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Electric Vehicle Battery Charging System Design with Dual Flyback Type Converter

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Abstract*—The main reason for the global climate change problem and at the same time the main source of the prosperity achieved by humanity is the use of more energy. However, most of the energy produced on a global scale is of fossil origin, and the high price, limited resources and many negative effects such as causing excessive global warming have made it necessary to increase the use of renewable energy sources. One of the main reasons for the global warming problem has been to develop and use electric vehicles, especially in the automotive sector, in order to overcome the emission of carbon dioxide gas emitted by vehicles with internal combustion engines. The biggest obstacle in the spread of electric vehicles is that the range limit depending on battery performance has not yet reached the desired levels. However, vehicle ranges that have improved as a result of scientific studies on battery technologies in recent years have rapidly increased the number of electric vehicles in the market. Correct analysis of the battery pack, which is one of the critical subsystems of electric vehicles, affects important performance criteria that directly concern the user, from driving performance to range. In this study, a battery charging system for an electric vehicle was designed and simulated using a dual-flyback converter. Theoretical analysis, modeling, fuzzy logic-based control design and evaluation of system performance of the proposed battery pack and charging circuit were carried out in Matlab/Simulink environment.

Keywords— Electric vehicles, dual type flyback converter, fractional PID controller, battery charger.

1. INTRODUCTION

Humanity has faced a new problem called global warming in the last 50 years [1]. Sea water temperatures are given as a result of global warming for the last 120 years. 0 degrees (reference point) is determined as the average temperature between 1961-1980 in the graph. The sea water temperature has increased by approximately 0.8 degrees in the last century. One of the most important causes of global warming is the decrease in fossil fuel resources and its negative effects on the environment, so the interest in the production of renewable energy is increasing day by day [2]. While fossil fuels that cause pollution and climate change are not easily accessible in all geographical regions of the world, it is a more efficient way to benefit from more accessible renewable energy sources [3]. Faced with limited and gradually decreasing fossil fuel reserves, most of the countries are now looking for alternative energy sources [4]. For economic and social development and human life; Reliable, cheap and clean energy supply has become the most important problem today [5]. As it is known, as an alternative to traditional energy production methods, the most effective ways to produce electrical energy without harming the nature are to use solar [6], wind[7-8], hydraulic[9] and biogas [10-11] energies, respectively.

2. BATTERY CHARGING SYSTEM DESIGN

The charging circuit that provides energy to a battery should be designed in such a way that it can safely charge by providing the necessary current and voltage control according to the electrical characteristics of the battery. In general, battery charging circuits are briefly called chargers. The batteries of electric vehicles are generally charged by methods such as constant voltage, constant current, uncontrolled current, pulse load, negative pulse, drip, float, random, constant current-constant voltage [12-13]. A wide variety of rechargeable batteries have been developed in the electric vehicle industry, but among all available types, lithium-ion batteries are considered the best because of their properties and performance. The most popular battery charging procedure for these batteries is the constant current - constant voltage method. The constant current - constant voltage charging characteristic of the lithium-ion battery is given in Figure 1.

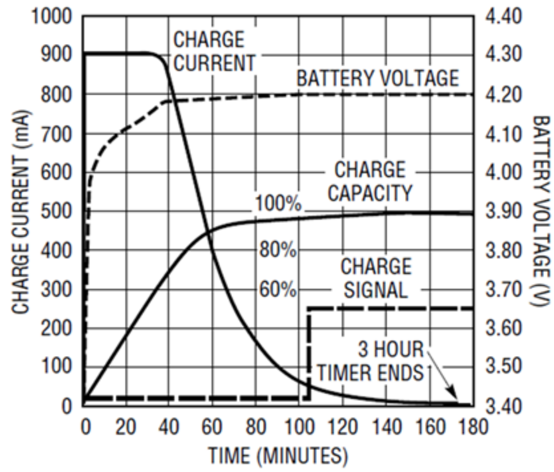

Fig. 1. *Charge Characteristics of Lithium-Ion Battery*

Constant current charging is the maximum rate of charge that the battery can withstand without damage. Special precautions need to be taken to maximize the charge rate and at the same time ensure that the battery is fully charged while avoiding overcharging. Therefore, before the cell voltage reaches its upper limit, the charging method is replaced with constant voltage. This situation requires lithium-ion cell chargers to be able to control the charging current and battery voltage. In constant current mode, the charge-to-charge rate occurs very quickly until the upper limit of the battery voltage is reached. After the battery voltage reaches the upper limit, it is switched to constant voltage mode and the charging voltage is kept at this level. During this period of constant voltage, the charging current begins to decrease. When a predetermined minimum current point is reached (usually 3% to 5% of the charge current value), cut-off occurs, indicating that the battery has reached full charge. Lithium-ion batteries have a nominal voltage of 3.6 V and are usually charged up to 4.2 V. Here, the capacity of the IC battery is ampere-hour (In cases where electrical power conversion is required, power electronic converters are used. For applications that require insulation and low power, forward and flyback converter types are mostly preferred [14]. Flyback-based transformer circuit designs are easy to control and few However, the leakage inductance of the transformer used in Flyback type converters is an important problem. This leakage inductance causes serious voltage increase in the control switch of the converter and negative effects such as high power losses. There are some techniques to improve these problems. One of these techniques can use a braking resistor (RCD) to limit voltage spikes at active switches [15]. With this method, the energy stored in the transformer's leakage inductance is dissipated over the RCD resistor.

2.1 Dual Type Flyback Converter

In power conversion, two-switch dual-type flyback converter structure can be used to recycle the leakage energy of transformers [16]. However, two active switches are needed in this circuit topology [17]. An active clamp circuit can be implemented to eliminate the voltage spike in active switches. In addition, this converter can also provide zero voltage switching for the active switch. However, this converter uses two transformers for high power applications [18]. The circuit configuration of the proposed converter is shown in Figure 2. The proposed converter consists of a switch S, two transformers T_1 and T_2, three diodes and three capacitors [19]. The windings in transformers T_1 and T_2 have the same relative directions of turns, $N_{1p} = N_{2p}$ and $N_{1s} = N_{2s}$ and their turns ratios $a = N_{1s} / N_{1p} = N_{2s} / N_{2p}$. The leakage energies of transformers T_1 and T_2 can be converted back to capacitors C_1 and C_2 through the diode D_1 in the closed period S. Therefore, power losses can be reduced. To simplify the circuit analysis of the proposed converter, all components are assumed to be ideal. Therefore, the losses of the circuit elements are not taken into account. Also, the capacitors in the circuit are large enough. The voltages across these capacitors are considered constant during each switching period [20].

An equivalent circuit of the dual flyback converter is shown in Figure 3. The S switch is controlled using the pulse width modulation strategy. Mutual magnetic inductance of transformers T_1 and T_2 is Lm1p and L_{m2p}, and leakage inductances L_{k1p} and L_{k2p} are modeled as ideal transformers. Since the windings of transformers T_1 and T_2 are equivalent, magnetization inductance equation (1) and leakage inductances are considered equal as given in equation (2). The coupling coefficient k of transformers T_l and T_2 is given in equation (3).

$$L_m = L_{m1p} = L_{m2p} \qquad (1)$$

$$L_k = L_{k1p} = L_{k2p} \qquad (2)$$

$$k = \frac{L_{m1p}}{L_m + L_k} \qquad (3)$$

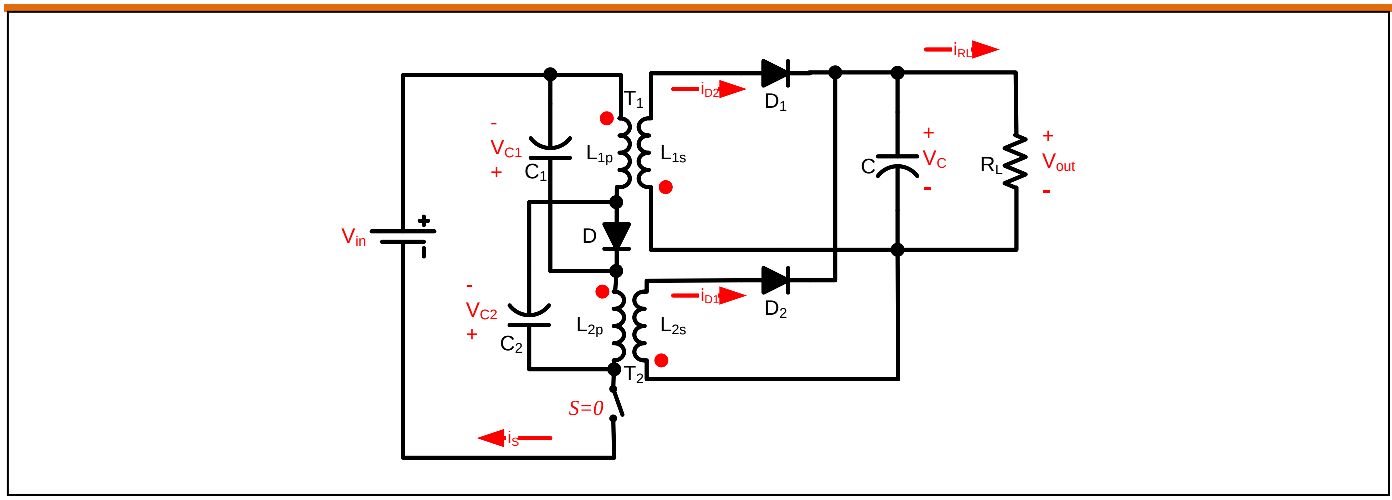

Fig. 2. *Dual flyback converter simple circuit model.*

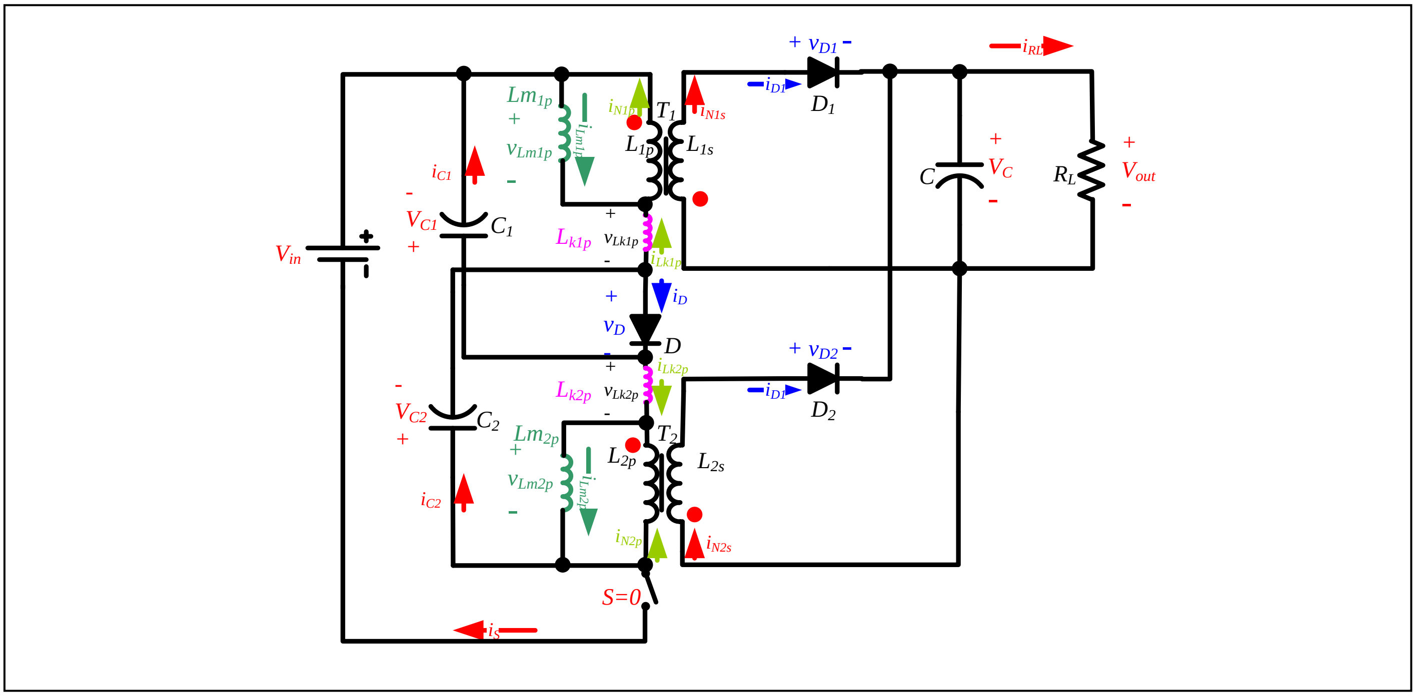

Fig. 3. *Charge Matlab/Simulink Circuit of the proposed dual flyback converter*

Current-voltage expressions of some circuit elements in the proposed dual flyback converter circuit during a switching period in continuous operation mode (CCM) are given in equations (4) - (8), current-voltage (i-v) waveforms are shown in Figure 4.

$$v_{Lm} = v_{Lm1p} = v_{Lm2p} \quad (4)$$

$$v_{Lk} = v_{Lk1p} = v_{Lk2p} \quad (5)$$

$$i_{Lm} = i_{Lm1p} = i_{Lm2p} \quad (6)$$

$$i_{Lk} = i_{Lk1p} = i_{Lk2p} \quad (7)$$

$$V_c = V_{c1} = V_{c2} \quad (8)$$

In order to explain the continuous current operating mode of the proposed dual flyback converter, detailed circuit analyzes at certain time intervals of the operating period of the switch in the circuit have been examined in some studies [21].

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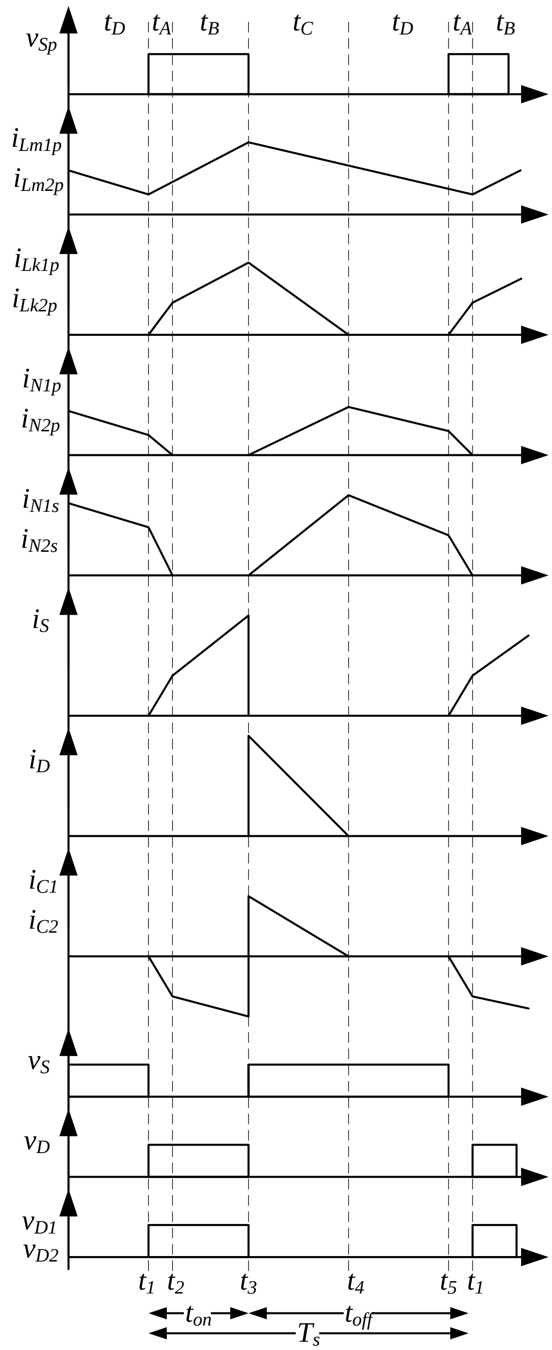

Fig. 4. *Charge Characteristics of Lithium-Ion Battery*

2.2 Fractional PID Controller Design ($PI^{\lambda}D^{\mu}$)

Fractional type PID controllers can be defined as the generalized form of PIDs. In other words, the system output data can be summarized as a linear combination of the input, a fractional derivative of the input, and a fractional integral of the input [22-24]. Fractional PIDs are also known as $PI^{\lambda}D^{\mu}$ controllers; where λ and μ are the order of integration and differentiation; if both values are 1, the result is a regular PID (hereinafter called an "integer" PID as opposed to a fractional PID). $PI^{\lambda}D^{\mu}$ controllers are advanced controllers that can give better results than conventional PI controllers. They are widely used because they can adjust more precisely than PID controllers. The best known are the descriptions of M. Caputo, Grunwald-Letkinov and Reimann-Liouville [25-26]. The $PI^{\lambda}D^{\mu}$ controller general block diagram is shown in Figure 5 [27-30].

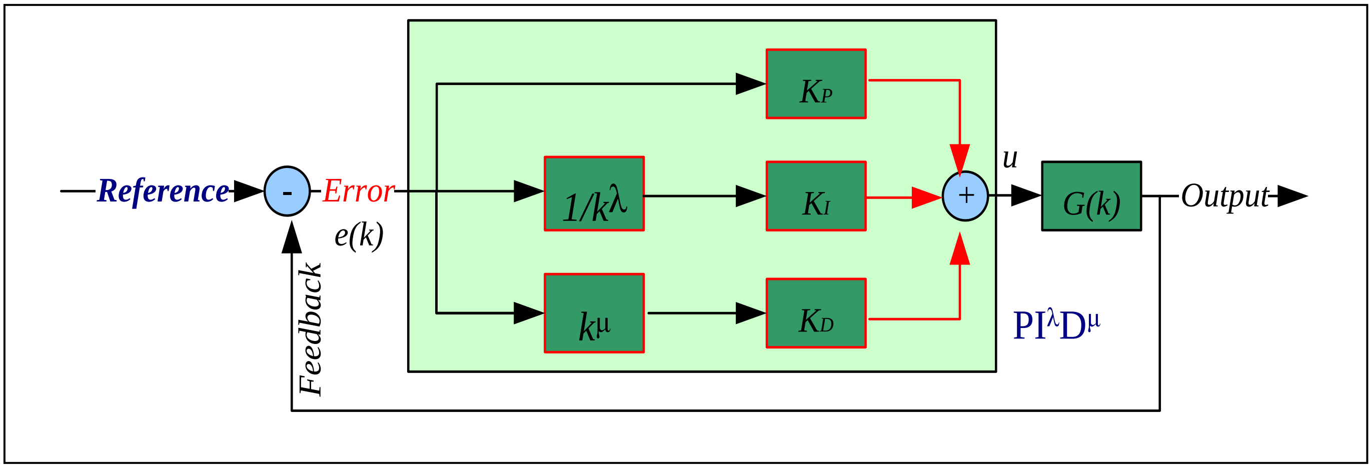

Fig. 5. *Basic configuration of the $PI^{\lambda}D^{\mu}$ PID Controller.*

In this study, λ and μ ≥0, λ is the integration order and μ is the differentiation order. K_P, K_I and K_D are PID controller gains. U(s) and E(s) are control and error signals, respectively. In this study, $PI^{\lambda}D^{\mu}$ controller software was made by FOMCON Toolbox [31]. The system output is as seen in *C(k)* equation 9.

$$C(k) = K_P + \frac{K_I}{k^{\lambda}} + K_D k^{\mu} \quad (9)$$

2.3 Simulation Model of the System

The simulink model of the system, which includes the modeling of the proposed electric vehicle (EV) battery pack and the designed charger in the MATLAB/Simulink environment and simulation studies, is given in Figure 6. The controller charges the battery by controlling the charger according to the measured current and voltage values of the battery pack, and when the battery is full, it finishes the charging process.

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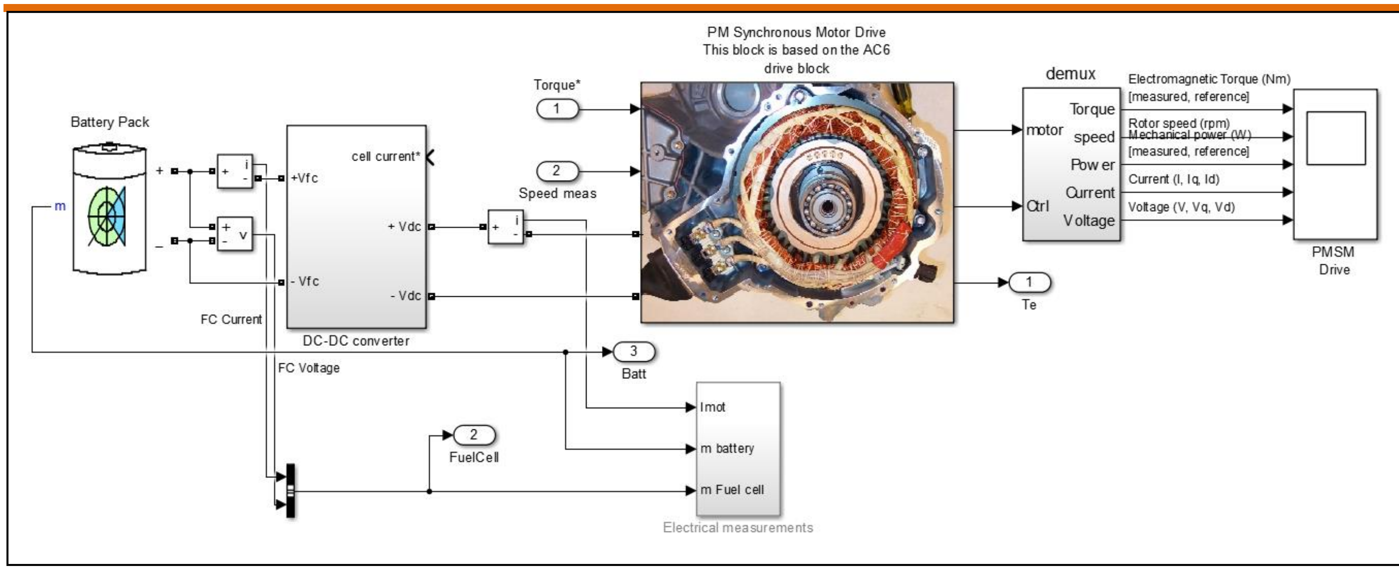

Fig. 6. *Battery Charging System Model*

Battery charging system works with constant current-constant voltage method and current and voltage control is done by 2.2 Fractional PID controller. The battery pack is charged with a constant current of 29 A until the battery pack reaches the maximum charge voltage value of 268,8 V. After the output voltage reaches the maximum charging voltage level, the battery pack continues to be charged with constant voltage. When the current drawn value drops to 3% of the maximum current value, the charging process is interrupted.

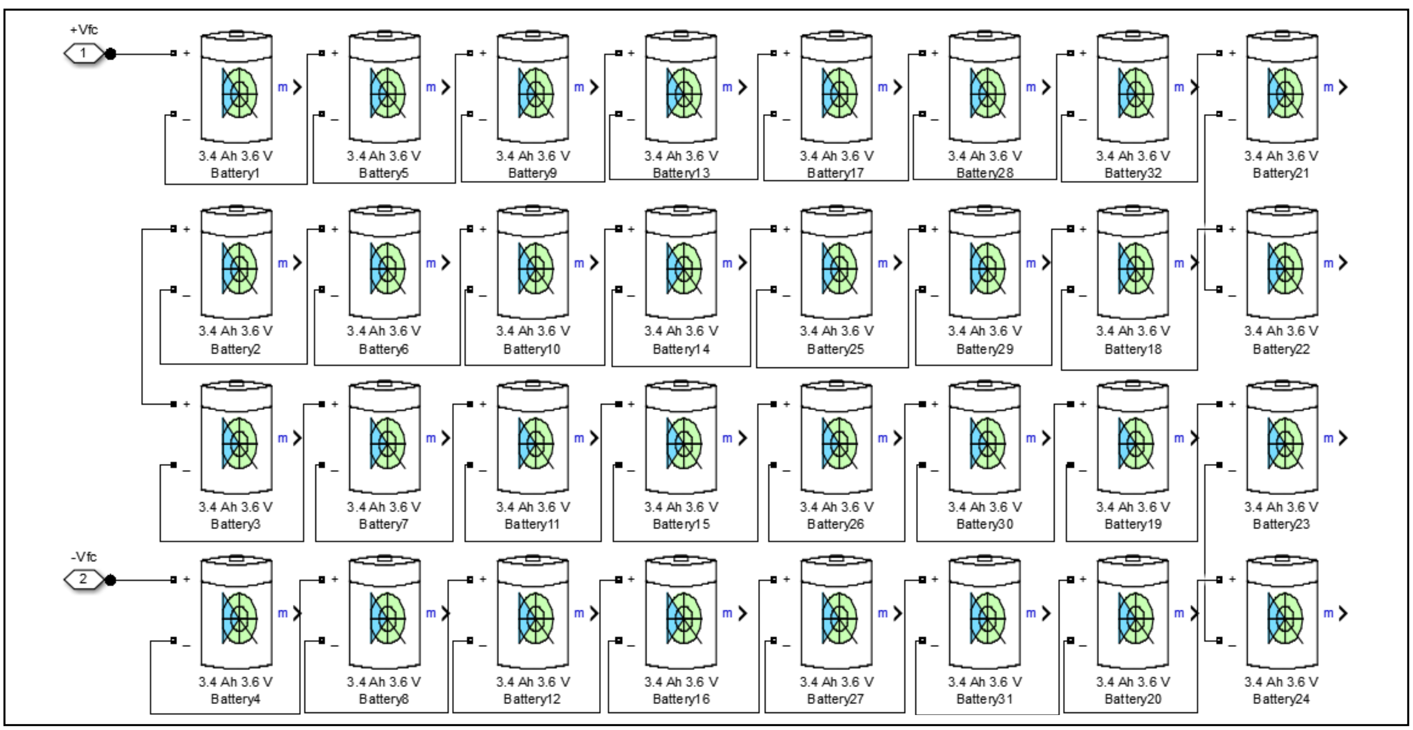

Fig.7. *Battery Pack Model*

Table 1: Battery Pack Parameters

Parameter	**Value**
Battery Capacity	3400 mAh
Battery Rated Voltage	3.6V

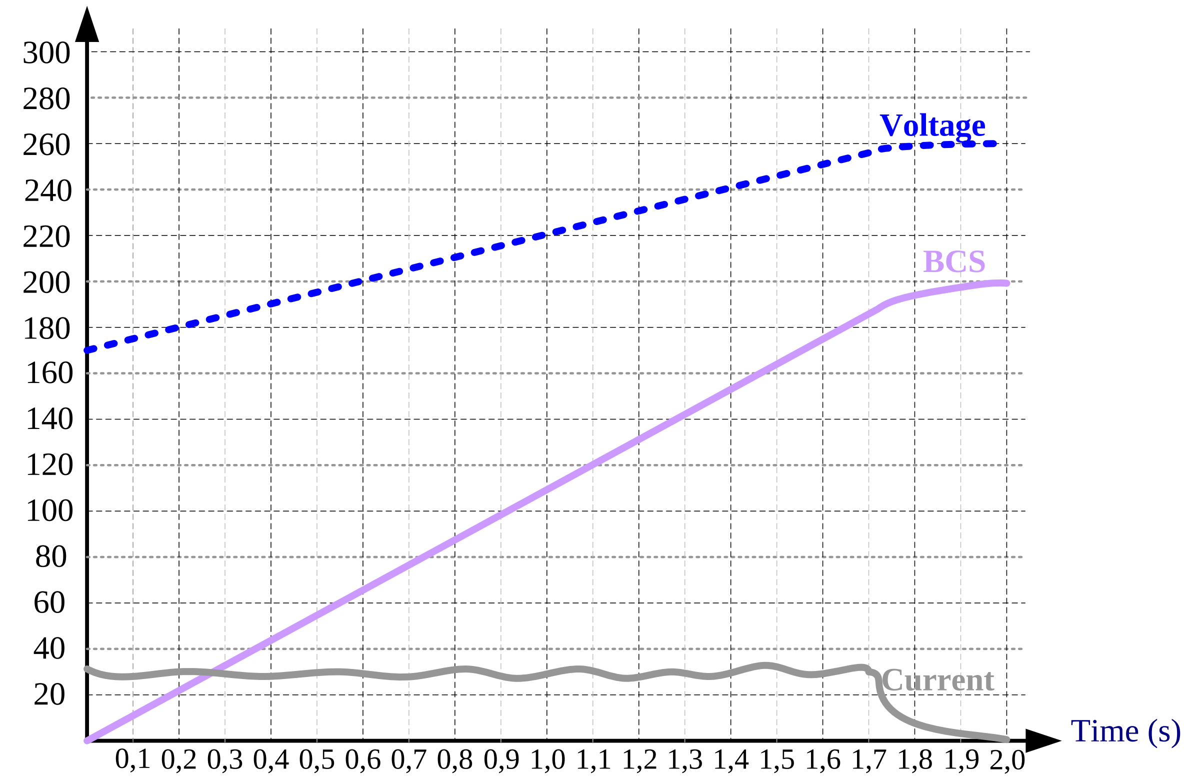

Fig. 8. *Battery Pack Charge Response*

3. CONCLUSIONS

In this study, a dual flyback type DC-DC converter based charging system is designed with a battery pack consisting of lithium-ion batteries of an electric vehicle. The system model was created in the MATLAB/Simulink environment. Constant current-constant voltage technique was used as the charging method. In the study, the battery pack was successfully charged. The battery pack switched from constant current mode to constant voltage mode with approximately 92% charge in 1.7 hours. In about 2 hours, it reached a full state. In the charging process with a reference value of 29 A in constant current mode, a current fluctuation of around 7% occurred. It is envisaged that the current ripple can be further reduced by using fuzzy-based controllers instead of PID type classical controllers in the system.

4. References

[1] Zenk, H. (2018). Low Cost Provides of the Energy Needs of Plateau Houses by Using Photovoltaic Systems. Turkish Journal of Agriculture-Food Science and Technology, 6(12), 1768-1774.

[2] Guner, F., & Zenk, H. (2020). Experimental, Numerical and Application Analysis of Hydrokinetic Turbine Performance with Fixed Rotating Blades. Energies, 13(3), 766.

[3] Şenol, H., & Zenk, H. (2020). Determination of the biogas potential in cities with hazelnut production and examination of potential energy savings in Turkey. Fuel, 270, 117577.

[4] Zenk, H. (2018). Investigation of Energy Efficiency in Turkey. Annals of the Faculty of Engineering Hunedoara, 16(1), 93-96.

[5] Zenk, H. (2019). Comparison of the Performance of Photovoltaic Power Generation-Consumption System with Push-Pull Converter under the Effect of Five Different Types of Controllers. International Journal of Photoenergy, 2019.

[6] Zenk, H. & Akpinar, A. S. (2013). Solar Power Generation Potentials of The Houses in Turkey. International Conference on Environmental Science and Technology (ICOEST 2013).

[7] Güner, F., Başer, V., & Zenk, H. (2021). Evaluation of offshore wind power plant sustainability: a case study of Sinop/Gerze, Turkey. International Journal of Global Warming, 23(4), 370-384.

[8] Demir, E., Zenk, H., & Başer, V. (2021). Technical Aspects of Analysis of Offshore Wind Power Plant Installation in Turkey. In 2nd International Conference on Agriculture, Technology, Engineering andSciences (ICATES 2019), pp. 529-535.

[9] Guner, F., & Zenk, H. (2019). Hydrokinetic Energy Conversion Systems in Turkey an Experimental Analysis. In 2nd International Conference on Agriculture, Technology, Engineering and Sciences (ICATES 2019), pp. 589-597.

[10] Zenk, H. (2019). The Electric Energy Potential of Samsun City from Animal Manure. European Journal of Science and Technology, (17), 1307-1312.

[11] Şenol, H., & Zenk, H. (2019). Biogas Production and Current Purification Methods. In 2nd International Conference on Agriculture, Technology, Engineering and Sciences (ICATES 2019), pp. 515-521.

[12] Zenk, H. (2019). Effective Control of the Developmental Current of a Serial DC Motor with a Fuzzy Tuned-PI Controller Zeta Converter. Karadeniz Fen Bilimleri Dergisi, 9(1), 196-211.

[13] Zenk, H., Şenol, H., & Güner, F. (2019). Lunar Excursion Module Landing Control System Design with P, PI and PID Controllers. Karadeniz Fen Bilimleri Dergisi, 9(2), 390-405.

[14] Keçecioğlu, Ö. F., Gani, A., & Kılıç, E. (2019). Robust Control of Boost Converter using Interval Type-2 TSK Fuzzy Logic Controller. In CISET-2nd Cilicia International Symposium on Engineering and Technology (pp. 10-12).

[15] Kilic, E. (2019). DA-DA Yükselten Dönüştürücü Ile Elektrikli Araç Batarya Şarj Cihazi Tasarimi. Kahramanmaraş Sütçü İmam Üniversitesi Mühendislik Bilimleri Dergisi, 22(4), 281-287.

[16] Kim, M. G., & Jung, Y. S. (2009). A novel soft-switching two-switch flyback converter with a wide operating range and regenerative clamping. Journal of Power Electronics, 9(5), 772-780.

[17] Murthy-Bellur, D., & Kazimierczuk, M. K. (2011). Zero-current-transition two-switch flyback pulse-width modulated DC–DC converter. IET power electronics, 4(3), 288-295.

[18] Spiazzi, G., Mattavelli, P., & Costabeber, A. (2011). High step-up ratio flyback converter with active clamp and voltage multiplier. IEEE Transactions on Power Electronics, 26(11), 3205-3214.

[19] Zenk, H. (2018). Comparison of Electrical Performances of Power Electronics Switches and an Effective Switch Selection Algorithm. Acta Physica Polonica A, 133(4), 897-901.

[20] Zenk, H. (2018). DC-DC Converters and Simulink Applications. Innovative Approaches in Engineering, 167-194.

[21] Zenk, H. (2020) Fotovoltaik Enerji Kaynaklı İkili Yapılı Flyback Dönüştürücünün Fuzzy-Tuned PI ve Fractional PID Tipi Denetleyicilerle Gerilim Kararlılığının Karşılaştırılması. Karadeniz Fen Bilimleri Dergisi, 10(2), 443-465.

[22] Zenk, H., Zenk, O., & Akpinar, A. S. (2011). Two different power control system load-frequency analysis using fuzzy logic controller. In 2011 International Symposium on Innovations in Intelligent Systems and Applications (pp. 465-469). IEEE.

[23] Zenk, H., & Akpinar, A. S. (2013). PI, PID and fuzzy logic controlled SSSC connected to a power transmission line, voltage control performance comparison. In 4th International Conference on Power Engineering, Energy and Electrical Drives (pp. 1493-1497). IEEE.

[24] Zenk, H. (2016). A Comparative Application of Performance of the SEPIC Converter Using PI, PID and Fuzzy Logic Controllers for PMDC Motor Speed Analysis. Journal of Multidisciplinary Engineering Science Studies (JMESS), 2(12), 1226-1231.

[25] Zenk, H., & Akpınar, A. S. (2012). Multi zone power systems load-frequency stability using fuzzy logic controllers. JECE, Journal of Electrical and Control, 2(6), 49-54.

[26] Zenk H., Kara A.,Güney M. S, Güner F., & Zenk O. (2018). PMDC Motor Speed Control With Fuzzy Logic Controlled Zeta Converter. 4rd International Conference on Engineering and Natural Sciences (ICENS 2018), 4(1), 502-502.

[27] Zenk, H., & Altinkok, A. (2017). Output Voltage Control of PI And Fuzzy Logic Based Zeta Converter. IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), 12(6), 63-70.

[28] Zenk, H., & Zenk, O. (2017). The Eight Zones Power Systems Load-frequency Stability Using Different Type Controllers. DEStech Transactions on Environment, Energy and Earth Sciences, (PEEM2016), pp. 63-68.

[29] Shah, P., & Agashe, S. (2016). Review of fractional PID controller. Mechatronics, 38, 29-41.

[30] Rasoanarivo, I., & Sargos, F. M. (2013, October). Multi-objective analysis for designing and controlling micro-grids under multi-control with PID, MHCC and FOPID controllers. In 2013 IEEE Industry Applications Society Annual Meeting (pp. 1-8). IEEE.

[31] Tepljakov, A. (2017). FOMCON: fractional-order modeling and control toolbox. In Fractional-order Modeling and Control of Dynamic Systems (pp. 107-129). Springer, Cham.

[32] Ahmed, R., Gazzarri, J., Onori, S., Habibi, S., Jackey, R., Rzemien, K., ... & LeSage, J. (2015). Model-based parameter identification of healthy and aged li-ion batteries for electric vehicle applications. SAE International Journal of Alternative Powertrains, 4(2), 233-247.

[33] Finney, S. J., Williams, B. W., & Green, A. T. C. (1996). RCD snubber revisited. IEEE Transactions on Industry Applications, 32(1), 155-160.

[34] Zenk, O., & Ertuğral, B. (2018). An Investigation of Increasing the Performance of Electric Rickshaw-Pedicab Batteries. International Journal of Engineering and Information Systems (IJEAIS), 2(12).

[35] Zenk H., & Ertuğral B. (2018). Comparison of the Electrical Performance of NiCd, NiMH and Li-Ion Batteries by Simulation. International Conference on Agriculture, Technology, Engineering and Sciences (ICATES 2018), 1(1), 352-363.