Solar Power for Operating a Sprayer and House Lighting

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Abstract - *A solar-powered system was designed and developed to run a sprayer and house lighting. There are 3 units in the system; i) solar energy conversion and energy storage unit, ii) spraying unit and iii) house lighting unit. It consists of a solar panel of 17 W, a LM317 voltage regulator, a sealed lead acid battery of 12 V, 9 Ah, a DC motor run the pump, a switch to on/off the motor, a tank to hold the pesticide, diaphragm pump to send pressurize liquid to nozzle, a lance with a nozzle, and a circuit for operating 3 LED bulbs. The efficiency of the solar panel is 16 % but it is only 7.48 % when providing power to the motor. The total weight of solar operated sprayer with 16 L spray liquid is 27.78 kg. The field capacities of the sprayer were 81.60 L/h, 166.57 L/ha, 2.04 ha/h and 0.49 h/ha. The time required for charging the full battery capacity of 12 V, 9 Ah by analytically and practically was found to be 6.33 h and 10.5 h, respectively. The duration of the spraying will be around 4.9 hours after leaving 25% charge in the battery. However, the discharge time will be more when the battery will be operated while being charged and discharged simultaneously. The Overall Discomfort Rate (ODR), Body Part Discomforts Score (BPDS) and heart rate were 4, 21 and 107 beats min^{-1} respectively for operating the solar-powered sprayer. On the other hand, those were 6, 43 and 131 beats min^{-1} respectively for operating the lever operated knapsack sprayer. It was observed that ODR, BPDS, and heart rate were lesser for the solar-powered sprayer. The sprayer used hardly 90 days per year at the rate 5 hours per day so rest of the days of the year would be used for house lighting. It was not possible to measure the financial benefit of crop protection and operators health. However, the system would be saved US$ 6.44 electricity billing cost per year only for using for house lighting. Since the system reduces drudgery, is quite economical by saving billing cost and eco-friendly, it will be accepted by the by small and marginal farmers of Bangladesh.*

Key Words: **Solar Power, sprayer, house lighting, solar panel efficiency, LED bulb, and ergonomics**

1. INTRODUCTION

Bangladesh is an agro-based country and agriculture contribution 14.2% to total GDP. Most of the people of this country are directly or indirectly related to agriculture. They contribute an overwhelming impact on major macroeconomic objectives. Farmers of this country do a lot of field work, such as weeding, reaping, sowing etc. Apart from these, spraying is also an important operation to be performed by the farmers to protect the crops. Most of the farmers use Lever Operated Knapsack (LOK) or engine operated sprayers to protect their crops from pests attack. A person maintains a pressure in the tank by pumping air with a lever with one hand and directs the spray lance with the other hand for operating a LOK sprayer. It is very difficult to maintain constant pressure and causes user fatigue [1], [2] and [3]. Heart rate and energy required for operating a LOK sprayer varied from 97 to 120 beats per minute and 19.27 to 25.54 kJ min^{-1} respectively [4]. The maximum discomfort experienced in the left clavicle region, followed by lower back, neck, left thigh and right clavicle parts of the body for operating LOK sprayer [5], [6], [7] and [8]. In addition, the lever operation induced greater variation in spray pressure resulted in the inconsistency of spray application which adversely affects the pest control [9], [10] and [11]. The vibration of engine operated sprayers is also harmful because shaking transmits to human body parts results in early fatigue, increase heart rate, source of long-term health hazards and reduced the performance of the operators [12], [13], [14], and [15]. In addition, petrol use in the engine to the operate sprayers which pollutes the environment. On the other hand, the world, as well as Bangladesh, faces an energy crisis problem due to decreasing the supply of petroleum, gas, and coal [16], [17], [18] and [19]. To meet the future energy demands, the use of solar energy as an alternate solution is inescapable. Solar radiations are collected by a solar panel and then convert it into electrical energy by photovoltaic conversion process [20]. The operation of the solar powered sprayer is more economical mainly due to the lower operation and maintenance costs. It has a less environmental impact than engine operated sprayer. Farmers of Bangladesh do not have electricity in their house and others have the electricity but face load shading. However, a solar operated sprayer will be used for a limited time (maximum 350-400 hours per year) for spraying so it became uneconomical. The solar-powered system can be used for multi-purpose applications such as house lighting, charging the battery of the mobile, and operating the radio etc. which makes it more economically viable [21]. Therefore, research was undertaken to design and development of a solar system to operate a sprayer and house lighting.

2. METHODOLOGY

The main functional parts of the solar system are; a solar panel, a voltage regulator, a sealed lead acid battery, a DC motor, switches, a pump, extension wires, a spray tank, pipe, lance with nozzle, bulbs etc. The parts required for developing the solar-powered system were selected by solving equations with assuming reasonable values and their availability in the market. The total weight of solar-powered sprayer should be such that an operator can carry it comfortably for 6 hours without any discomfort and does not affect his health.

2.1 Selection of parts for the system

The tank of a LOK sprayer was selected because it was easily available in the market and most of the farmers of Bangladesh used this tank. The sprayer is a device where a pump pressurizes the pesticides and sends it through a nozzle. Therefore, it is important to select the nozzle and pump for a desire spraying. Nozzles used by the farmers of Bangladesh were collected from the markets and determined the discharge rates for different spraying pressures. It was observed that the mean discharge rate varied from 0.3 to 1.8 l/min and pressures ranges from 0.5 to 2.2 kg/cm^2.

A diaphragm type DC pump was selected whose maximum pressure, discharge rate, weight, dimension, and price were 2.5 kg/cm^2, 2 L/min, 500 gm, 95x40x35mm and $5.0 respectively. The DC pump was selected because of the number of advantages such as less in noise, longer in life, maintenance free, self-lubricated and motor speed could be varied in the larger extent by varying the supply voltage.

A motor is used to operate the pump and lifted the pesticide from the tank and delivered to the spray gun. A mathematical equation was derived after adopting suitable assumptions of pressure head, the discharge rate of fluid, motor efficiency, pump efficiency and coefficient of friction of fittings for calculating the power of the motor required for spraying. The power requirement of the motor was computed with the following equation and considering different values as shown below;

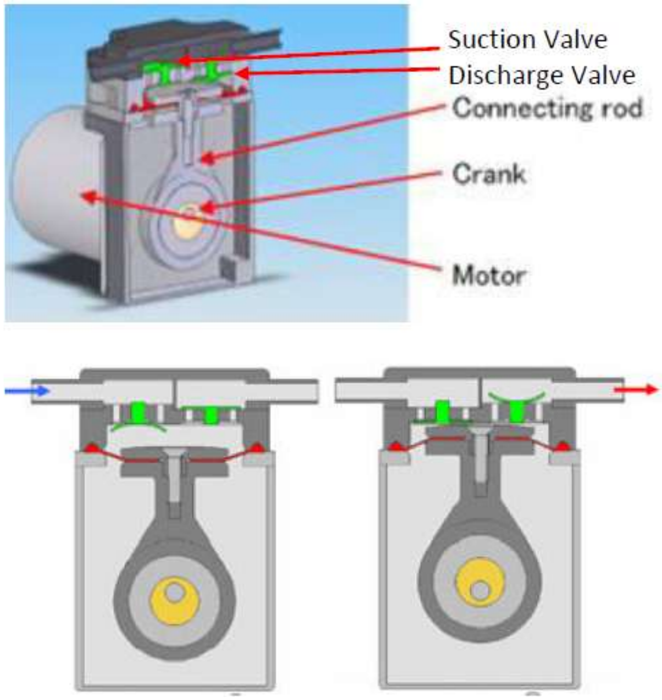
$$P = (Q*h*C)/(e_f *e_p *e_m)$$

Where,

P = motor of power, W
Q = discharge rate, 2 L/min
h = total head of pump, 3 m
e_p = pump efficiency, 0.6
e_f = coefficient of friction for pipe and fittings, 0.5
e_m = motor efficiency, 0.7
C = unit conversion factor, 9.816

Thus, the required power of the motor was 5.8 W by considering a 25% safety factor. The diaphragm type DC pump with a DC motor was selected on the basis of the power requirement of the motor. The power and current rating of the motor were 5W-12W and 0.6-3A respectively. Figure 1 shows the structure and operating principle of the diaphragm pump [30]. There was an inbuilt operating pressure switch to cut off the pump from the motor when the pressure exceeds the max value (2kg/cm^2).

A battery is needed to store the energy developed by the solar panel and operate the motor for spraying. The stored energy of the battery would be used for house lighting. Therefore, a maintenance-free sealed lead acid battery of 12 V, 9 Ah was selected on the basis of the power requirement of the motor for spraying. The size, weight, and price of the battery were 151×65×94 mm, 2.7 kg and US$ 23 respectively. The standby use, the cycle use, and maximum initial current of the battery were 13.5 V- 13.8 V at 25°C, 14.4 V – 15 V at 25°C and 2.7 A respectively.



Suction stage Discharge stage

Figure 1: Structure and operating principle of the diaphragm pump with the motor

The size of the solar panel is directly dependent on the size of the motor to pump spray and the solar irradiance available in the study area. The solar panel was selected by considering the weight as well as its ability to charge the battery [1]. The current produced by the solar panel and charging time of battery were determined using the following equations;

$$I_{sp} = P_{max}/V_b \quad ..... (1)$$
$$T = I_{hb}/I_{sp} \quad ...... (2)$$

Where,

I_{sp} = current produced by the solar panel, A
P_{max}= maximum power of the solar panel, W
V_b = voltage of the battery, V
T = theoretical charging time of battery, h
I_{hb} = current rating of battery, Ah

The power and weight of solar panel were collected from Chavan et al [1]. Markets were visited to collect the sizes and power ratings of different solar panels. The theoretical charging time of battery was determined using the equation (2) for a battery of 12V and 9Ahr. The retaliations among the theoretical charging time of the battery, size of solar panel and weight of the solar panel versus the power rating of the solar panel were determined and presented in Figure 2.

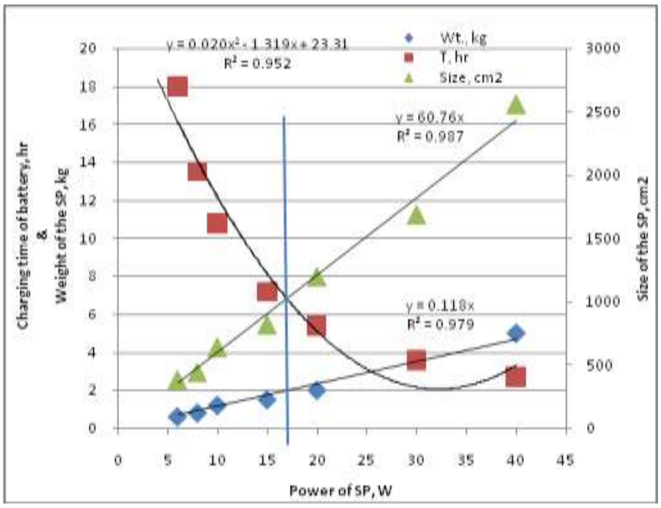


Figure 2: The retaliations among charging time of battery, weight, and size of the solar panels versus the power rating of the solar panel. The capacity of the battery is constant, 12 V, 9Ahr.

It is observed that as the rating of the solar panel increases its weight increases but the time for charging the battery decreases if the solar panel is operating at its maximum rating. As figure 2, a solar panel of 17 W power rating was selected for this experiment. The detailed technical specifications of the selected solar panel were as follows;

Type of Solar Cell: Monocrystalline UV resistant

Open Circuit Voltage: 22.4 V

Voltage at maximum power: 18.9 V

Current at maximum power: 930 mA

Maximum Power, P_{max}: 17.6 W

Power Tolerance: +/-10%

Size: 27.4 cm x 39.3 cm x 0.5 cm
Weight: 680 gm and Price: US$ 130

A sprayer is used for a limited time in the field and that makes it uneconomical. However, the solar power of the sprayer can be used for multi-purpose applications such as house lighting, charging the battery of the mobile, and operating the radio etc. which makes it more economically viable [21]. Some farmers of Bangladesh do not have electricity in their house and some farmers have it but face load shading frequently and cost for electricity use. Therefore, a provision was attached in the system to operate 3 LED white bulbs in the farmer's house. The circuit diagram of house lighting is shown in Figure 3.

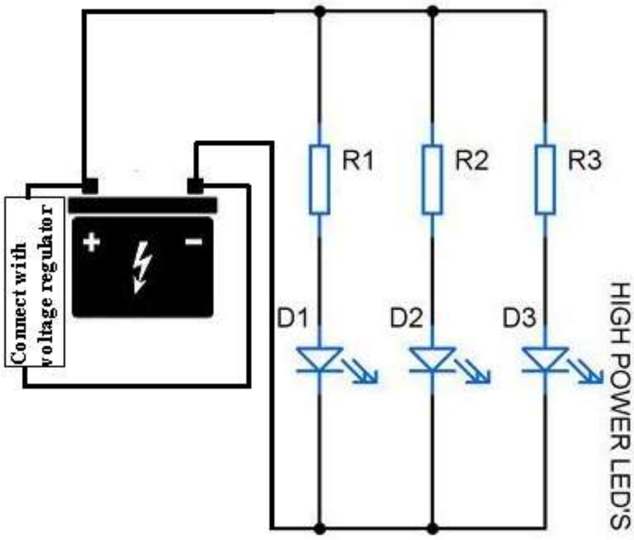


Figure 3: Circuit diagram for house lighting

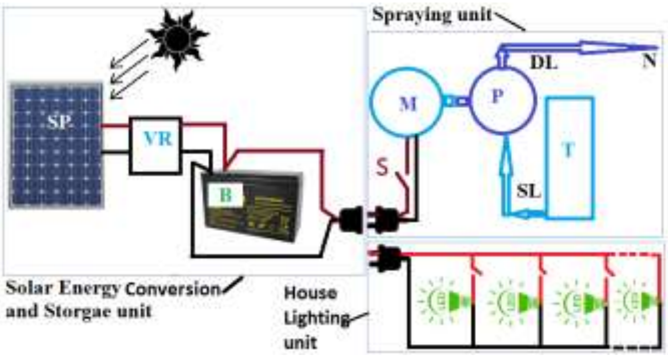
The resistances (R1, R2 & R3) were used to limit the current provide to the LED bulbs. LED bulb is selected because it is efficient, long lasting and environment friendly than these traditional sources of light. They also produce more light in comparison to incandescent bulbs with equivalent wattage. The Specifications of LED bulb is shown in Table 1 [24].

Table 1: The Specifications of LED bulb

Voltage Available	12 V DC
Nominal Power	3 W
Average Lumens	260 Lm
Material:	Plastic + PC
LED Chip	Epistar SMD
Life Span:	50,000 Hours
Luminous Efficacy	80-90 lm/W
Beam Angle	120° Degrees
Working temperature	-25 ~ +55°C
Protect Class	IP50
Power Factor	>95%
CRI	Ra ≥80
Light Color	2700K or 6400K
Socket	E27 or B22

2.2 Construction and working principle of the solar power system

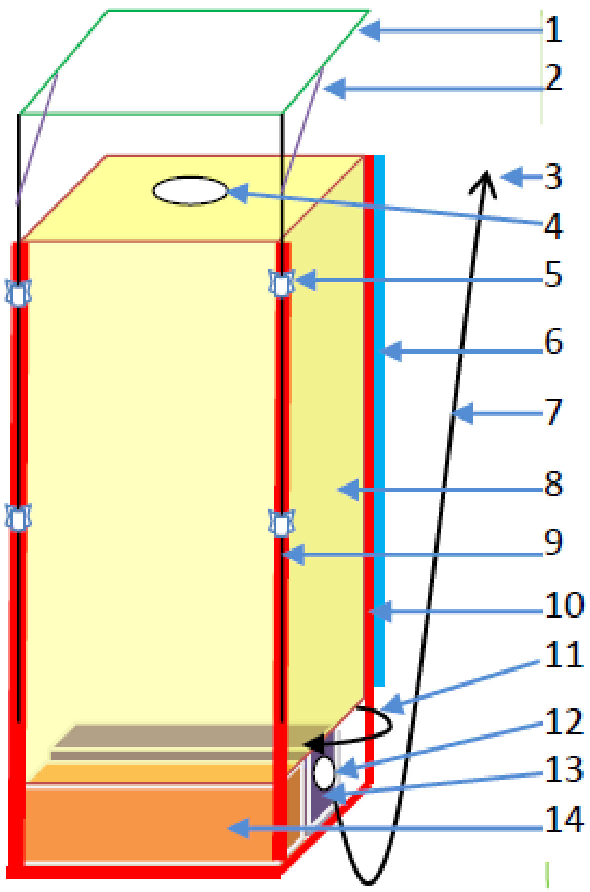
There are 3 units in the solar power system; i) solar energy conversion and energy storage unit, ii) spraying unit and iii) house lighting unit. In the energy conversion and storage unit, the solar radiation is collected by the solar panel and then converted it into electrical energy by the photovoltaic conversion process. The electric energy passes to LM317 voltage regulator through the diode D1 and store in the sealed lead acid battery. The stored energy is used for either operating the sprayer or house lighting by plug in any one of two units. Sprayer would be used hardly 350-400 hours per year so the rest of the time would be used for house lighting by plug in house lighting unit. The parts and electric circuit board of the solar power system are shown in Figure 4.



Components: SP = Solar Panel (18.9 V, 930 mA,17.6 W), VR= Voltage Regulator (LM317), B = Battery (12 V, 9 Ah, M=Motor (5-12 W & 0.6-3 A), P =Pump (2.5kg/cm^2, 2 L/min), T= Spray tank (16 L), S= Switch, SL= Suction Line, DL= Discharge Line, and N= Nozzle

Figure 4: Parts and Circuit board of the solar powered system for operating a sprayer and house lighting

In the spraying unit, the tank is used as a reservoir of spray mix and the top opening of the tank with a cover is for filling of spray liquid. An outlet orifice was constructed at the extreme bottom of the tank for suction spray liquid by the pump. The frame for holding the tank, battery, pump and solar panel was made by the light materials (Aluminum). The maximum performance of SPV found when the irradiation falls perpendicular to the panel surface [28] so an adjustable frame was designed to alter the angle of SPV as per latitude of the site. The height of the solar panel is also adjustable according to the height of the operator. The electric energy produced by the solar panel is supplied and stored in the battery. The battery is connected with the DC motor to operate the pump. The operating switch of the pump is fixed with the trigger of the sprayer. When the switch is connected, the pump sucks the spraying liquid from the tank and sprays it through the nozzle. Figure 5 shows the isometric view of the solar powered sprayer. The weight of the solar panel, battery, motor, spray lance, frame, and tank with 16 L spray liquid were measured by a weighing machine and add the values to find the total weight of solar operated sprayer.



Legend: 1. Solar Pane, 2. Flat bar to adjust the angle of solar panel, 3. Nozzle, 4. Lid of tank, 5. Hook for adjust height of the solar panel, 6. Foam, 7. Lance, 8. Spray tank, 9. Rod for support the solar panel, 10. Frame for holding the spray tank, battery, motor & pump, 11.suction pipe from spray tank to pump, 12.Motor, 13. Pump and14. Battery

Figure 5: Isometric view of the solar powered sprayer.

2.3 Determination of the Performance of the Solar Panel and Battery

The actual time of full charging of the battery was determined by keeping the solar panel under the sunlight for 2 days from 9 a.m. to 4 p.m. and measured the voltages and currents in every half an hour by arranging voltmeter, ammeter and variable resistor as shown in Figure 6. Initially, the resistance was set to the lowest value, current and voltage were measured and record. Then, the value of the resistor was changed a little bit and noted current and voltage. It was repeated until the output voltage became nearly zero. Current and voltage were plotted in a graph and the maximum power was calculated by multiplying the current and voltage generated at the 'knee' point of the curve [22]. The maximum power (16.93 W) was obtained after 10.5 hours charging of the battery. The temperature was recorded by a temperature gauge during this experiment.

The short circuit current (I_{sc}) and open circuit voltage (V_{oc}) of the solar panel were also obtained from the recorded data.

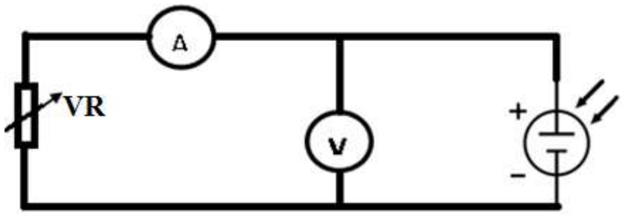


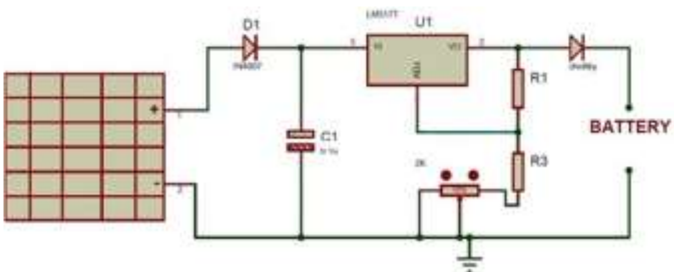
Figure 6: Circuit diagram to measure current and voltage produced by the solar panel

The solar panel generates 22 V so it is necessary to control the voltage by a voltage regulator for charging the battery of 12 V. The bank voltage of a 12 V supply voltage lead-acid battery is 16 V and allows charging to 14.4 V (6 x 2.40 V/cell). It was done by adding an LM317 voltage regulator in the circuit as shown in Figure 7 [23]. The current from the solar panel passes to LM317 voltage regulator through the diode D1. The diode was connected to eliminate the risk of reverse flow of current during night time. A pot or voltage divider was connected with ADJ pin to adjust the output voltage obtained from the circuit. Two restores, R1 & R3, were connected to obtain the desired voltage output from the circuit. The values of resistances R1 & R3 were calculated using the following equations for an output voltage of 16 V from the voltage regulator. A Schottky diode and rectifier were attached with a voltage output line of the regulator to get a low forward voltage drop and very fast switching action.

$$R1 = R3 * \frac{1.25}{Vout - 1.25}$$

$$R3 = R1 * \frac{Vout - 1.25}{1.25}$$

$$Vout = 1.25 * (1 + \frac{R3}{R1})$$



Circuit Components: Solar panel 17.6 W, LM317 voltage regulator, DC battery 12V & 9Ah, diode 1N4007, capacitor 0.1uF, Schottky diode, resistors R1=100 and R3=1180 ohms, Pot – 2K, connecting wires, VO = voltage out and VI = voltage in.

Figure 7: The circuit diagram of battery charging from the solar panel

Current consumption of the motor during spraying was measured and recorded. The total discharging time (T_d) of the 100% charging battery was calculated using the following equation;

$$T_d = I_{hb}/I_m$$

Where,

T_d = Total discharging time of battery, h
I_{hb} = Current rating of battery, Ah
I_m = Current consumption of the motor, A

The maximum solar panel efficiency was determined using the following equation;

$$e_{spt} = (P_{max}/P_s)x100$$
$$P_s = S_i*A$$

Where,

e_{spt} = maximum solar panel efficiency, %
P_{max} = maximum power produced by the panel, W
P_s = solar power intercepted by the panel, W
S_i = incident Solar radiation, 1,000W/m^2
A = area of the Solar panel, 0. 107682 m^2

However, the actual power (P_{actual}) deliver to the motor is equal to the voltage (V) across the motor times the current (I) through the motor. The current and voltage of motor were measured during the operation of spraying and calculated actual efficiency of the solar panel (e_{spa}) using the following equation;

$$e_{spa} = P_{actual}/P_s$$

2.4 Determination of the Performance of Sprayer

The capacity, size, weight with and without pesticide of the tank were measured and recorded. Flow rates of nozzles were determined by spraying for a certain time. The time was recorded by a stopwatch and amount of spraying was measured by a conical flask. The spraying pressure was recorded from a pressure gauge. The procedure was repeated four times and the discharge rate was calculated using the following formula.

Flow rate (L/min.) = Volume of liquid collected in cylinder (L)/Time (min)

The tank was filled with 16 L spray liquid and operated in rice field until finished the tank. The time required to finish the tank was recorded by a stopwatch and covered area was measured by a tape. The field capacities of the sprayer were determined as L/h, L/ha, ha/h and h/ha.

$C (L/h) = V_s / T_s$
$C (L/ha) = V_s / A_s$
$C (ha/h) = A_s / T_s$
$C (h/ha) = T_s / A_s$

where,

C = field capacity of the sparyer

V_s = volume of liquid sprayed, L

T_s = time of spraying, h

A_s = area of spraying, ha

For the assessment of overall discomfort rating (ODR) and body part discomfort score (BPDS), a 10 point psycho physiological rating scale was used. Two operators of nearly the same age and weight were spraying for 4 hours. One of them used conventional lever-operated knapsack sprayer and the other one used the solar powered sprayer. Both of them were asked to indicate their ODR and BPDS level on the 10 point rating scale and the heartbeat was measured at the end of 4 hours of spraying.

2.5 Determination of the Performance of LED bulbs

The duration of the lighting of 3 LED white bulbs powered by the rechargeable sealed lead acid battery of 12 V, 9 Ah battery was calculated using the following equation and assumptions.

$$T_L = I_{hb} / I_L$$

Where,

T_L = Duration of lighting, h

I_{hb} = Battery rating, Ah

I_L = Total current consumptions of 3 LED bulbs, A

Total costs for using LED and incandescent bulb (mostly used by the rural people of Bangladesh) were estimated by collecting data from the market and website [25]. It was considered that a single 3 W LED bulb can be equivalent to a 30 Watt incandescent lamp [26] and the rate of electricity was Tk. 4.00 (US$ 0.047) per unit [27].

3. RESULTS AND DISCUSSIONS

The maximum power, short circuit current and open circuit voltage of the solar panel were measured in the location of the field experiment. Current and voltage were plotted in a graph and the maximum power was calculated by multiplying the current and voltage generated at the 'knee' point of the curve. The results from the experiments and values supplied by the manufacturer are shown in Table 2. It was observed that variations of values were not remarkable. The temperature was recorded by a temperature gauge during this experiment and it was varied between 18 – 29 ºC. The time required for charging the full battery capacity of 12 V, 9 Ah by analytically and practically was found to be 6.33 h and 10.5 h, respectively.

Table 2: Voltage, current and power of the solar panel supplied by manufacturer and obtained in experimental area

	Unit	As manufacturer	As experiment
Open Circuit Voltage (V_{oc})	V	22.40	22.10
Voltage at maximum power	V	18.90	18.70
Current at maximum power	A	0.93	0.92
Maximum Power	W	17.60	17.11
Short Circuit current (I_{sc})	A	-	1.13

The solar power intercepted and maximum power produced by the panel was calculated and these were 107 W and 17.20 W respectively. Thus, the solar panel efficiency was 16% by the panel which was very close to other researchers [1] and [29]. The actual efficiency of the solar panel when providing power to the motor and it was 7.48%.

The size of the tank was measured and it was 370×150×510 cm. The total weight of solar operated sprayer was found by measuring the weight of the solar panel, battery, motor, spray lance, frame and tank with 16 L spray liquid and it was 27.78 kg. It is expected that an operator is able to carry it comfortably for 6 h without any discomfort and affecting his performance and health. Flow rates of nozzles were determined by spraying for a certain time. It was observed that the mean discharge rate varied from 0.3 to 1.8 l/min and pressures ranges from 0.5 to 2.2 kg/cm^2. The tank was filled with 16 L spray liquid and operated in rice field until finished the tank. The time required to finish the tank was recorded by a stopwatch and covered area was measured by a tape. The field capacities of the sprayer were determined as 81.60 L/h, 166.57 L/ha, 2.04 ha/h and 0.49 h/ha.

Current consumption of the motor was measured during spraying and it was 1.38 A. The current rating of the battery is 9 Ah which implies that the battery can power the motor for 6.53 hours before recharging the battery. However, it is necessary to leave a 25% charge in the battery. Therefore the suggested duration of the spraying will be around 4.9 hours. However, the discharge time will be more when the battery will be operated while being charged and discharged simultaneously.

The Discomfort Rate (ODR), body part discomforts score (BPDS) and heart rate were 4, 21 and 107 beats min^{-1} for operating the solar-powered sprayer. On the hand, those were 6, 43 and 131 beats min^{-1} for operating the lever operated knapsack sprayer. It was observed that ODR, BPDS, and heart rate were lesser for the solar powered sprayer. The majority of discomfort reported by the operator of LOK sprayer in clavicle right shoulder, left shoulder and lower back due to the alternate up – down of lever. Those problems were not reported by the solar-powered sprayer except a little bit more weight.

The stored energy of the battery is used for either operating the sprayer or house lighting by plug in any one of two units. The sprayer used hardly 90 days per year at the rate 5 hours so rest of the days of the year would be used for house lighting. The duration of the lighting of 3 LED white bulbs was calculated on the basis of the voltage (12 V DC) and power (3 W) of each LED bulb. Thus, the total current consumptions for 3 LED bulbs were 0.75 A. Since the current rating of the battery was 9Ah so the duration of lighting was 9 hours after leaving 25% charge in the battery.

The total costs for using LED and incandescent bulb (mostly used by the rural people of Bangladesh) were estimated by collecting data from the market and website. The comparison of cost for using incandescent & LED bulbs is presented in Table 3.

Table 3: Comparison of cost for using incandescent & LED bulbs

Items	Unit	Incandescent	LED
Source of power		220 V AC	12 V DC
Watts used	W	30	3
Average cost per bulb	US$	1	4
Average lifespan	hours	1,200	50,000
Number of bulbs for 50000 hrs	No.	42	1
Purchase price of bulbs for 50000 hours	US$	42	4
Cost of electricity (50,000 hours at $0.04/kWh)	US$	60	0
Total cost for 50000 hrs	US$	102	4
Duration for 50000 hrs operation @ of 10 h/d	Years	15.2	15.2
Cost/yr	US$	6.7014	0.2628

The total cost of the solar power system is US$ 185. It was not possible to measure the financial benefit of crop protection and operators health. However, the system would save US$ 6.44 electricity billing cost per year only for using for house lighting.

Conclusion:

A solar power system was designed and developed in Bangladesh Agricultural University, Mymensingh, to operate a sprayer and house lighting. The DC is generated by the solar panel of 17 W and charged the battery of 12 V, 9 Ah which run a DC motor to pump the pesticide and sent through a nozzle. The time required for charging the full battery capacity of 12 V, 9 Ah by analytically and practically was found to be 6.33 h and 10.5 h, respectively. The field capacities of the sprayer were determined as 81.60 L/h, 166.57 L/ha, 2.04 ha/h and 0.49 h/ha. It was found that ODR, BPDS, and heart rate were lesser for the solar-powered sprayer. These results indicate that the solar-powered pump reduced the fatigue of the operator due to the continuous operating of a manual knapsack sprayer. The solar system would be used for daily 10 hours for house lighting when this will not be used for spraying. It was not possible to measure the financial benefit of crop protection and operators health. However, the system would be saved US$ 6.44 electricity billing cost per year only for using for house lighting. It can be concluded that the system would be accepted by the small and marginal farmers of Bangladesh due to reducing drudgery for spraying, economical and eco-friendly.

ACKNOWLEDGMENT

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