Effect of Energy Consumption for the Solar Light Rail

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Abstract

A power supply method for a light rail system which runs on 100% renewable energy is proposed by authors, and several experiments with a small scale model and solar panels are carried out to verify the effects of proposal. In this paper, the experiment that is carried out to verify the effect of factors, the number of passengers and interval of rapid charges, on continue running for a long time, is reported. Two passengers rode the railcar 6 to 12 times in 15 to 30 minutes during the science workshop held on 23rd August 2018. The voltage of the primary and secondary electric double layer capacitor (EDLC) units, storage devices for this system, decreased at every running. After the workshop, one person rode the railcar every 15 minutes. The voltage of EDLC units was kept better value during this term. It is confirmed that the number of passenger directly affects energy consumption for one trip, and interval of rapid charge influences energy consumption per unit of time.

Keywords: transportation, renewable energy, electric double layer capacitor

1. Introduction

A power supply method for a light rail system which runs on 100% renewable energy such as solar, wind and hydro power is proposed by authors, and this light rail system is named as “the Solar Light Rail”. Fig. 1 shows the proposed power supply method: 1) Solar panels are mounted on roofs of station platform, small scale wind turbines are installed at the station. Furthermore, solar panels and wind turbines are installed around the station. 2) An electric double layer capacitor (EDLC) unit is installed at the station as an energy storage device. This EDLC unit which is called as “the primary EDLC” in this system is always charged with solar panels and wind turbines. 3) Railcars also have energy storage devices. An EDLC unit used for energy storage device mounted on the railcar, and it is called as “the secondary EDLC” in this system. When the railcar stops at the station, the secondary EDLC is charged rapidly from the primary EDLC. 4) The railcar runs to the next station with charged

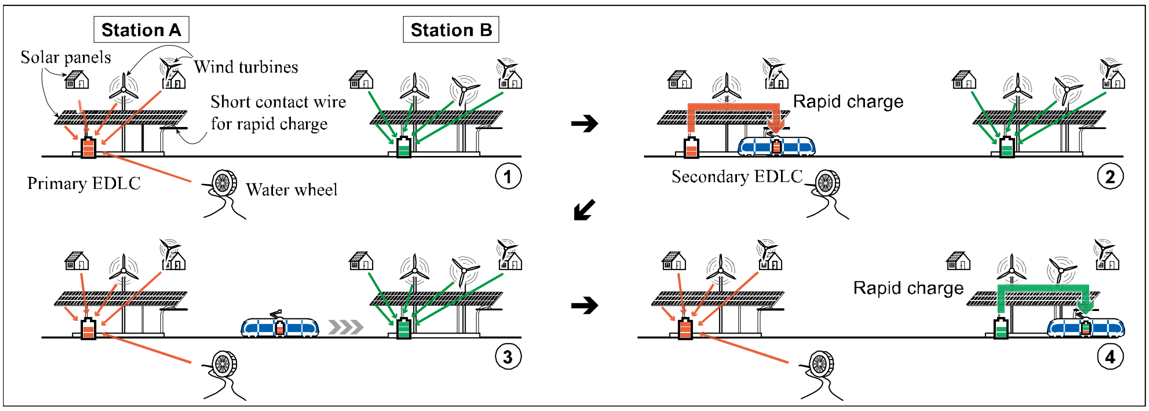

Fig. 1: Proposed power supply method for the Solar Light Rail

doi:10.18086/swc.2019.51.03 Available at http://proceedings.ises.org

electricity. There is also renewable energy generation and the primary EDLC at the next station, and the secondary EDLC is charged again. The railcar continues running through this cycle.

EDLCs are suitable energy storage device for this system. In this system, energy storage devices are always charged and discharged, and rapid charges during train stopping at the station are required. Recharge cycles of EDLCs are at least 10 to 100 times longer than that of rechargeable batteries. High electric current is able to be put into and out from EDLCs. According to the test outcome by the Railway Technical Research Institute of Japan, their hybrid light rail vehicle consumes 8.9 MJ of electricity per kilometers at the maximum air conditioning load. If the interval between stations is 500 m for the assuming Solar Light Rail line, 4.5 MJ of electricity is required to reach the next station. When the voltage of secondary EDLC is 1500 V, the required capacitance of 4 F is calculated with eq. 1. The required time for rapid charge is calculated with eq. 2. It takes 6 seconds to charge required electricity from primary EDLC to secondary EDLC at 1000 A.

$$W = \frac{1}{2}CV^2 \qquad \text{[J]} \qquad \text{(eq. 1)}$$

$$Q = CV = It \qquad \text{[C]} \qquad \text{(eq. 2)}$$

Several experiments with the ride-able small scale model and solar panels are carried out in order to verify the effects of proposed power supply system. Fig. 2 shows the voltage transition during one of the previous experiments, held on 1st November 2016, at Tama Art University, Tokyo, Japan. The sunrise of the day was 6:03 and sunset was 16:46. It was rainy in early morning, and it became sunny in the afternoon. In this experiment, an author whose weight is 65 kg rode the railcar, and went forward and backward 1time on the 14.4 m of straight rail after 2 minutes of rapid charge. Interval of rapid charge was fixed to 15 minutes at the beginning of the experiment, and the interval was shortened from 15 minutes to 10 minutes after 19:00. The voltage of primary EDLC rose high enough during daytime, and railcar continued running with charged electricity after sunset. Finally, the railcar stopped at 22:56 and the final rapid charge was carried out at 22:50.

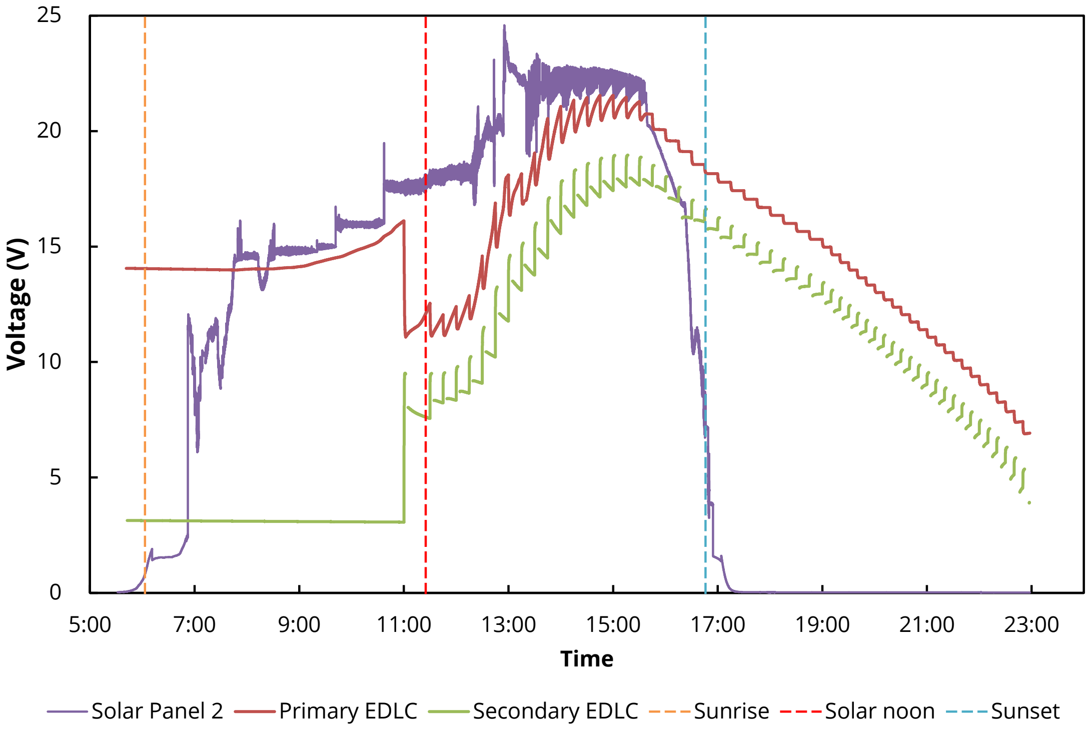

Fig. 2: Voltage transition under the experiment held on 1st November 2016 in Tokyo, Japan

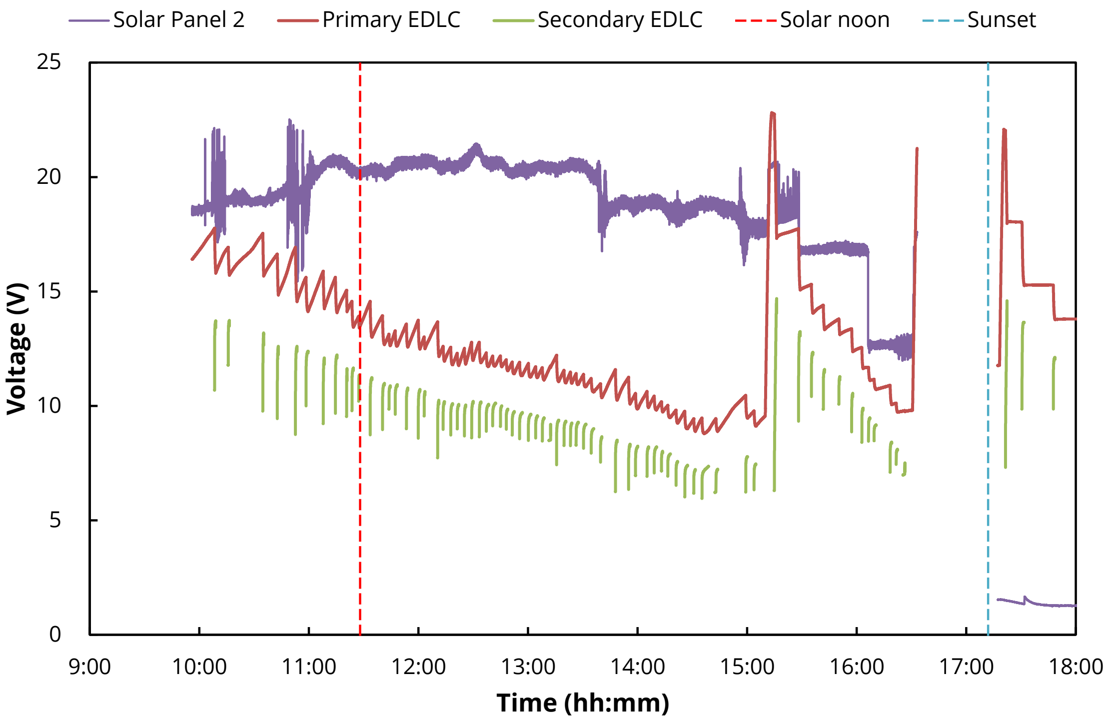

Fig. 3: Voltage transition under the science workshop held on 10th October 2016 in Tokyo, Japan

The final rapid charge would be carried out at 24:45 if the interval was not changed.

A science workshop for children was held on 10th October 2016 at Tokyo Tower, Tokyo, Japan. Fig. 3 shows the voltage transition recorded during the workshop. It was overcast from early morning. The event started at 10:00. Many children and their parent rode and enjoyed round trips. The railcar worked without rest, and the voltage of primary EDLC and secondary EDLC continued falling from the beginning of the event. Since the voltage of primary EDLC and secondary EDLC became too low to continue running, the primary EDLC was charged from a battery which is charged with the biomass fired Stirling engine generation system at 15:10, 16:30 and 17:18, and the railcar was able to continue running until the end of the event.

Three factors, daylight, interval of rapid charge and number of passengers, are different between these two experiments, and these three factors seem important to obtain better result. In the former experiment, enough daylight to raise the voltage of primary EDLC, 15 or 10 minutes of fixed interval for rapid charge and 65 kg of 1 passenger brought good result. On the other hand, unfortunate result was obtained from the latter experiment with low daylight, irregular and short interval for rapid charge and 2 passengers. Two types of experiments under similar daylight, different interval and number of passengers, was held in one day. In this paper, what factor is more influential to keep the voltage of EDLC units higher in order to continue running for a long time after sunset, is reported.

2. Experimental method

Fig. 4 shows the summary of experimental equipment. Three solar panels, Solarland SLP025-12U, are connected in parallel to the primary EDLC. The primary EDLC is made with eight 1200 F EDLC cells, Maxwell Technologies BCAP1200 P270, which are wired in series. The maximum voltage of the primary EDLC is 21.6 V and the capacitance becomes 150 F. Eight 650 F EDLC cells, Maxwell Technologies BCAP0650 P270, are wired in series for the secondary EDLC. The maximum voltage of the secondary EDLC is 21.6 V and the capacitance becomes 81.25 F. During the rapid charge, the secondary EDLC is connected to the primary EDLC through a limited current circuit for safety. The maximum current is limited under 12.5 A by this circuit.

A science workshop for children was held on 23rd August 2018 from 10:00 to 12:30 at Coppin State University, Baltimore, USA. Participants were divided into three groups and each group enjoyed for workshops in turn.

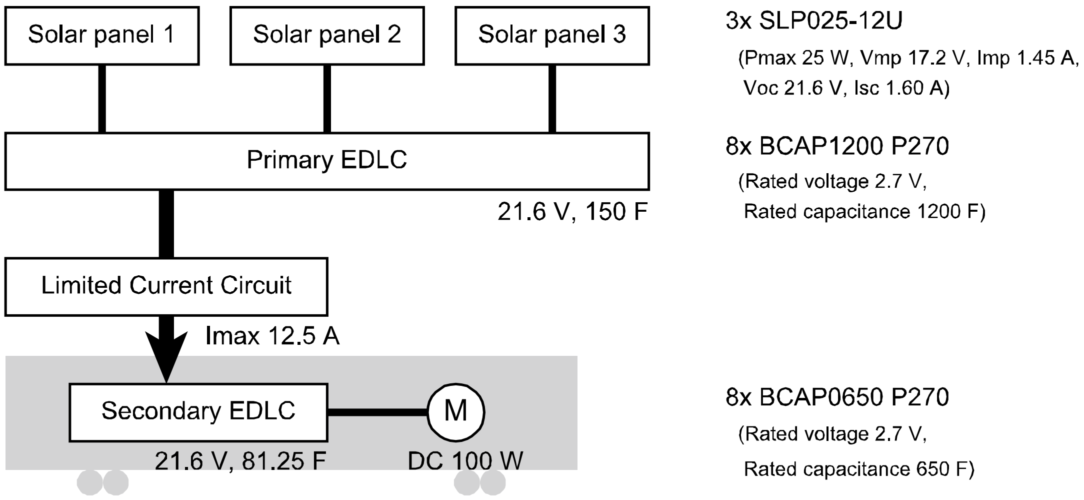

Fig. 4: Summary of experimental equipment

Demonstration of the Solar Light Rail was carried out during the workshop. Two participants rode the railcar, and went forward and backward on the 13.7 m of straight rail. The secondary EDLC was charged during explanation to passengers, and each charging time was less than one minute.

After the workshop, the railcar was operated at fixed intervals. Rapid charges from the primary EDLC to the secondary EDLC were carried out for two minutes. The author, 65 kg in weight, rode the railcar alone and went forward and backward on the 13.7 m of straight rail after the rapid charge. An interval between a rapid charge and the next rapid charge was kept in 15 minutes, and this fixed interval experiment was carried out from 13:00 to 17:00.

Voltage of a solar panel, the primary EDLC and the secondary EDLC were recorded with data acquisition system IOtech Personal Daq/55.

3. Results and Discussion

Fig. 5 shows the voltage transition of a solar panel, the primary EDLC and the secondary EDLC on the day. Three demonstration sessions were held from 10:20 to 12:30, and an experiment at fixed interval was carried out from 13:00 to 17:00. In this paper, the former period is named as “Workshop phase”, and the latter period is named as “Experimental phase”. Sunrise was 6:26, solar noon was 13:09 and sunset was 19:50 on 23rd August 2018 in Baltimore, USA.

Fig. 6 shows details of voltage transition during demonstration session for the 1st group of workshop participants. In the beginning of the session, the voltage of secondary EDLC was 17.18 V, and the voltage was dropped to 14.85 after two round trips for two pairs. After the rapid charge, the voltage of secondary EDLC increased to 15.28 V, and the voltage of primary EDLC became 18.88 V. Voltage of secondary EDLC during the trip was not recorded since the cable for recording was disconnected during running. From the 3rd pair, rapid charge from primary EDLC to secondary EDLC was always carried out after the trip. In this session, the voltage of primary EDLC hardly rose during each trip. The voltage of primary EDLC after rapid charge (blue circles on the figure) decreased from 18.88 V to 18.37 V, and the voltage of secondary EDLC after rapid charge (orange circles on the figure) was also dropped from 17.18 to 14.34. Decreasing the voltage of primary EDLC and secondary EDLC after rapid charge leads to the electricity shortage to continue running for a long time.

Fig. 7 shows the voltage transition during the demonstration session for the 2nd group. The voltage of primary EDLC after the first rapid charge in this session was 18.42. During the second trip for this session, the voltage of primary EDLC rose to 18.47. In this session, the voltage of primary EDLC rose every time during the trip. However, the voltage of primary EDLC after rapid charge decreased from 18.42 V to 17.94 V, and the voltage of secondary EDLC after rapid charge dropped from 17.06 V to 14.91 V. Fig. 8 shows the voltage transition

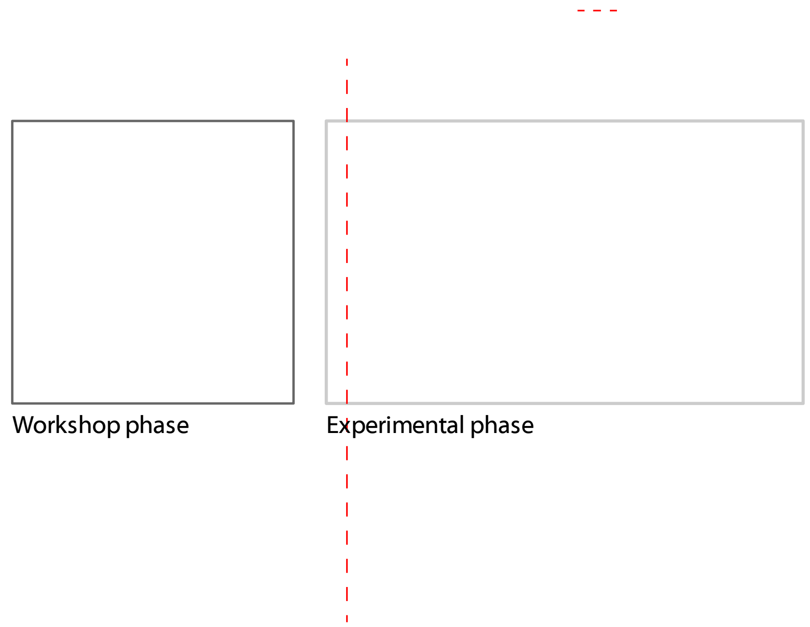

Fig. 5: Voltage transition under the science workshop and experiment after the workshop on 23rd August 2018

during the 3rd demonstration. The best result was expected since this period was nearest from the solar noon in the Workshop phase. The voltage of primary EDLC rose during the trip likewise the 2nd session. However, the voltage of primary EDLC after rapid charge decreased from 18.43 V to 17.92 V, and the voltage of secondary EDLC after rapid charge declined from 16.75 V to 14.44 V.

Fig. 9 shows the voltage transition of a solar panel, primary EDLC and secondary EDLC during the

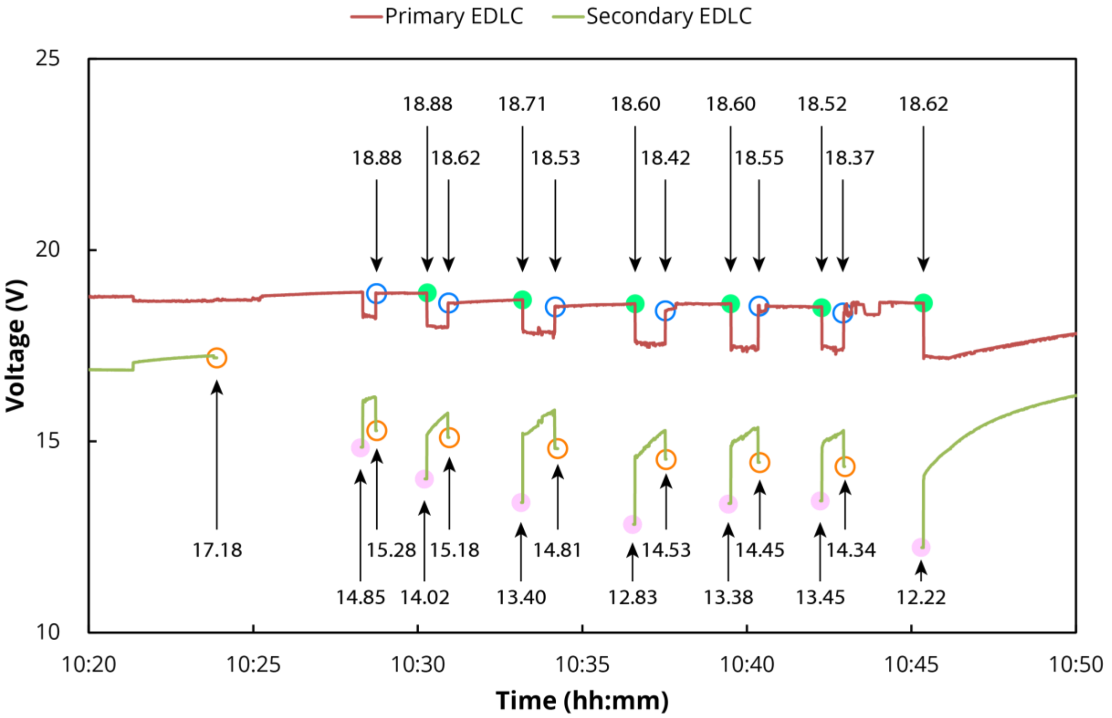

Fig. 6: Voltage transition of the primary EDLC and the secondary EDLC during workshop for the 1st group

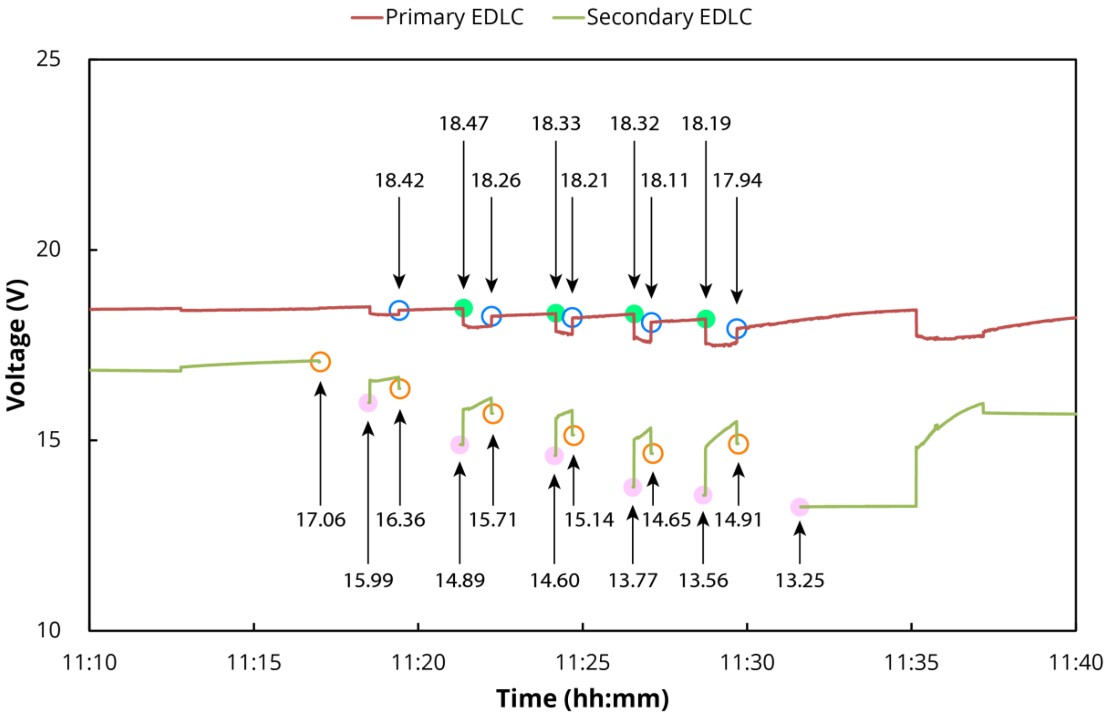

Fig. 7: Voltage transition of the primary EDLC and the secondary EDLC during workshop for the 2nd group

Experimental phase. Since rapid charges carried out every 15 minutes, the voltage of primary EDLC dropped at equal interval. The voltage of a solar panel fluctuated after 14:15, and sometimes became lower than the voltage of primary EDLC. Buildings around the workshop booth cast shade on the solar panels put on the ground from 16:00. After 16:00, the voltage of primary EDLC decreased by rapid charges, and the voltage of primary EDLC after rapid charge became lower than 18 V at 16:17. The voltage of secondary EDLC after round trip leveled off,

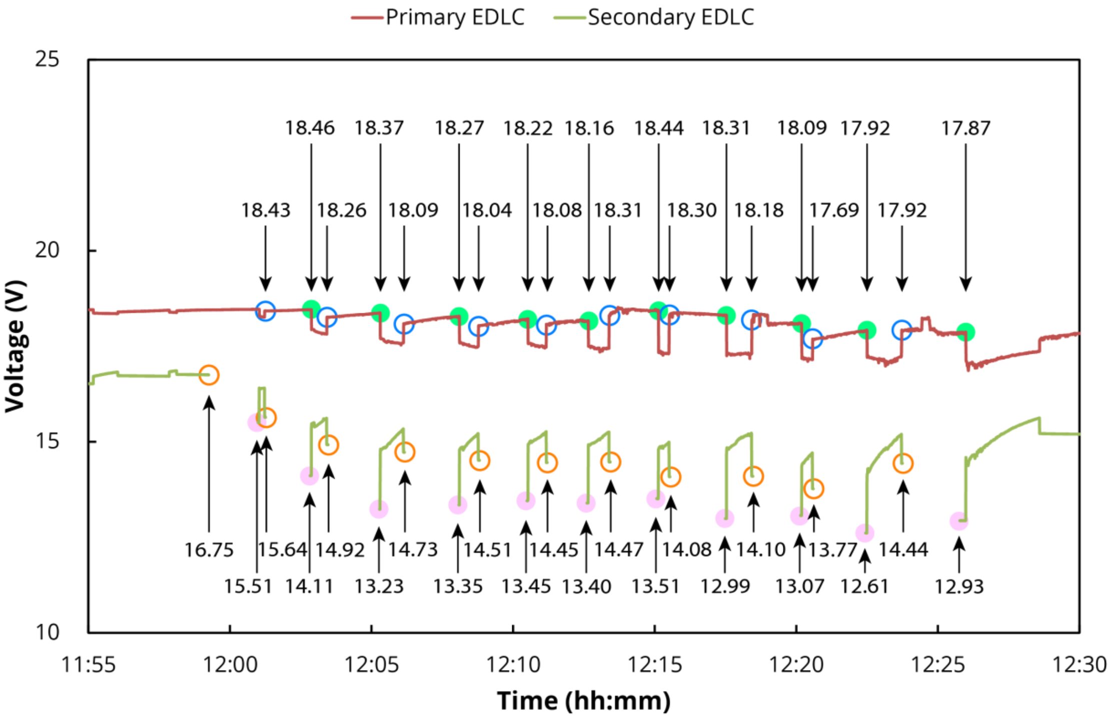

Fig. 8: Voltage transition of the primary EDLC and the secondary EDLC during workshop for the 3rd group

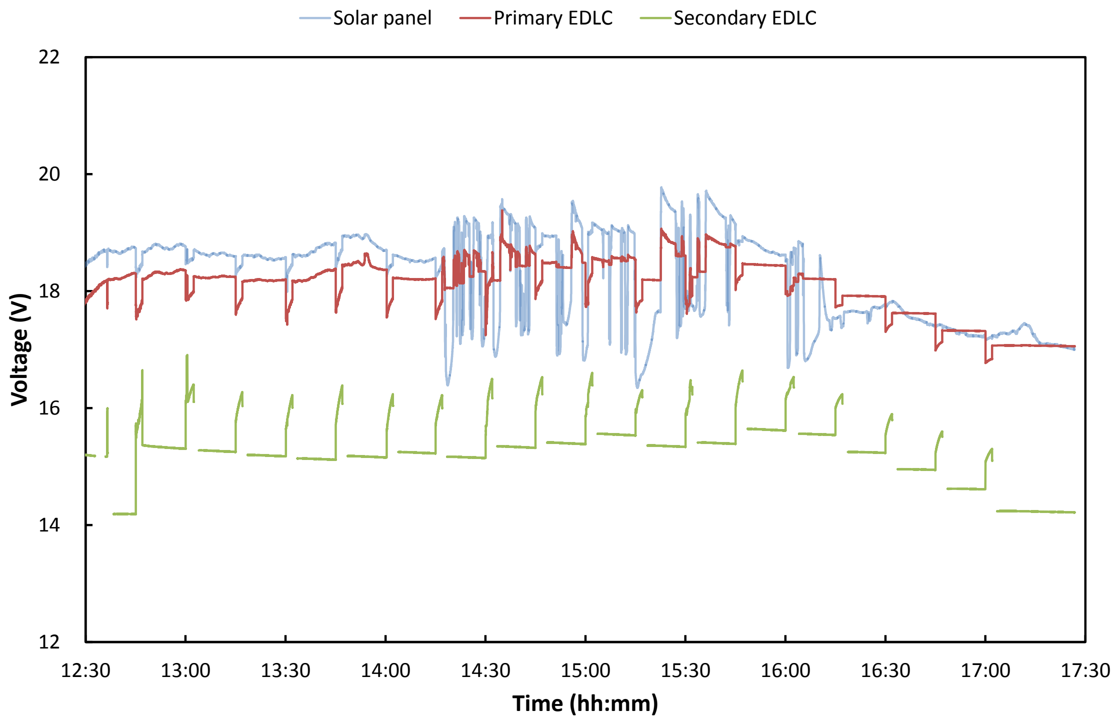

Fig. 9: Voltage transition of the primary EDLC and the secondary EDLC during the Experimental phase

and was kept higher than 15 V until 16:33.

Fig. 10 shows the details of the voltage of primary EDLC and secondary EDLC from 13:00 to 14:15. The voltage of primary EDLC after the first rapid charge completed at 13:02 was 18.25 V. The primary EDLC's voltage was only 18.24 V at 13:15 even though the primary EDLC was charged with solar panels for 13 minutes. Similarly, the voltage of primary EDLC changed from 18.16 V to 18.20 V, from 18.18 V to 18.38 and from

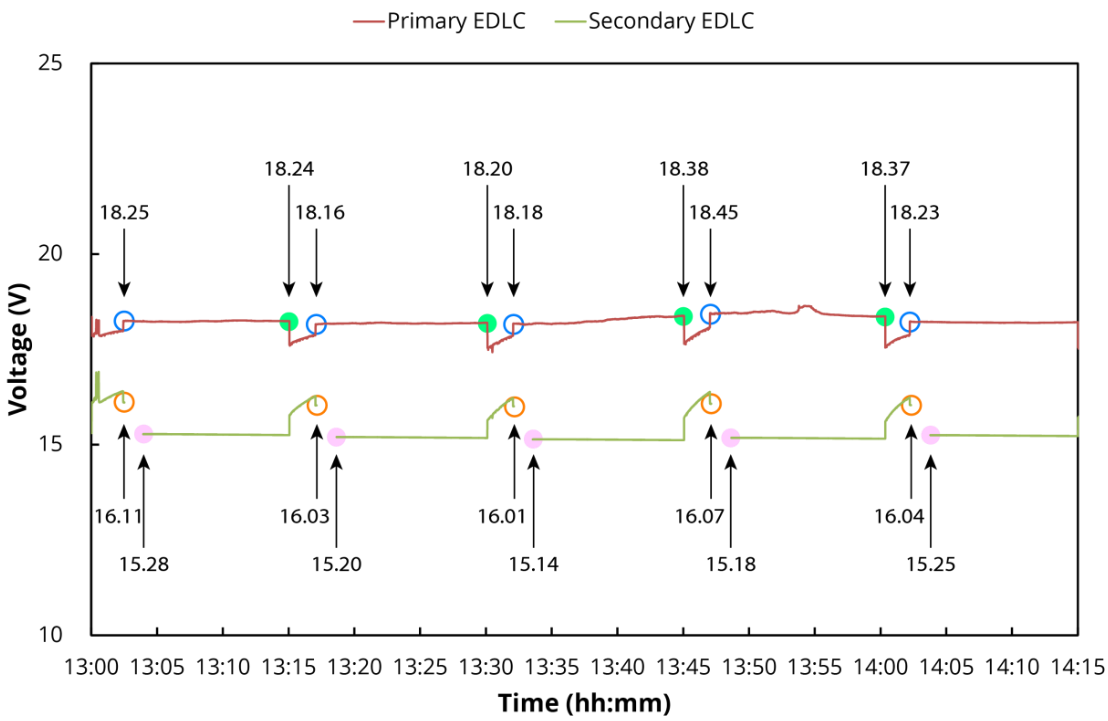

Fig. 10: Voltage transition of the primary EDLC and the secondary EDLC from 13:00 to 14:15 (Experimental phase)

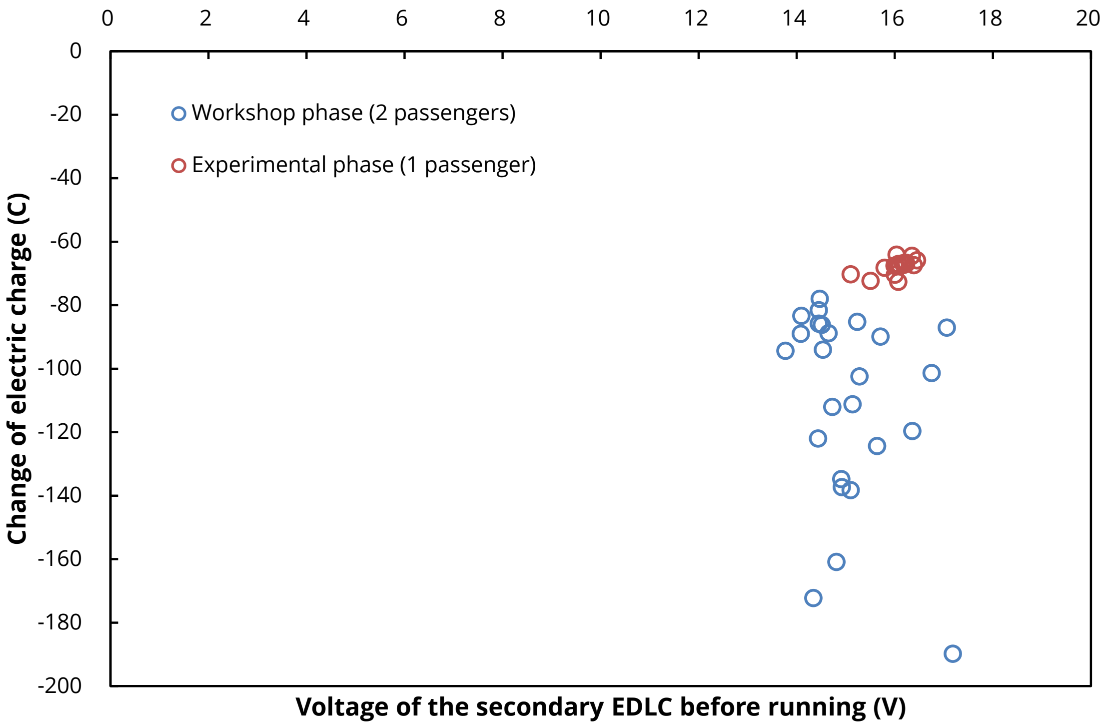

Fig. 11: Change of electric charge for each running

18.45 V to 18.37 V during 13 minutes. The voltage of primary EDLC after rapid charge leveled off from 13:00 to 14:15. The voltage of secondary EDLC after rapid charge and after trip also changed like plateau.

Number of passengers is one of the featured factors in this paper. At the first trip for 2nd group in Workshop phase, the voltage of secondary EDLC dropped from 17.06 to 15.99 as shown in Fig. 7. Since the capacitance of secondary EDLC is 81.25 F, 86.94 C of change of electric charge (Q) is calculated with eq. 2. Fig. 11 shows the change of electric charge for each running. It is clear that decrease of electric charge for 1 passenger is lower than that of 2 passengers. Decrease of electric charge means energy consumption, and weight of passengers means load for a railcar. Lower load causes lower energy consumption.

Interval of rapid charge is also important factor in this experiment. In the Workshop phase, the voltage of primary EDLC increased 0.23 V in 1 minute 52 seconds from 12:20 to 12:22 as shown in Fig. 8, and primary EDLC voltage rose several times during trips. However, the voltage of primary EDLC hardly increased during 15 minutes interval in the Experimental phase. In this experiment, voltage raise of primary EDLC was not expected, and clear advantage was not found from fixed and longer interval. However, interval of rapid charge influences energy consumption per unit of time. In the Experimental phase, the interval of rapid charge was 15 minutes, and in average 70 C of electric charge was decreased in 15 minutes. In the Workshop phase, railcar went trips for 6 times, and 631.31 C of electric charge was decreased from 11:17 to 11:31.

Number of passenger means load for the railcar, and influences energy consumption for one trip. Interval of rapid charge influences energy consumption per unit of time. In the Workshop phase, the voltage of primary EDLC and secondary EDLC continued decreasing since total amount of energy consumption was higher than obtained electricity from solar panels. In the Experimental phase, the voltage of primary EDLC and secondary EDLC did not decrease until 16:00 since total amount of energy consumption was equal or lower than obtained electricity from solar panels. Low machining accuracy and inefficient electric circuit for equipment also influence energy consumption for one trip. There is room for improvement on our handmade equipment, and further result is expected in the future.

4. Conclusion

Two different types of experiment were carried out in one day to verify the effect of factors, number of passenger and interval of rapid charge, on continue running for a long time. During the science workshop held in the morning of the day, two participants rode the railcar, and the railcar ran 6 to 12 times in 15 to 30 minutes. The voltage of primary EDLC and secondary EDLC continued decreasing during the workshop. After the workshop, an author rode the railcar alone every 15 minutes for four hours. The voltage of primary EDLC after rapid charge was kept over 18 V until 16:17, and the voltage of secondary EDLC after rapid charge was kept over 15 V until 16:33. 1 passenger brought lower decrease of electric charge, and low load caused low energy consumption for one trip. Longer interval of rapid charge did not bring raise of the voltage of primary EDLC in this experiment. However, it is confirmed that interval affects energy consumption per unit of time. Improvement of handmade equipment also influences energy consumption for one trip, and better experimental result with improvement is expected to realize the Solar Light Rail in the future.

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