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Ridwan Siskandar[1*], Aceng Hidayat[2,], Rina Martini[3], Anita Ristianingrum[4], Doni Sahat Tua Manalu[4], Wahyu Budi Priatna[5], Purana Indrawan[6], Edi Wiraguna[7], Helianthi Dewi[8], Sari Putri Dewi[9], Agief Julio Pratama[10], Beata Ratnawati[11], Fiona Kharismatunnisaa[12], Muhammad Danang Mukti Darmawan[1], Fiqri Nurfadillah[1], Ester Angeline Sitompul[1], Chika Hayya Sabilla[1], Muhammad Faiz Assariy[1], Daffa Zulqisthi[1]

[1] Computer Engineering Technology Study Program, College of Vocational Studies, IPB University, Indonesia
[2] Department of Resource and Environmental Economics, Faculty of Economics and Management, IPB University, Indonesia
[3] Management of Food Service and Nutrition, College of Vocational Studies, IPB University, Indonesia
[4] Agribusiness Management Study Program, College of Vocational Studies, IPB University, Indonesia
[5] Department of Agribusiness, Economic and Management Faculty, IPB University, Indonesia
[6] Industrial Management Study Program, College of Vocational Studies, IPB University, Indonesia
[7] Technology and Management of Plantation Production, College of Vocational Studies, IPB University, Indonesia
[8] Department of Ecotourism, College of Vocational Studies, IPB University, Indonesia
[9] Livestock Management and Technology Study Program, College of Vocational Studies, IPB University, Indonesia
[10] Production Technology and Development of Agricultural Communities, College of Vocational Studies, IPB University, Indonesia
[11] Environmental Engineering and Management Study Program, College of Vocational Studies, IPB University, Indonesia
[12] Software Engineering Technology, College of Vocational School, IPB University, Indonesia

*Corresponding Author: ridwansiskandar@apps.ipb.ac.id

Abstract An environmentally-friendly solar charging station has been successfully designed, manufactured and tested as a charging solution for electric-powered agricultural machinery (SoltarinE). Two principal methodologies are employed: the design method and the performance test method. In principle, solar panels equipped with a solar tracker system, assisted by light-dependent resistor (LDR) light sensors and actuators, are capable of absorbing the optimum solar intensity. Subsequently, the conversion of solar intensity into chemical energy is employed to charge the batteries of electrically powered agricultural machinery. The automated solar panel system was able to effectively move the two-axis solar tracker with the assistance of a light sensor, resulting in a 37.21% increase in the power produced by the solar panels. The battery system demonstrates that the SoltarinE storage battery exhibits a rated voltage value on the battery that is indicative of a satisfactory condition, as it remains above 24 V. The CCA capability value also indicates a normal condition, as evidenced by a CCA value above 400. Moreover, the analysis of the SOC and the SOH indicates that the battery is still in an optimal condition, with a value of 100%. The power charge system has also been successfully implemented as a charging source for electric agricultural machines.

Keywords: Charger, Eco-Friendly Solar Charging Station, Electric Power Farm Machinery, Solar Panel, Solar Tracker.

1. Introduction

The application of agricultural machinery technology in Indonesia is certainly inseparable from the situation and conditions of the strategic environment of the local community. Facts show that the development and modernisation of agricultural machinery technology has a real impact on current agricultural changes [1]. The application of modernisation of advanced agricultural technology has been able to increase efficiency and effectiveness towards increasing productivity. The importance of time efficiency and effectiveness of activities in farming is well recognised, especially due to labour limitations [2].

Parvez et al. [3] in their research revealed that the use of traditional agricultural machinery has not been able to increase efficiency and effectiveness towards increasing productivity and farming performance. This is indicated by the length of time for the spraying process, the use of costs and the use of labour [4–6].

The presence of drone technology in the midst of Indonesian agriculture is clear evidence that the progress of modernisation of the use of agricultural machinery has been used as an alternative solution to modernisation of agricultural mechanisation. Mogili and Deepak; and Andrasto et al. [7,8] revealed in their research that drones have a time-saving impact on the pesticide spraying process when compared to other traditional spray methods.

However, it needs to be realised that until now the main obstacle of electric-powered agricultural machinery technology is its limited power source. Makarim MF et al. [9]

revealed the results of testing and analysis of their research, that the drone can only fly for 1 minute 45 seconds using a 2200 mAh Lipo 3S battery when the total mass of the drone is 2500 gr. Other research developments related to agricultural machinery associated with solar energy have also been studied. Kayode et al. [10], researched a remotely controlled semi-automatic knapsack sprayer. This agricultural machine operates using a 100 Ah battery charged by four 30 W solar panels. The weakness found is that the power runs out before the spraying process is complete.

Following up on the above statement, there is currently a need for a charger solution for electric agricultural machinery. The purpose of this research is to design, manufacture, test and implement SoltarinE: Solar Charging Station Eco Friendly as a charger solution for electric farming machines.

Conceptually, SoltarinE is designed like a charging station. In principle, solar panels equipped with a solar tracker system assisted by LDR (Ligh Dependent Resistor) sensors and actuators will absorb optimum solar intensity. The conversion of solar intensity into chemical energy can then be used to charge the battery of the electric-powered agricultural machine. The charging design is made in two modes, namely direct charging from solar panels and charging from SoltarinE power storage.

2. Materials and Methods

The research was conducted in March-July 2024 at the Hardware Laboratory and workshop laboratory of the Computer Engineering Technology Study Programme, Vocational School of IPB. The tools and materials used are shown in Table 1.

Table 1. The need for tools and materials

No	Function, Sub-function	Main Tools and Materials Used	Alternative Tools and Materials
1	Reading the intensity of the sun. Comparing the solar intensity value read by the 4 light detection sensors used.	LDR sensor	Photodiodes, other light sensors
2	Device to absorb and convert solar intensity into electrical energy.	Solar panel	Solar panel
3	Software for machine language programming	Arduino IDE	Arduino IDE
4	Data processing microcontroller.	Arduino Uno	Arduino Mega, Arduino Nano, ESP32
5	Solar tracker drive motor	12 VDC actuator	12 VDC actuator
6	Power storage for converting solar intensity into electrical energy.	Lithium battery design (153 Ah 28 watt)	Accu
7	Connector between devices	Jumpers / cables	Jumpers/cables
8	As tracker support pole, tracker bracket and solar panel bracket	SoltarinE mechanics made of strong iron	SoltarinE mechanics

The research method is divided into two main parts, namely design and performance testing. The design is divided into five, namely the design of the solar tracker, the design of the electrical power requirements and the number of solar panels, the design of the power storage, the design of the power station, and the design of the SoltarinE system integration [11]. Likewise, the performance test method is divided into five parts, namely solar tracker performance test, I-V output testing (without solar tracker and using solar tracker), power storage performance test, power station performance test, and SoltarinE system integration performance test.

2.1. Design

The design of SoltarinE is carried out to get good results, so that the implementation of SoltarinE in the field is successfully used, feasible and useful for farmers.

2.1.1. Solar Tracker Design

The solar panel automation system utilises a 12 V DC actuator for the solar tracker movement, and a light sensor to determine the actuator movement towards the optimum sunlight intensity [12]. While the solar charge controller (SCC) is used to regulate the current when charging to the battery [13]. All three are controlled by a microcontroller. The control is divided into two parts, namely the solar tracker motion system and the battery charging system. The solar panel automation system algorithm is shown in Figure 1.

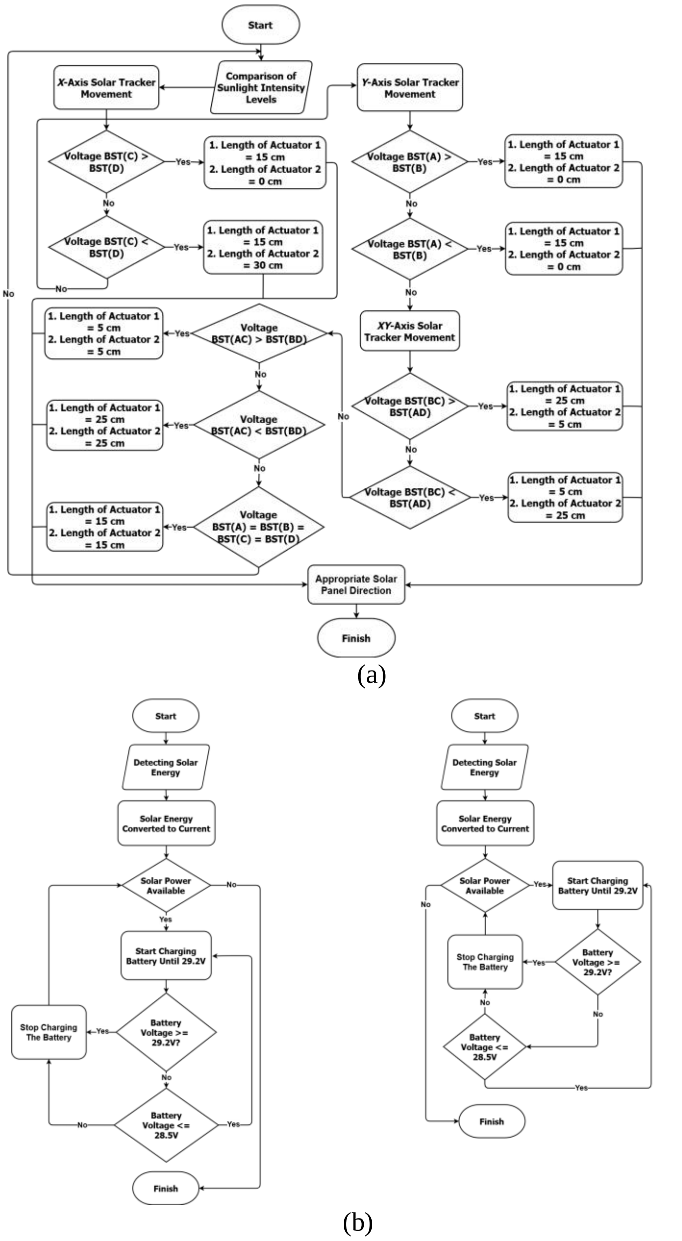


Figure 1. Algorithm of solar panel automation system: (a) solar tracker motion system; (b) battery charging system

The solar tracker system uses the main components shown in Figure 2 and Figure 3. Figure 2(a) describes the solar pin diagram, while Figure 2(b) describes the electronic circuit of the solar tracker system. While Figure 3 shows the design of the solar tracker made. The diagram in Figure 2 describes the components used and the wiring of the solar tracker system. The microcontroller used is an Arduino Uno connected to four motor drivers of the BTS7960 type to control four actuators used to determine the motion of the solar tracker (2 axis); and four light sensors that read the sunlight intensity value to determine the degree position of the solar tracker [14]. The numbers on the lines in the diagram indicate the pins on the Arduino Uno that are used to connect with other devices. In addition, a line pointing out from the Arduino Uno indicates the component is an output component and one pointing in indicates the component is an input component.

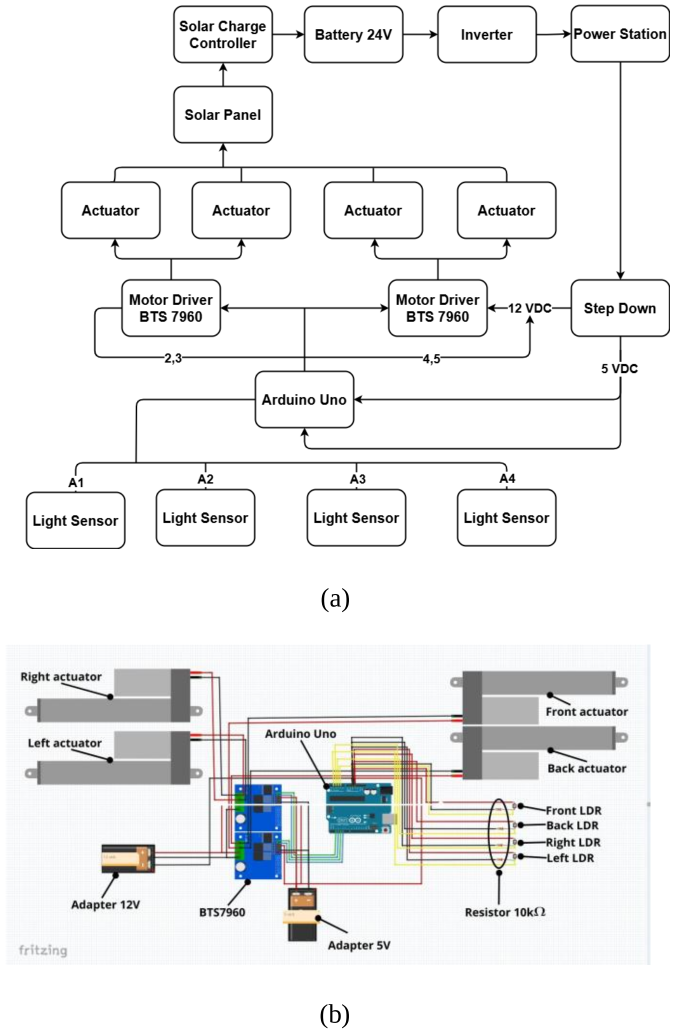


Figure 2. Solar tracker system: (a) solar pin diagram; (b) electronic circuitry

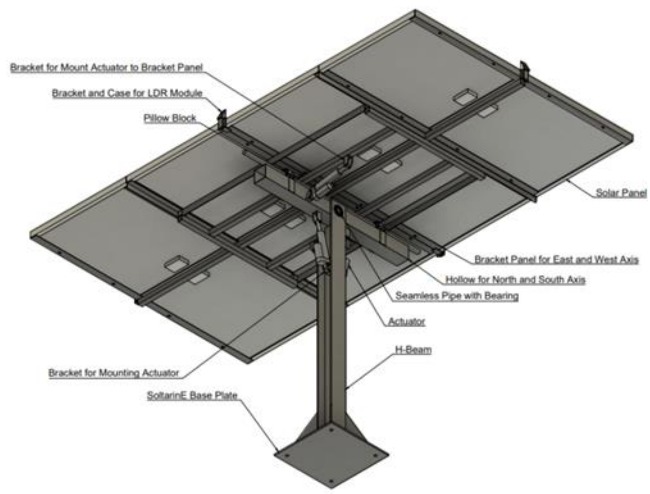


Figure 3. Solar tracker design

2.1.2. Design of Electrical Power Requirements and Number of Solar Panels

Electric power data collection is devoted to fulfilling the battery charging needs of electric-powered agricultural machinery [15]. Electric power data collection is done by recording the needs of electronic components and the number that must be used, as well as the specifications of these components. This is done to obtain information on the total electricity (watts) used. More details, the power requirements for one operation are shown in Table 1.

Table 2. Power requirements for battery charging of electric power agricultural machines

Voltase Baterai Mesin Peratanian	Quantity (pieces)	Charging Period (hour)	Daya (watts)	Total Power (watts)
Semi-automatic backpack sprayer: 12 VDC	8	1	25	200
Drone: 24 VDC	8	3	50	1200
Branch cutter: 12 VDC	4	2	30	240
WagnerEco WS-060 cordless nano spray gun with UV lighting: 12 VDC	4	2	20	160
Trenching machine: 40 VDC	5	5	40	1000
Total				2800

Table 2 shows that the total power requirement for the charging plan of 8 batteries of semi-automatic knapsack sprayers, 8 batteries of drone machines, 4 batteries of limb cutting machines, 4 WagnerEco WS-060 cordless nano spray guns with UV lighting, and 5 trencher machines is 2800 watts. Since the electrical energy generated by the solar panel is not 100% usable (30% of the electrical energy is lost during the transition from the panel to the electronic circuit), it is necessary to add 30% of the total electrical power used, so that the total power prepared is 3640 watts.

In determining the need for solar panels, exposure to solar intensity is very important to note. In Indonesia, the optimal photovoltaic process only lasts 5 hours, so to calculate the number of solar panels used can be done using equation 1 [16].

$$PS = \frac{T_d}{t_{op}} \quad (1)$$

where, *PS* is the solar panel, *Td* is the total power and *top* is the optimal charging time [17]. Thus, the solar panel requirement is 728 Wp. However, because conventional solar panels are generally only 50 Wp and 100 Wp, the use for solar panel requirements uses 8 pieces of 100 Wp solar panels.

2.1.3. Power Storage Design

Electrical energy in batteries generally cannot be 100% utilised. When inverterised, the potential energy loss can reach 5%, so a 5% reserve needs to be added. Based on this, then to calculate the total power can use equation 2.

$$T_d = \frac{T_{da}}{(100\% - 5\%)} \quad (2)$$

where *Td* is the total power, *Tda* is the initial total power [17,19]. So, based on equation 2, the reference electrical power used to determine battery requirements is 3822 watts. Based on this reference, it can be obtained the amount of battery capacity needed for the power requirements of the sprayer system (40 V battery voltage requirement). Battery capacity can be calculated using equation 3.

$$K_b = \frac{T_d}{K_{vb}} \quad (3)$$

where, *Kb* is the battery capacity, *Td* is the total power and *Kvb* is the battery voltage requirement. So, based on equation 3, the required battery capacity value is 95.55 Ah. The battery to be used is the Lion 18650 type with 3.4 V specifications with a capacity of 1.8-2 Ah. To get a voltage of 40 V (battery voltage requirement), the process of connecting 12 batteries in series is carried out. Furthermore, to get a battery capacity of 95.55Ah, the process of assembling at least 52 previous series to be paralleled is carried out. So, it can be calculated that the number of Lion 18650 type batteries needed is 624 batteries.

2.1.4. Power Station Design

The power station is designed with five terminals, where the output voltage generated from each terminal is 220 VAC (after being assembled using a 5000 watt 19.5-28.5 volt inverter). The power station is used to charge the electrical devices (batteries) of electric farming machines, such as semi-automatic knapsack sprayers, drones, branch cutting machines, WagnerEco WS-060 cordless nano spray gun with UV lighting, and trencher machines. For charging needs that require 5 VDC and 12 VDC power, it can also be done directly from the PWM solar charge controller device. More details, the power station design is shown in Figure 4.

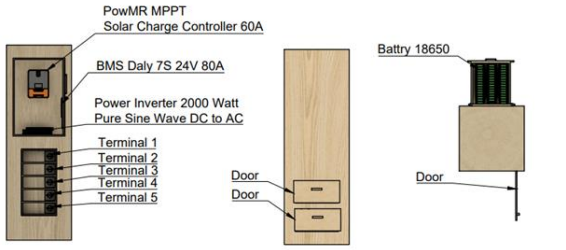


Figure 4. Desain power station

2.1.5. Power Station Design

The SoltarinE design is divided into three main parts, namely the solar tracker, power storage/battery, and output/power station. All three work integrated with each other. An illustration of SoltarinE's working system is shown in Figure 5.

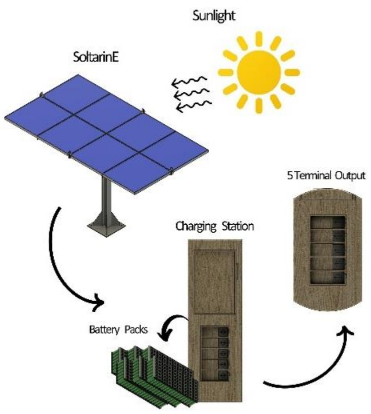


Figure 5. Illustration of SoltarinE's working system

Figure 5 shows the process of optimum solar intensity captured by the light sensor, then moving the actuator towards the optimum light intensity. The charging process takes place as long as the solar panel captures the intensity of sunlight. The conversion of solar intensity into electrical energy is stored in a battery with a capacity of 95.55 Ah. The process of charging the agricultural machine battery is carried out at a power station with 220 VAC voltage.

2.2 Performance Test Methods

The performance test method is divided into five, namely solar tracker performance test, I-V output test (without solar tracker and using solar tracker), power storage performance test, power station performance test, and SoltarinE system integration performance test.

2.2.1. Solar Tracker Performance Test Method

The test carried out is to ensure the functional mechanics of the solar tracker function properly. In the functional testing of the solar tracker mechanics, the conditions tested are the solar tracker movement (2 axis) and the change in the length of the actuator (drive motor) based on the value of sunlight intensity from the readings of the four light sensors used [16]. The instruments used are multimeter and ruler.

2.2.2. I-V output testing method (without solar tracker and with solar tracker)

There are two tests performed, namely comparing the voltage and power output of using solar tracker and without solar tracker; and calculating the efficiency of SCC by comparing the SCC power input and SCC power output.

Testing the effectiveness of the solar tracker is done to obtain the value of voltage and current at the output probe of the solar panel both without solar tracker and with solar tracker. Measurement data was carried out nine times (at 08.00 AM; 09.00 AM; 10.00 AM; 11.00 AM; 12.00 AM; 01.00 PM; 02.00 PM; 03.00 PM and 04.00 PM). The type of solar panel used is a 100 Wp kawachi brand poly solar panel. The mechanism is the use of solar tracker will produce greater voltage and power output than without the use of solar tracker [20,21]. The instrument used is a multimeter.

In testing the efficiency of the SCC, the measurements taken are comparing the SCC power input and SCC power output. The measurement data was carried out 10 times (at 02.00 PM; 02.20 PM; 02.40 PM; 03.00 PM; 03.20 PM; 03.40 PM; 04.00 PM; 04.20 PM; 04.40 PM; 05.00 PM). The mechanism is said to be efficient if the SCC power input value is close to the SCC power output value [22]. The instrument used is a multimeter.

2.2.3. Battery Performance Test

Battery testing is carried out to determine the condition and quality of the battery used [23,24]. Measurements taken include cold cranking ampere (CCA), SOC, SOH and internal restinance. The instrument used is a lancol micro battery tester [25]. Cold Cranking Ampere (CCA) is a measure of a battery's ability to start an engine at low temperatures. It is an important indicator of battery strength and performance, especially in cold weather conditions. State of Charge (SOC) is a measure of the percentage of energy capacity remaining in the battery compared to its total capacity. It helps determine how full or empty the battery is at any given time. State of Health (SOH) is an indicator of the overall health of the battery, reflecting the battery's ability to store and release energy compared to its manufacturer's specifications. Internal Resistance is the internal resistance present within the battery that can affect the charging and discharging efficiency of the battery [26-28].

2.2.4. Power Charge Performance Test

Power charge testing is carried out to ensure the value and quality of the voltage issued by the power charge is appropriate, namely 220 VAC. Testing is carried out on all five power charge terminals. In addition, battery charging tests were also carried out on electric power agricultural machines sourced from the power charge terminal [29,30]. The instrument used is a multimeter.

2.2.5. SoltarinE System Integration Performance Test

The test carried out is testing the SoltarinE system wiring between the three devices (solar tracker, battery, and power station). This is done to ensure the SoltarinE battery charging process is functioning properly. The instrument used is a multimeter.

3. Result and Discussion

3.1. SoltarinE Prototype

The application of the SoltarinE prototype for charging electric agricultural machinery is shown in Figure 6. SoltarinE is designed and made with the aim of providing efficiency and effectiveness benefits to the use of electric agricultural machinery which is currently still largely constrained by the battery capacity of each agricultural machine.

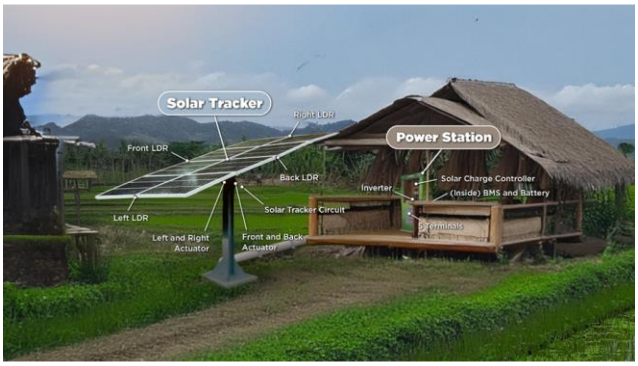


Figure 6. SoltarinE prototype

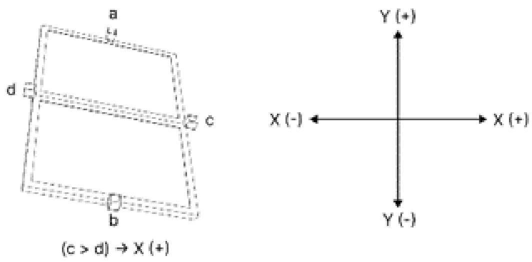
Figure 6 shows that SoltarinE can operate well as a power station. The performance of SoltarinE is divided into three main parts. The solar tracker section has been able to position the solar panel according to the optimum sun intensity position assisted by a light sensor as a detection of sun intensity for the movement of the actuator in 2 axis. The power storage / battery section has been able to be fully charged (battery capacity 95.55 Ah) for 1 day using 8 solar panels with a capacity of 100 wp. The power station section has been successfully used to charge the battery of the electric power farm machine according to the type of machine shown in Table 1. The power station is divided into 2 charging, namely 5 VDC, 12 VDC directly from SCC, while the 5 temninal power station is used for AC supply.

3.2. Performance of Solar Tracker Movement System

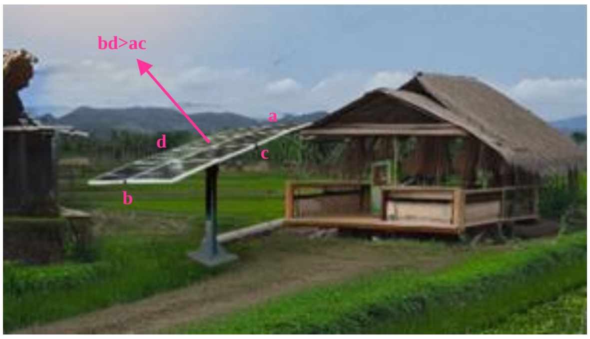
The performance of the actuator as the driving motor of the solar tracker is determined from the readings of the light sensors installed on each side of the solar panel (sensor a, sensor b, sensor c and sensor d). There are eight algorithm conditions used (Table 2). An illustration of the solar tracker movement is shown in Figure 7. The solar tracker can operate in 2 axis. The movement of the actuator shows that the integration performance of the BST light sensor with the solar tracker has been successfully carried out. Table 2 shows the test results of the light sensor integration performance with the solar tracker.

Tabel 3. Test results of light sensor integration performance with solar

Condition	Solar Tracker Direction	Actuator 1	Actuator 2	Actuator 3	Actuator 4	Description
a>b	Towards y(+)	0	30	15	15	Successful
a<b	Towards y(-)	30	0	15	15	Successful
c>d	Towards x(+)	15	15	0	30	Successful
c<d	Towards x(-)	15	15	30	0	Successful
bc>ad	Towards x(+) y(-)	25	5	5	25	Successful
bc<ad	Towards x(-) y(+)	5	25	25	5	Successful
ac>bd	Towards x(+) y(+)	5	25	5	25	Successful
ac<bd	Towards x(-) y(-)	25	5	25	5	Successful
a=b=c=d	Balanced	15	15	15	15	Successful



(a)

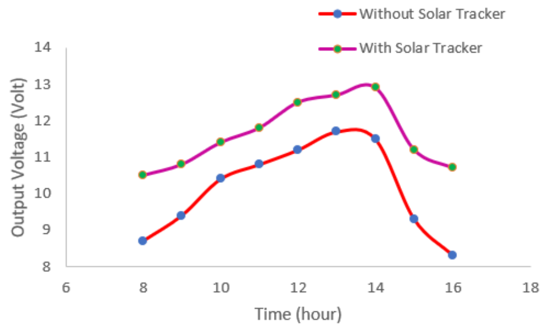


(b)

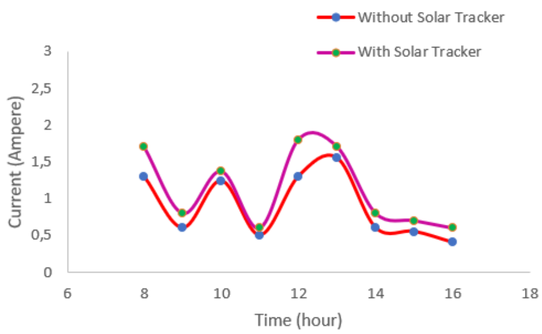
Figure 7. Solar tracker motion: (a) illustration; (b) test results bd>ac

3.3. I-V output test method (without solar tracker and with solar tracker)

Measurements were taken at 08.00 AM; 09.00 AM; 10.00 AM; 11.00 AM; 12.00 AM; 01.00 PM; 02.00 PM; 03.00 PM and 04.00 PM. The type of solar panel used is poly solar panel 100 Wp kawachi brand as much as one piece. Figure 8 (graph of the relationship between time vs. voltage output) shows a trend of decreasing voltage values that are much slower in systems that use solar trackers (shown at 02.00 PM to 04.00 PM), even the results of voltage output carried out nine times in systems that use solar trackers are always higher voltage values than without solar trackers. This shows that the light sensor implemented in the solar tracker system works well as a light detection sensor. For the graph of electric current produced although it has a similar curve shape, but the value of electric current produced is greater when using a solar tracker system.



(a)



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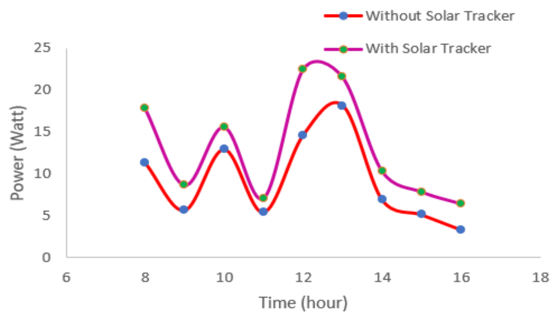


(c)

Figure 8. Graph of test results without solar tracker versus using solar tracker: (a) voltage; (b) current; and (c) power

Thus, based on the voltage and current output data generated from nine measurements, the implementation of the solar tracker system is much better than without the solar tracker. In addition, shown in Figure 8 (graph of time vs power relationship), it shows that the results of power optimisation calculations using solar tracker and without solar tracker have a difference in power generated by 31.11%.

Furthermore, testing the ratio values of Pout and Pin is carried out to ensure that the performance of the solar charge controller can work very well on the SoltarinE system. Table 3 shows that the largest Pout and Pin value at 03:40 PM is 98.95%. The average Pout and Pin is 92.65%. It is concluded that the solar charge controller can work very well because the input power value is close to the output power of the solar charge controller. More details of the test results of the Pout and Pin ratio values are shown in Table 3.

Table 3. Pout and Pin ratio values based on testing solar charge controller input power and solar charge controller output power

Waktu (PM)	**V_{in} (V)**	**I_{in} (A)**	**P_{in} (W)**	**V_{out} (V)**	**I_{out} (A)**	**P_{out} (W)**	**Rasio P_{out} terhadap P_{in} (%)**
02:00	51,2	5,4	276,48	28,9	8,35	241,32	87,28
02:20	46,24	5,37	248,31	28,89	8,31	240,08	96,68
02:40	45,98	5,38	247,37	28,89	8,29	239,50	96,82
03:00	45,8	5,29	242,28	28,87	8,22	237,31	97,95
03:20	45,2	5,22	235,94	28,87	8,07	232,98	98,74
03:40	44,62	5,2	232,02	28,88	7,95	229,60	98,95
04:00	44,57	5,18	230,87	28,89	7,9	228,23	98,86
04:20	43,68	5,16	225,39	28,9	6,81	196,81	87,32
04:40	43,66	5,16	225,29	28,9	6,39	184,67	81,97
05:00	43,64	5,16	225,18	28,86	6,39	184,42	81,90

3.4. Battery Performance

The test results show that the battery is said to be full when the battery voltage has reached 28.5 V. The initial battery voltage at the beginning of charging is 25.85 V. This is because the characteristics of each type of battery are different, including the factor of the average current flowing into the battery to cause fast or long charging. The results of charging the battery using a solar tracker are shown in Figure 9.

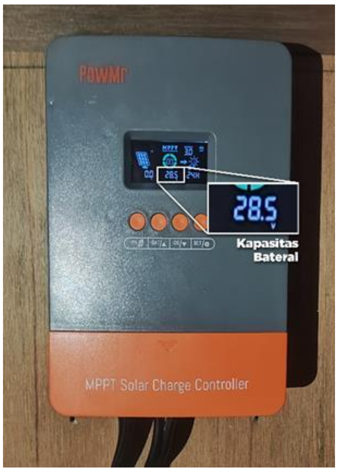


Figure 9. Results of charging the battery using the solar tracker

The limitation of 28.9 V (Vout in Table 3) refers to the maximum voltage applied to the battery. However, the charging results show that the battery is capable of being charged up to 28.5 V. This is due to the voltage difference, i.e. the battery voltage varies during the battery charging process. Another point states that it can occur due to the temperature compensation factor, i.e. the battery voltage is affected by temperature. At higher temperatures, the battery voltage is higher. At lower temperatures, the battery voltage is lower. Battery charging is likely to use a higher voltage to compensate for the lower temperature. The battery tolerance factor also affects this. Li-Ion batteries have a voltage tolerance of (+/- 10%). The battery can be charged with a voltage slightly higher than its nominal voltage without damage.

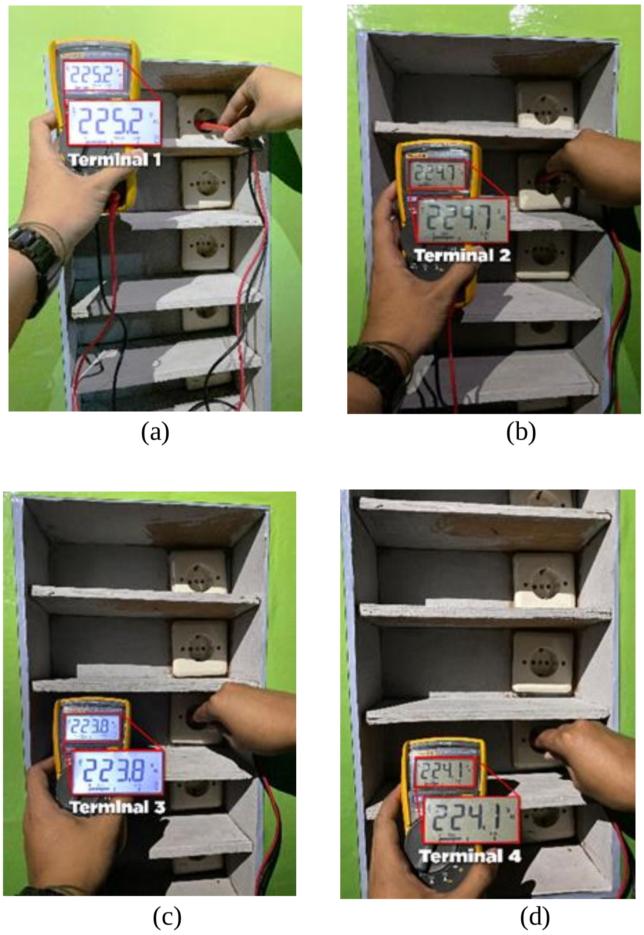
Testing the battery can determine the condition and quality of the battery used. Based on the measurement data in Table 4, it is concluded that the rating voltage value on the battery is in good condition because it is still above 28 V. For the Cold Cranking Ampere (CCA) ability value, it is still in normal condition because the CCA value is above 400. Furthermore, the SOC and SOH analysis is also still very good because it shows a value of 100%. This is due to the condition of the battery is still in a new state. It can also be seen that the internal resistance value of all batteries is below 5.5 mOhm (< 5.5 mOhm). This indicates that the battery is in good condition.

Tabel 4. Battery test result data

Repeat	Rating voltage (V)	CCA	SOC (%)	SOH (%)	*Internal resistance* (mOhm)
1	28,87	575	98	100	4,25
2	28,90	570	98	100	4,20
3	28,89	570	98	100	4,19

3.5. Power Charge Performance

Power charge testing is carried out to ensure the value and quality of the voltage released by the power charge is worth 220 volts AC or more. There are five power charge electrical terminals tested. The test results of the voltage output from the five electrical terminals show a voltage of 223.2 volts AC; 224.7 volts AC; 223.8 volts AC; 224.1 volts AC and 225.1 volts AC. More details of the test results are shown in Figure 10.



(a) (b) (c) (d)

(e)

(f)

Figure 10. Voltage test results at the power charge electrical terminals: (a) 1st electrical terminal; (b) 2nd electrical terminal; (c) 3rd electrical terminal; (d) 4th electrical terminal; (e) 5th electrical terminal; (f) electrical devices are charged

3.6. Performance of SoltarinE System Integration

Testing is carried out on the main device circuit wiring, namely the light sensor electronic circuit. This is done to ensure that the SoltarinE battery charging process functions properly with the help of a solar tracker. The test results show that the light sensor electronic circuit wiring system is well connected. This is shown by the mass life curves of the four light sensors that function properly during one week of operation. More clearly, the lifetime curve of the light sensor is shown in Figure 11.

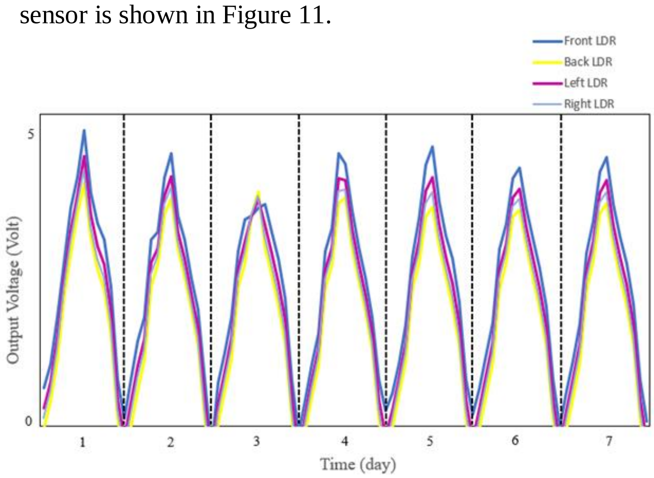


Figure 11. Lifetimes of the light sensors in the SoltarinE system

Figure 11 shows the lifetime curve of the four LDR sensors used in the solar tracker functioning properly for one week of testing. This is indicated by the output voltage measured from the four LDR sensors. During one week the four sensors are still functioning properly with relatively the same output voltage value.

4. Conclusion

An eco-friendly solar charging station as a charging solution for electric agricultural machinery (SoltarinE) has been successfully designed, built, tested and implemented. In principle, solar panels equipped with a solar tracker system assisted by LDR (Ligh Dependent Resistor) light sensors and actuators (drive motors) successfully absorb the optimum solar intensity. The conversion of solar intensity into chemical energy can then be used to charge the batteries of electric-powered agricultural machinery.

The solar panel automation system succeeded in moving the 2-axis solar tracker assisted by the light sensor effectively so that the power generated by the solar panel increased by 31.11%. The battery system shows that the quality of the SoltarinE storage battery has a voltage rating value on the battery in good condition because it is still above 24 V. For the Cold Cranking Ampere (CCA) capability value, it is still in normal condition because the CCA value is above 400. Furthermore, the SOC and SOH analysis are also still very good because they show a value of 100%. The power charge system shows that it has also been successfully implemented as a charging source for electric agricultural machinery. The charging method is made in two modes, namely charging directly from the solar panel (for voltages of 5 VDC 12 VDC and 24 VDC) and charging from the power storage connected to the SoltarinE power charge (power station).

Thus it can be concluded that the performance of SoltarinE as a charger for electric agricultural machinery designed, built, tested and implemented operates well.

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