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Experimental Verification of Electric Vehicle Using Electric Double Layer Capacitor

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Abstract – This paper discusses to conduct experimental verification of two types of micro electric vehicles (EV) in order to realize improvement in electric mileage and shorten a charging time of the battery. First, electric double layer capacitor (EDLC) systems to use as a secondary battery are proposed. The internal resistance of EDLC is small compared with a rechargeable battery, and it is suitable for momentary charge-discharge of EV. Next, control circuits of the capacitors to increase the regenerative electric power are utilized. Then, a novel method to charge a main battery of the EV is introduced. Finally, experimental results demonstrate the validity of the proposed method.

Keywords: Electric Vehicle, Electric Double Layer Capacitor (EDLC), Regenerative Power

1. Introduction

Recently, electric vehicles research and development has been investigated in order to solve the problem of global warming and fossil fuel depletion. EV does not emit exhaust gas at the time of driving. Motor toque generates fast and accurate, and it can be measured precisely. Thus, the major advantages of electric drives are the effective control traction force applied between the tire and the road surface [1]-[3].

However, range between recharges of EV is shorter than internal-combustion engine car, because EV cannot load many batteries from restrictions of weight of vehicle or capacity. And, charging time of EV is longer than refueling time of internal-combustion engine car.

Here, this paper verify new charger which employ a new charging method (Advanced I.C&C Technique) developed by Techno Core International Co., Ltd to shorten the charging time [4].

And then, this paper presents applications of Electric Double Layer Capacitor (EDLC) into rechargeable batteries [5], [6]. For example, the electric vehicle Capacitor COMS, which has only EDLC as the electric energy source, has been reported in the literatures [7] and [8].

Since EDLC is based on a physical reaction and the resistance is also small, the electric capacity is large and it is possible to charge and discharge rapidly compared with rechargeable batteries. In this research, EDLC is connected in parallel with main rechargeable battery in order to reduce the electricity consumption of the battery and increase regenerative power from the driving motor. Finally, experimental results demonstrate the validity of the proposed method by two types of micro EVs (COMS LONG and e-ZONE).

2. Specifications of Electric Vehicles

In this research, we have used two type of micro EV to verify the characteristic of the charge and drive. Below we have listed specifications of micro EVs.

2.1 COMS LONG

COMS LONG is a one-seat EV which is made by Toyota Auto Body Co., Ltd. Fig. 1 shows its outlook. As the motors are very small, two motors, which are permanent magnet synchronous motors, are installed in rear wheels with planetary gears. Its drive train consists of rechargeable batteries, three phase inverters, dc-dc converter and PMSMs. Table 1. shows specification of COMS LONG.

2.2 e-ZONE

e-ZONE is a two-seater small EV made by CT&T. The type of car in Japan is a kei car. Fig. 2 shows the outer appearance of e-ZONE.

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Fig. 1. COMS LONG

Table 1. Specification of COMS LONG

Vehicle Total Weight	405[kg]
Maximum Speed	50[km/h]
range	45[km]
Battery	12[V]-52[Ah] (Lead Acid)*6 in series
Charging Time	13 [hour]
Number of Seats incl. driver's	Single Passenger
Motor	PMSM (Max 2[kW])
Inverter	Transistor Inverter
Control Method	PWM vector control
Drive System	Rear Wheel Drive

Fig. 2. COMS LONG

Table 2. Specification of e-ZONE

Vehicle Total Weight	520[kg] (except batteries)
Maximum Speed	54[km/h]
range	50-70[km]
Battery	12[V]-165[Ah] (Lead Acid)*6 in series
Charging Time	8 [hour]
Number of Seats incl. driver's	Double Passenger
Motor	IM (Max 7[kW])
Maximum Torque	90[Nm]
Drive System	Rear Drive

The specification of e-ZONE is described in Table 2. The drive train comprises rechargeable batteries, single PMSM, inverter, gears and drive shaft. The batteries are lead acid rechargeable batteries which the total voltage is 72[V] same as COMS LONG.

3. EDLC System

3.1 Electric Double Layer Capacitor (EDLC)

The driving performance of EVs is very good, but range between recharges of EV is shorter than internal-combustion engine car. In this paper, Electric Double Layer Capacitor (EDLC) is used to lengthen range of the EV and assist the main battery.

High energy density batteries have been developed for many years which are utilized as energy sources for many electric vehicles. However, these have some problem such as low time constant and low power densities. EDLC is a high power density and low internal resistance energy storage device that can deliver excellent charge-discharge cycle life in comparison with common rechargeable batteries [9]. Because the internal resistance of EDLC is small compared with rechargeable batteries, it is suitable for momentary charge-discharge of EV. Then, recently, EDLC is widely used to assist batteries of mechatronics equipment.

Fig. 3 depicts our EDLC module by Nippon Chemi-Con Corporation. Table 3. indicates the nominal value of EDLC module.

3.2 Capacitor Control Circuit

In this research, EDLC is connected in parallel with main rechargeable batteries. Furthermore, we have utilized a capacitor control circuit (CCC) in parallel with batteries and EDLC to increase the ratio of utilization of EDLC. The proposed capacitor control circuit is installed between rechargeable batteries and EDLC, as shown in Fig. 4. The capacitor control circuit can be disconnecting the batteries by measuring the battery terminal voltage and the circuit current. Accordingly, the capacitor control circuit can reduce the power consumption and the self-discharge of the batteries. Here, Fig. 5 shows the capacitor control circuit made by Nissin Denshi Kogyo Co., LTD.

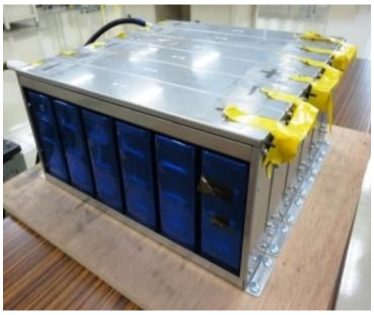

Fig. 3. EDLC module

Table 3. Specification of EDLC module

Voltage	90[V]
Capacitance	66.7[F]
Internal Resistance	36[mΩ]
Weight	24.6[kg]

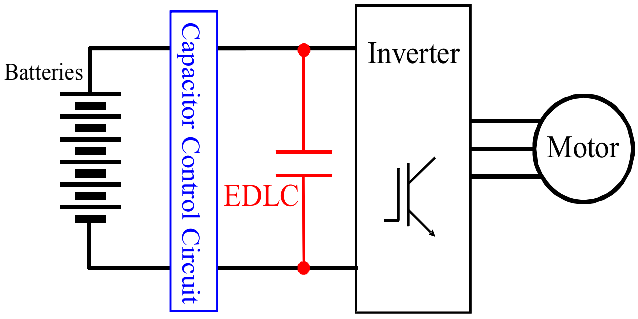

Fig. 4. EDLC System

Fig. 5. Capacitor Control Circuit

4. Charging

4.1 Normal Charging (COMS LONG)

COMS LONG is equipped with normal vehicle installation charger. Charging of the charger is initiated by connecting the charge plug to commercial power source (AC100[V]). Fig.6 shows the charging result (normal charge). From this figure, the charging method of the charger has been constant current charge and constant voltage charge. Here, maximum charging voltage was 100.2[V], maximum charging current was 9.4[A] and charging time was about 11.0[hour].

4.2 Normal Charging (e-ZONE)

e-ZONE is also equipped with normal vehicle installation charger (AC100[V]). Fig. 7 shows the charging result (normal charge). From this figure, the charging method of the charger has been constant current charge and constant voltage charge in the same way as COMS LONG.

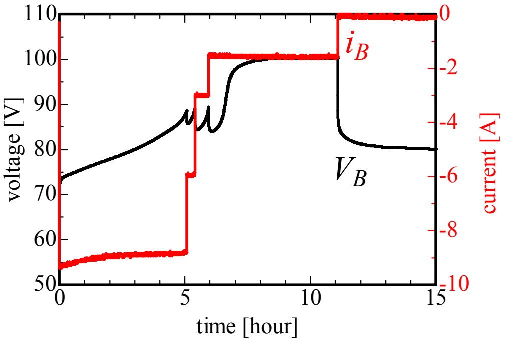

Fig. 6. Charging Result (COMS LONG, Normal Charge)

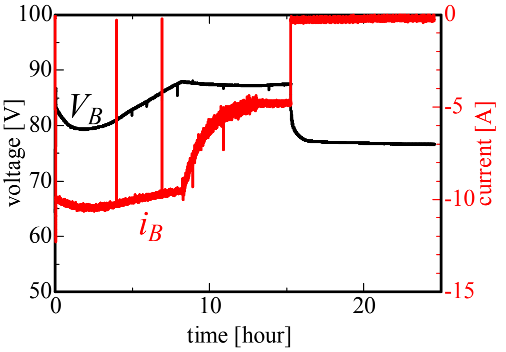

Fig. 7. Charging Result (e-ZONE, Normal Charge)

Here, maximum charging voltage was 88.0[V], maximum charging current was 12.4[A] and charging time was about 15.0[hour].

4.3 Advanced I.C & C Rapid Charging (COMS LONG)

In general, the normal charging of EV is employed constant-current method and constant voltage method. However, if we charge the electric battery using that method, the charging time becomes long. Moreover the battery will become depleted by overcharge. Therefore, in this paper, we have utilized Advanced IC&C principle as battery charging method. In the method, the charging current is the square pulse wave as shown in Fig. 8. Therefore, the open-circuit voltage can be measured, and we can estimate state of charge (SOC) of batteries. When the open-circuit voltage has reached a check voltage, we increase the next check voltage. And we will record the number of times of charging cycles which open-circuit voltage reaches the next check voltage. If the present number of times of charging cycles is twice the last number, charging is terminated.

Fig. 9 shows the normal charging result using Advanced I.C&C method. From this figure, we can see that the charging time was about 4.1[hour], and charging voltage was about 84.2[V].

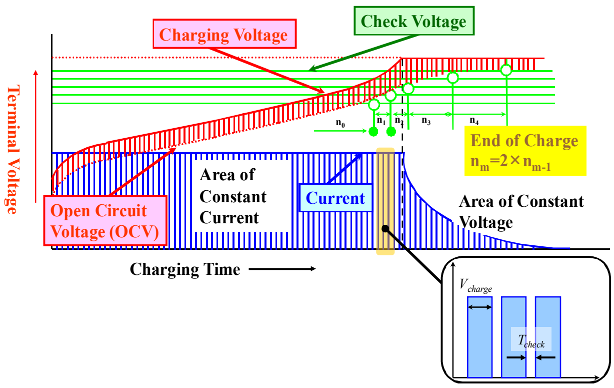

Fig. 8. Advanced I.C & C Charging Theory

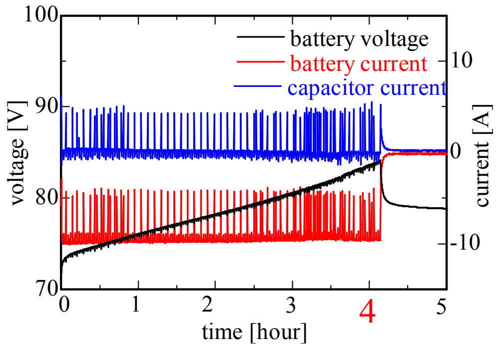

Fig. 9. Charging Result (Advanced I.C & C, Normal Charge)

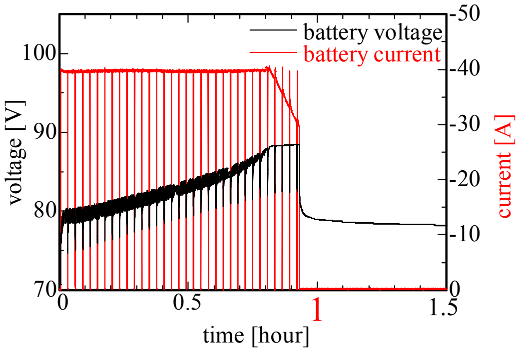

Fig. 10. Charging Result (Advanced I.C & C, Rapid Charge)

Fig. 11. Rapid Charger

Therefore, the charging time and the charging voltage have been significantly reduced than the existing charger. In addition, Fig. 10 indicates the rapid charging result utilizing the rapid charger which made by MEIKO Co., LTD as shown in Fig. 11 [10]. It can be seen that the maximum charging current is 40[A] and the charging time was 1.0[hour].

5. Driving Results

5.1 Stop & Go Drive (COMS LONG)

As previously described, in this research, we propose the capacitor system to EV in order to reduce the power consumption of the main batteries. The driving experiments have been conducted to clarify the validity of the capacitor system.

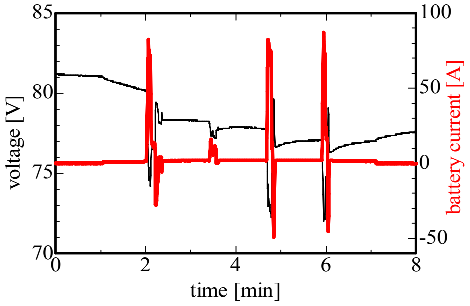

Fig.12. Experiment Result (COMS LONG, Without Capacitor System)

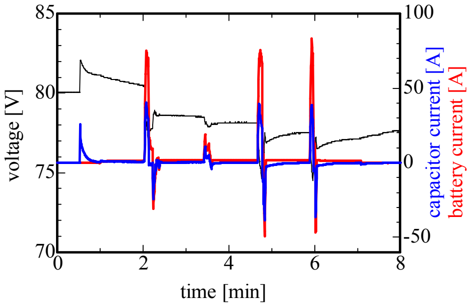

Fig.13. Experiment Result (COMS LONG, With EDLC)

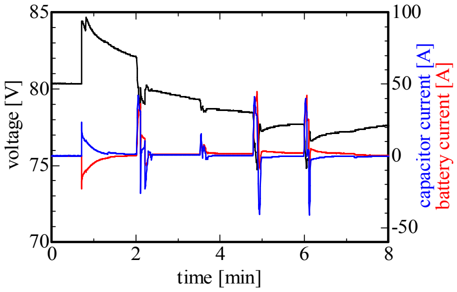

Fig.14. Experiment Result (COMS LONG, With Capacitor System)

Fig. 12 shows the driving experimental result of the stop-and-go without the capacitor system using COMS LONG. Fig. 13 shows the driving experimental result with EDLC. And Fig. 14 shows the driving experiment result with the capacitor system (EDLC and CCC).

Table 4. Stop and Go Results (COMS LONG)

	Max i_B[A]	Min i_B [A]	W [Wh]
Without	82.4	-49.1	7.1
With EDLC	75.6	-49.5	6.2
With Capacitor System	45.0	-8.9	4.8

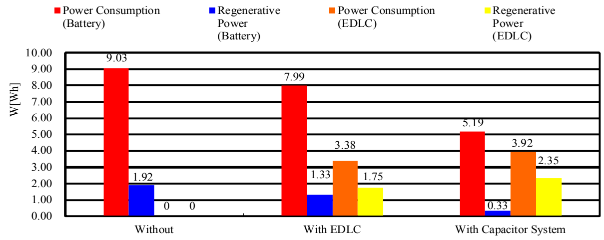

Fig.15. Consumption and Regenerative Power (COMS LONG)

Table IV indicates the driving experiment results of COMS LONG. Here, Fig. 15 is a graphical representation of average of the power consumption and regenerative power of the rechargeable battery and EDLC.

From the results, it is confirmed the effectiveness of capacitor system for COMS LONG.

5.2 Stop & Go Drive (e-ZONE)

Similarly, we have experiment on e-ZONE. Fig. 16 indicates the driving experimental result of the stop-and-go without the capacitor system using e-ZONE. Fig. 17 shows the driving experimental result with EDLC. And Fig. 18 shows the driving experiment result with the capacitor system. And Table V indicates the driving experiment results of e-ZONE. Then, Fig. 19 is a graphical representation of average of the power of the rechargeable battery and EDLC.

Here, the driving motor of e-ZONE is an induction motor. However, there is not the mechanism of the regenerative power of the motor back EMF. Thus, the effectiveness of the capacitor system is small compared to COMS LONG. However, the consumption power of the battery has decreased by 5% using the capacitor system.

By the way, regardless of no regenerative power, the battery current has not been zero when the vehicle stopped. Therefore, in order to charge EDLC, the battery current continues flowing to EDLC.

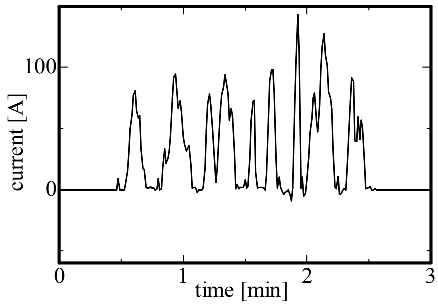

Fig.16. Experiment Result (e-ZONE, Without Capacitor System)

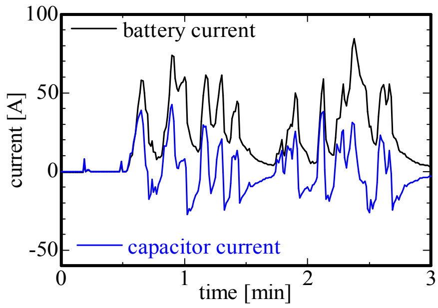

Fig.17. Experiment Result (e-ZONE, With EDLC)

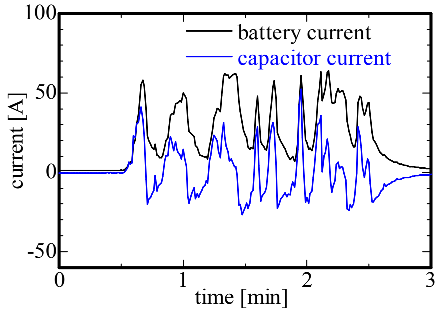

Fig.18. Experiment Result (e-ZONE, With Capacitor System)

Table 5. Stop and Go Results (e-ZONE)

	Max i_B[A]	Min i_B [A]	W [Wh]
Without	143.1	0	84.3
With EDLC	84.4	-27.5	82.8
With Capacitor System	64.1	-26.6	80.7

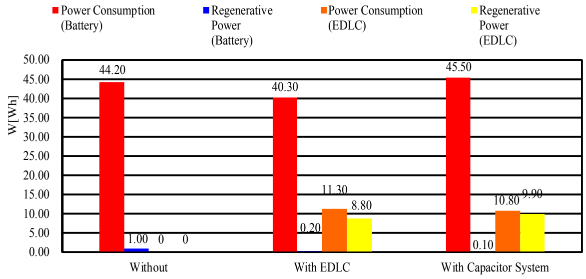

Fig.19. Consumption and Regenerative Power (e-ZONE)

5.3 Mileage per Charge (COMS LONG)

Next, we show the driving results of the mileage per charging, where we have investigated the comparison of the usage of the proposed capacitor system which is EDLC or EDLC plus Capacitor Control Circuit same as the condition of the stop-and-go driving. Fig. 20 and Fig. 21 show the battery voltage and the battery current of the driving experimental results without the capacitor system, respectively. Fig. 22 and Fig. 23 also reveal the results using EDLC. Furthermore, Fig. 24 and Fig. 25 are indicative of the results using the capacitor system. Where, in these figure, black line indicates the battery voltage, blue line indicates the battery current and blue line indicates the EDLC current, respectively.

The results of the mileage per charge driving using COMS LONG are summarized in Table 6. From these results, compared with existing COMS LONG, the method using the EDLC allowed the driving range extension about 12.5 [%]. In addition, the result using the capacitor system (EDLC + Capacitor Control Circuit) has the advantages of the suppression of the battery current in comparison with other experiments. However the method proved hard to extend the driving range. Therefore it remains a challenge for future research to design ratio of the capacity between the batteries and EDLCs.

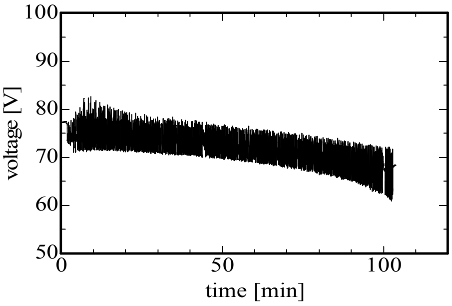

Fig.20. Experimental Result (COMS LONG, Battery Voltage of Mileage per Charge, Without Capacitor System)

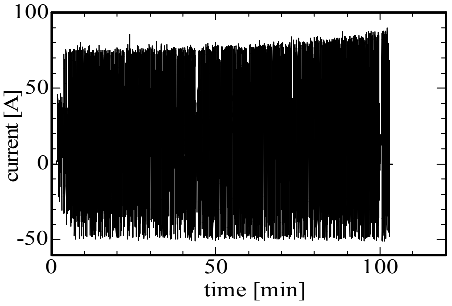

Fig.21. Experimental Result (COMS LONG, Battery Current of Mileage per Charge, Without Capacitor System)

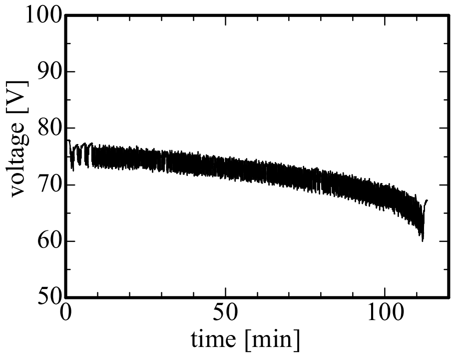

Fig.22. Experimental Result (COMS LONG, Battery Voltage of Mileage per Charge, With EDLC)

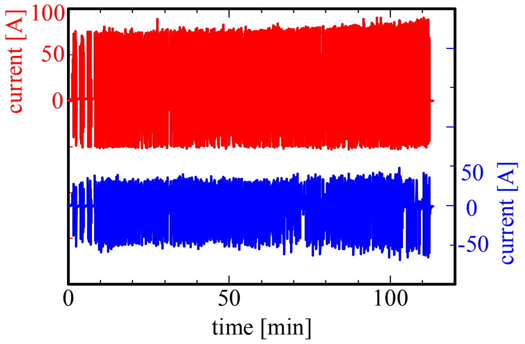

Fig.23. Experimental Result (COMS LONG, Current of Mileage per Charge, With EDLC)

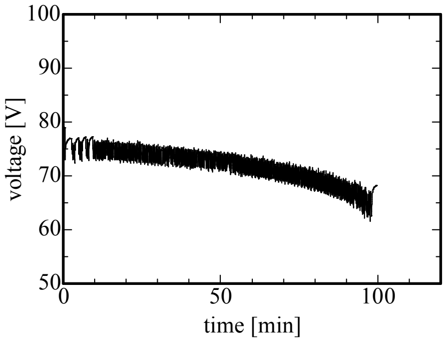

Fig.24. Experimental Result (COMS LONG, Battery Current of Mileage per Charge, With Capacitor System)

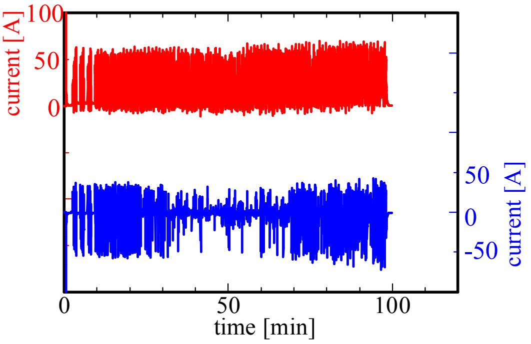

Fig.25. Experimental Result (COMS LONG, Current of Mileage per Charge, With Capacitor System)

Table 6. Driving Results of mileage per charge

	Range [km]	Max. Battery Current [A]	Min. Battery Current [A]	Battery Consumed Energy [Wh]
Without	47.3	90.0	-51.0	3234
With EDLC	53.2	90.0	-53.3	3489
Capacitor System	47.5	69.8	-11.0	3000

5.4 Mileage per Charge (e-ZONE)

Fig. 26 and Fig 27 show the results of the mileage per charge driving using e-ZONE without EDLC. Fig. 28 and Fig. 29 also show the results with EDLC. Where, the maximum battery current of using only battery is 250 [A] and of using EDLC paralleled battery is 204 [A].

From these figure, it is showed that the method using EDLC is much better effect of the suppression of the ripple of battery voltage and the battery current than the existing e-ZONE. Here the range of the results without EDLC is 20.0[km] and the range with EDLC is 24.2[km]. Therefore, the proposed method is effective for the suppression of the battery consumption even when the regeneration is not installed.

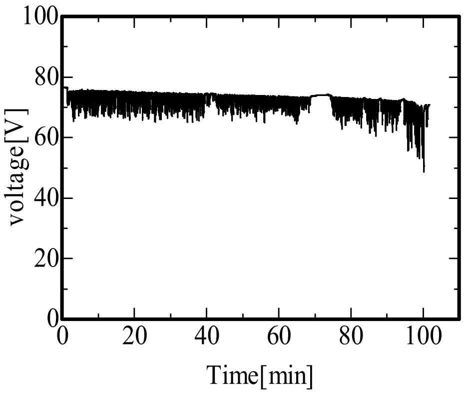

Fig.26. Experimental Result (e-ZONE, Battery Voltage of Mileage per Charge, Without EDLC)

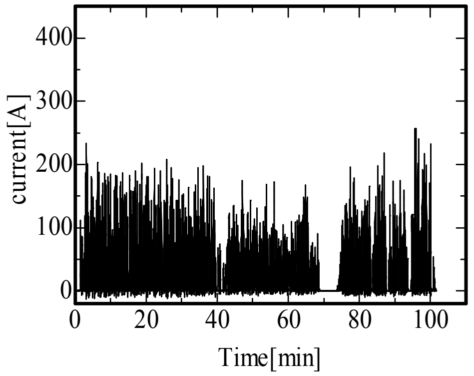

Fig.27. Experimental Result (e-ZONE, Battery Current of Mileage per Charge, Without EDLC)

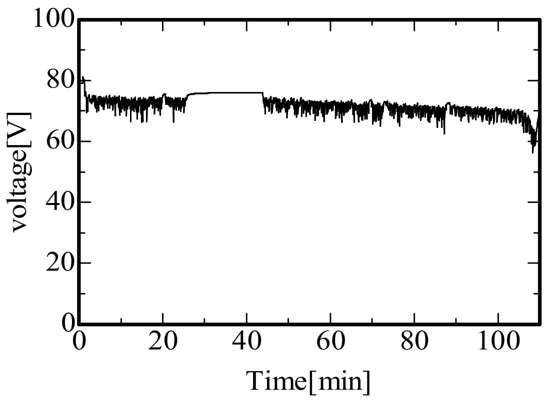

Fig.28. Experimental Result (e-ZONE, Battery Voltage of Mileage per Charge, With EDLC)

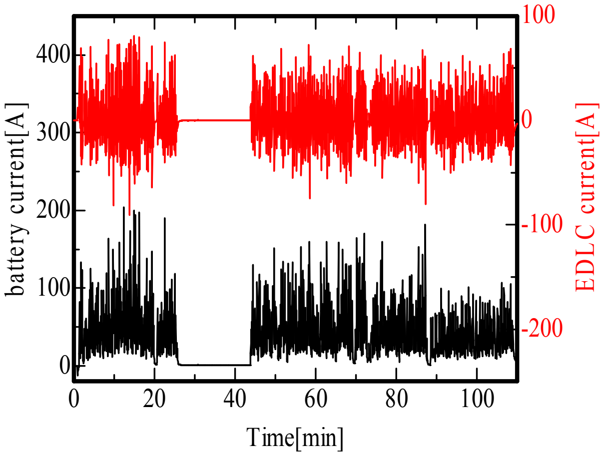

Fig.29. Experimental Result (e-ZONE, Current of Mileage per Charge, With EDLC)

6. Conclusion

In this paper, we conducted the charging experiment and the driving experiment using COMS LONG and e-ZONE.

In the first place, we applied the charging method of Advanced I.C&C to the rechargeable battery which is the power supply of EV. From the experiment results, it was confirmed that the charging method is useful and applicable to many battery charging system.

Secondary, we proposed the capacitor system which consists of the electric double layer capacitor and the capacitor control circuit in order to reduce the consumption power of the rechargeable batteries and extend the driving range. Hence, the validity of the proposed system has been shown by the results of the driving experiments.

The topic of our future researches is to determine the optimal electric capacity of EDLC in view of the cost-effectiveness.

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