Automobile Battery Lifetime Improvement and Evaluation

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Abstract: - In recent years, it is a worldwide problem that air pollution of a big city by automobile exhaust. And improvement plan of global warming is examined. As an example of promotion the development of high-efficiency battery, Rechargeable Battery power supply, hybrid electric vehicle and electric vehicle are developed. In some places, idling stop is carried out, and it is in the situation in which the battery is overworked the commercial vehicle. Therefore, this study discusses an electric double layer capacitor together with the battery in a car power system using conventional battery. Furthermore, new battery simulation model is constructed for a car power supply system. Simulation tool and evaluate improvement method of battery lifetime are studied.

Key-Words: - Idling stop, Automotive battery, Commercial vehicle, Electric double layer capacitor, State Of Charge, State Of Health, State Of Life,

1 Introduction

Recently, in terms of the global environment, the increase of CO_2 is a worldwide problem. The spread of hybrid vehicle and the development of electronic vehicles which are considering for environment protection are actively advanced. In addition, in order to reduce CO_2, a part of Japanese transportation companies encourage driver to do idling stop. However, for commercial vehicle, a battery is overworked by doing idling stop.

This study trend is to combine power storage devices such as EDLC (Electric Double Layer Capacitor) with current established automotive power system, so that it can supply more energy to all kinds of electronic equipments in the automobile together with battery. Battery lifetime can be also extended. The biggest characteristic of EDLC is that it can charge and discharge the for enough times. Base on previous research: ‘Countermeasure for Stop Idling Policy for Automobile Power System’, and actually measured data, a simulation tool is built up with a model of electronic equipments. How to improve battery lifetime with double layer capacitor is presented [1-4].

2 Outline of research

2.1 Automobile electronic system

In automobile, there are kinds of electrical equipments, such as navigation system, power steering and power window. These systems are running all the time after starting the automobile. In order to simplify the above mentioned automobile electronic system, a typical fundamental model is constructed as Fig. 1 shown below.

Fig.1 is the automobile power system supported by alternator and battery. Alternator will change mechanical energy into electronic energy. Mechanical energy is generated by engine which is connected through belt with alternator. The engine rotation speed changes according to automobile’s driving condition, so that the rotation speed of alternator also changes according to the engine rotational speed, so dose voltage. When engine speed increases especially high, regulator control voltage within certain volume to supply the usage of electronic equipments. For a 24V truck, alternator control the voltage to 28.5V. Fundamental model of this research is constructed for a 24V commercial automobile. The battery in the model is to supply power for starter and all sorts of electronic equipments in automobile, and it is charged when automobile runs [6, 8, 11].

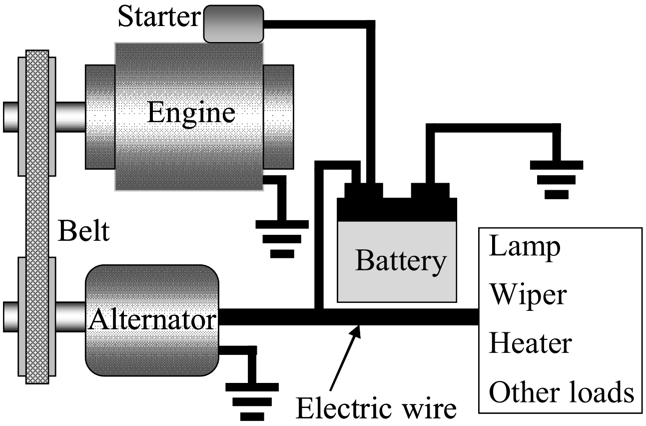

Fig.1. Power system of automobile

2.2 Model of automobile power system

Fig.1. is power system configuration of an automobile which is modeled in Fig.2 as a simplified electronic circuit. R_g is the internal resistance inside of alternator model. As for battery model, it is simulated by capacity and resistance. In order to monitor loss power of charge and discharge, an R_b is connected together with capacity.

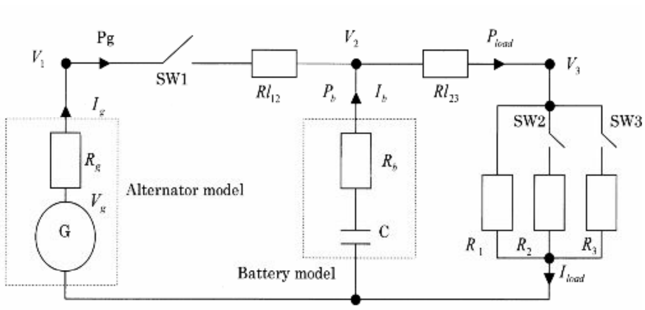

Fig.2. Electrical circuit of automobile Power system

Some data error exists between the simulation result and really automobile because the battery for an actual automobile is an electrical storage device with chemical reaction.

2.3 Automobile battery

With the increase of electronic equipments in the automobile, power consumption of battery is also over loaded. For example, the battery needs to supply power to starter when the engine starts and the battery is charged by electric power from the alternator when automobile runs. Moreover, the battery lifetime is dominant to the condition of automobile. Fig.3 shows the power consumption in a large-scale commercial vehicle [5, 7, 9, 13] .

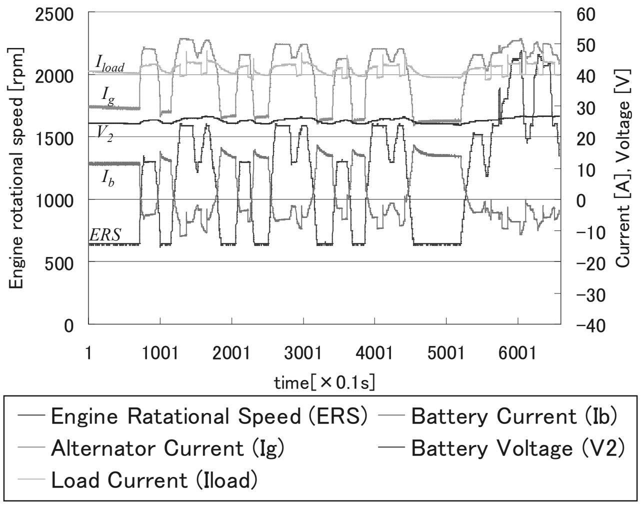

Fig.3. Power consumption graph in large-scale commercial vehicle

Positive current shown in Fig.3 means battery discharge status and negative is charge status. Only from the graph, the battery is kept charging and discharging. The battery is used for all the time and eventually it gets useless. Then the battery has to be replaced. Sometime, due to this problem, the battery is running out of power and even cannot supply enough power to starter to start engine. In a word, even when automobile is not used, battery deterioration progresses and eventually it becomes useless.

2.4 SOC, SOH, SOL

Two indices SOC (state of charge) (1), SOH (state of health) (2) are commonly used as defined [10,12].

$$SOC = \frac{\text{Remaining capacity [Ah]}}{\text{Full charged capacity [Ah]}} \quad \cdots\cdots (1)$$

$$SOH = \frac{\text{Nominal capacity at present time [Ah]}}{\text{Nominal capacity at initial [Ah]}} \quad \cdots\cdots (2)$$

However, in fact, currently exact definition of SOH is not available. Generally it is defined as Eq.(2). Since the full charge capacity decreases due to battery deterioration, SOH will also decrease. So does SOC. Currently the measurement of SOH is still difficult. Then, this research employs SOL (State Of Life) in order to understand the battery lifetime clearly, so that we can also evaluate the battery. SOL is defined with a unique method. Since SOH has been only defined recently, it is very difficult to calculate the full charge capacity under battery's deterioration status. The calculation method has not been established though we have done various researches. Therefore, the definition of SOL is shown below in Eq. (3).

$$\text{SOL} = \frac{\int |i| dt}{70[\text{Ah}] \times 3600[\text{s}] \times 1000\,[\text{times}] \times 2} \quad \cdots\cdots(3)$$

70[Ah] denotes the capacity of the battery of the truck. 1000 (times) × 2 shows 1000 (times) of battery charging and 1000 (times) of discharging. The change of SOL shows the using status of battery. The smaller value of SOL means the longer lifetime of battery. In a word, the smaller of SOL means the better of battery. So use SOL can be used to evaluate battery lifetime.

2.5 Battery model

The charge and discharge of automobile battery is carried out by chemical reaction. Therefore, a highly accurate simulation model of battery is required regarding, and the simulation model is built into the automobile electrical system circuit model. The model is featured by temperature characteristics and the charge-discharge characteristics. In order to evaluate validity of simulation tool, lead battery model shows below as Fig.4, which has the same characteristics with automobile battery that is used shows the characteristics of V-SOC-I [14].

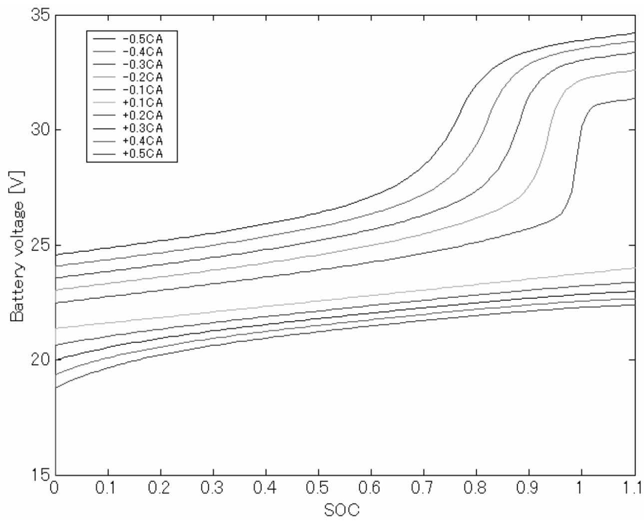

Fig.4. Battery model V-SOC-I characteristic

2.6 Electric double layer capacitor

Large-capacity electric double layer capacitor (EDLC) comes into being for commercial use. This research also focuses on how to use for a commercial automobile. EDLC has a lot of advantages compared with rechargeable batteries. For instance, electrical charge and discharge cycle lifetime is long and the power density is large. Moreover, it is environment-friendly because it doesn't use the heavy metal for the composition material. Fig. 5 shows the relation between the energy density and the power density of the aluminum electrolytic capacitor, EDLC, and the rechargeable battery (lead-acid) [15].

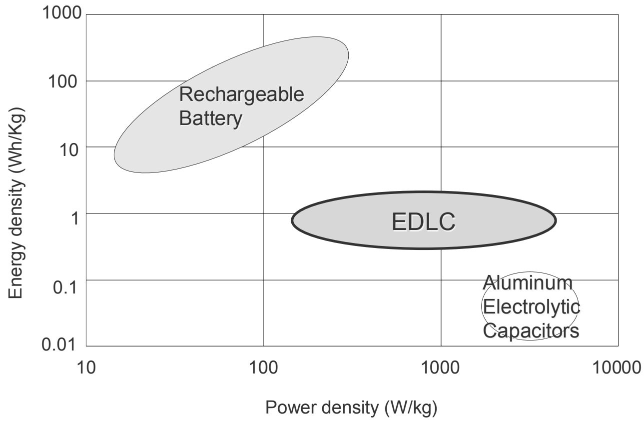

Fig.5. Energy density and relations of power density of aluminum electrolytic capacitors, EDLC, rechargeable battery (lead-acid)

2.7 Power supply system modeling

This research is simulated based on the model of large-scale commercial vehicle. 10-15 mode is used as the running mode. Therefore, the simulation time is 660[s]. The automobile electrical system circuit shown in Fig.6 is a circuit that used battery and EDLC respectively so that accuracy may improve.

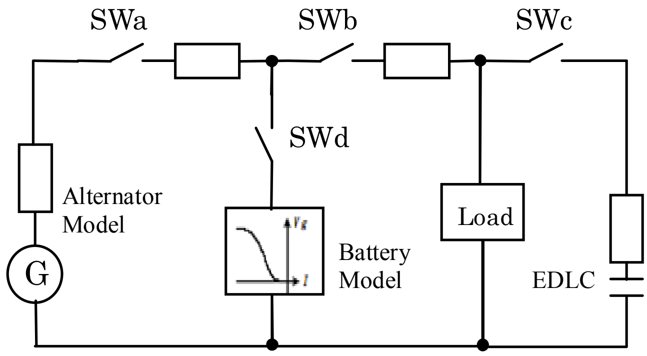

Fig.6. Automobile power system circuit

Fig.7 shows the equivalent automobile power supply system. SWa imitates the diode. SWb is always connected. SWc is also always connected in order to keep charge-discharge of capacitor and supply electric power to Load. SWd opens and closes according to alternator voltage. Arrow ① shows that when automobile runs, alternator voltage will charge battery and supply power to Load. Arrow ② shows that when alternator electronic energy decreases or when alternator is heavy loaded, battery will supply the shortfall to load. Arrow ③ shows that when idling stop, battery will supply the power to load. However, this time added EDLC, in which the capacity is charged from the alternator, so that in stead of battery, EDLC will supply the power to load when idling stops.

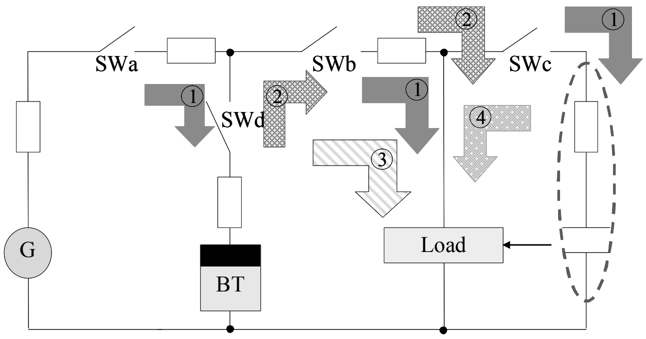

Fig.7. Equivalent automobile power supply system

The simulation condition of SWd in Fig.7 is shown below in Table 1. The switch off point is assumed to be a constant value, and the switch on point is set as 0.5[V] different from each other. Moreover, the difference between the switch on and off is set within 10[V]. The simulation studies are performed on the above-mentioned condition and the voltage and SOL fluctuations are obtained.

Table 1 Simulation condition of SWd

ON Voltage [V]	OFF Voltage [V]
30	30
29.5	30
29	30
⋮	⋮
19	25.5
18.5	25.5
⋮	⋮
10.5	20
10	20

3 Simulation result

Fig.8 is a voltage fluctuation for the simulation result. The voltage of the alternator, that of the battery and that of the capacitor are assumed as V_1, V_2 and V_3 respectively.

The SWd in the circuit is controlled according to the voltage change of the alternator. When the voltage of the alternator drops below the pre-set value of the SWd, the switch turns off. On the other side, the SWd turns on when the voltage of the alternator exceeded the pre-set value of the SWd. Fig.8 shows the simulation results of the conventional power supply system. V_3 in this conventional power supply system is assumed to be a load voltage. Fig.9 shows the current change.

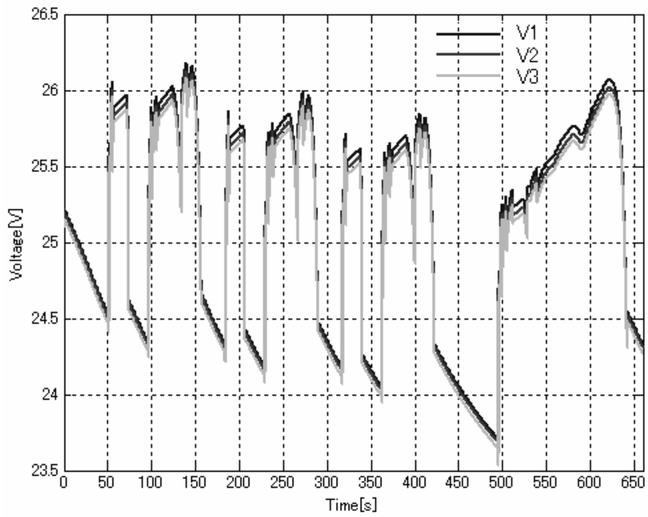

Fig.8. Voltage fluctuation

The current of the alternator, that of the battery, that of the capacitor and that of the load are assumed as I_1, I_2, I_3 and I_4 respectively.

Moreover, positive value is assumed as the electrical discharge and negative value shows assumed as the electrical charge. When the current of the alternator (I_3) exceeds the demanded load current (I_4), the battery will be charged as shown in Fig.9. However, when the capacitor is not used, the current of the capacitor is 0[A]. Fig.10 shows the change of SOC. The electrical charge and discharge are dependent to the voltage change of Fig.8. Fig.11. shows the change of SOL. As the electrical charge and discharge of the battery are performed iteratively, the battery working time becomes longer and the value of SOL increases.

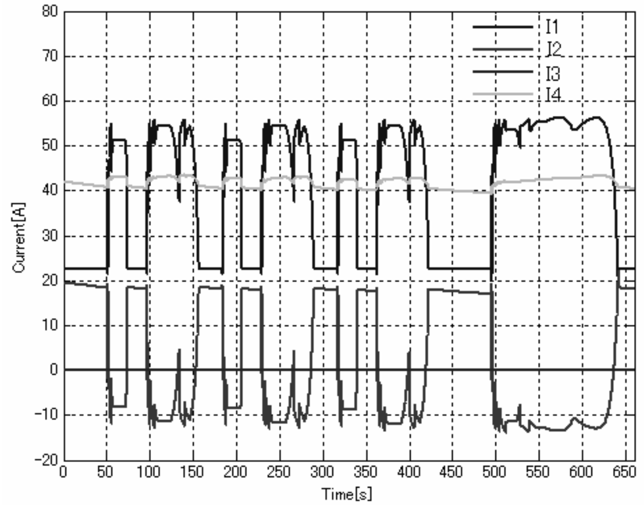

Fig.9. Current fluctuation

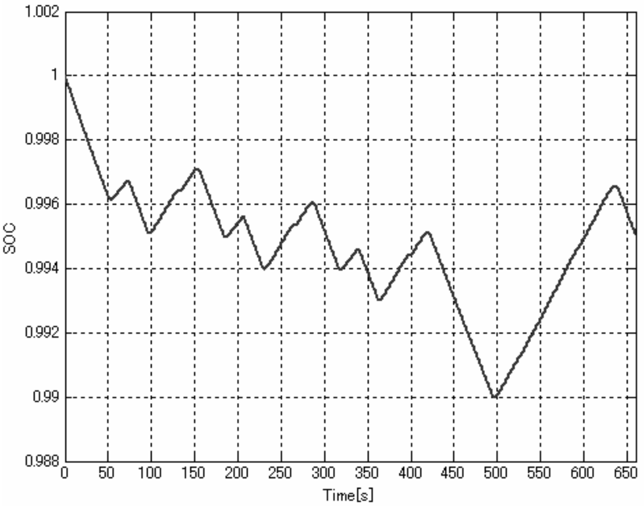

Fig.10. SOC fluctuation

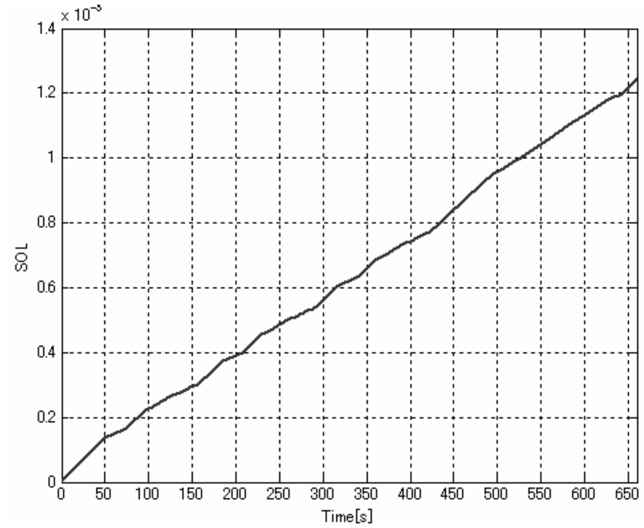

Fig.11. SOL fluctuation

Next, voltage behavior is discussed regarding SOL value. Fig.13 shows the voltage change when the turning on point of SWd set to 21[V] and the turning off point set to 25.5[V]. SWd turns on when voltage V_1 of the alternator is less than 21[V], and when it becomes 25.5[V] or more, the voltage change shown in Fig.12 turns off. First of all, the voltage decrease is identified at about 0-30[s]. SWd turns on since at drops below about 21[V] at 30[s]. Afterwards, the switch of SWd opens during 40-210[s] since it exceeds 25.5[V]. SWd closes at about 210[s] again because it goes below 21[V]. Then, SWd opens at about 220[s] because it goes over 25.5[V] or more. As mentioned above the switch iterates opening and closing.

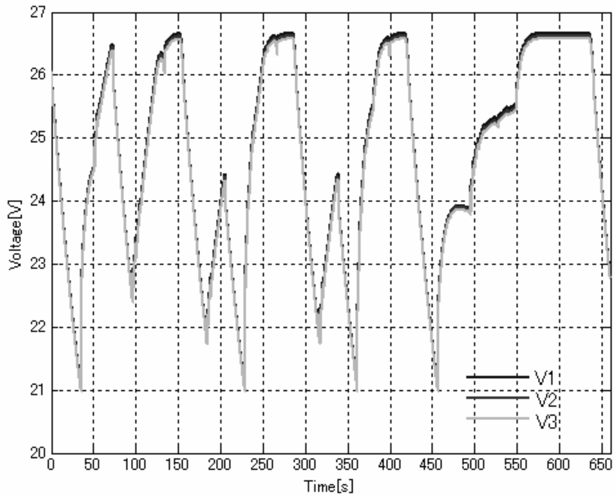

Fig.12. Voltage change of 21[V] and 25.5[V] in turning off point in turning on point

Current dynamics are shown in Fig.13. Around 40[s], SWd is open because the voltage V_1 of the alternator exceeds 25.5[V]. Thus, the current I_2 of the battery becomes 0[A], the deficient current is supplied with the current I_4 of the capacitor.

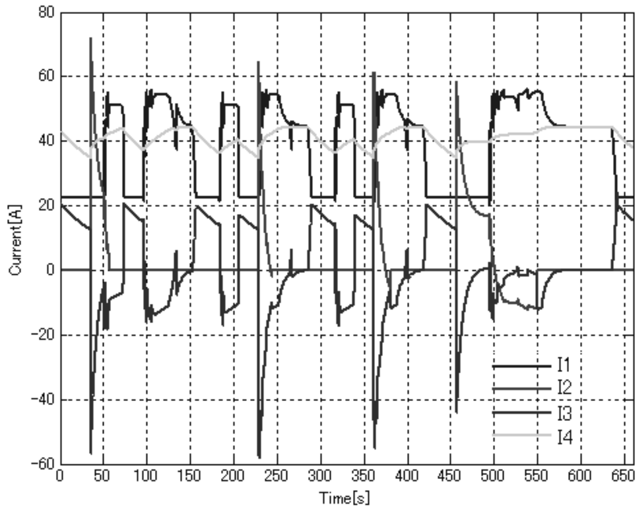

Fig.13. Current change of 21[V] and 25.5[V] in turning off point in turning on point

SWd opens because voltage V_1 of the alternator exceeded 25.5[V] in about 40[s] as for SOC shown in Fig.14. The battery is not used again at the time of about 210[s] when SWd turns on.

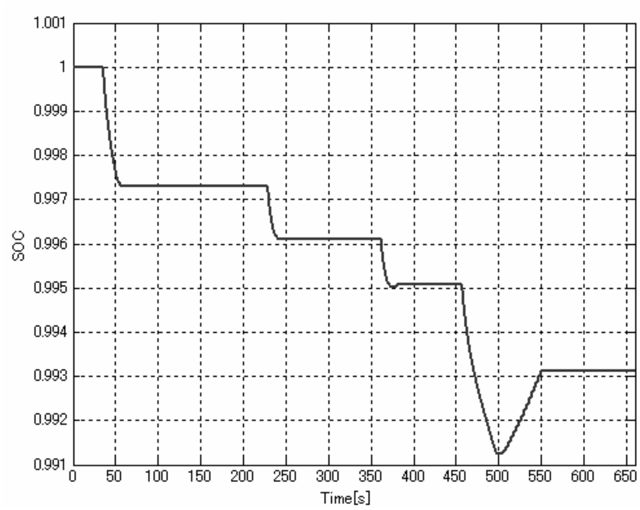

Fig.14. SOC of 21[V] and 25.5[V] in turning off point in turning on point

When SWd opens, the change is not found in the value in the SOL behavior in Fig.15 as well as that of SOC in Fig.14. However, when the battery is used, whether it is charge or discharge, the SOL value is raised as shown is in Fig.16.

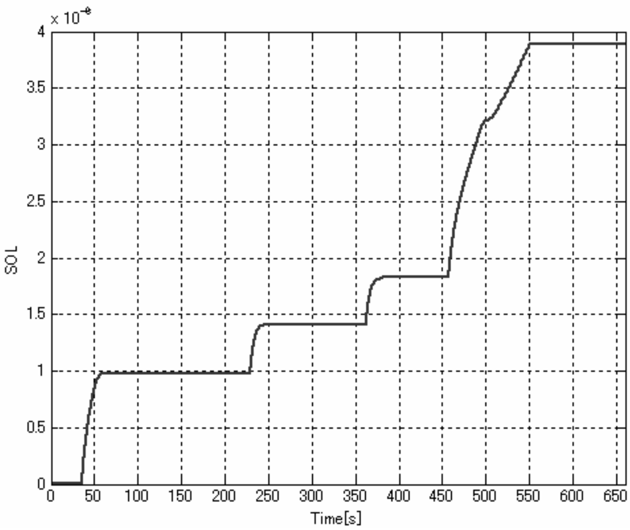

Fig.15. SOL of 21[V] and 25.5[V] in turning off point in turning on point

4 Conclusion

This research conducted simulation study on the battery model and the capacitor model in addition to the power supply system of the conventional car, to build into the program, and to extend the lifetime of the battery. Simulation results show that the battery and the capacitor are controlled by the status of SW.

However, as shown in the simulation result, capacitor is charged from the battery also when the battery switch is closed. For the further study, this problem will be discussed to find out the solution. In addition, since the turn-off point of SWd is too low, the amount which is able to be charged is also decreased. It is desired not only that SOL should be small but also that the amount of the charge should be adjusted.

Moreover, the model with whom the capacitor and driving pattern of 10-15 mode is designed this time. Each electricity load pattern and various running pattern are modeled from the actual car data, those will be incorporated. As a result, the enhanced simulation can be employed. Such a lot of simulation results are to be compared with actual car data, the accuracy of the model is validated, and the numerical parameter is corrected.

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