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The Effect of Voltage Variations on Temperature and Time During the Charging of Electrical Vehicle Batteries

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ABSTRACT

The advancement of sustainable and efficient energy has made electric vehicle (EV) technology a prominent topic. The battery is a critical component in EVs, and its stability during the charging process is enhanced by using the Constant Current Constant Voltage (CCCV) charging method. An EV's performance is highly dependent on its battery charging strategy, with users demanding rapid charging performance, long-range travel, and impressive acceleration. Currently, multiple charging strategies are used, but on-going research aims to determine the most optimized and affordable approach. Modeling and simulation are important in identifying the best charging current or voltage and establishing charging circuit pattern to minimize the charging time for electric cars. This research proposed a method and design that involves modifying the output voltage using a boost converter circuit to observe the effects of time and temperature during the charging process. The simulation results give a picture of the time taken to charge a Lithium-ion (Li-ion) battery. With an input voltage of 420 V and a current of 153 A, the battery reaches full charge in 4500 seconds, with a maximum temperature of 38° C. The fastest charging time achieved was 1200 seconds, with an output voltage of 450 V and a peak temperature of 62° C. In addition, a 10 V change in voltage led to a 6°C increase in temperature and a charging time of 600 seconds for each cycle. for every cycle.

Keywords: Li-ion Battery, charging, EV, performance, time, temperature

INTISARI

Kemajuan energi yang ramah lingkungan dan efisien telah membuat teknologi kendaraan listrik (EV) menjadi topik yang menonjol. Baterai adalah komponen penting dalam EV, dan stabilitasnya selama proses pengisian daya ditingkatkan dengan menggunakan metode pengisian daya Tegangan Konstan Arus Konstan (CCCV). Performa EV sangat bergantung pada strategi pengisian daya baterainya, dengan konsumen yang menuntut kemampuan pengisian daya yang cepat, perjalanan jarak jauh, dan akselerasi yang mengesankan. Saat ini, berbagai teknik pengisian daya digunakan, tetapi penelitian yang sedang berlangsung bertujuan untuk menentukan pendekatan yang paling optimal dan dapat diandalkan. Pemodelan dan simulasi penting dalam mengidentifikasi arus atau tegangan pengisian daya terbaik dan menetapkan pola sirkuit pengisian daya untuk meminimalkan waktu pengisian daya untuk mobil listrik. Penelitian ini mengusulkan sebuah desain dan metodologi yang melibatkan modifikasi tegangan output menggunakan rangkaian konverter boost untuk mengamati efek waktu dan suhu selama proses pengisian daya. Hasil simulasi memberikan gambaran mengenai waktu yang dibutuhkan untuk mengisi daya baterai Lithium-ion (Li-ion). Dengan tegangan input 420 V dan arus 153 A, baterai mencapai daya penuh dalam waktu 4500 detik, dengan suhu maksimum 38°. Waktu pengisian tercepat yang dicapai adalah 1200 detik, dengan tegangan output 450 V dan suhu maksimum 62°. Selain itu, perubahan tegangan sebesar 10 V menyebabkan kenaikan suhu sebesar 6°C dan waktu pengisian daya selama 600 detik untuk setiap siklus.

Kata kunci: Baterai Li-ion, pengisian, kendaraan listrik, performa, suhu, temperatur

I. INTRODUCTION

Since the issuance of Presidential Regulation No. 55 of 2019 concerning the acceleration of battery-based electric motor vehicle programs [1], the development of the electric vehicle (EV) industry in Indonesia has been growing. EV development has to be followed by infrastructure for battery charging to prevent consumers from having charging problems, thus stimulating a larger number of people to convert into EVs.

Transportation technology is evolving alongside the development of increasingly sophisticated technology. An electric car is a great example of the progress of this transportation business [2]. The

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development of EV technology has recently progressed quite rapidly. This is due to the fact that EVs are among the options for future vehicles based on the energy source of batteries [3].

During the end of the nineteenth and early twentieth centuries, EVs gained significant popularity. However, their widespread use diminished as internal combustion engine technology advanced and gasoline-powered vehicles became more affordable. Despite the decline, the EV offers multiple benefits compared to conventional combustion engine vehicles [4]. Most notably, an EV does not release any vehicle waste gases, thus contributing to the reduction of air pollution and having a beneficial effect on the environment [5]. As a result, there is hope that EVs may eventually replace gasoline-powered vehicles. To achieve this transition, exploring effective strategies to efficiently use EVs is essential.

One of the essential elements of an EV is its battery, which plays an important role in providing electric current to power the starter system, engine, lights, and other electrical components [6]. However, a significant drawback of EVs is the long charging time, due to the large amount of electrical energy required. Currently, it takes several hours, even up to 7-8 hours, to fully charge an electric car using existing charging systems. However, with the advent of fast charging technology, the charging time has been reduced to about 3-4 hours [7]. Therefore, the current challenge lies in developing even faster charging technologies that can enable electric cars to be fully charged within 1-2 hours.

Over the last few years, a lot of research has been conducted to increase the speed charging of a battery. Among the carried-out research was the exploration of wireless fast charging through the utilization of constant current techniques, leading to an estimated charging duration of 3 hours. In accordance with standard SAE J1772 Level II charging, this particular experiment was classified as fast charging, as it allowed the battery to be fully charged within 4 hours [8]. In the context of the progress of EV charging in Indonesia, the introduction of charging stations is already being implemented. However, it should be noted that the charging time of EVs to reach full power at these stations still takes about 4-5 hours [3].

This paper proposes an approach to improve charging time by utilizing various changing voltage techniques. This would be investigated to ascertain its impact on the time and temperature of charging by leveraging a voltage boost circuit. Here, voltage converter output is regulated and controlled with a Pulse Width Modulation, which is driven by a PI (Proportional Integral) controller. The incorporation of this PI controller is anticipated to result in quick rise time, minimum steady state error, and commendable system stability. The purpose of this investigation is to accelerate the battery charging process, and through the implementation of the proposed design and experiments, it is expected that the charging process will be further optimized compared to previous studies, thus making it more efficient to charge electric vehicles.

II. THEORY

A. *Battery Charger Circuit*

The charging process of electric vehicle (EV) batteries is regulated in this paper by utilizing a DC converter that amplifies the input voltage. The converter is composed of a DC voltage source (Vs), inductor (L), electronic switch, diode, output capacitor (C), and load resistor (R) [9][10]. The input voltage is assumed to be 90 Vdc from the solar panel in this circuit configuration. Figure 1 shows a schematic representation of the converter circuit.

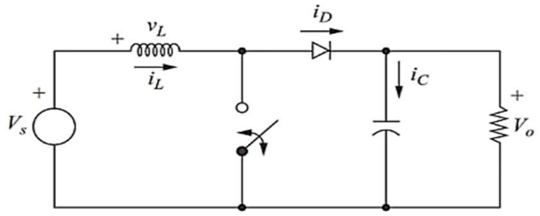

Figure 1. DC converter as a charger circuit

Furthermore, several component values are required for the design of the boost converter. This design entails various parameter values, including the input voltage denoted as Vs, which is measured at 90 Vdc. The output voltage, referred to as Vo, is recorded at 450 Vdc. Additionally, the output current, represented by Iout, is measured at 153 A. The operating frequency is set at 25000 Hz. The inductor, denoted as L, has a value of 2.05 µH, while the capacitor, denoted as C, has a value of 7 µF. Finally, the resistor, denoted as R, is measured at 100 Ω.

B. *Control Proportional Integral*

To adjust the boost converter's voltage output, this research utilizes a PI control design, which ensures a constant DC voltage as input. PI control is made of two properties, i.e. proportional (P) and integral (I) control,

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each with its unique features. Proportional control is responsible to accelerate response of output plant to attain the set point [11][12]. On the other hand, integral control allows for minimizing a steady-state error of the controller's plant output. Equation 1 illustrates on a relation between error signal e(t) and output signal u(t) of a plant using P control.

$$u(t) = K_p\, e(t) \quad (1)$$

Meanwhile, Equation 2 depicts the relationship between the output signal u(t) of an I-controlled plant and the error signal e(t).

$$u(t) = K_i \int_0^t e(t)\, d(t) \quad (2)$$

The optimizing of P and I control parameters leads to the implementation of PI control, which effectively overcomes the limitations of each control parameter [13] [16]. The s-domain block diagram of PI control is illustrated in Figure 2.

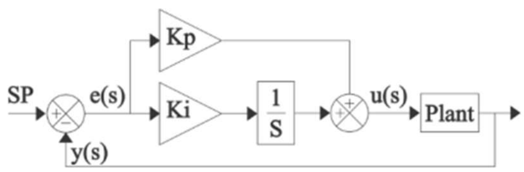


Figure 2. Block diagram Proportional integral

The deviation from the set point and output voltage signal y(s) of a plant being controlled is denoted by the value e(s), while the PI controller's output signal is represented by u(s) [13-15].

III. RESEARCH METHODOLOGY

The purpose of this research is to simulate and model the enhancement of battery charging duration through the application of super-fast charging. The aim is to ascertain the optimal approach to achieve super-fast charging using voltage-boosting techniques, while also examining its impact on battery charging time and temperature.

Using this model will provide fundamental information for the design of an autonomous charging model for EV batteries using solar panels as a direct energy source. Here, a DC converter as shown in Figure 1 is used with a significant voltage increase to acquire the rated charging voltage. Since the charging is done by constant current constant voltage (CCCV) method like [17]. This method provides greater charging behaviour to the battery during the charging process.

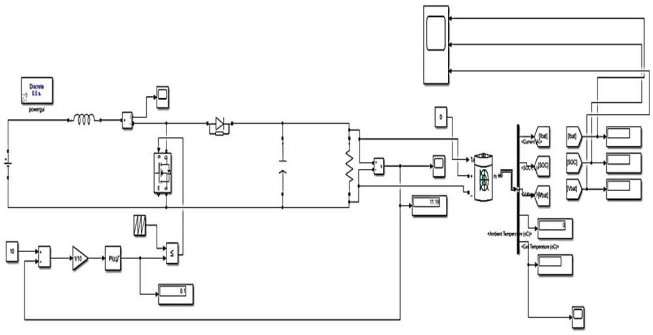
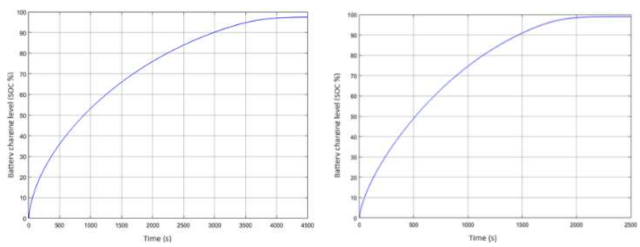


Figure 3. Simulation Circuit

The test procedure was carried out using simulations in MATLAB, as illustrated in Figure 3. It includes varying voltage output under 8 various conditions, in order to observe their impact on time and temperature during battery charging. For this simulation, the battery pack was modeled based on data obtained from an EV battery. A battery basically contains a series of electric cells that serve as a power source [14]. Furthermore, a Lithium-ion battery that is designed for EVs, with an input of 420 Vdc, 153 Ah, and a power capacity of 58 kWh, is used in this simulation. The Lithium-ion battery charging process starts from 0% charge level and ends at 100%. After performing several tests, the data obtained will be analyzed to ascertain the time and temperature generated by the battery.

IV. RESULT AND DISCUSSION

Simulations have been performed on the charging process of EV batteries with an initial state of 0%. The tested battery was a 58 kWh Lithium-Ion battery with a voltage of 420 V and a current of 153 Ah, and the battery cell temperature was measured at 38°C. This simulation varies the charging voltage ranging from 380 to 450 V. The results are designed to determine the effect of various voltages on the battery's (SOC) and the time taken for the charging to complete the process.



(a) (b)

Figure 4. SOC battery with, (a) 420 V; (b) 430 V

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During the first stage with a voltage of 380 V, charging could not occur and only stopped at the 5% state. This indicates that the circuit is unable to perform when the current voltage of the charging circuit is less than the initial battery state. However, it started to store when the charging voltage was equal to or greater than the initial state, as shown in Figure 4a-b. Using charging voltages of 420 V and 430 V, the battery took 4500 seconds and 2550 seconds, respectively.

Stages of testing to be able to observe the implications of various charging voltages, with a 153 A charging current the circuit is set to the maximum limit of 450 so that the battery is still safe (<10% of the maximum capacity of the battery). This change has a great impact on accelerating the time of the battery charging but in line with the followed by a quite high-temperature increase. For a voltage of 450 V, the battery can be charged in just 1200 seconds, but because the voltage is set to be constant until 100% SOC is not good enough for battery conditions where the temperature reaches 62 ºC.

Several data can be summarized from the performed experiments like battery charging time and temperature, which are shown in Table 1.

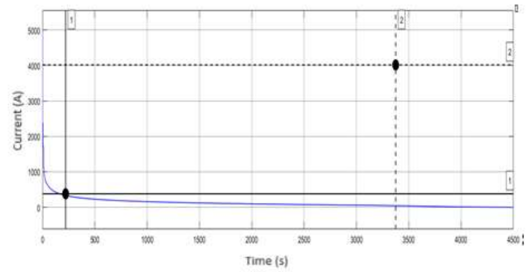
Table 1. Various stages of test results

Testing Condition	Vin (V)	Vout (V)	SOC (%)	Time (s)	Temp (°C)
Condition 1	76	380	5	210	-
Condition 2	78	390	8,3	430	-
Condition 3	80	400	16	590	-
Condition 4	82	410	48	2330	-
Condition 5	84	420	100	4500	38°
Condition 6	86	430	100	2550	43°
Condition 7	88	440	100	1850	48°
Condition 8	90	450	100	1200	62°

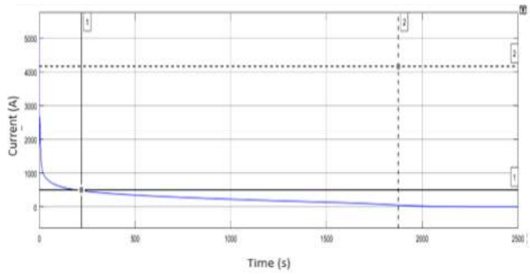
From the table above, it can be seen the difference of performance of every voltage variation. From the 6 stages of testing, it shows that improvement of the input voltage is possible as long as it meets the minimum requirements of the charged battery. Moreover, these results also show that changes to the charging voltage can only be made within the specified safe limits to shut down the safety of the battery during the charging process. This also has an impact on the health condition of the battery such as overheating which will be discussed in the next section.

To investigate the impact of voltage variations on the duration required for the battery to reach full charge, the charging time for each 10 V increase in voltage under different conditions can be assessed in relation to temperature. The temperature had a consistent increase of about 6°C in all conditions. However, in state 8, there is a significant temperature difference, with the temperature doubling as the voltage increases. This difference arises due to the occurrence of the maximum temperature point at 220 seconds, as illustrated in Figure 5. Moreover, a current spike of about 120 A occurs when the output voltage is increased by 10 volts in each condition.

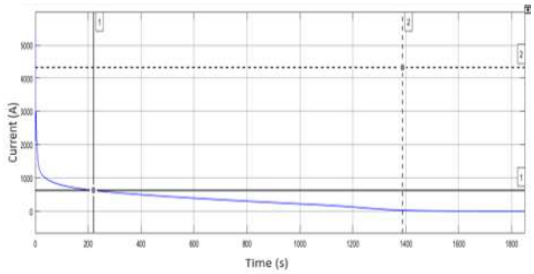
In Figure 5a-c, in condition 5, either at 220 seconds or when the temperature reaches its peak, the recorded current is 380.99 A. Similarly, in condition 6, the current measures 502.97 A, and in condition 7, the current reaches 625.58 A. The temperature difference that occurs is about 6°C, as depicted in Figure 6.



(a)



(b)



(c)

Figure 5. Current condition at 220 seconds (a) condition 5; (b) condition 6; (c) condition 7

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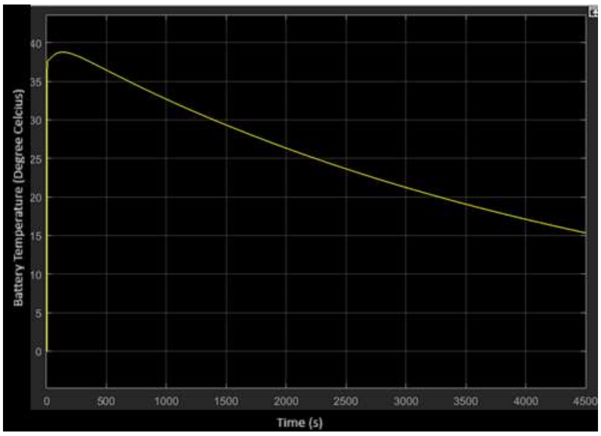
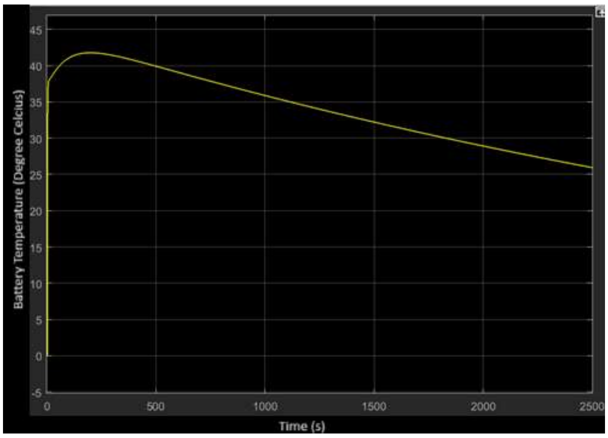


(a)



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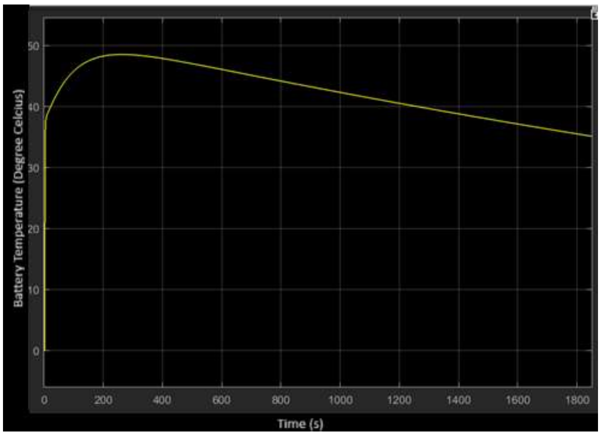
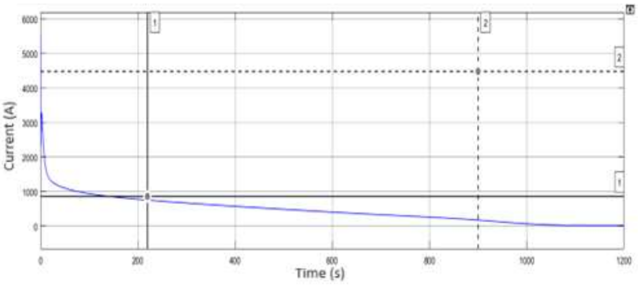


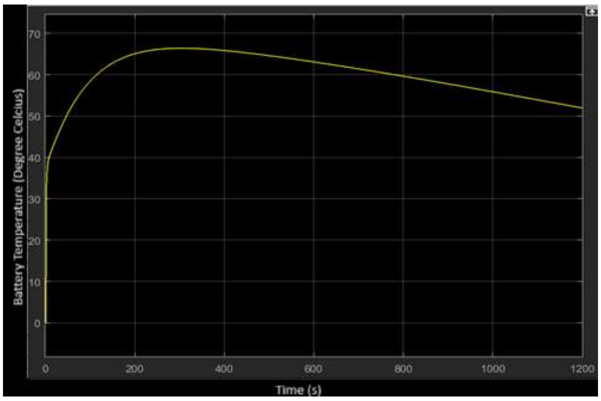
(c)

Figure 6. Temperature battery in (a) condition 5; (b) condition 6; (c) condition 7

Under condition 8, an increase of 10 V in the output voltage caused a significant increase in temperature compared to the previous experiment. This observation is illustrated in Figure 8, where there was a substantial spike of about 240 amperes in the current, which resulted in a significantly higher battery temperature of 15°C. It should be noted that the temperature rises in proportion to the increase in current. Moreover, for every 10 V increase in voltage, it also affects the charging time of the battery, with a time difference of about 600 seconds between each voltage change.



(a)



(b)

Figure 7. (a) Current and (b) temperature battery in condition 8

Battery life is affected by various factors, including power, voltage, current and charging time. Varying the voltage during battery charging has a direct impact on the charging speed. In particular, a higher output voltage results in a faster charging process. Also, an increase in voltage leads to a corresponding increase in current. However, it is important to note that too high a current level may cause the battery temperature to increase, potentially leading to overheating. Therefore, to ensure a stable output, the addition of a PI controller is essential.

V. CONCLUSION

Electric vehicle battery charging performance testing has been completed successfully with an improved source provided with a voltage boost and constant voltage charging control circuit. The performance of constant current constant voltage charging has been demonstrated under various state of charge conditions from 380V up to 450V. From the experiment, it is shown that a voltage change of 10 V produces an increase of 6°C of temperature and 600 seconds of charging time for each cycle. The results of MATLAB simulation show that it is possible to fully charge a Lithium-ion battery with an input voltage of 90 Vdc for a battery voltage of 420 Vdc. It was found that at 420 V, the charging time was 4,500 seconds (equivalent to 1.15 hours), while that of 450 V was determined to be 1,200 seconds (equivalent to 20 minutes).

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