

## Portable Solar Charger System with Energy Measurement and Access Control

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### ABSTRACT

*The utilization of green energy is one trending issue at the current time. People try to increase the portion of energy gained from renewable sources such as wind, solar, hydro, and geothermal energy. In this paper, the authors propose a portable solar charger system (PSCS) that can be used to charge cellular devices when electricity access is not available such as during a power shutdown or when traveling to remote locations. The PSCS is made compact in two parts: the solar panel and the utility box, making the whole system easy to carry. The energy obtained from the solar panel is stored in a dry battery, with the process carefully regulated by a solar charge controller. The PSCS is equipped with passcode protection and gained energy monitor. The electric current from the battery flows to the load through a DC-DC converter and a relay only if a correct passcode is entered via a keypad. The amount of gained energy by the solar panel is monitored by measuring the voltage across the panel and the current flowing through its circuit. The functionality of the PSCS is successfully tested. Eight experiments each with a 3-hour duration are conducted on 6 different days. The amount of gained energy varies from 5.26 Wh to 9.88 Wh (1,300 mAh to 2,670 mAh), which corresponds to 14.5 % and 31.5 % of the potential average daily output energy for the location of Cikarang, Indonesia.*

**Keywords:** solar charger, portable, energy measurement, passcode protection

### ABSTRAK

*Pemanfaatan energi hijau merupakan salah satu isu yang sedang tren saat ini. Orang berusaha untuk meningkatkan porsi energi yang diperoleh dari sumber terbarukan seperti angin, matahari, hidro, dan energi panas bumi. Dalam makalah ini, penulis mengusulkan sistem pengisi daya portabel bertenaga surya (portable solar charger system, disingkat PSCS) yang dapat digunakan untuk mengisi daya perangkat seluler saat akses listrik tidak tersedia seperti saat mati listrik atau saat bepergian ke lokasi terpencil. PSCS dibuat kompak dalam dua bagian: panel surya dan kotak utilitas, membuat seluruh sistem mudah dijinjing. Energi yang diperoleh dari panel surya disimpan dalam baterai kering, dengan proses yang diatur secara seksama oleh pengontrol pengisian daya. PSCS dilengkapi dengan pengamanan akses menggunakan kode sandi dan tampilan monitor energi yang diperoleh panel surya. Arus listrik dari baterai mengalir ke beban melalui konverter DC-DC dan relai hanya jika kode sandi yang benar telah dimasukkan melalui keypad. Jumlah energi yang diperoleh oleh panel surya dipantau dengan mengukur tegangan melintasi panel dan arus yang mengalir melalui rangkaianannya. Fungsionalitas PSCS berhasil diuji. Delapan percobaan masing-masing dengan durasi 3 jam dilakukan pada 6 hari yang berbeda. Jumlah energi yang diperoleh bervariasi dari 5,26 Wh hingga 9,88 Wh (1.300 mAh hingga 2.670 mAh), yang setara dengan 14,5% dan 31,5% dari potensi energi keluaran harian rata-rata untuk lokasi Cikarang, Indonesia.*

**Kata kunci:** pengisi daya surya, portabel, pengukuran energi, perlindungan kode sandi

## **1. Introduction**

The growing environmental awareness makes people realize that energy production and consumption must be performed sustainably. By doing this, other challenges such as economical level-up, community progress, and environmental sustainability can also be tackled simultaneously.

Renewable energy can be found in the forms of hydro, solar, geothermal, and biomass According to research conducted by the UNDP, Indonesia has a technical renewable energy potential of 162,360 MW, with only 32,898 MW in the form of installed capacity[1].

One of the essential sources of renewable energy is solar energy. The radiant light and heat from the sun can be harnessed in different ways such as by using photovoltaic cells, concentrating collectors, or solar hot water heating with thermal collectors. Solar energy is free and its abundant availability makes it an interesting and appealing source of electricity.

On the other hand, nowadays life cannot be separated from the use of cellular devices. Most people already consider cellular devices as a basic need to support their daily activities. To secure the user's communication access, a cellular device is expected to be sufficiently charged, independent of time and place.

The above-mentioned facts motivate the authors to propose a portable solar charger system (PSCS). The system is required to be compact, lightweight, and easy to carry. The system serves to supply energy to the cellular devices in situations where electricity from the power line is not accessible due to power shutdown or traveling to remote areas. Furthermore, this paper contributes to the application of practical measurement of the acquired energy of a solar and its theoretical calculation. The comparison between the two values gives an insight into the solar panel's capability in generating energy under the effect of real environmental conditions. This can be useful in determining the feasibility of implementing the solar panel in other applications.

## 2. Literature Review

Sahbana et al in [2] proposed an interesting design of a portable solar charge for a power bank, which is applied to a jacket. However, the system is not equipped with energy storage. Thus, the charging process of cellular devices can be done only when the sun is available. A design of mobile power bank charger using microcontroller ATmega 328 is found in [3]. The measure to avoid overcharging of the battery is not explicitly described. In [4], a circuit for a portable solar charge using the buck-boost converter is presented. In all research mentioned above, including [5], the aspect of portability was not completely assessed, lacking information regarding the dimension and the weight of the solar panel and the overall system.

The PSCS proposed in this paper is expected to be compact in the sense that it can be carried conveniently by a person. Besides, the system will be equipped with a battery to store energy when the solar radiation can be collected. A solar charge controller is to be used to prevent battery overcharging. The amount of energy gained is to be shown in a display, enabling to user to monitor it at any time. The last feature of the PSCS is access control by using passcode protection.

## 3. Theoretical Background and Design Specifications

### 3.1 The Solar Panel

A solar panel is a device capable to convert radiation energy to electrical energy. A solar panel commonly in the market, if zoomed in, consists of many photovoltaic cells, with each of them responsible to generate a potential difference of 1.2 V. Each photovoltaic cell is formed of a two-layer semiconductor, usually *n*-type and *p*-type silicon. The *n*-type is negatively doped and carries more electrons while the *p*-type is positively doped and carries more vacant spaces called holes.

If the two layers are in contact, the electron of the *n*-region moves through the junction to the *p*-region, creating a positively charged layer in the *n*-region and a negatively charged layer in the *p*-region. As the layer is created, an electric field is

built up and at a certain level, the electron cannot move to the *p*-region anymore. This layer is called the depletion layer. See Figure 1.

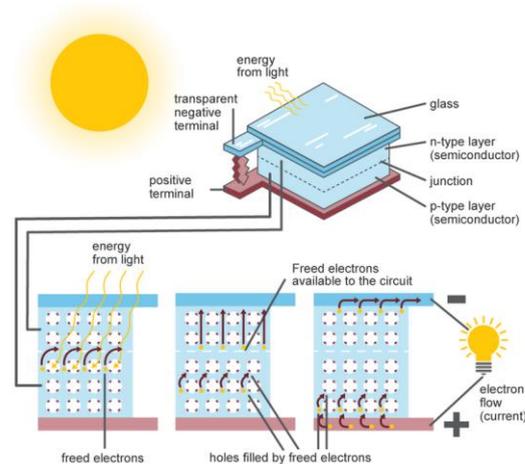


Figure 1 The mechanism inside a photovoltaic cell [6]

When the photons hit the surface of a photovoltaic cell and reach the neutral atoms in the depletion layer, they will induce some free electrons of n-type as well as the holes of p-type to the depletion junction [7]. The electric field pushes the electron out of the silicon junction to the n-region, while the hole is pushed to the p-region.

If the negative and the positive terminal of the regions are connected, then electric current flows. There are metal conductive plates that collect the electrons and transmit them to the wires connected with the desired load [7]. With the linear sum of many cells connected in series, it becomes usable power.

Figure 2 shows the polycrystalline solar panel with the size of 30 cm × 35.4 cm, which will be used in constructing the PSCS. The solar panel's specification is given in Table 1.



Figure 2 The SLP010-12 solar panel

Table 1 The Specification of the SLP010-12 Solar Panel

Items	Descriptions
Type	Polycrystalline
Model	SLP010-12
Open Circuit Voltage	21.6V
Optimum Operating Voltage	17.0V
Short Circuit Current	0.68A
Optimum Operating Current	0.58A
Maximum Power	10WP
Standard Test Condition	AM1.5 and 25°C
Weight	2.15 kg
Size	30 cm × 35.4 cm × 3 cm

### 3.2 The Energy Output of The Solar Panel

The energy output of a solar panel,  $E$ , in kilowatt-hour (kWh/day), can be estimated as [8]:

$$E = A \cdot r \cdot H \cdot PR \quad (1)$$

where  $A$  is the total surface area of the solar panel in  $m^2$ ,  $r$  is the solar panel efficiency,  $H$  is the solar radiation incident in  $kWh/m^2/day$ , and  $PR$  is the performance ratio of the photovoltaic system.

The solar panel efficiency  $r$  is the electrical power of one solar panel's Watt-peak (Wp) divided by the area of panel  $A$  at a given standard test condition, which is  $1000 W/m^2$ . This gives

$$r = \frac{W_p}{1000 \cdot A} \quad (2)$$

The data of solar radiation incident  $H$  on a horizontal surface is shown in Table 2 [9]. The data is applicable for Cikarang, Indonesia, which is located at  $-6.283^\circ$  latitude and  $107.168^\circ$  longitude. Furthermore, that data is averaged between 1984 and 2021.

All of these data are modeled using a mathematical equation. The certain location of a surface in the earth by latitude and longitude must be given exactly so that the result can be calculated accurately.

The performance ratio ( $PR$ ) of the photovoltaic system may take a value between 0.5 and 0.9, with the default value of 0.75 [8].

The gained actual energy from the solar panel is obtained by accumulating the product of the voltage and the current every second, which has the unit of watt-second ( $Ws$ ).

$$P = \sum_t V \cdot I \quad (3)$$

This value can later be converted to watt-hour ( $Wh$ ) by dividing the accumulation result by 3,600.

Table 2 Averaged Monthly All-Sky Solar Radiation Incident ( $H$ ) On a Horizontal Surface For Cikarang, Indonesia ( $kWh/m^2/day$ ) [6]

Month	$H$
January	4.39
February	4.74
March	5.19
April	5.22
May	5.04
June	4.85
July	5.24
August	5.90
September	6.26
October	5.84
November	5.06
December	4.42

### 3.3 The Dry Battery

A dry battery is a battery that is made of gel electrolyte instead of liquid electrolyte. The gel endures longer than the liquid since the gel does not evaporate. The drawback is the price since a dry battery with a gel electrolyte is more expensive compared to one with a liquid electrolyte.

Figure 3 shows a dry battery NS Hawk HAWNXXZ67 with an operating voltage of 12 VDC and a charge capacity of 7 Ah.



Figure 3 The HAWNXXZ67 dry battery

HAWNXXZ67 is chosen to become the storage for the energy gained from the solar panel in the proposed PSCS. Indeed, this battery is classified as a starter battery designed to discharge only a small part of its capacity in a short high-current burst. On the other side, a deep-cycle battery is more suitable for solar power applications, since this kind of battery can be deeply discharged to use most of its capacity. However, in the realization of this project, HAWNXXZ67 is still an affordable alternative to a deep-cycle battery.

### 3.4 The Solar Charge Controller

The main function of a solar charge controller is to insulate and mechanize the charging of the battery. It prevents the battery from overcharging by reducing the voltage from the solar panel to the desired voltage of the battery. Besides, the controller also detects whether the voltage of a battery is low. If this occurs, the controller disconnects the load from the battery to anticipate the battery from draining [10].

Figure 4 depicts the solar charge controller used to build the PSCS. The operating voltage of the regulated battery can be chosen between 12 V and 24 V.



Figure 4 The Shinyoku solar charge controller

### 3.5 The Microcontroller

In the realization of this project, the Arduino Mega 2560 R3 is chosen. It is a microcontroller board that utilizes an ATmega2560 chip, as can be seen in Figure 5. This microcontroller has many I/O pins, making it suitable for implementations that require many components to be connected. The I/O pins include 16 analog input pins, 4 UART (serial port hardware) pins, and 54 digital I/O pins where 15 of which are allocated for PWM (Pulse Width Modulation).

It is also equipped with a 16 MHz oscillator, USB port, DC power jack, ICSP header, and reset button [11].

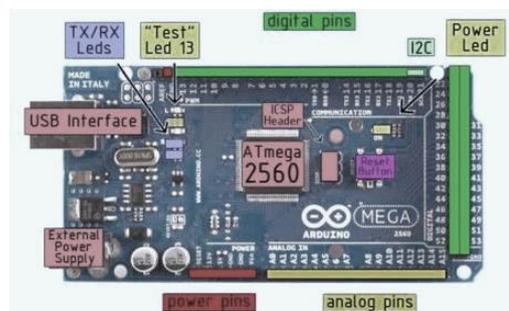


Figure 5 The Arduino Mega microcontroller

### 3.6 The DC-DC Converter

A DC-DC converter is an electrical component that converts a source of direct current from one voltage value to another. In the proposed PSCS, the 12 VDC from the dry battery needs to be converted to 5 VDC, which is the maximum voltage allowed to be used in charging cellular devices. The current is regulated up to a maximum of 3 A [12].

Figure 6 shows the DC-DC converter used in building the system. The input terminals of the converter are to be connected with the terminals of a voltage source, whether directly or indirectly via a solar charge controller.



Figure 6 The CPT DC-DC converter

### 3.7 The Current Sensor Module

The ACS-712 is a sensor that senses flowing current for both AC and DC signals. This sensor gives an output of an analog voltage signal linearly with the sensed current. The VCC of the sensor requires 5 VDC. The IC contains a conductive material, across which a certain voltage will be produced when electric current flows through it. The voltage appears due to the magnetic field generated by the flowing current. The zero current corresponds to the output voltage of 2.5 V, while the maximum current is 5.0 V [13].

Figure 7 shows the appearance of the current sensor, while Table 3 shows its specifications.

The ACS-712 module has two terminals, positive and negative. They are connected in series with the power source and the load. Each of the three module pins is connected to the microcontroller according to a certain function. The VCC is

connected to the power 5 V pin, the OUT pin is connected to one of the analog input pins, and the GND pin is connected to the ground [13].

Table 3 The Specifications of the Current Sensor ACS712 [13]

Specifications	Description	
Type	20 A Module	30 A Module
Supply Voltage	5 VDC	5 VDC
Range	-20 to +20 A	-30 to +30 A
Voltage at 0A	$VCC/2 \cong 2.5$ VDC	$VCC/2 \cong 2.5$ VDC
Scale Factor	100 mV/A	66 mV/A



Figure 7 Current sensor ACS712

### 3.8 The Voltage Sensor Module

A voltage sensor is a device capable to measure voltage. Its measurement is commonly based on a voltage divider. The voltage of a source is converted into a voltage value that can be read by the microcontroller in the range of 0 to 5 V. Then, the microcontroller reads the input as a digital value. Figure 8 shows the appearance of the voltage sensor module that is used to construct the PSCS, with the specification as given in Table 4.

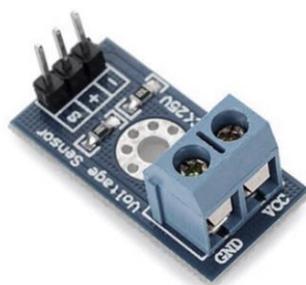


Figure 8 The voltage sensor

Table 4 The Specifications of the Voltage Sensor

Specifications	Description
Voltage Supply	25 VDC (max)
Input-Output Ratio	5:1
Voltage Detection Range	0.02445 to 25
Analog Voltage Resolution	0.00489V

### 3.9 The Block Diagram

The block diagram of the PSCS is shown in Figure 9. The blue arrows represent the flow of information or control signal, while the red arrows show the flow of power signals.

The Arduino Mega is connected to a matrix membrane keypad and an LCD. Both of them serve as the interface between the user and the system. Activities such as entering the passcode and selecting the display of the gained energy can be done by using the keypad.

The output terminals of the solar panel are connected to the voltage sensor and the current sensor. Then, both sensors feed the measurement results to the microcontroller. The amount of gained solar energy is displayed on the LCD and is updated every second. The value of the energy is shown on the LCD in the unit of Watt-second (Ws). When the user enters a correct passcode on the keypad, the microcontroller will switch the relay on and the current may flow to supply the load.

The output terminals of the solar panel are also connected to the solar charge controller. This controller maximizes and secures the charging process of the dry

battery so that the resulted voltage does not exceed the maximum allowable limit. This is to avoid the overcharging effect of the battery. As long as the battery is not full, the controller allows the solar panel to charge the battery. By the time the battery is full, the controller disconnects the current flow to the battery.

A converter will first reduce the DC voltage of the battery (12 VDC) to the common voltage for charging cellular devices (5 VDC).

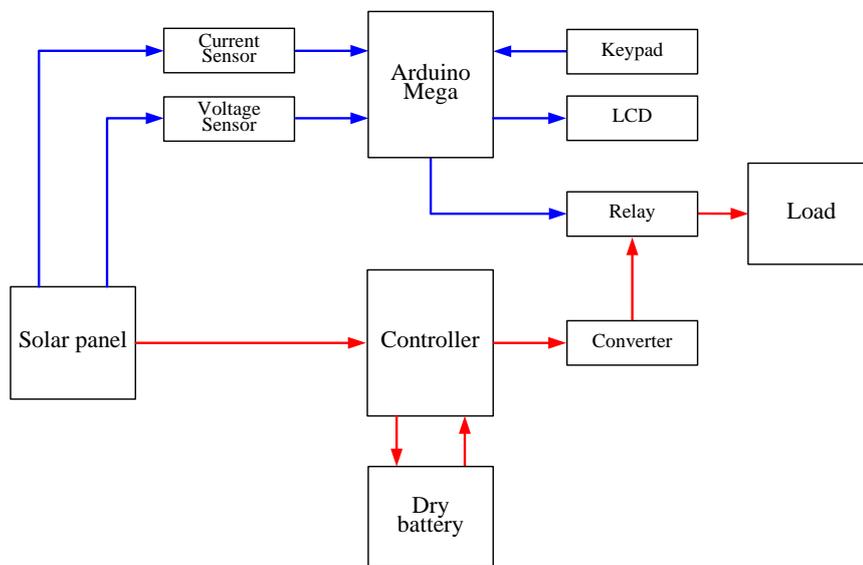


Figure 9 The block diagram of the proposed system

### 3.10 The Flow Chart

Figure 10 shows the flowchart of the PSCS's program, with the main tasks of passcode protection and the display of energy measurement. Both processes are conducted in series. The passcode entering process is required to be done quickly, where the authorized users are expected to input a 4-character passcode within 4 seconds. The passcode is evaluated immediately. If the passcode is correct, the status "Connected" is shown on the LCD, the relay is connected, and power is flown to the load. If the passcode is incorrect, the message "Please try again" is shown, the relay is opened, and no current can flow to the load.

After the passcode check process is done, the process directly proceeds to the calculation of the gained energy. First, the corresponding sensors read the current and

the voltage from the connection to the terminals of the solar panel. The instantaneous power is then calculated and displayed. Afterward, the cycle restarts from the beginning.

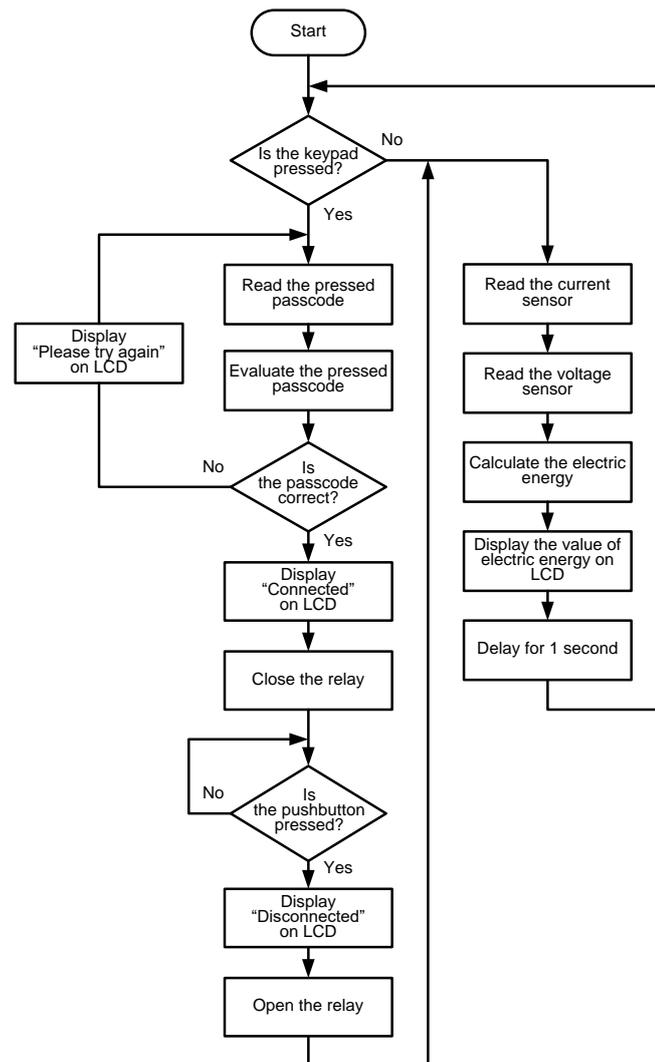


Figure 10 The flowchart of the proposed system

## 4. Results and Discussion

### 4.1 The Schematic Design

Figure 11 shows the schematic design of the PSCS utility box. A toolbox is modified so that it can contain all components as shown in Figure 9 except the solar panel and the load.

The keypad, the LCD, and the push button are mounted on the top side. The DC power jack from the solar panel and the USB power input port for the Arduino Mega can be found on the right side. The USB power output port can be found on the left side. This port is to be connected to the cellular device that needs to be charged.

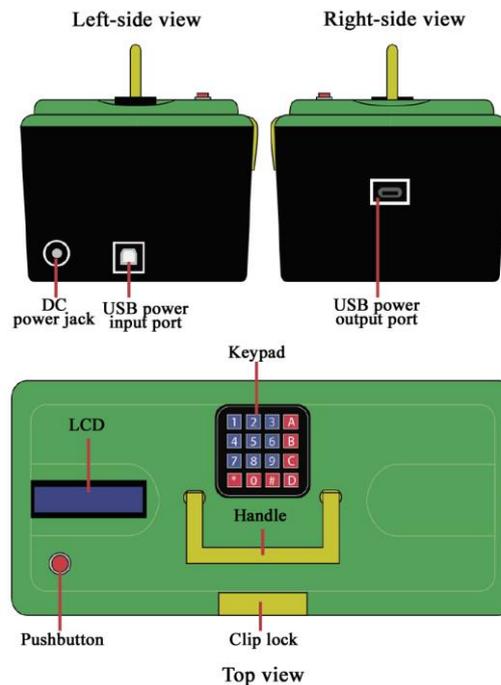


Figure 11 The schematic design of the utility box

### 4.2 The Design Realization

The realization of the PSCS utility box is presented in Figure 12. As mentioned in the previous subsection, all of the components are placed inside the box except the solar panel and the load. Figure 12(b) shows the inside compartment of the box by the time it is opened. For a proper weight balance, the battery as the heaviest component is placed in the middle of the box.

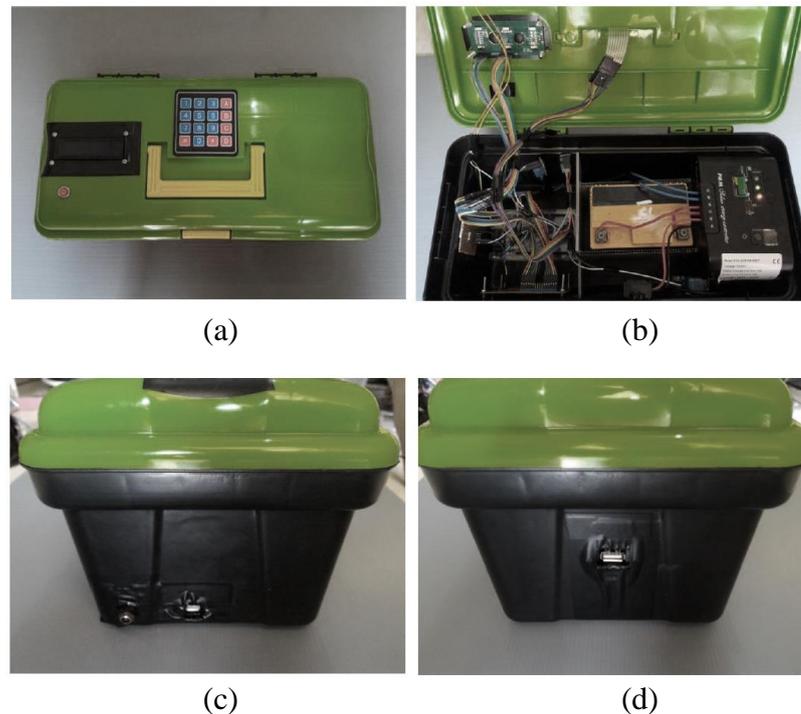


Figure 12 The realization of the PSCS utility box; (a) top view with the lid closed; (b) top view with lid opened; (c) left-side view; (d) right-side view

On one side next to the battery, the circuits of Arduino Mega for the LCD, and the push buttons are put together. On the other side next to the battery, the DC-DC converter, the relay, and the solar charge controller are placed together. This gives an easier way for the output-regulating components to make a connection with the load.

In total, the box weighs approximately 2.8 kg. Together with the solar panel, the weight of the whole PSCS is approximately 4.95 kg. This weight is considered conveniently portable.

### 4.3 Test of Passcode Entry

The load charging will start only after a correct passcode is entered by using the keypad. The passcode is integrated into the Arduino program. For this project, the passcode is set to "09AB". The passcode input process is finalized by pressing the asterisk button (\*).

Figure 13 shows the appearance of the LCD by the time each character of the passcode is entered. After the last character (B) is entered, the asterisk button is to be pressed and the power to the load will be connected.



Figure 13 The process of entering the passcode “09AB”

Figure 14 shows the possible response after a passcode is entered. 14(a) depicts the LCD when a correct passcode is entered, acknowledged by the word “Connected”. Otherwise, if the entered passcode is wrong, the LCD will show the message “Please try again”, as shown in 14(b).



Figure 14 Connecting the PSCS;

(a) Successful with a correct passcode; (b) Failed with a wrong passcode

The current flowing to the power output port can be disconnected at any time by pressing the push button. Figure 15 shows the LCD immediately after the push button is pressed. After 1 second, the display returns to the main screen, showing the amount of gained energy in Ws.



Figure 15 Disconnecting the PSCS

#### 4.4 Test of Power Reading in Serial Monitor

Figure 16 shows an exemplary result of power reading through the serial monitor. The instantaneous results of the product of V and I are accumulated every second, and the results are shown in the figure.

The zero time reference is the last zero value before the first nonzero value. After the first 10 seconds, the result shows 149.62 Ws, as pointed by the upper arrow. After 20 seconds, the value shown is 218.77 Ws, as pointed by the lower arrow.

The average of the first 10 seconds is 14.96 Ws or equivalent to a projected 14.96 Wh if it is constant for 1 hour. The average of the first 20 seconds changes to 10.94 Ws or equivalent to a projected 10.94 Wh if it is constant for 1 hour. It can be seen that the amount of gained solar energy varies from time to time. The radiation intensity is indeed influenced by many factors. In this case, they are the time of the day and atmospheric conditions such as cloud, dust, and water vapor.

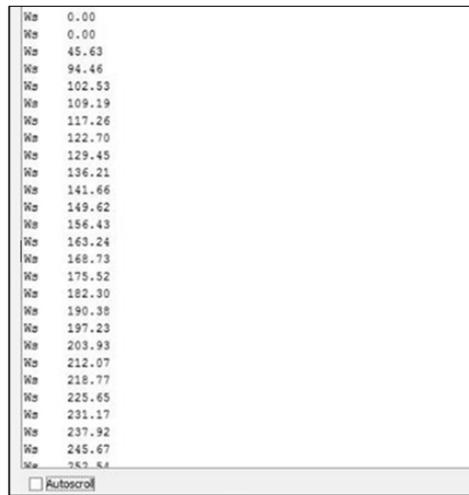


Figure 16 The accumulated gained energy printed on the serial monitor

#### 4.5 Test of Battery Charging

The potential value of solar energy varies based on geographical location and on time. Table 2 shows that the average solar radiation in Cikarang, Indonesia varies by month. In January, the monthly average for Cikarang is 4.39 kWh/m<sup>2</sup>/day, while in April, 5.22 kWh/m<sup>2</sup>/day.

A series of experiments were conducted to measure the amount of energy gained by the PSCS, as the battery is charged up. The experiments were done in 2017 in Cikarang, Indonesia. In each month 4 experiments were conducted, each with a 3-hour duration, spread on 3 different days. The results are shown in Table 5 and Table 6.

Table 5 The Test Result of Battery Charging in January

Date	Time	Weather Condition	Voltage		Gained Energy	
			Initial	Final	[Ws]	[Wh]
13	09.00 –12.00	Cloudy, fairly foggy	8.97	10.01	17,352	4.82
13	12.00 –15.00	Cloudy, fairly foggy	10.01	11.15	17,280	4.80
19	09.00 –12.00	Sunny with little clouds	8.18	11.21	35,568	9.88
20	12.00 –15.00	Sunny with little clouds	9.21	11.52	29,448	8.18

Table 6 The Test Result of Battery Charging in April

Date	Time	Weather Condition	Voltage		Gained Energy	
			Initial	Final	[Ws]	[Wh]
10	09.00 –12.00	Sunny with little clouds	10.04	12.56	30,681	8.52
11	12.00 –15.00	Sunny with little clouds	10.97	12.97	31,440	8.73
12	09.00 –12.00	Cloudy, fairly foggy	11.46	12.67	18,942	5.26
12	12.00 –15.00	Cloudy, fairly foggy	10.20	11.76	21,069	5.85

The experiments show that the battery can be successfully charged. As it is charged, the battery voltage increased to reach the final value close to its nominal voltage. The amount of energy gained varies from 4.80 Wh on a cloudy and foggy day to 9.88 Wh on a sunny overcast day. With the operating voltage of a cellular device's battery rated at 3.7 V, the energy gained can readily be converted to the equivalent values of approximately 1,300 mAh and 2,670 mAh.

#### 4.6 Discussion

A series of calculations are now undertaken to compare the amount of energy gained by the PSCS, between the experimental results with the theoretical calculations.

The calculation of the solar panel's energy output requires the area of the solar panel  $A$ , the solar panel efficiency  $r$ , the solar radiation incident based on a specific location on earth and a specific month  $H$ , and the performance ratio of the photovoltaic system  $PR$ , as required by the Equation 1.

The total surface area of the solar panel in this project is  $0.1062 \text{ m}^2$ . The corresponding solar panel efficiency is calculated by using Equation 2, such that

$$r = \frac{10 \text{ W}}{(1000 \text{ W/m}^2)(0.1062 \text{ m}^2)} = 0.0942 \quad (4)$$

For the month of January, the author uses  $H = 4.39$  and for the month of April, the author uses  $H = 5.22$ , as taken from Table 2.

By using Equation 1, the potential output energy based on the formula for one day in January can be calculated as:

$$\begin{aligned}
 E &= (0.1062 \text{ m}^2)(0.0942)(4.39 \text{ kWh/m}^2/\text{day})(0.75) \\
 &= 0.0329 \text{ kWh/day} \\
 &= 32.9 \text{ Wh/day}
 \end{aligned}
 \tag{5}$$

With the same procedure, the potential output energy for the month of April is:

$$\begin{aligned}
 E &= (0.1062 \text{ m}^2)(0.0942)(5.22 \text{ kWh/m}^2/\text{day})(0.75) \\
 &= 0.0392 \text{ kWh/day} \\
 &= 39.2 \text{ Wh/day}
 \end{aligned}
 \tag{6}$$

The comparison between the energy gained based on experiments and the potential energy based on calculations is presented in Table 7 and Table 8.

Table 7 The Comparison Between Measured and Calculated Results For January

Date	Time	Weather Condition	Gained Energy		
			Actual [Wh]	Potential [Wh]	%
13	09.00 –12.00	Cloudy, fairly foggy	4.82	32.9	14.6
13	12.00 –15.00	Cloudy, fairly foggy	4.80		14.6
19	09.00 –12.00	Sunny with little clouds	9.88	39.2	30.0
20	12.00 –15.00	Sunny with little clouds	8.18		24.8

Table 8 The Comparison Between Measured and Calculated Results For April

Date	Time	Weather Condition	Gained Energy		
			Actual [Wh]	Potential [Wh]	%
10	09.00 –12.00	Cloudy, fairly foggy	8.52	39.2	21.8
11	12.00 –15.00	Cloudy, fairly foggy	8.73		22.3
12	09.00 –12.00	Sunny with little clouds	5.26	39.2	13.4
12	12.00 –15.00	Sunny with little clouds	5.85		14.9

Assuming that the sun normally shines for 12 hours a day in locations close to the equatorial line, in each experiment the PSCS only operates for 25% of the potential working hour. In the periods between 09.00 to 12.00 and 12.00 to 15.00, the solar radiation intensity in these periods is expected to be higher than in the periods between 06.00 to 09.00 and 15.00 to 18.00. Thus, in cases where the sun shines optimally throughout the day, the percentage of solar energy gained during the first mentioned periods will be higher than 25% (the value if the intensity of solar radiation is uniform).

This mark was surpassed on 19 January, when the energy gained is 30.0% of the potential, and nearly reached on 20 January with 24.85%. During these 2 experiments, the sky is sunny and with only little clouds. On 10 and 11 April, with around the same sky conditions, only the values of around 22% were reached. In the other 4 experiments with a cloudy and foggy sky, the energy gained was only around 15%.

The main reason why the energy gained was lower than its theoretical potential is that the experiments were not conducted in a completely open space. The location is surrounded by constructions such as house walls and fences. Thus, the solar radiation cannot fully reach the surface of the solar panel. This makes the amount of energy collected by the panel less than the optimal value. Besides, the additional effect of smog, as the experiment location is in the middle of an industrial estate, may also contribute to decreasing the incoming radiation.

The factors rooted in weather and sky conditions such as clouds, fog, and water vapor are not considered as the cause why the energy gained is lower than the theoretical value. These factors are already considered in obtaining the data given in Table 2. The data in this table is the averaged monthly solar radiation for all-sky conditions. However, man-made smoke and other atmospheric pollutants may also be present in the sky above Cikarang, since it is a dense industrial estate.

## **5. Conclusions**

A portable solar charger system (PSCS) is proposed in this paper. The system is successfully realized, consisting of a solar panel part and a utility box part. The total weight of the prototype is 4.95 kg, which supports the portability of the system. The PSCS is equipped energy measurement feature so that the user can monitor the solar energy gained via an LCD. Besides, the system also has access control, so that only privileged people may use the system to charge their cellular devices. These two features are successfully tested.

Furthermore, the PSCS is tested to collect solar energy in 8 experiment sessions, each 3-hour long or 25% of the daytime. The energy gained ranges from 4.80 Wh to 9.88 Wh, which corresponds to 14.6% to 30.0% of the potential solar energy of a day. With the operating voltage of the cellular device's battery of 3.7 V, the gained energy is equivalent to 1,300 mAh and 2,670 mAh of battery energy.

Further improvements to the PSCS includes the use of more efficient and lighter solar panel to improve the amount of energy gained while maintaining portability. Additional light sensors can help the user manually position the solar panel while in operation. This will increase the amount of energy gained, while keeping the system's energy consumption low, by omitting the use of servo motors that are required in automatic positioning.

## References

- [1] United Nations Development Programme, "Achieving Sustainable Energy for All in the Asia-Pacific," Internet: <http://www.undp.org>, August 2013 [8 November 2021].
- [2] M. A. Sahbana, S. Sabarudin, S. Saputro. "Analisa Pembuatan Portable Solar Charger yang Diaplikasikan Pada Jacket." *Transmisi*, 12(1), pp. 9-14, 2016.
- [3] A. Ismangil, H. P. Susanto. "Design of Power Bank Mobile Using Solar Panel Based Microcontroller ATmega 328," in *Proc. International Conference on Global Optimization and Its Application (ICoGOIA 2019)*, IOP Conf. Series: Materials Science and Engineering, 2018, pp. 1-7.
- [4] N. Z. Elfani, P. Sasmoko. "Power Bank Portable Solar Charger Menggunakan Sistem Buck-Boost Converter Berbasis Mikrokontroler Atmega 32," *Gema Teknologi*, 18(4), pp. 15-20, 2016.
- [5] S. Suwarno, M. F. Zambak. "Implementasi Charger HP Dengan Panel Surya," *JETri: Jurnal Ilmiah Teknik Elektro*, 19(2), pp., 2022.
- [6] U.S. Energy Information Administration. "Solar explained: Photovoltaic and electricity,". Internet: <https://www.eia.gov>, [14 January 2022].

- [7] A. J. McEvoy, T. Markvart, L. Castañer, L. Castaner, L. Castaner. *Solar Cells: Materials, Manufacture and Operation*, 2nd ed, Waltham, MA: Elsevier/AP, Academic Press, 2012, pp.214.
- [8] "How to calculate the annual solar energy output of a photovoltaic system?". [Internet: <https://photovoltaic-software.com/principle-ressources/>, [1 January 2022].
- [9] NASA Prediction of Worldwide Energy Resources“, Internet: <https://power.larc.nasa.gov>, [16 November 2021].
- [10] Shinyoku, "Solar Charger Controller Manual Book".
- [11] Arduino, Arduino Mega 2560 Data Sheet. Internet: <https://store.arduino.cc>, [October 2021].
- [12] Current Logic, "CPT/Fulree DC-DC Converter Data Sheet Terms and Specifications". Internet: <http://www.current-logic.com>, [2 October 2021].
- [13] Allegro Microsystems, ACS712 Linear Current Sensor. Internet: <http://www.allegromicro.com>, [7 December 2021].