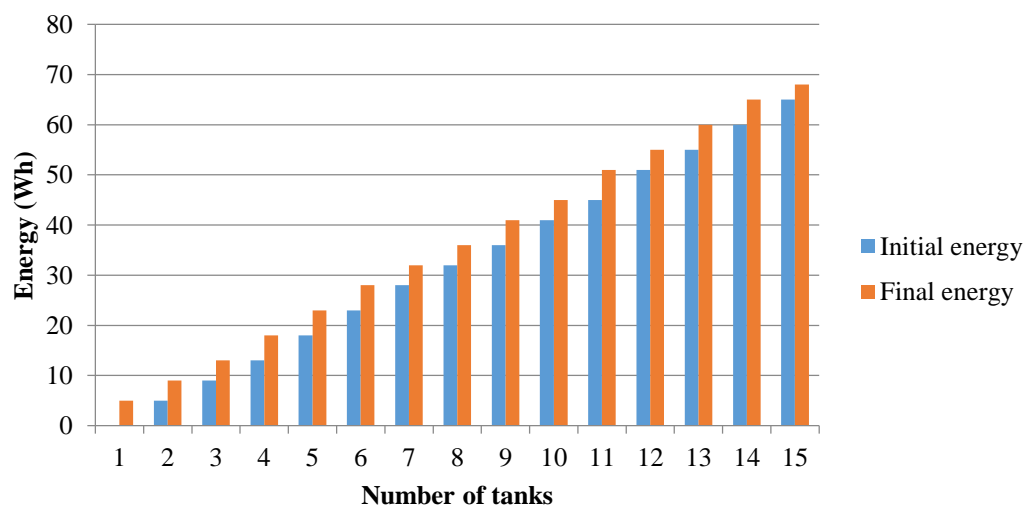


Figure 8: Initial and Final Energy Used Per Tank

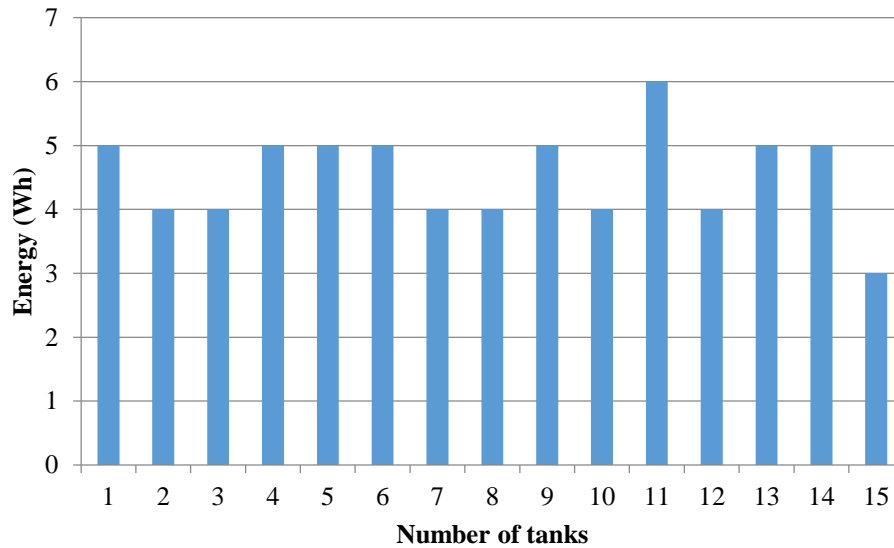


Figure 9: Energy Used Per Tank

The discharge rate of the system per tank is shown in Figure 10. This figure is a pointer to the fact that as the volume dispensed increases, the discharge rate reduces. This is because of the gradual reduction in the battery voltage. It can also be said that, the lesser the pump terminal voltage, the lesser the discharge rate. One major importance of this sprayer that is worth mentioning is that, if the farmer is not spraying, the system can be used to charge phones and other mobile devices. It can also be used to light up homes with DC light emitting diode (LED) bulbs. If fully charged and is to be used for lighting only, it will be able to light up two pieces of 3 W bulbs for approximately 11 hours ($68 \text{ Wh} \div 6 \text{ W}$).

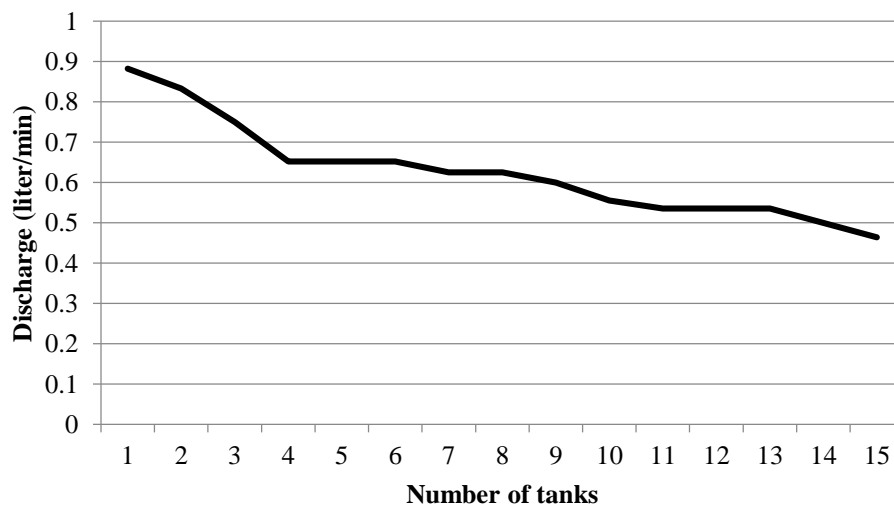


Figure 10: Discharge Rate for the Sprayer

Bill of Engineering Measurement and Evaluation (BEME)

The materials used in the construction of this project are readily available in the market. The exchange rate as at the time of this study was approximately four hundred and fifty naira to a US dollar ($\text{₦}450 = \$1$). Table 2 shows the cost of production of this project work when it was carried out. Since the exchange rate is $\text{₦}450$ to $\$1$, the amount of producing a solar powered spraying machine in US dollar is $\$178.22$.

Table 2: Bill of Engineering Measurement and Evaluation (BEME)

S/N	Description	Quantity	Unit price ₦: k	Amount ₦: k
1	50 W Solar panel	1	14,900	14,900
2	20 A Charge controller	1	8,998	8,998
3	3.2 V, 6 Ah LiFePO ₄ Battery	4	7,419	29,676
4	10 A Battery Management System (BMS)	1	6,969	6,969
5	12 V DC Operated powered Pump	1	7,957	7,957
6	Switch Button	1	2,000	2,000
7	15 liters Storage Tank	1	8,500	8,500
8	Connecting wire	6 meters	200	1,200
TOTAL				80,200

4. CONCLUSION

An existing design of a solar based agricultural sprayer has been modified by allowing the decoupling of the solar panel and controller from the sprayer, pump and battery. The developed system helps remove the bulkiness and additional weight associated with the existing solar based sprayers. Components used were readily available in market and relatively affordable. The system was tested and confirmed effective and efficient. The tests carried out on the developed sprayer showed that 223 liters of water were dispensed with an energy consumption of 68 Wh. Test results also showed that the average energy required to dispense the water in a tank is 4.64 Wh. From the results obtained, it can be concluded that, as the volume of liquid dispensed increases, the battery voltage reduces, thereby reducing the discharge rate of the liquid. Further research could come up with modifications that will allow an electronic display for monitoring of the sprayer's parameters.

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