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Electric Vehicle Application of Fuzzy Logic Controlled Z Connected DC Converter Topology

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Abstract—This article proposes a new fuzzy logic controlled Z-source dc-dc converter topology for electric vehicles. Compared with existing dc-dc converter circuits used in electric vehicles, it can reduce the inrush and high harmonic current on the battery, provide a wider output dc voltage range, and increase reliability. In terms of energy efficiency, it can work as voltage fed and current fed in cases where the source and load are changed. It can perform both the function of increasing and decreasing the output voltage in the two proposed operating states. The working principle and fuzzy logic control method of this new topology proposed for electric vehicles are presented. Analysis and simulation results of a voltage-fed Z source dc-dc converter are shown in an example Matlab / Simulink electric vehicle application.

Keywords— Electric vehicles, DC-DC converter, Z-source, Bi-directional power flow, fuzzy logic.

1. Introduction

In recent years, some countries have been trying to increase the share of green-renewable energy in production and use with different economic incentive approaches, as a solution approach to the problem of global warming and climate change, which are one of the most destructive results of unnecessary and excessive energy consumption of humanity [1-5]. For a realistic and sustainable global energy policy, it is very important to increase the share of renewable-green energy resources on the energy production side. When these energies are ranked according to the size of their production share, dam or canal-based hydraulic power plants [6-12], wind-based production methods [13-16], photovoltaic-based energy production methods [17-22], different biogas-based production techniques [23-30] and geothermal sources [31] should be more involved.

From a global perspective, there is a need for a global energy policy that prioritizes energy efficiency on the side of energy transmission, distribution and consumption. In this respect, efficiency in consumption has a very important place. In order to reduce the energy used by internal combustion engine vehicles, which is one of the main causes of global warming, and the carbon dioxide gas emissions they emit, all kinds of scientific researchers are important for increasing the share of use and improving the efficiency of electric vehicles [32-39].

DC-DC converters are used in a significant part of the power electronics-based systems required for the control of electric motors used in electric vehicle technologies [40-45]. The circuit connections and dynamic response of the Z-source DC converter can reduce inrush and high harmonic current values on the motors and batteries of electric vehicles. Various algorithms can be evaluated for the appropriate selection of Z-connected semiconductor switches and diodes to be used in the circuit [46].

The Z source dc converter [47], which can be a new circuit topology for EV, overcomes some of the theoretical obstacles and limitations of conventional converters as a common voltage source and current source. The working principle and application of this converter for fuel cell systems has been demonstrated in various publications [48-49]. The concept of Z source can also be used in direct AC-to-AC power conversion [50-52]. Similarly, it can be extended to DC-DC power conversion. In this study, Z-source DC conversion topology for EVs is proposed and its basic working principle, the relationship between input parameters and system output parameters, and the effect of the control method are discussed.

2. Z-Connected DC Converter Circuit Topology

The basic structure of the Z connected converter consists of two switches, two diodes, two coils and two capacitors properly connected. Figure 1(a) shows the proposed Z connected DC converter. The converter has two operating modes, voltage-fed and current-fed. When a dc voltage source is connected to the input of this converter, the circuit shown in Figure 1(b) is formed. Another operating state is the one shown in Figure 1(c) where a dc current source is connected, which can be defined as the current fed state. The operating modes of the converter are realized with the use of switches S_1 and S_2 [53]. Each switch consists of a MOSFET or BJT as a power switch and an anti-parallel (or freewheeling) diode to allow bidirectional current flow. Small value inductors and capacitors are used for filtering.

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Switches of this proposed DC converter type operate like conventional DC converters with PWM duty ratio logic. In voltage-fed operating mode, the active part of switch S_2 and the diode of switch S_1 open and close complementary, while the other two devices are switched when the power flow is reversed. Similarly, in current-fed operation mode, the active part of switch S_1 and the diode of switch S_2 are switched on and off complementary, while the other two devices are switched when the power flow is reversed. Table 1 shows the steady-state input-output voltage gains of these converters as a function of the D duty ratio of the active device. The output voltage is regulated as desired by controlling the duty ratio.

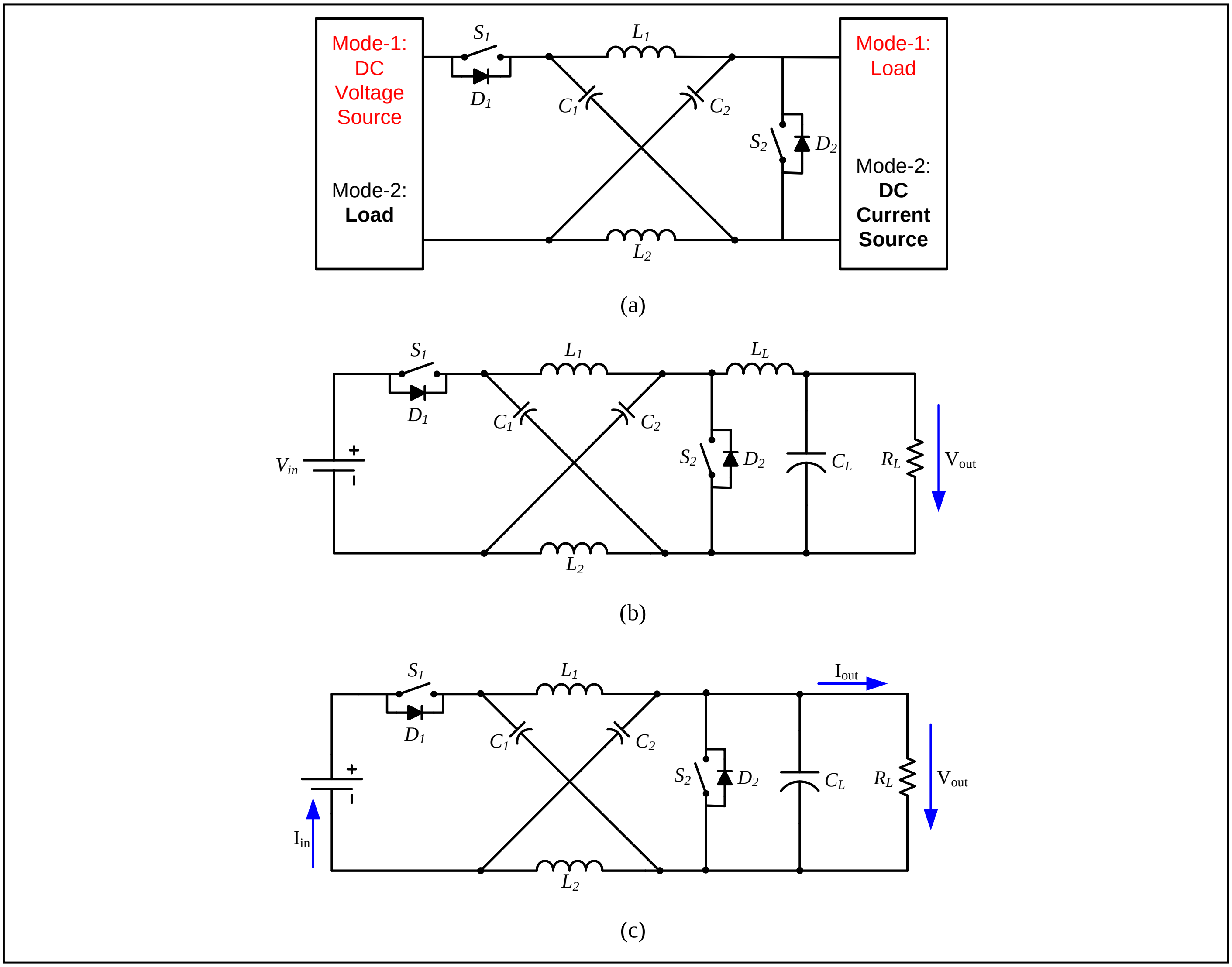

Fig. 1. *Z-connected type converter (a) topology, (b) voltage fed, (c) current fed operating mode.*

Table 1: Voltage Gain Ratio of Z Source DC Converter

Z Source DC Converter	Voltage Gain
Voltage Fed	$\frac{1-D}{1-2D}$
Current Fed	$\frac{2D-1}{D}$

2.1 Mode-1: Electrical Analysis and Matlab/Simulink Simulation of Voltage Feed Z-Type Converter

In general, the operation of the circuit analysis of the Z source dc converter with a voltage supply connection in Figure 1(b) is explained with Mod-1. Analysis of a voltage-fed Z-connection and analysis of a current-fed Z-circuit are very close. The situation in Figure 2(a), where the energy flow from the source to the load, should be carefully studied so that circuit analysis can be done more easily. There are two states in this circuit; Figure 2 shows the equivalent circuits (b) and (c).

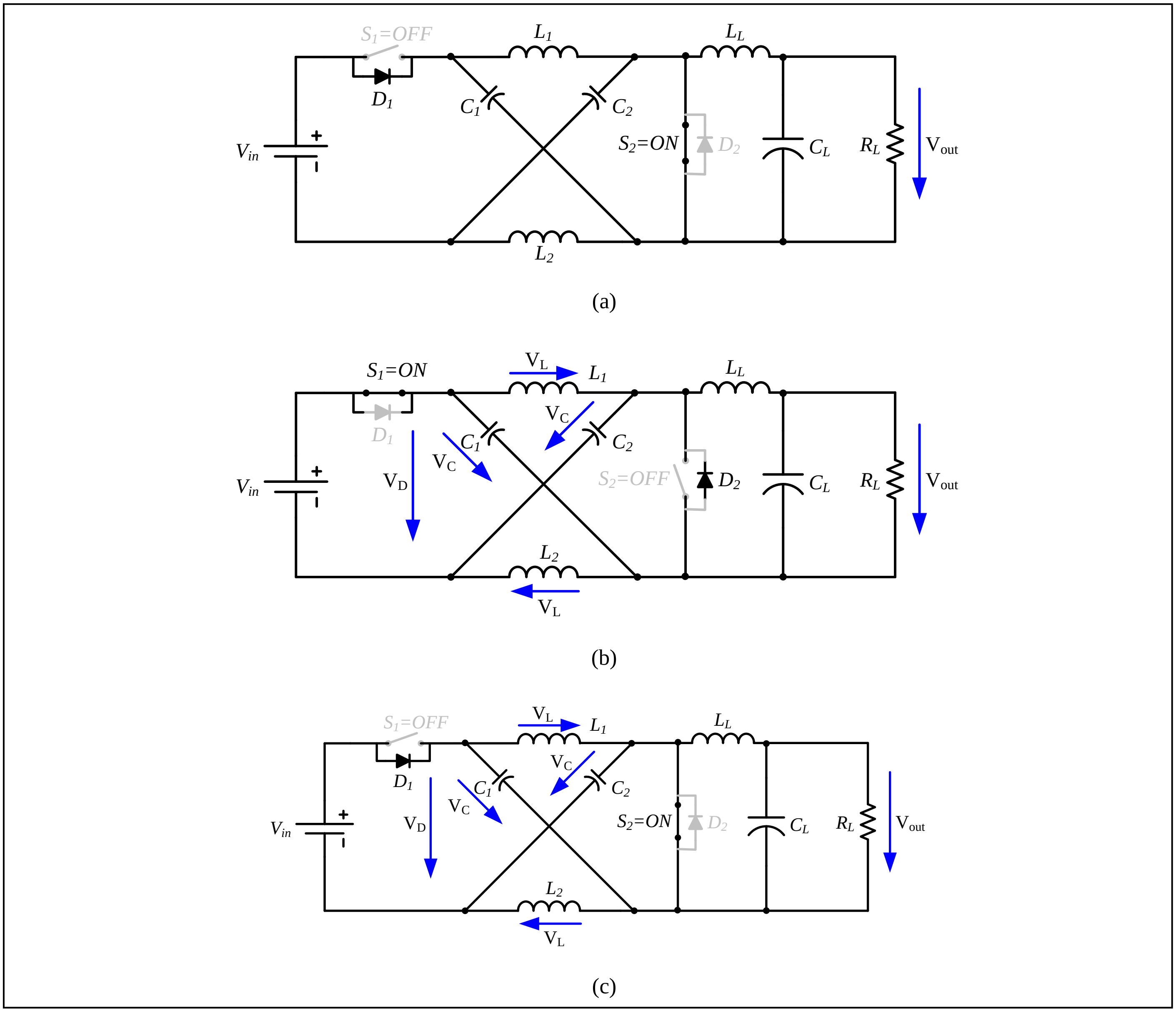

Fig. 2. *Z converter (a) voltage fed topology, (b) State 1: S1 is on and S2 is off, (c) State 2: S1 is off and S2 is on.*

Inductors L_1 and L_2 of the Z source dc-dc converter have the same inductance (L) value and capacitors C_1 and C_2 have the same capacitance (C) value. V_1 can be calculated from symmetry and equivalent circuits.

$$V_{C1} = V_{C2} = V_C \qquad (1)$$

$$V_{L1} = V_{L2} = V_L \qquad (2)$$

In the 1st operating state, the switch S2 is OFF and S1 is closed, assuming it is ON. While the DC voltage source charges the z-connected capacitors C_1 and C_2, the inductors L_1 and L_2 transfer their energy to the load at the output. In this case, the range of the working transducer is *(1-D)T*. D is the duty ratio of the S_2 switch and T is the switching period in seconds.

$$V_C = V_{in} - V_L \qquad (3)$$

$$V_{out} = V_{in} - 2V_L \qquad (4)$$

In the 2nd operating state of the converter, the position of switch S_1 is OFF and the position of switch S_2 is ON. Z-connected capacitors are de-energized while inductors charge energy to release and transfer the charge to the charge. It is the mathematical equivalent (DxT) value of the time interval in which the converter operating in this second operating state is operating.

$$V_C = V_L \qquad (5)$$

$$V_{out} = 0 \qquad (6)$$

The equations describing the circuit parameters in the steady state operating process are given in (1) - (6) respectively. Accordingly, the output voltage must be zero. From here,

$$\frac{V_C}{V_{in}} = \frac{1-D}{1-2D} \qquad (7)$$

From here, the peak output voltage of the Z converter in a switching cycle is as follows.

$$V_{out} = 2V_C - V_{in} = \frac{V_{in}}{1-2D} \qquad (8)$$

The average output voltage of the Z type converter is expressed by equation (9).

$$V_{out} = V_C = \frac{1-D}{1-2D} V_{in} \qquad (9)$$

By controlling the duty ratio D of the switches in a Z converter, the dc-dc conversion, that is, the output voltage can be adjusted. Also, the output voltage can be in-phase or out-of-phase with the input voltage, depending on the operating regions of the duty period. Since the switching frequency is very high in this Z-connection, the inductance and capacitance values of the circuit can be selected small, so the size and weight of the whole system is low. Figure 3 describes the Matlab/Simulink model of a Z-connected, DC voltage sourced converter.

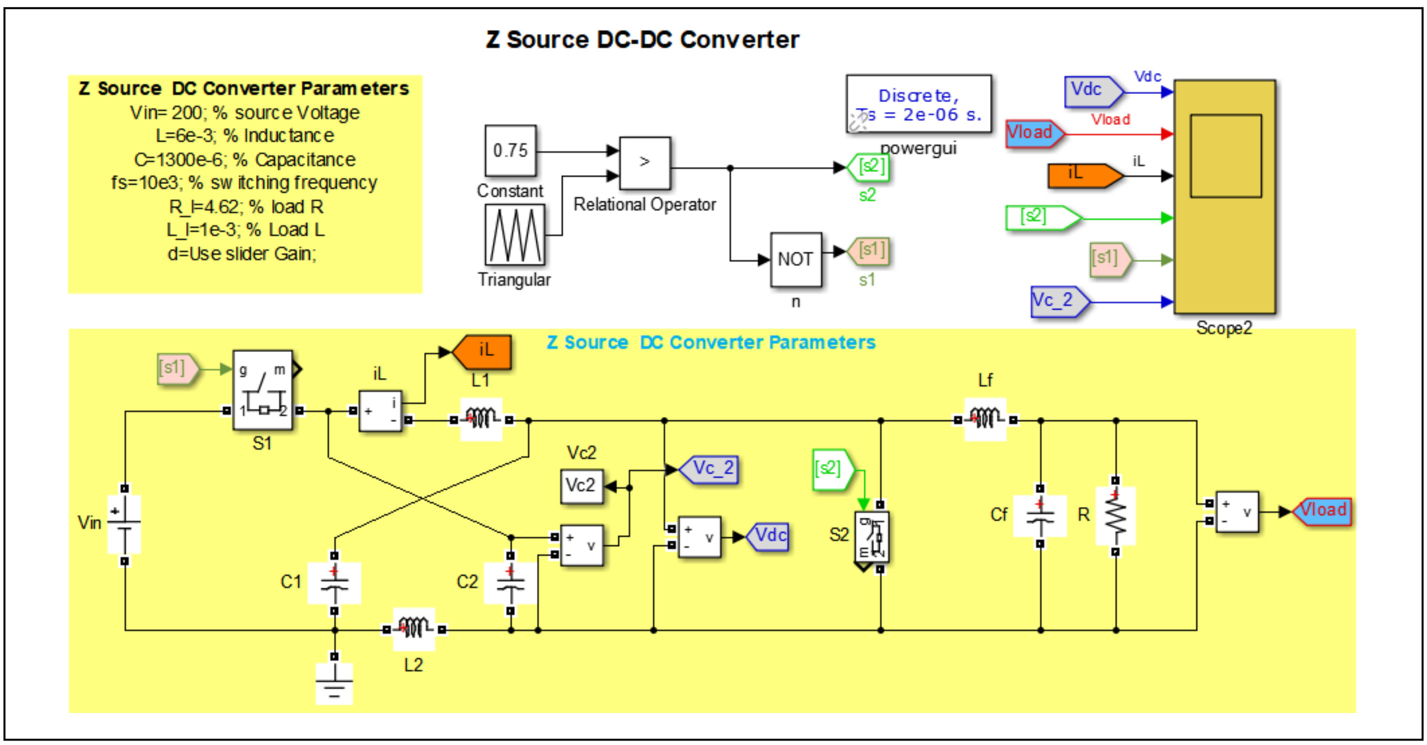

Fig. 3. *Z source DC Converter Simulink Circuit Model*

2.2 Fuzzy Logic

The article published by Zadeh in 1965 is considered an important point in the evaluation of the concept of uncertainty in the modern sense. In this article, Zadeh introduced the "fuzzy set theory" of objects with imprecise boundaries [54]. Fuzzy set theory was developed to solve problems where imprecise, ambiguous definitions pass. A fuzzy set is characterized by a membership function with a membership degree between 0 and 1. Purpose of fuzzy set theory; It is to assign a degree of membership to concepts that express uncertainty, which are difficult to define or difficult to understand, to bring certainty to them. The specificity approach arises from the transformation of the bivalued set theory into the multivalued set theory. With the use of fuzzy sets, which are the numerical representation of imprecise information, new mathematical techniques have been developed to be used in modeling the uncertain structure of real world problems. The methods developed in this uncertainty are quite different from classical linear programming. It can be said that fuzzy sets are sets with fuzzy boundaries compared to classical sets. Because of this feature, fuzzy sets are compatible with real life and have a wider application area compared to classical sets [55]. Fuzzy set theory is about a subset of A in the universe X. The fuzzy subset does not have well-defined boundaries when universe X covers a finite class of elements. For A, which is a classical subset of the X universe, the membership is represented by the characteristic function $\mu_A(x)$ and varies between [0,1] as follows [56].

$$\mu_A(x) = \begin{cases} 1, & If\ x \in A \\ 0, & otherwise \end{cases} \qquad (10)$$

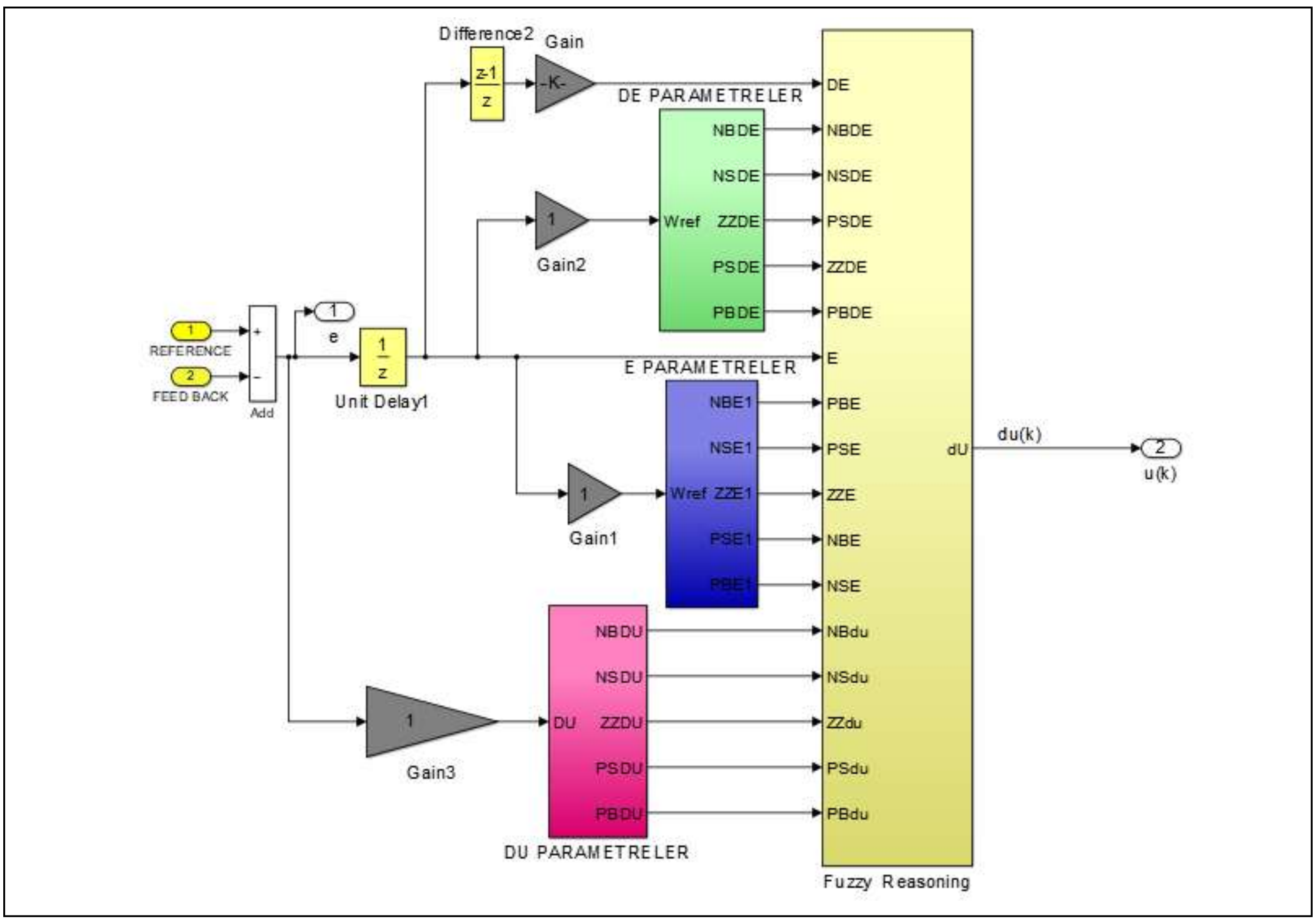

Fig. 4. *Fuzzy Logic based controller Simulink model.*

If the cluster value is indeed allowed to be in the range of [0,1], then the set A is called the "Fuzzy Set". $\mu_A(x)$ is the "membership degree" of X in set A, and for values of $\mu_A(x)$ close to one, the membership of x in set A increases. A fuzzy set is characterized by a set of ordered pairs. The fuzzy set A in the universal set X is represented as a set of ordered pairs. The ordered pairs of a fuzzy set A are shown in equation (11). The meaning of this expression is expressed as follows; The first of the elements of a fuzzy set, A, consisting of ordered pairs, is the element of the set, and the second is the value indicating the membership degree of this element [57-60]. The degree of belonging or membership of x to A is denoted by $\mu_A(x)$.

$$A = \{(x, \mu_A(x)) \| \; x \in A\} \qquad (11)$$

As a result; fuzzy sets help to express ambiguous and fuzzy concepts in language mathematically. Fuzzy set theory was developed to describe and solve problems with no clear boundaries. The symbols and expressions used in fuzzy sets and most of the expressions used in classical sets are similar to each other. For a Fuzzy Logic based Matlab/Simulink model, the behavior of the system to be controlled should be observed first. Appropriate membership functions and rule table are obtained by considering the control signal applied to the system, the error signal produced by the system and the changes in the error. Figure 4 shows the Simulink block diagram of fuzzy logic control [61-71].

2.3 Simulation Model of the EV System

The model in MATLAB / Simulink environment of the system representing the proposed Z source DC converter and the battery unit of the EV and the motors is given in Figure 5. A fuzzy logic-based controller is used as the controller in the system. In order to examine the electrical performance of the designed converter, the input voltage, load voltage, inductance current, capacitance voltage, and the generated switching signals are shown in Figure 6.

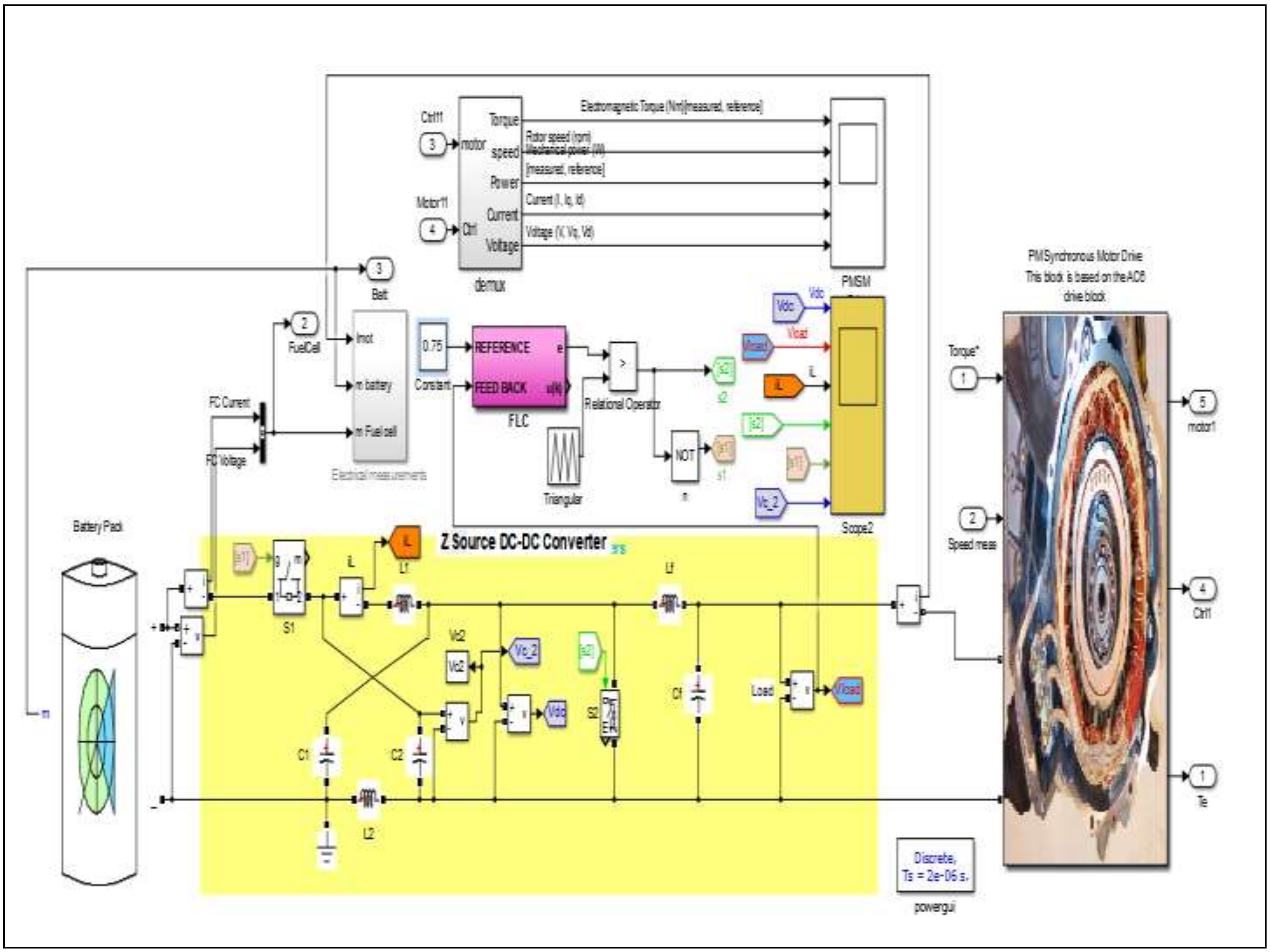

Fig. 5. *System Matlab/Simulink Model*

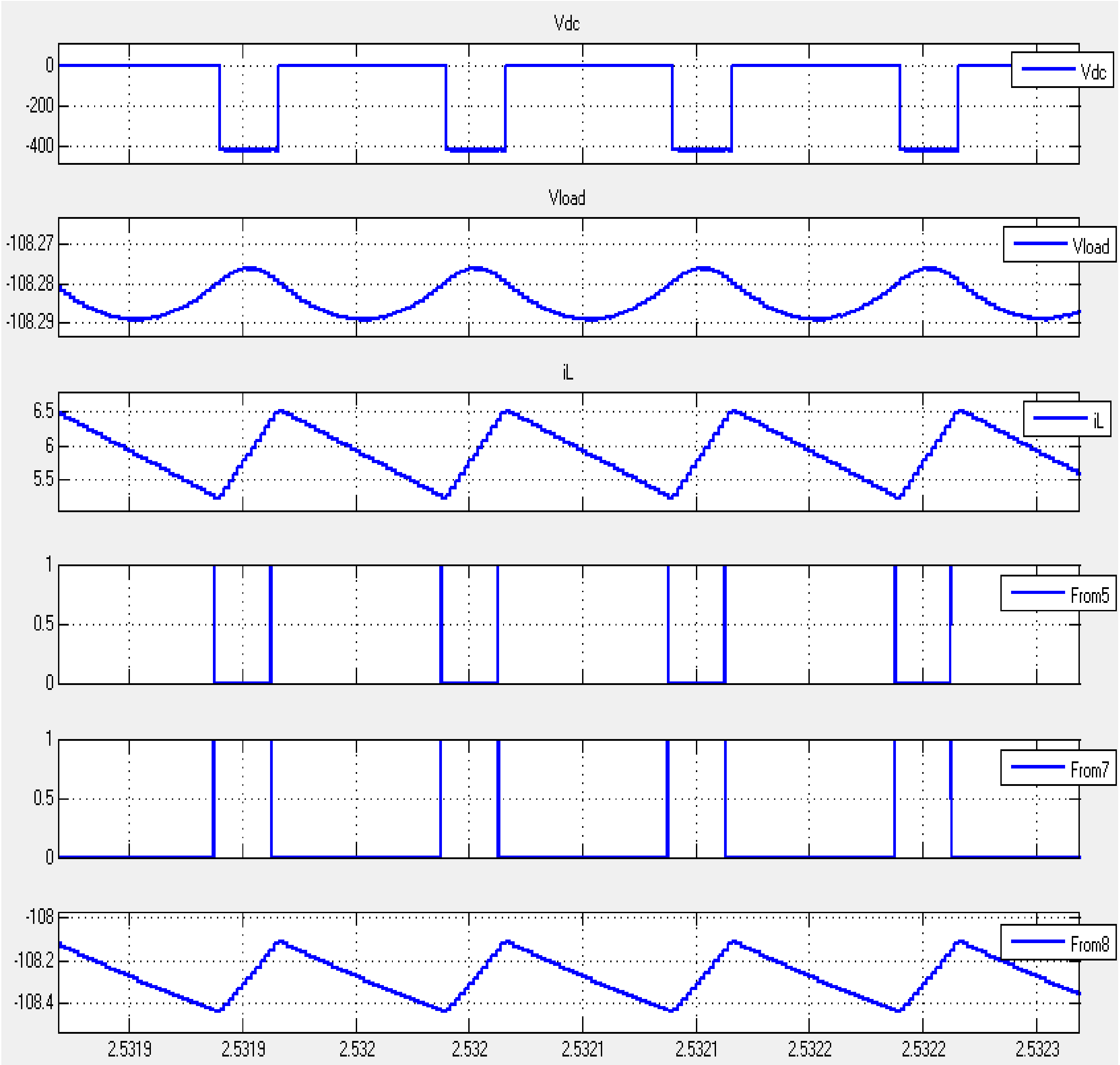

Fig. 6. *System Outputs*

The 16-second simulation of some physical data of the vehicle is given in Picture 4. These data are reference and measured variation of vehicle speed, acceleration, driving torque. Moreover; The electrical power changes of the motor, generator and battery are also given.

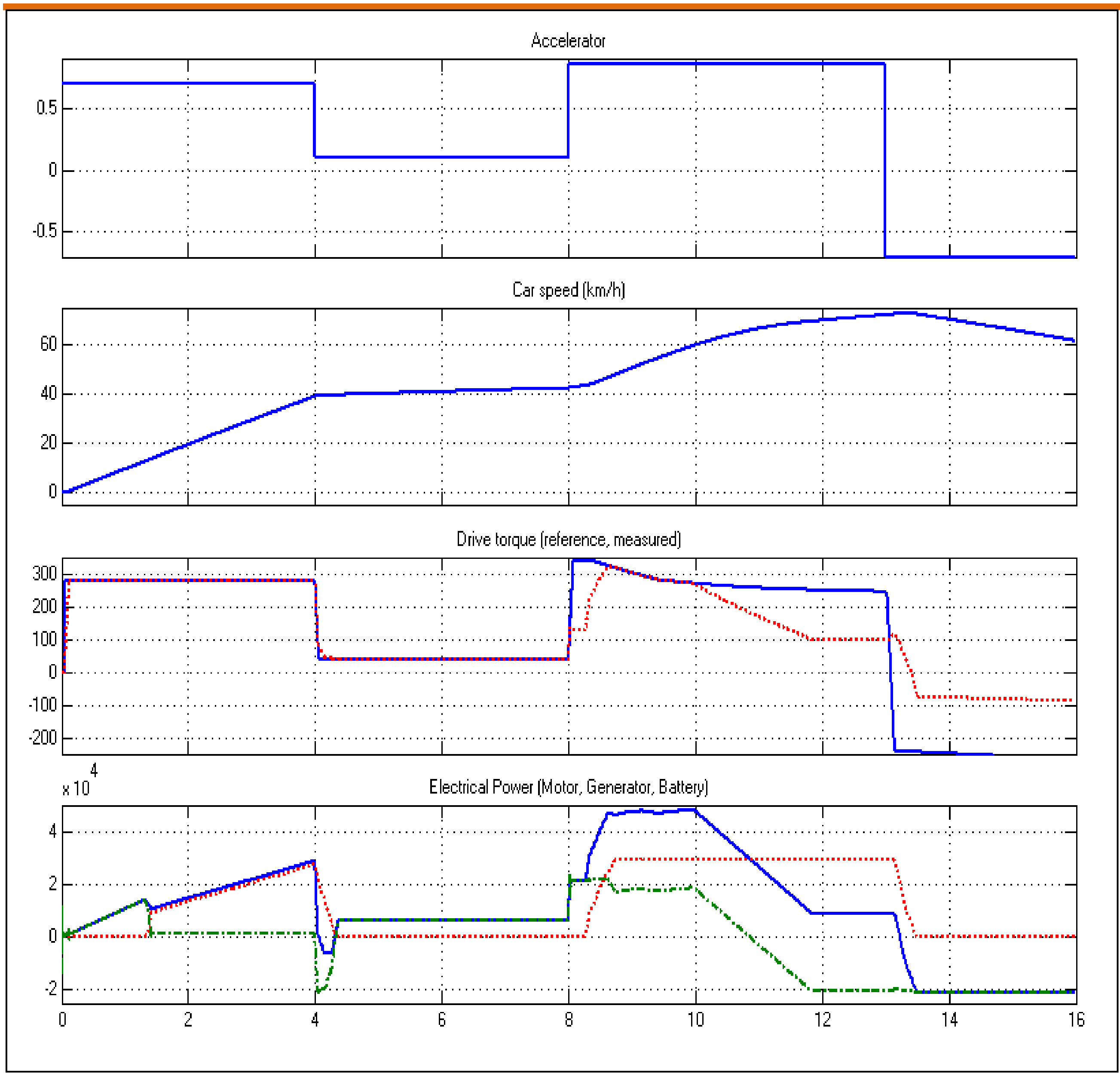

Fig. 7. *Car Outputs*

3. CONCLUSIONS

In this study, fuzzy logic-based control of a Z-linked converter selected as a DC-DC power converter between the battery pack and motors and other electrical loads of an electric vehicle and an efficient design of the system are studied. The dynamic model of the system was created in the MATLAB/Simulink digital environment. Voltage-fed Z source dc-dc converter simulations were made for electric vehicles. The simulation results are the parameters of a Z-connected converter are $L_1=L_2=L=500\mu H$, $C_1=C_2=C=1.000uF$. It was observed that when the input dc voltage is 220V nominal value and 50% voltage drop is 110V, with the PWM duty ratio control, it can keep the 170V output voltage constant. The converter works in buck mode when the input voltage is normal at its rated voltage, the output and input voltage are reversed, and the converter works in boost mode during voltage drop. In the simulation, while the switching frequency was 10 kHz, it was worked in harmony between the battery and the load. In the system, it is predicted that speed control is realized effectively by using fuzzy based controllers instead of PI, PID or Fuzzy Tuned PI / PID type classical controllers.

4. References

[1] Gillingham, K., Newell, R. G., & Palmer, K. (2009). Energy effici. eco. and policy. Annu. Rev. Resour. Econ., 1(1), 597-620.

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

[3] Lovins, A. (2017). Energy efficiency. Energy Economics, 1, 234-258.

[4] 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.

[5] Sorrell, S., & O'Malley, E. (2004). The economics of energy efficiency. Books.

[6] Sims, G. P. (1991). Hydroelectric energy. Energy Policy, 19(8), 776-786.

[7] Mimikou, M. A., & Baltas, E. A. (1997). Climate change impacts on the reliability of hydroelectric energy production. Hydrological Sciences Journal, 42(5), 661-678.

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

[9] Pandey, B., & Karki, A. (2016). Hydroelectric energy: renewable energy and the environment. CRC Press.

[10] 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.

[11] Zenk H., Güney M.S., Zenk O. & Güner F. (2018). A New Energy Conversion System Design with Vertical Hydrokinetic Turbine with Fixed Router Wing. 4rd International Conference on Engineering and Natural Sciences (ICENS 2018), 4(1), 501.

[12] Ozturk, R., & KINCAY, R. (2004). Potential of hydroelectric energy. Energy Sources, 26(12), 1141-1156.

[13] Madariaga, A., Martín, J. L., Zamora, I., De Alegría, I. M., & Ceballos, S. (2013). Technological trends in electric topologies for offshore wind power plants. Renewable and Sustainable Energy Reviews, 24, 32-44.

[14] 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.

[15] Fernández-Guillamón, A., Das, K., Cutululis, N. A., & Molina-García, Á. (2019). Offshore wind power integration into future power systems: Overview and trends. Journal of Marine Science and Engineering, 7(11), 399.

[16] 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.

[17] Buresch, M. (1983). Photovoltaic energy systems: Design and installation. New York.

[18] 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.

[19] Moustafa, K. (2016). Toward future photovoltaic-based agriculture in sea. Trends in biotechnology, 34(4), 257-259.

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

[21] Green, M. A. (2002). Photovoltaic principles. Physica E: Low-dimensional Systems and Nanostructures, 14(1-2), 11-17.

[22] Zenk, H. (2020). Comparison of Voltage Stability of Photovoltaic Power Source Dual Structure Flyback Converter with Fuzzy-Tuned PI and Fractional PID Type Controllers. Karadeniz Fen Bilimleri Dergisi, 10(2), 443-465.

[23] Torrijos, M. (2016). State of development of biogas production in Europe. Procedia Environmental Sciences, 35, 881-889.

[24] 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.

[25] Abbasi, T., Tauseef, S. M., & Abbasi, S. A. (2011). Biogas energy (Vol. 2). Springer Science & Business Media.

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

[27] Gomez, C. D. C. (2013). Biogas as an energy option: an overview. The biogas handbook, 1-16.

[28] 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.

[29] Balat, M., & Balat, H. (2009). Biogas as a renewable energy source—a review. Energy Sources, Part A, 31(14), 1280-1293.

[30] Bianco, F., Şenol, H., Papirio, S., Zenk, H., Kara, A., & Atasoy, S. (2022). Combined ultrasonic–hydrothermal pretreatment to improve the biomethane potential of hazelnut shell. Biomass and Bioenergy, 165, 106554.

[31] Dickson, M. H., & Fanelli, M. (2013). Geothermal energy: utilization and technology. Routledge.

[32] Zenk, H., & Güner, F. (2021). Innovation Process of Electric Vehicles. Research & Reviews in Engineering - I, pp. 201-224.

[33] Letcher, T. M. (2019). Why do we have global warming?. In Managing global warming (pp. 3-15). Academic Press.

[34] Zenk, O., & Ertuğral, B. (2021). Electric Vehicle Battery Charging System Design with Dual Flyback Type Converter. International Journal of Engineering and Information Systems (IJEAIS), 5(12), pp. 12-20.

[35] Barker, T., Ekins, P., & Johnstone, N. (Eds.). (1995). Global warming and energy demand. London: Routledge.

[36] 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), pp. 44-51.

[37] Zenk, H. (2021). Simulink Based Modeling of Fuel Cell and Rechargeable Battery Powered Electric Vehicle. International Journal of Engineering and Information Systems (IJEAIS), 5(12), pp. 31-31.

[38] Dincer, I., Midilli, A., Hepbasli, A., & Karakoc, T. H. (Eds.). (2009). Global warming: engineering solutions. Springer Science & Business Media.

[39] Zenk, H., &Guner, F. (2019). Investigating Electric Transport Vehicle Alternatives of Hazelnut Harvesting in Mountainous Fields. In 2nd International Conference on Agriculture, Technology, Engineering and Sciences (ICATES 2019).

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

[41] Zenk, H. (2018). An Effective Flyback Converter Design for PMDC Motor Control. Karadeniz Fen Bil. Dergisi,8(2), 207-215.

[42] Williams, B. W. (2008). Basic DC-to-DC converters. IEEE Transactions on Power Electronics, 23(1), 387-401.

[43] 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.

[44] 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.

[45] Kislovski, A. (2012). Dynamic analysis of switching-mode DC/DC converters. Springer Science & Business Media.

[46] Fang, X. (2008, April). A novel Z-source dc-dc converter. In 2008 IEEE International Conference on Industrial Technology (pp. 1-4). IEEE.

[47] Peng, F. Z. (2003). Z-source inverter. IEEE Transactions on industry applications, 39(2), 504-510.

[48] Fang, X. P., ming Qian, Z., Gao, Q., Peng, F. Z., & Yuan, X. M. (2004, June). Current mode Z-source inverter-fed ASD system. In 2004 IEEE 35th Annual Power Electronics Specialists Conference (IEEE Cat. No. 04CH37551) (Vol. 4, pp. 2805-2809). IEEE.

[49] Fang, X. (2008, April). A novel Z-source dc-dc converter. In 2008 IEEE International Conference on Industrial Technology (pp. 1-4). IEEE.

[50] Fang, X. P., Qian, Z. M., & Peng, F. Z. (2005). Single-phase Z-source PWM ac-ac converters. IEEE Power Electronics Letters, 3(4), 121-124.

[51] Zhang, F., Fang, X., Peng, F. Z., & Qian, Z. (2006, March). A new three-phase ac-ac Z-source converter. In Twenty-First Annual IEEE Applied Power Electronics Conference and Exposition, 2006. APEC'06. (pp. 4-pp). IEEE.

[52] Fang, X. (2006, August). Three-phase Z-source ac-ac converter. In 2006 12th International Power Electronics and Motion Control Conference (pp. 621-624). IEEE.

[53] 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.

[54] Zadeh, L. A. (1965). Fuzzy sets. Information and control, 8(3), 338-353.

[55] Malczewski, J. (1999). GIS and multicriteria decision analysis. John Wiley & Sons.

[56] Zadeh, L. A. (1999). From computing with numbers to computing with words. From manipulation of measurements to manipulation of perceptions. IEEE Transactions on circuits and systems I: fundamental theory and applications,46(1),105-119.

[57] Zenk, H., & Altaş, İ. H. (2010). Farklı Kural Tabanlı Bulanık Mantık Denetleyicilerle DA Motorunu Denetlerken Performanslarının Kıyaslanması. TOK, 10, 21-23.

[58] Mamdani, E. H. (1977). Application of fuzzy logic to approximate reasoning using linguistic synthesis. IEEE transactions on computers, 26(12), 1182-1191.

[59] Akyazı, Ö., Zenk, H., & Akpınar, A. S. (2011, May). Farklı Bulanık Üyelik Fonksiyonları Kullanarak Sürekli Mıknatıslı DA Motorunun Hız Denetiminin Gerçeklenmesi. In 6th International Advanced Technologies Symposium (IATS'11) (pp. 16-18).

[60] Zenk, H., Zenk, O., & Akpinar, A.S. (2011, June). 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.

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

[62] Pappis, C. P., & Mamdani, E. H. (1977). A fuzzy logic controller for a trafc junction. IEEE Transactions on Systems, Man, and Cybernetics, 7(10), 707-717.

[63] Zenk, H., & Akpinar, A. S. (2014). Dynamic Performance Comparison of Cúk Converter with DC Motor Driving and Using PI, PID, Fuzzy Logic Types Controllers. Universal Journal of Electrical and Electronic Engineering, 2(2), 90-96.

[64] Rahim, R. (2017, December). Comparative analysis of membership function on Mamdani fuzzy inference system for decision making. In Journal of Physics: Conference Series (Vol. 930, No. 1, p. 012029). IOP Publishing.

[65] Zenk, H. (2016). In push-pull converter output voltage stability comparison with using fuzzy logic, PI and PID controllers. International Journal of Engineering Research and Management (IJERM), 3(12), 1-6.

[66] 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), 63-68.

[67] Elkan, C., Berenji, H. R., Chandrasekaran, B., De Silva, C. J. S., Attikiouzel, Y., Dubois, D., ... & Zadeh, L. A. (1994). The paradoxical success of fuzzy logic. IEEE expert, 9(4), 3-49.

[68] 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.

[69] 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.

[70] Alavi, N. (2013). Quality determination of Mozafati dates using Mamdani fuzzy inference system. Journal of the Saudi society of agricultural sciences, 12(2), 137-142.

[71] Zenk, H., & Akpinar, A. S. (2013, May). 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.