Automatic transfer switch for DC system application

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Article Info

Article history:

Received Jun 1, 2023
Revised Sep 8, 2023
Accepted Sep 28, 2023

Keywords:

Automatic transfer switch
DC load applications
Multiple input
Renewable energy
Solar charge controller
Uninterruptible power supply

ABSTRACT

Automatic transfer switches (ATS) have the potential to be important in ensuring uninterruptible power supply across a wide range of sectors, enabling smooth transitions between utility and emergency RES power sources, generators, and more. Utilizing DC electricity provides a cost advantage and is suitable for short-distance transmission. The author proposes a 12-volt DC backup system that corresponds to a minimum input voltage of more than 10 Vdc and can be applied in various DC load applications. The ATS design incorporates multiple inputs and uses algorithms to prevent simultaneous operation of all sources and reduce feedback. These developments in backup system technology, coupled with the shift to renewable energy, are contributing to the creation of a sustainable and resilient electricity grid. In experiments, the ATS system demonstrated its ability to provide 24 hours of backup power with a specified load (lighting bulbs, light-emitting diodes (LEDs), motors, and fans) discharging 0.27–2.25 Amperes. Using the millis programming language, it supports the performance of a constant switch transition speed of around 0.6453 seconds for a switch from buck to SCC. 0.658 seconds for solar charge controller (SCC) to power supply (PSU), 0.656 seconds for PSU to CC PSU, and 0.61 seconds for PSU to OFF.

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1. INTRODUCTION

Backup systems have an important role in maintaining continuity in a network system, especially in renewable energy systems, which have limited availability of natural resources that depend on weather conditions and time spans [1]–[4]. Like solar panel energy with radiation, wind turbine energy based on wind speed, Pico hydro energy with flowing water [5], [6]. On solar panel energy with battery storage, the challenge faced is that when energy use is divided into two processes, namely charging the battery and supplying energy to the load, the load goes into the charging process, which reduces the energy going into the battery storage, so it is not suitable for day and night. load the application [7], [8]. This research focuses on maintaining the continuity of a system, especially for household use with DC operating voltage, or DC house [9]. The solution offered to maintain the continuity of the system is to add several alternative sources so that the energy storage process in the battery is not disturbed [10], [11]. The added source is the buck converter as the first alternative source, which functions to lower the voltage from the solar panel so that the voltage from the solar panel matches the load criteria [12]. The second alternative is that when there is no sunlight or solar radiation, the buck converter turns off and the energy from the battery charger controller will be active. The third alternative is that when the energy source from alternatives 1 and 2 goes out, the AC-DC power supply will function as a backup supply to the load directly [13]. The fourth alternative is energy stored in the battery charger controller, connected to an AC-DC power supply as a charging source, and when the third alternative goes out, the energy from the battery charger controller will function as an emergency energy supply. To maintain system continuity, automatic control is needed to reduce delay time by using an automatic transfer switch, also known as an automatic transfer switches (ATS) [14]–[16]. In this study, the DC system is superior for short-distance transmission due to minimal energy conversion losses from renewable energy with a 12-volt DC reference voltage, where a 12-volt DC voltage is more compatible with various devices such as lighting and other electronic devices. In this study, besides focusing on ATS control with Arduino Mega 2560 [17], [18], it also pays attention to additional protection when test conditions are obtained, where when the charger controller is connected to one output, a reverse current occurs, so an additional algorithm is added. Protection so that during the charging process, the source from the battery does not feedback the input source of the charger controller. This research has several significant advantages. First, this research is designed for DC system applications that are specifically for short-distance transmission and applied to the electrical load of small-scale homes [19], [20]. Another advantage is the ease of installing renewable energy sources in ATS control. Input terminals on the front side of the panel box are provided so that when changing or maintaining renewable energy, there is no need to touch the system cables [21], [22]. Users can easily install PV for renewable energy. Another advantage is minimizing interference and additional costs when the ATS device must be moved. Thus, this research not only presents innovative technical solutions but also emphasizes efficiency, ease of use, and affordability. The DC ATS in this research has made a major contribution to the development of the ATS system, especially for DC load applications. Apart from that, the ATS plays a role in maintaining system continuity by minimizing energy conversion losses by implementing a DC system and using four sources in the ATS to maximize the function of the DC ATS.

2. METHOD

In previous research, ATS was used as a backup system with various aims and technological developments, including the aim of saving costs through energy management with a switch power panel between power from the state electricity company and solar panels [23], using a PLC, Arduino as a control [24], and IoT [25]. This research focuses on developing a backup system for DC load applications supplied by four alternative sources: a buck converter [26], energy storage from a PV charger controller [27], an AC-DC power supply, and energy storage from a charger controller power supply. To control the generation source switching mechanism, an optocoupler-based mechanical relay with an Arduino Mega 2560 module is used [28], [29]. The data that can be displayed on the Arduino is the voltage value from four alternative sources: the load current value, the PV controller charger voltage input value, the voltage input value from the charger controller power supply, and the battery charging current value from the power source. PV charger controller and charger controller power supply. This research method includes: i) ATS design, ii) simulation using proteus software, and iii) experimental data collection. Then, the conclusion will be derived from data analysis.

2.1. ATS Design

The ATS design can be seen in Figure 1 regarding the wiring diagram of automatic transfer switch. The automatic transfer switch has the same specifications as in the network: the voltage capacity ranges from 12 to 17 volts with a power of 120 watts. on the control and protection side it uses a 12 volt and 10 A relay. On the sensor side it uses an ACS712 current sensor with a capacity of 30 A and a voltage divider-based voltage sensor with a maximum voltage reading of 24 volts. The system consists of four sources. In the source 1 uses a 20-watt solar panel with a maximum voltage of 17 volts but is converted using a buck converter with a maximum capacity of 200 watts to obtain a voltage close to the 12-volt reference and this section is controlled by a relay to regulate the source to the load. In the source 2 it consists of a 20-watt solar panel which is converted and controlled by a 10 ampere 12-volt charger controller for charging the 12-volt 7.2 AH valve regulated lead–acid (VRLA) battery, the output of the charger controller is equipped with a relay for load regulation. Source 3 consists of an ac to dc power supply unit 12 to 17-volt 30 Amperes, in the output section there is a relay for regulating the source to the load. Source 4 consists of the output from source 3 which is paralleled and enters the 12-volt 10 ampere charger controller input for charging the 7.2 AH VRLA battery and the charger controller output is controlled by a relay to regulate the source to the load. The source section that enters the relay is equipped with each DC voltage sensor, with a maximum reading of 24 VDC which is connected to the Arduino Mega 2560 microcontroller. To support performance monitoring, the PV/PSU charger controller on the ATS is equipped with current and voltage readings on the input side of the charger controller to monitoring the energy entering the charger controller and adding relays on the input side and on the output side of the charger controller. This functions as additional protection when charging, so it can trigger the output section when a load is connected. To test the effectiveness of the

ATS backup system, an experiment was carried out by collecting data for one full day. which aims to measure the performance of various system components as a whole. This evaluation includes the capabilities of four connected sources and the ability to charge energy to the battery. By collecting data from these various aspects over a long period of time, this experiment aims to provide deep insight into the efficiency and backup capabilities of the system.

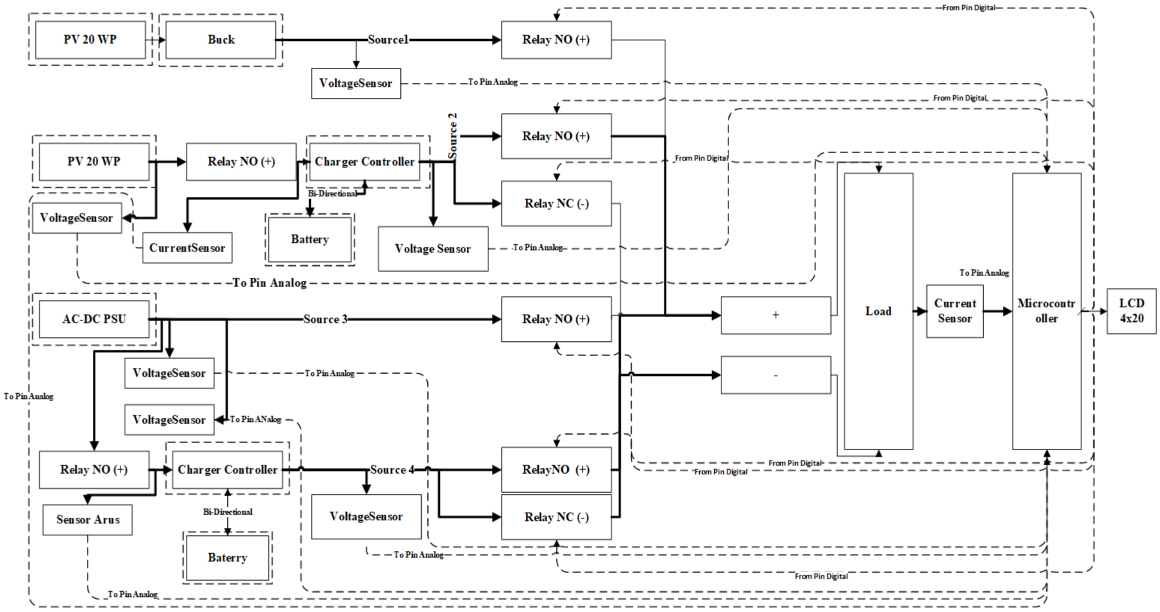

Figure 1. Wiring diagram of automatic transfer switch

2.2. Simulation using proteus software

To determine the performance of the automatic transfer switch, alternative logics 1, 2, 3, 4 are created, and if the conditions are not met, the system is turned off. Table 1 is an important guide in channeling transition energy and how effective tools are in responding to and utilizing the various resources available. Each alternative is tested via a switch from the main source to the alternative. To optimize the performance of the tool, ensure that available resources are used efficiently, and achieve the desired results.

Table 1. Alternative conditions of automatic transfer switch

Alternate energy	Buck converter	Charger controller PV	Power supply	Charger controller power supply	Load
I	ON	OFF	OFF	OFF	ON
II	OFF	ON	OFF	OFF	ON
III	OFF	OFF	ON	OFF	ON
IV	OFF	OFF	ON	ON	ON

In Table 1, the condition of the ATS system describes the condition of the system when ATS is fully applied:

- Alternate I: Buck converter > 10 Vdc; the system will automatically activate during the day or when the sun produces energy.
- Alternate II: Charger controller PV > 10 Vdc; in this alternate, the system will automatically activate when there is no sun and a battery source from charger control is available.
- Alternate III: Power supply > 10 Vdc; in this alternate, the system will be active when the energy source from the battery charger controller PV does not meet the requirements.
- Alternate IV: Charger controller power supply > 10 Vdc; in this alternate, the battery from the charger controller power supply system will be active when there is no source from step down DC-DC, battery from charger controller PV, or power supply.

If all alternative generator conditions are not met. Buck converter, charger controller PV, power supply and charger controller power supply <10 Vdc, all systems off. To start the simulation in the Proteus application, first we open the Arduino IDE application, then run and copy the existence file (Hex), then open the Proteus application that has been designed and paste the Hex existence file into the Arduino module, then run Proteus and the data will appear as following.

To carry out an experiment to switch electrical resources according to the alternative condition automatic transfer switch, a switch experiment was carried out using the proteus application in Figure 2. The results of the algorithm used were able to carry out a switch when the conditions in the alternative condition were met. If the transition test is successful, the performance of the automatic transfer switch is then determined by applying a DC load. The data displayed on the serial monitor is source transition status data (photovoltaic/buck converter, SCC photovoltaic/SCC PV, power supply/PSU, SCC power supply/SCC PSU) and voltage data displayed. DPV represents the buck converter, SPV represents SCC PV, DPS represents the PSU, and SPS represents CC PSU and load to measure the load current, while to measure the energy entering the charger controller measures current and voltage (PV input measures the voltage entering the solar panel, power supply input measures the voltage entering the charger controller input, and PV charging is the current that flows to the PV charger controller input and PLN charging is the current that flows to the PSU charger controller input.

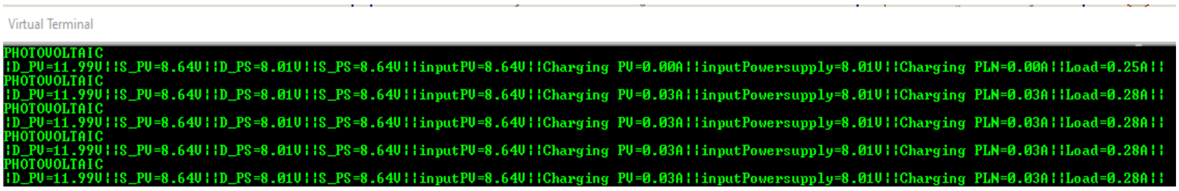

Figure 2. Simulation of alternative ATS conditions using proteus application

2.3. Experimental data collection

In this experiment, we tested the performance of the automatic transfer switch (ATS) in three different modes, namely mode with delay, mode without delay, and mode using the millis function. We investigate the ATS's ability to switch electrical resources precisely and efficiently between four different power sources. In addition, this experiment also focuses on ATS resilience in the face of energy supply disruptions. We implement careful energy management to ensure that the ATS can operate continuously even in conditions of power supply instability. This is done with the aim of testing the ATS's ability to maintain continuity of power on crucial DC loads or daily usage in the Table 2. These experiments help evaluate ATS performance in various operational situations, as well as improve overall ATS system reliability.

Table 2. Modelling and schedule of DC home daily load applications

Time	Load	Total Current
11:05-12:00	3 White	0.27 A
12:01-13:04	6 White LED+ 2 Fan	0.80 A
13:05-13:45	6 White LED Strip Putih +2 Fan + Pump	0.92 A
13:46-15:05	6 White LED +2 Fan	0.80 A
15:06-16:20	6 White LED + 2 Fan	0.80 A
16:21-03:49	6 White LED +2 Fan+ 4 Lamp Bulb + 3 Blue LED + 4 LED white	2,25 A
03:50-04:19	3 White LED + 3 Blue LED	0.57 A
04:20-11:05	3 White LED	0.27 A

3. RESULTS AND DISCUSSION

Previous research has carried out various forms and applications of ATS to improve the performance of ATS that is integrated with various generation sources, including PLC control, power control, mechanical control, and monitoring applications. Implementation of an AC or DC system is a consideration. Over short transmission distances, DC systems benefit from the ATS design, which is simple, portable, and easy to implement across a wide range of DC components. In addition, answering the challenge of system sustainability with flexible design and using various alternative sources to maintain load stability the novelty of this research is the use of four-source integration in addition to using Arduino Mega 2560 control, which allows ATS input and output control with fast processing using experimental algorithms (without delay, delay, and millis) to optimize its performance. Delay, without delay, and millis are terms often used in programming microcontrollers or time-based systems to set waiting times or pauses in code. Delay is stopping program execution for a certain period of time, but can make the system unresponsive. Without delay is an approach to avoid using delay functions by utilizing actual conditions and time to schedule tasks.

Millis is a function for measuring the time in milliseconds since the program started, which allows the creation of responsive code and multitasking.

3.1. ATS transition switch experiments

The results of the automatic transfer switch research test produce output in the form of a portable device, and the results of testing the results of the performance of the automatic transfer switch in setting the load supply, the ability to switch, and the ability to charge the system will be displayed. In the daily loading test, it is modeled as Table 2 of the ATS load modeling, the load is designed according to the activity of the average household electricity usage. Taking into account time of use, energy design, and resource availability.

In Figure 3 and Figure 4 the experiment starting at 11:05 –12:05 with the use of 3 LED strip lights supplied by the buck converter, as shown in the graph above, with a voltage range of 14 volts, the resulting current value ranges from 0.17 to 0.20, different from the normal load current rating range of 0.27 A. This is due to the cloudy time of the test, so that the available voltage but the current from the PV are not sufficient to fully charge 1.15 A from the source. Then the source switches to the charger controller. At the next load, PV starts to lose energy, becomes cloudy, and because of the additional load, it causes a switching process so that it switches to the charger controller with a voltage of 13.29 with a load. At this transition, the load increases from 0.27 A to 0.8 A. This process only occurs for 45 minutes with a current supplied to the load of less than 0.8 A, and the battery drops to 10.5 volts, so that the electronic switch on the SCC breaks the path to the load and reads the value of the sensor voltage as 0 volts. Then proceed to the transition from SCC to buck, this is because the sun produces energy again and flows energy to the buck and meets the voltage requirements to accommodate the load, in this condition the value of the buck is less than 0.8 A, which is around 0.56 A due to an additional load dc motor for 30 minutes then continued at 16.35 o'clock the supply began to switch to the PSU with a maximum loading of 6 white LED strip lights, 2 fans, 4 bulb lights, 3 blue LEDs, 4 white strip lights with an average usage of 2.13 A but load usage will decrease when entering 3 am because some loads will be turned off and then drop to 0.5614 A at 4:20 o'clock energy use will still be sourced from the PSU until 08:05 o'clock or when energy from buck is available again. The power consumption of an ATS system under loading conditions with a specified load is obtained by a graph with data on power and current consumption on the system, with an average power usage of 13.44 watts and a maximum usage of 26.144 watts.

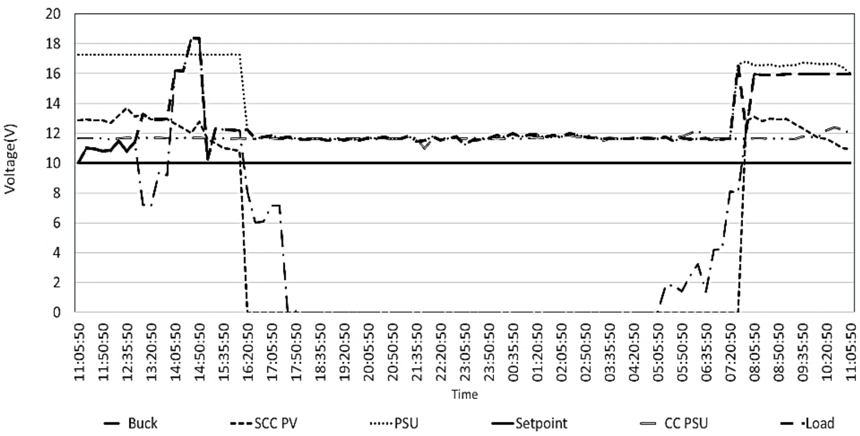

Figure 3. ATS transition switch experiments

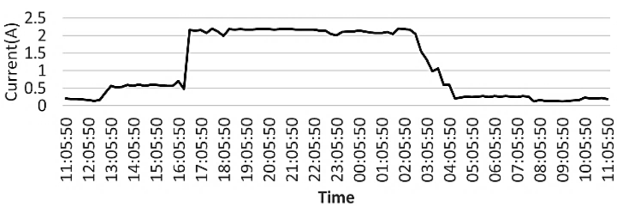

Figure 4. Current consumption on ATS transition switch experiments

3.2. ATS switching based on programming language

Experimental switching on the ATS DC system was carried out to determine the delay time for switching switches between sources. According to Figure 1 and Table 1, the speed and delay on the relay connected to the load refer to the time needed by the relay to operate and cut off the power supply to the connected load. In this experiment, using three program algorithms to determine the most optimal performance to be applied to the system.

To see the performance of ATS switching, see Figure 5. In the delay algorithm experiment with a delay of 500 ms or 0.5 seconds, without delay without providing a delay, and millis with a delay of 0.5 seconds. In the buck converter, charger controller transition process, for delay and without delay the value is not much different, which is around 1.2 seconds and for millis constant 0.66 seconds. for the average reading from each alternative source, namely 0.6453 seconds for switches from buck to SCC, 0.658 s for SCC to PSU, 0.656 seconds for PSU to CC PSU, and 0.61 seconds for PSU to off but for the SCC-CC PSU transition , PSU-CC delay time is longer when using delay and no delay programs because the program reading intervals are sequential so that in switching conditions it requires a delay, while for millis it allows simultaneous reading so that the delay from millis is more constant.

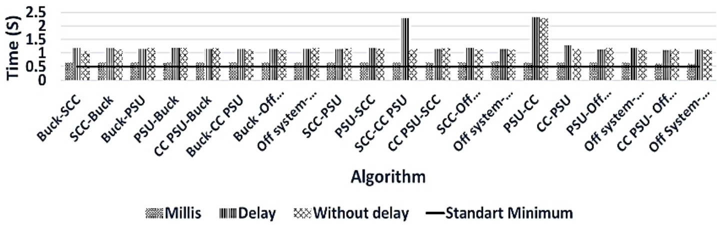

Figure 5. ATS switching based on programming language

3.3. Voltage and current charging using power supply and PV

Figure 6 shows the performance of a charger controller using photovoltaics. This experiment is to measure and ensure the performance and reliability of charger controllers used in solar-powered battery charging systems. Also, Figure 7 shows the performance of the charging controller using a power supply. In Figure 6 The experiment was carried out starting at 13:50 o'clock. The process of filling in the current and voltage values rose by charging the highest voltage injection of 14.4 volts at 13.50–14.16, which was the optimum charging time, but at 16:19 o'clock, the weather was cloudy, which caused the voltage value followed by the current to decrease until 14:51 o'clock. In this phase, the charging period is paused because the energy supplied has not reached maximum energy. Then the voltage value at 15:00 o'clock entered the bulk period, namely maintaining the position of charging voltage and current withdrawal because the battery capacity almost reached 100% full point with a voltage range of 14.3 volts and a current of 0.6 Amperes. Exactly from 15:32 to 16:00 o'clock, the battery maintains the charging position and avoids supplying power to the load, and the voltage and current slowly drop to about 13.4 volts and start to get close to zero. When the current approaches zero, the battery's charging stops. After carrying out experiments on using photovoltaics as the main source, then use the power supply to charge the battery.

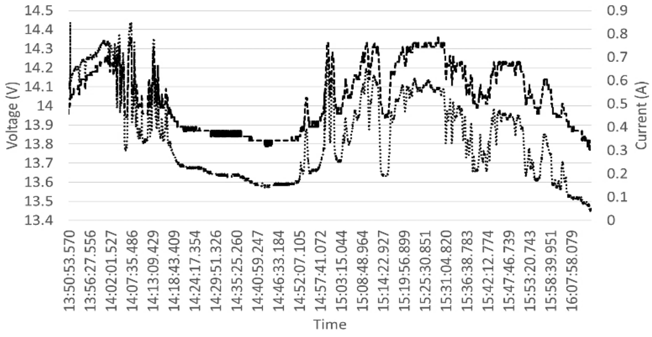

Figure 6. Voltage and current charging using PV

In the experiment on Figure 7 results of charging the VRLA battery using a power supply source, it was obtained that the input was injected constant at a voltage range between 17.64 volts and dropped to 17.58 volts. began to decrease the ability to supply voltage and current at 17:09 –17 :12 o'clock; in the next phase the battery maintained its voltage and current value, decreased at 17:13 o'clock, entered the float phase and stopped charging at 17:19 o'clock. In this experiment, the time required to charge the battery from 13.5v to 14.4 volts is about 15 minutes with a starting current of 1.9 Amperes. This is due to the constant value of the supply voltage, so charging goes fast. Unlike the use of a PV-charger-controller, which is supplied by a fluctuating PV-voltage and current, it requires a charging time of 260 minutes from 13:50 to 16:10 o'clock with a maximum current of 0.8 Amperes.

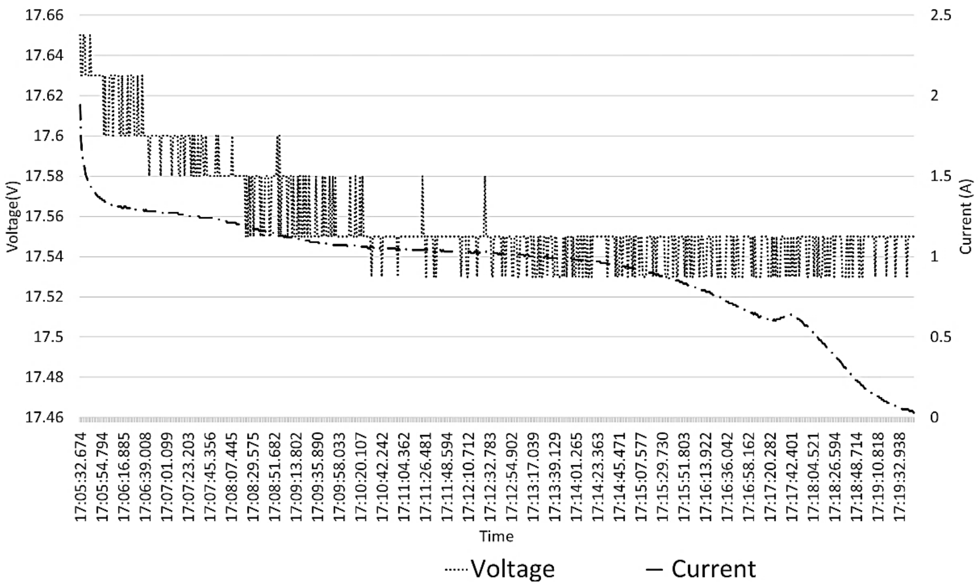

Figure 7. Voltage and current charging using power supply

4. CONCLUSION

The automatic transfer switch tested in this research can be applied on DC system application with the application of an algorithm that is designed to prevent backflow at the output of the charger controller to the SCC input. The ATS can be operated for four sources alternately according to the priority of the input voltage. Millis as coding, which provides a constant switch transition speed performance of around 0.6453 seconds for switches from buck to SCC, 0.658 seconds for SCC to PSU, 0.656 seconds for PSU to CC PSU, and 0.61 seconds for PSU to OFF. The charging process is also the focus of this research, considering that it is equipped with battery energy storage. In testing with a 13.5-volt discharge voltage. By using a PSU with a stable source, charging the battery can be done quickly and more efficiently within 15 minutes. However, keep in mind that fluctuating PV energy requires a longer time to achieve the same results in battery charging. Therefore, the selection of appropriate energy sources must be adjusted to meet the needs and environmental conditions. With a PV of 20 watts and an initial battery voltage of 13.5v, it can charge the battery fully with a charging time of 260 minutes.

ACKNOWLEDGEMENTS

This research was supported by the State Polytechnic of Malang, under Applied Master Thesis Research Grant, year of 2023.

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