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Araştırma Makalesi / Research Article

Effective Control of the Developmental Current of a Serial DC Motor with a Fuzzy Tuned-PI Controller Zeta Converter

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Abstract

In most applications where electrical energy needs to be converted to mechanical energy, the most common direct current motors are preferred after asynchronous motor. Since the motors used in most industrial systems are required to produce a high development momentum, it is inevitable to draw high currents from the grid at start times. This high starting current must be kept under control as it increases the power consumption and can seriously damage the stator and rotor windings of the motor. A suitable drive and monitoring system is required for this current control operation. Fuzzy logic controller has adaptive features; it can produce strong results in systems with uncertainties, variable parameters and load distribution. In this study, the starting current of a serial connected DA motor fed from the Zeta converter was first investigated by computer simulation using a fuzzy set-PI controller. The fuzzy-tuned-PI control method was compared to the same motor under the same conditions as conventional PI and fuzzy logic. Matlab / Simulink software was used for simulation. According to the simulation results, it is observed that the fuzzy-tuned-PI controller has a stronger response than the classical PI and fuzzy logic control and the motor draws lower current at the time of development.

Keywords: Zeta Converter, Serial DC Motor, DC Converter, Fuzzy tuned-PI controller, PI controller, Fuzzy logic controller.

Bulanık Ayarlı-PI denetleyicili Zeta Konvertörün Sürdüğü, Seri DC Motorunun Kalkınma Akımının Etkili Denetimi

Öz

Elektrik enerjisinin mekanik enerjiye dönüştürülmesi gereken pek çok uygulamada asenkron motordan sonra en yaygın olarak doğru akım motorları tercih edilir. Çoğu endüstriyel sistemde kullanılan motorlardan yüksek kalkınma momenti üretmesi istendiğinden, başlangıç zamanlarında şebekeden yüksek akımların çekilmesi kaçınılmazdır. Bu yüksek başlangıç akımı, güç tüketimini artırmasının yanında motorun stator ve rotor sargılarına ciddi zarar verebildiğinden mutlaka kontrol altında tutulmalıdır. Bu akım kontrol işlemi için uygun bir sürücü ve denetim sistemi gerekir. Bulanık mantık denetleyici uyarlanabilir özelliklere sahip olduğundan; belirsizliklere, değişken parametrelere ve yük dağılımına sahip sistemlerde güçlü sonuçlar üretebilmektedir. Bu çalışmada ilk olarak, Zeta Çeviriciden beslenen seri bağlı bir DA motorunun başlangıç akımı, bulanık ayarlı-PI denetleyici ile bilgisayar simülasyonu yoluyla incelenmiştir. Bulanık ayarlı-PI denetim metodu, aynı motora aynı durumlar altında klasik PI ve bulanık mantık ile karşılaştırılmıştır. Simülasyon için Matlab/Simulink yazılımı kullanılmıştır. Simülasyon sonuçları göre bulanık ayarlı-PI denetleyicinin klasik PI ve bulanık mantık denetime göre daha güçlü cevap verdiği ve motorun kalkınma anında daha düşük akım çektiği gözlenmiştir.

Anahtar Kelimeler: Zeta konvertör, Seri DA Motoru, Bulanık ayarlı-PI denetleyici, PI denetleyici, Bulanık mantık denetleyici.

1. Introduction

Hazardous wastes from fossil fuels have revealed the issue of global warming, which has encouraged researchers to work on renewable energy sources. In particular, photovoltaic systems (PV), which do not emit CO2 and have a modular structure, have a special place in renewable energy sources (Dinçer F.).

In recent years, photovoltaic systems have been rapidly spreading with increasing incentives in the world. As is known, photovoltaic solar panels produce DC output voltage. DC voltage and power obtained from solar panels are mostly used for feeding loads after conversion to AC voltage by various techniques. Various solar cell manufacturing techniques and materials have been developed. There are many solar panels made of many materials such as amorphous silicon, copper indium gallium selenite and cadmium telluride (Lee, T. D. and Ebong, A. U).

There are many studies on reducing the costs of solar panels and increasing their efficiency. Some researchers have shown that solar cells with more than 30% efficiency are produced today (Prayeen, J. and VijayaRamaraju, V.).

Photovoltaic power generation systems are designed in two ways, either on grid-connected or off grid-connected (Kaundinya, D.P. and at all.). Because the production of solar energy is directly related to weather conditions, a spare energy storage system, ie a battery, is needed to ensure the continuity of the off-grid systems. In the case of grid-connected systems, the energy produced is used as a storage element in a sense, so there is no need for battery use.

The designs of DC converters may vary. Design differences can make the converters superior or handicap compared to each other. Some of the DC converters reduce voltage, some increase them and some increase and decrease them. In order for the converters to function in the desired voltage range, they must also have a good control system. This control work is done by means of proportional control (P), proportional-integral control (PI), proportional-derivative control (PD), proportional-derivative control (PD) and proportional-integral-derivative control (PID) methods, which are commonly classical controllers (Wu, Z. and at all.). After the classical inspection, DC converters with fuzzy logic control (FLC) (Saygın and Kerem) algorithm, which give very successful results in all kinds of engineering applications, have become very popular.

Fuzzy logic-controlled DC converters have low electrical performance as well as low costs. Recently, Fuzzy-Tuned PI control (Rasoanarivo and at all.), which combines classical control with fuzzy logic control, has also yielded very good results.

2. Materials and Methods

The main scheme of the system consisting of a zeta converter consisting of a DC motor connected to the PI, Fuzzy and Fuzzy PI Tuned Controller, respectively, is proposed in Figure 1. The DC supply voltage is supplied by a zeta-type converter of the DC motor connected in series. Samples taken to control the development current of the motor within the desired reference range enter the control unit. The control signals at the controller output turn into PWM signals and operate the zeta converter switches. Thus, control of development flow is provided.

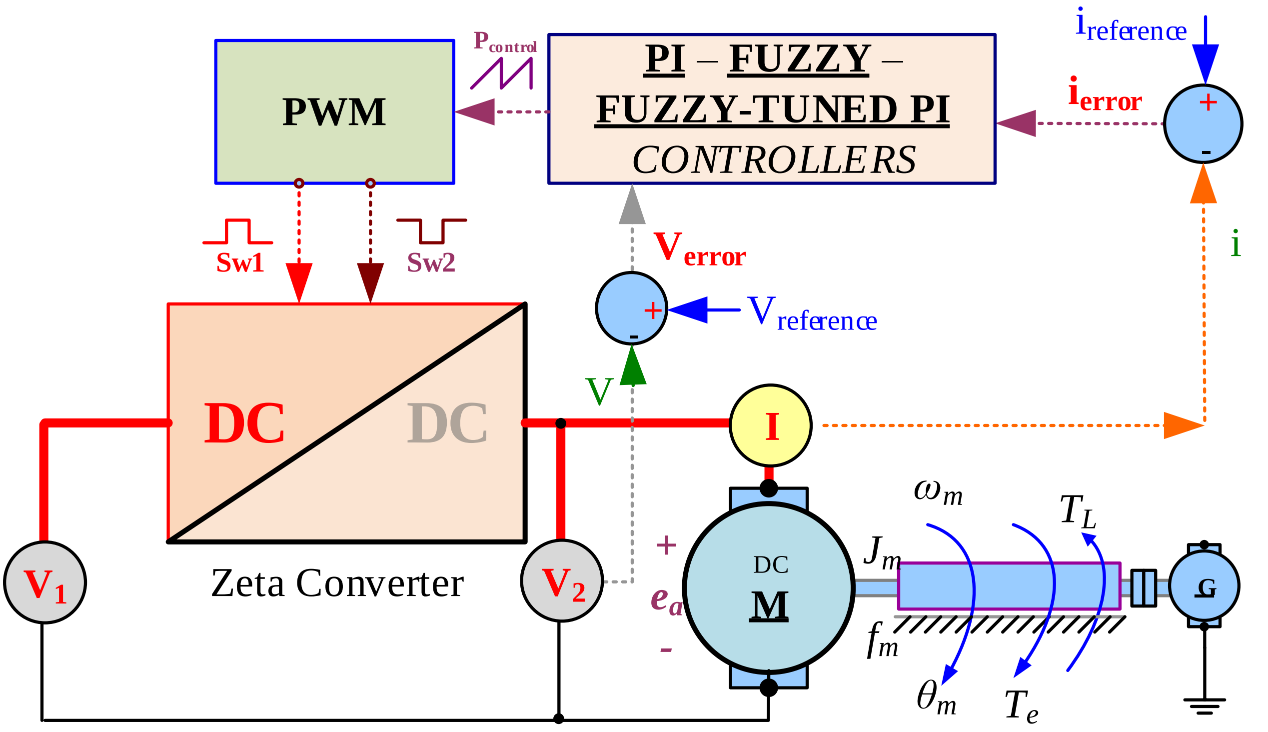

Figure 1. Starting Current PI, Fuzzy and Fuzzy-Tuned PI controllers and Zeta Converter Controlled Serial Connected DC Motor System Block Diagram

2.1. Zeta Converters

Zeta topology from switched mode DC / DC converters, which is an important operating area of power electronics, is a lesser known relative of the SEPIC topology.The most important feature of these two converters is that in converters that increase the voltage to high levels, they provide a positive output voltage that is equal to or smaller than the input voltage as well as reducing circuit complexity and cost.However, the Zeta converter also has the advantage of a significantly reduced output surge voltage. headings.

Zeta converters are used in power factor correction and voltage regulation designs. The traditional Zeta converter is configured from two inductors, a series of capacitors and a diode (Lin, B.R.). The most common operating modes of these PWM transducers can be described as continuous inductor current mode (CICM or CCM) and discontinuous inductor current mode (DICM or DCM) (Mattavelli, P.). The basic circuit connection of the Zeta converter is given in Figure 2.

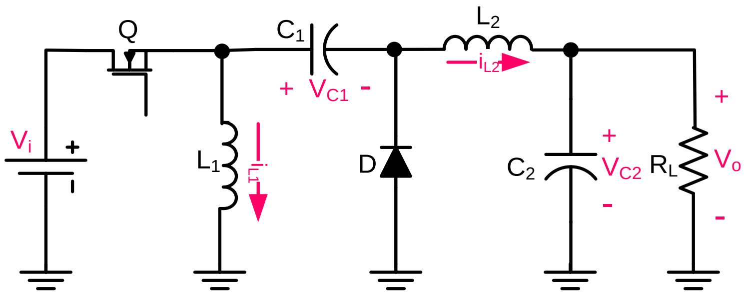

Figure 2. Circuit diagram of PWM Zeta Converter.

2.1.1. Continuous Conduction Mode (CCM)

In CCM mode, the switch has two lower operating ranges on and off. These are the duty cycle in the transmission mode of the switch and the duty cycle in the transmission mode of the diode. Assuming that the loss is 100% yield, the task cycle can be expressed by equation (1) in the D_1 statement for a Zeta converter running in CCM.

$$D = \frac{V_o}{(V_i + V_o)} \quad (1)$$

$$V_o = \frac{D_1 V_i}{(1 - D_1)} \quad (2)$$

$$\frac{V_o}{V_i} = \frac{D_1}{(1 - D)} = M_c \quad (3)$$

Here, V_i and V_o are the input and output voltages of the PWM Zeta converter. This can be rewritten as shown in equation (2) to obtain the output voltage of the converter in CCM mode.The maximum value of the Duty cycle is D_{1max}, the smallest value of the input voltage is in V_{imin} and the additional small value of the Duty cycle is D_{1min}, the maximum value of the input voltage is in V_{imax}. The DC to DC conversion ratio of the PWM Zeta converter is given in equation (Rashid M.H.).

2.1.2. Discontinuous Conduction Mode (DCM)

In DICM, the switching period is divided into three lower ranges.The third time interval of the operating cycle is not zero and the inductor current is not continuous.Three separate time intervals are D_1T_s, D_2T_s and D_3T_s with $D_1 + D_2 + D_3 = 1$ for a fixed switching frequency.The D_3 is the switch and diode shutdown ratio.The output voltage of the converter in DCM is given in equation (Mohan, N.). DC voltage conversion rate (M_d) is obtained by equation (Bose B. K.).

$$V_o = \frac{D_1 V_i}{D_2} \tag{4}$$

$$\frac{V_o}{V_i} = \frac{D_1}{D_2} = M_d \tag{5}$$

2.2. Modeling of Zeta Converter-Fed Serial DC Motors

Figure 3 shows a DC motor load connected to the Series fed by the Zeta Converter.It is assumed that the power switch in the converter circuit is ideal; there is no loss of inductance and capacitor, and Vi represents an ideal voltage source at the input without internal resistance.

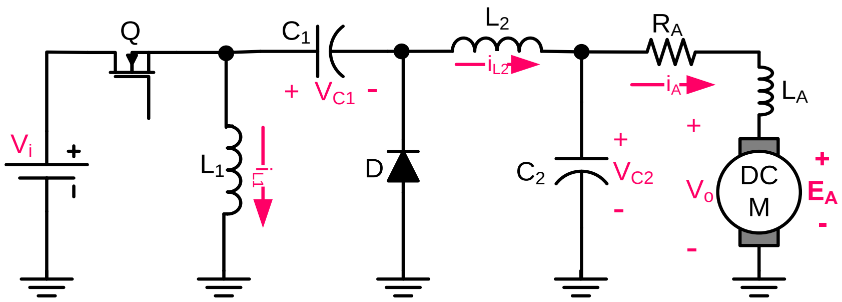

Figure 3. Zeta Converter-fed Serial DC motor load.

In view of the above assumptions, the state variables of the system in Figure 2 can be written in the form of the matrix form equation (6).In Equation 1, $i_L(t)$ is the transducer inductance current, $v_C(t)$ is the transformer voltage, $i_a(t)$ is the DC motor current, the V_i transducer is the input DC voltage and indicates the state of the power switch.DC motor equations consisting of mechanical and electrical components are given in equations (7) and (8).

$$\begin{bmatrix} \frac{di_L(t)}{dt} \\ \frac{dv_C(t)}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L}(1-s) \\ \frac{1}{C}(1-s) & \frac{-i_a(t)}{C} \end{bmatrix} \begin{bmatrix} i_L(t) \\ v_C(t) \end{bmatrix} + \begin{bmatrix} \frac{1}{L}s \\ 0 \end{bmatrix} V_i \tag{6}$$

$$L_A \frac{di_A(t)}{dt} = v_C(t) - R_A i_A - K_e w_s \quad (7)$$

$$J \frac{dw_s}{dt} = -Bw_s + K_t K_i - T_L \quad (8)$$

In summary, the expressions in Equations 6, 7 and 8; L_A: inductance of armature windings, R_A: resistance of armature windings, i_A: armature current, w_s: angular velocity of motor shaft, J: moment of inertia, B: friction viscous coefficient, T_L: load torque, K_e: a coefficient according to the number of motor windings and K_t : the motor is a coefficient calculated according to the number of poles.The inductance current i_L, capacitor voltage v_C, the motor armature current i_A and the angular velocity w_s in the formulas of equations 6, 7 and 8 can be easily solved by many numerical analysis methods.In this study, it was solved by the Euler method in mathematical process libraries in Matlab program.

2.3. Control Systems

2.3.1. PI Controller

The PI controller structure is simple and has a controller structure that provides very good results for many control systems (Pal A. K.). The control block diagram of the classical PI controller is given in Figure 4. According to DC converter reference voltage input circuit, output voltage, is controlled by the PI controller (Yanmaz, K. and at all). On activated equations are as follows.

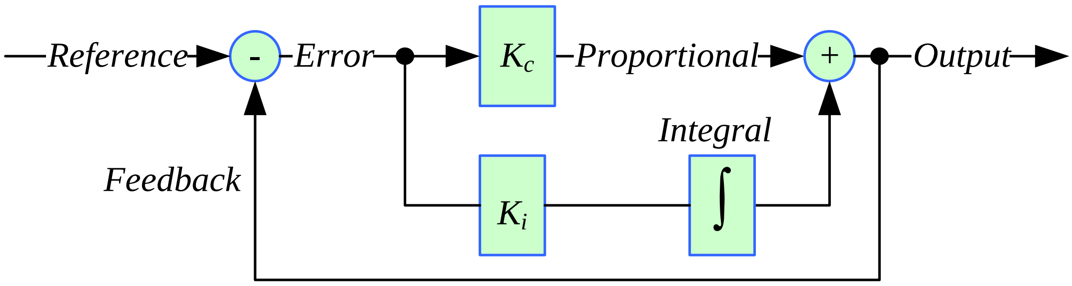

Figure 4. PI Controller Block Diagram

2.3.2. Fuzzy Logic Controller (FLC)

Fuzzy Logic control algorithm is based on digitizing a set of heuristic control rules.It is important to note that fuzzy logic is used to evaluate uncertain, fuzzy sets and rules for expressing linguistic terms (Zadeh L. A.). As is known, the structure of the fuzzy logic controller consists of three parts. These sections are briefly mentioned in the an “Fuzzification”sistem phase and the data obtained from the system are converted to fuzzy values (Elmas C. and at all). The second stage is “Rule Base”, where fuzzy data is processed by fuzzy rules. In the last stage, which is called “Defuzzification”, the data is converted to the exact number of fuzzy results. A fuzzy logic controller system is generally shown in Figure 5.

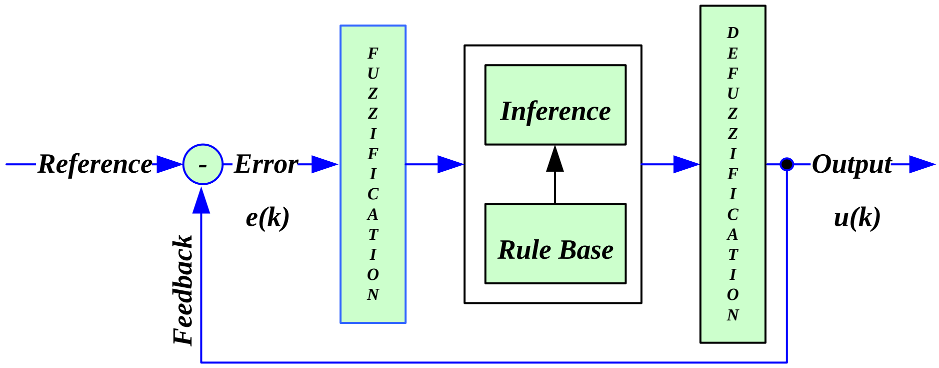

Figure 5. Basic configuration of a FLC.

2.3.3. Fuzzy-Tuned PI Controller (FT-PIC)

The simplified block diagram of the Fuzzy-Tuned PI Controller is shown in Figure 10. Membership functions for this controller type inputs error (e), change of error (de) and controller output (du) are defined on the normalized domain [-1, 1] as shown in Figure 11 (Mengi O. O.). Membership functions (MF) of β is defined on [0, 1] as shown in Figure 6.

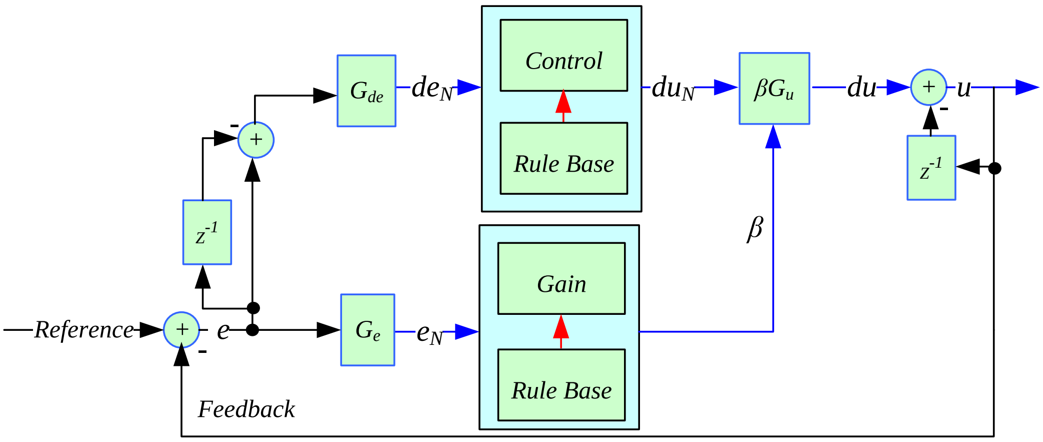

Figure 6. Basic configuration of a FT-PIC.

3. Simulation Results and Discussion

Figure 7 show the connection of this power system designed Simulink. The zeta converter in the system is connected to the PI, FLC and Fuzzy-Tuned PI controllers by manual switches. The reference voltage applied to these controllers is given in Figure 8. It provides the current error between the reference current and the output current signal produced by the zeta converter, which enables the transmission of power to the secondary winding by generating electrical docks for the primary windings of the transformers according to the PWM method with the control voltage of the control signals. According to the type of feedback signal of the controllers, the DC motor can control the voltage, current, torque or speed effectively.

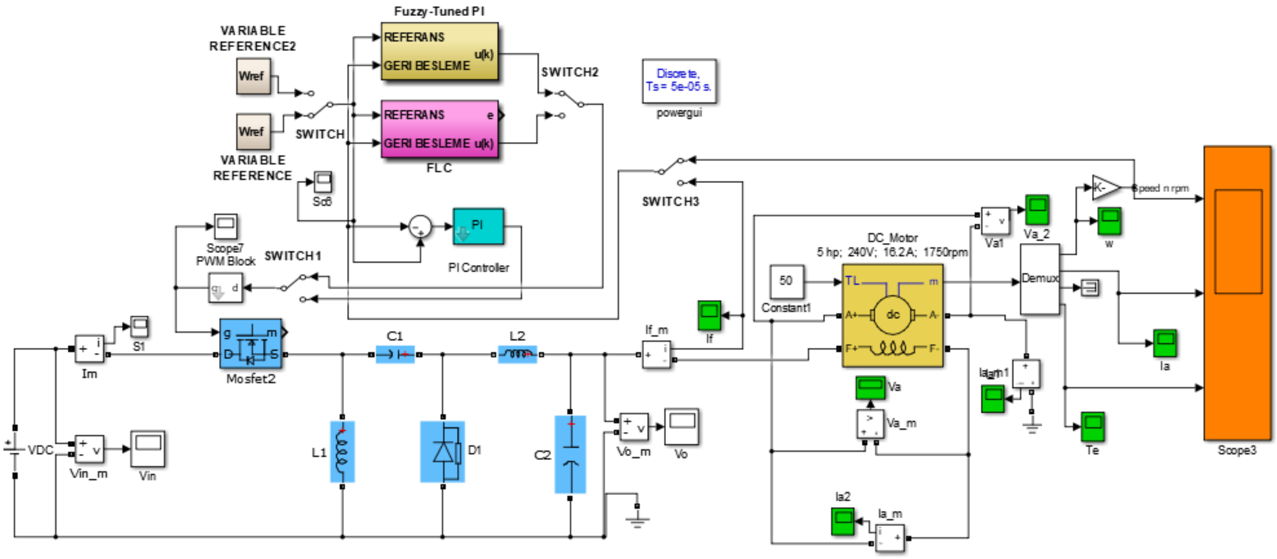

Figure 7. The block diagram of the whole system.

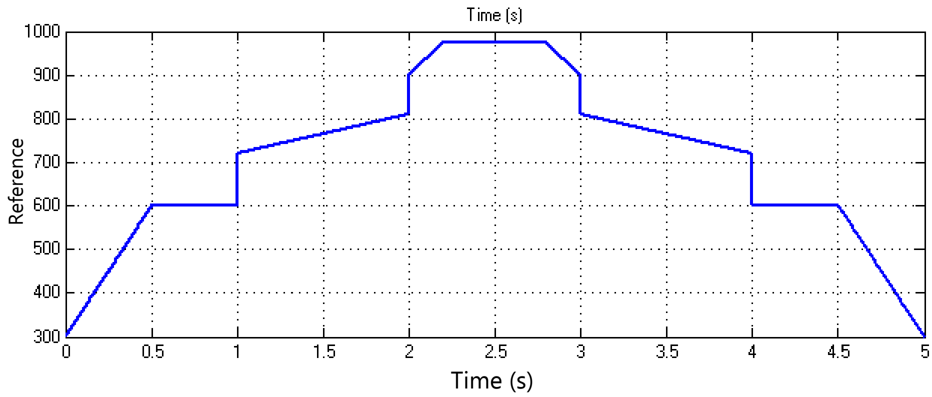

Figure 8. The reference output voltage signal.

Table 1 shows the motor parameters that are used in simulation.

Table 1. DC Motor parameters.

Parameter	Symbol	Value
Armature Resistance	R_a	1.1Ω
Armature Inductance	L_a	0,09H
Inertia Torque	J	0,053 kg.m^2
Friction Constant	B	0.01 N.m.s/rad
Motor Constants	K_e	0,97
Motor Constants	K_t	1,4
Load Torque	T_L	5N.m

System results with PI controller, Fuzzy logic controller and Fuzzy-Tuned PI controller obtained from simulation in Matlab / Simulink program are shown in separate figures. For each graph, the horizontal axis represents the time and the vertical axis represents the green electrical and mechanical parameters on the system.

3.1. CASE 1: Zeta Converter with PI Controller

Figure 9 shows the variation of the output voltage Vo with the given reference sine of the PI-controlled Zeta Converter. In Figure 10, v_o output voltage (Volt), w motor speed (rpm), i_A motor current (Amperes) and T_e torque (Newton.meter) value of the motor are given over time. Figure 11 also shows the current and voltage variations of the L_1, L_2, C_1 and C_2 elements in the Zeta converter circuit.

The results obtained when the indirect current control method with the PI controller is used to control of the zeta converter output voltage signals are shown Figures 9. The PI controllers used in the indirect current control method of the system under variable ambient conditions and constant change in load were set to $K_P = 10$, $K_I = 100$.

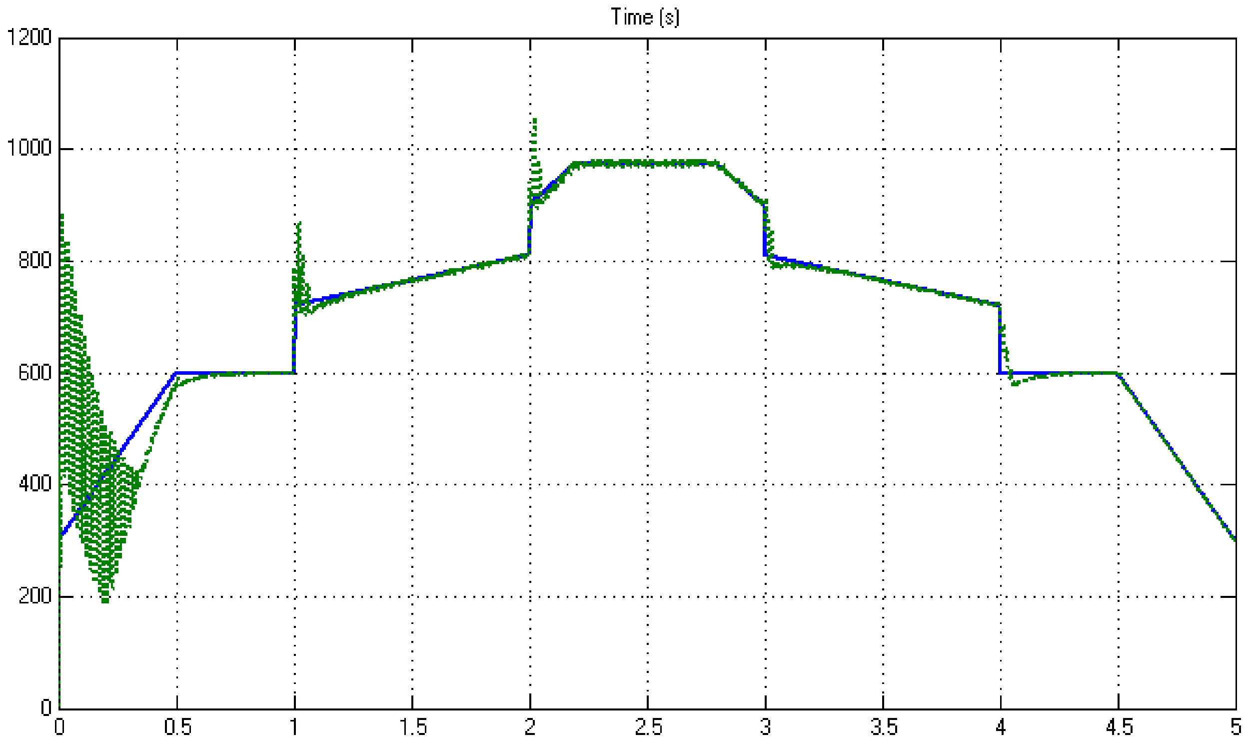

Figure 9. Variation of the output voltage v_o over time with the reference signal of the Zeta converter with PI control.

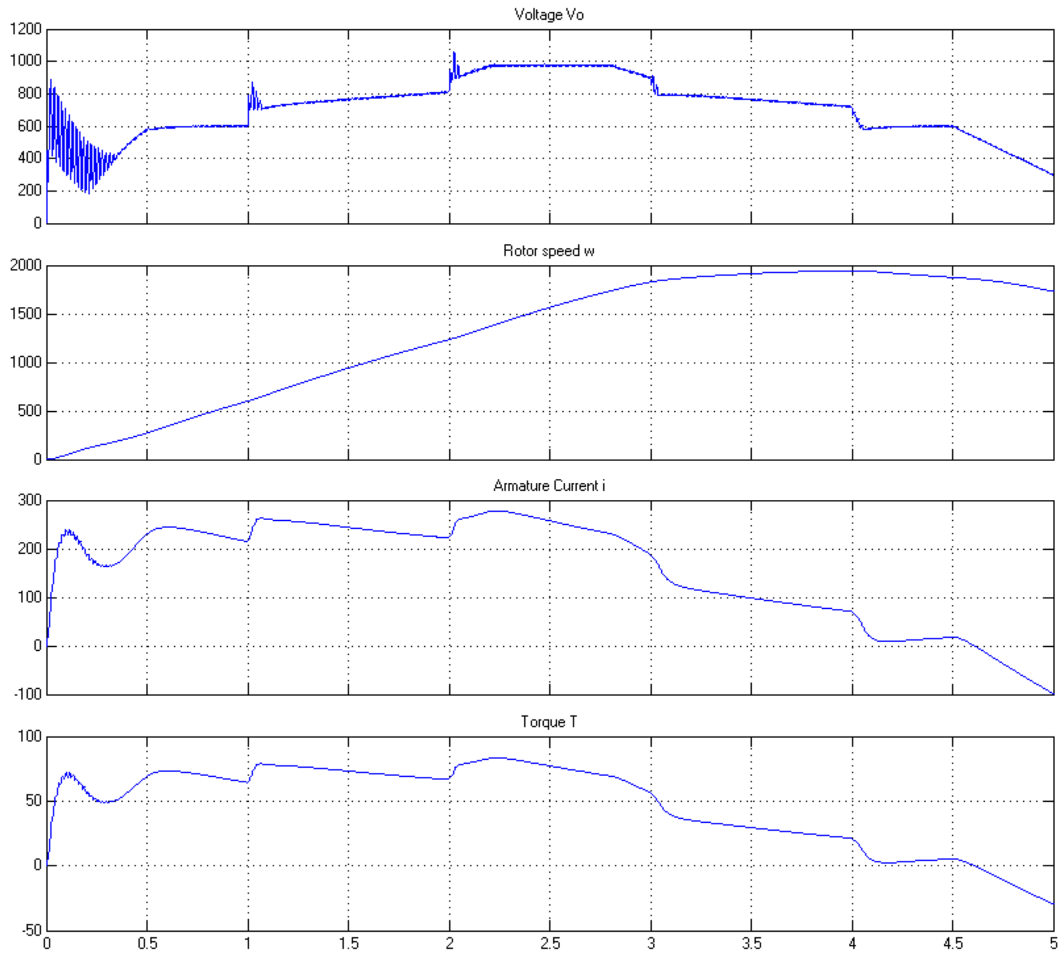

Figure 10. Variation of the output voltage, w motor speed, i_A motor current and T_e torque value of the motor with time controlled by PI controlled Zeta Converter.

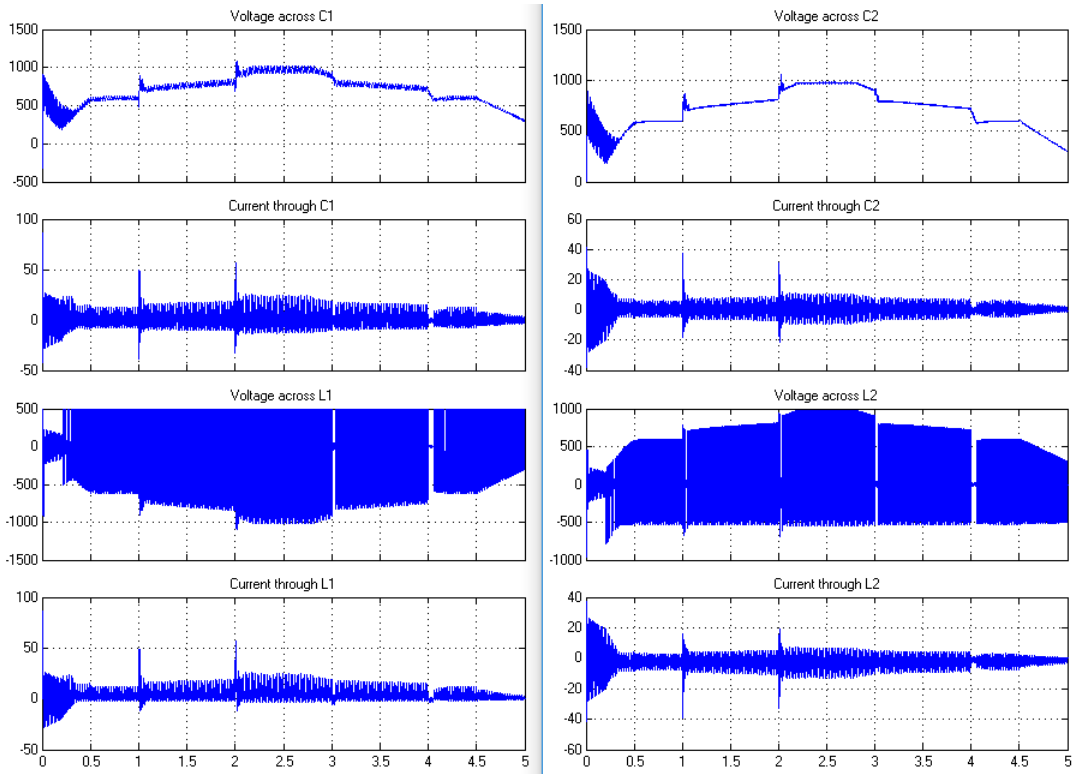

Figure 11. Current and voltage changes of L_1, L_2, C_1 and C_2 elements in the zeta converter circuit.

3.2. CASE 2: Zeta Converter with Fuzzy Logic Controller

Figure 12 shows the variation of the output voltage v_o with the given reference sine of the Fuzzy-controlled Zeta Converter. In Figure 13, v_o output voltage (Volt), w motor speed (rpm), i_A motor current (A) and T_e torque (Nm) value of the motor are given over time. Figure 14 also shows the current and voltage variations of the L_1, L_2, C_1 and C_2 elements in the Zeta converter circuit.

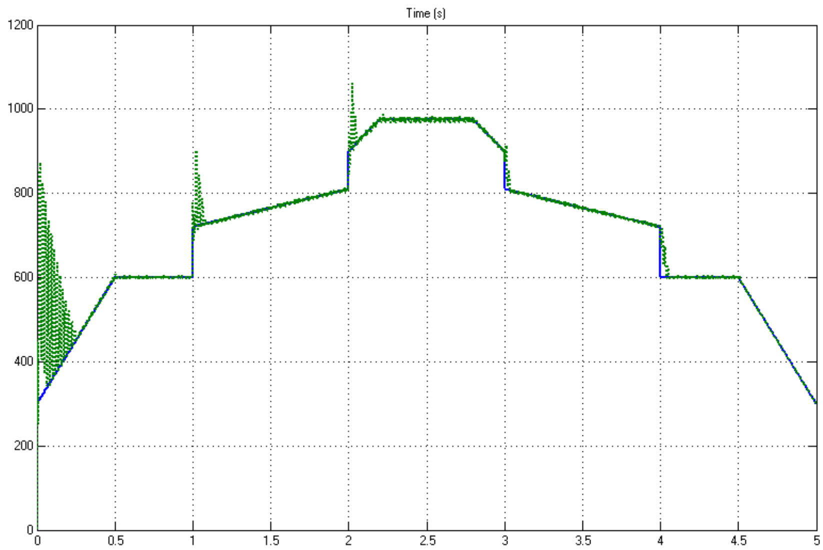

Figure 12. Variation of the output voltage v_o over time with the reference signal of the Zeta converter with Fuzzy Logic Control.

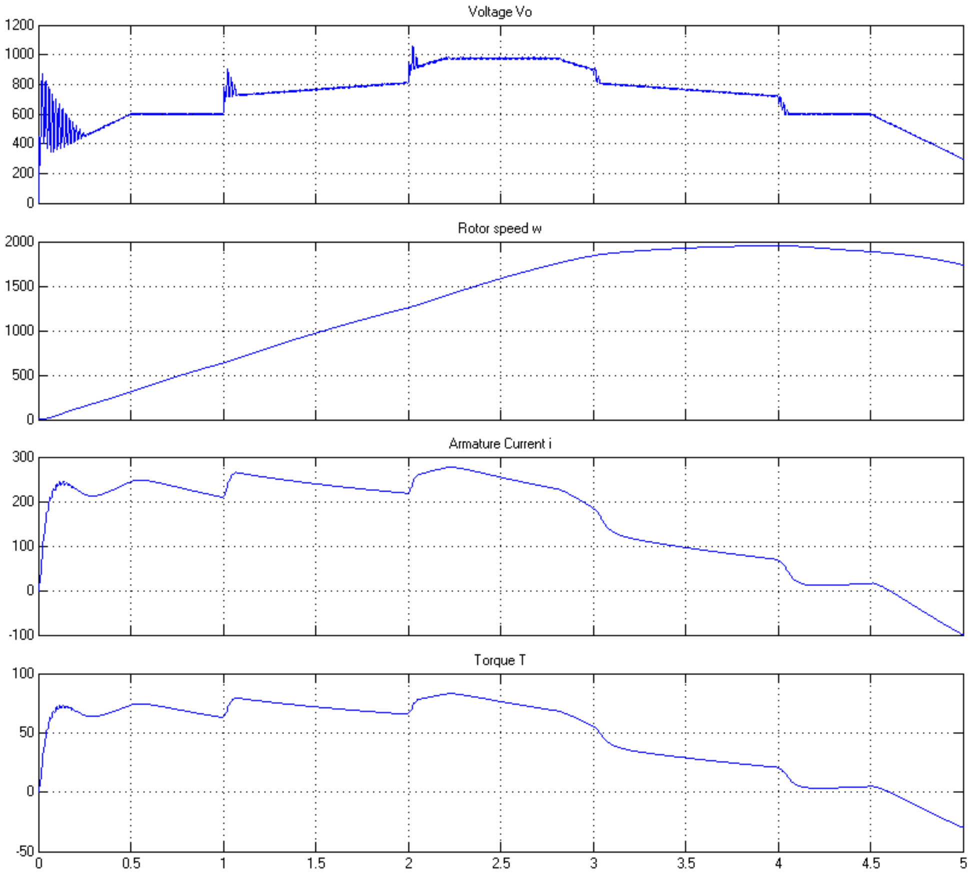

Figure 13. Variation of the output voltage vo, w motor speed, i_A motor current and T_e torque value of the motor with time controlled by Fuzzy Logic controlled Zeta Converter.

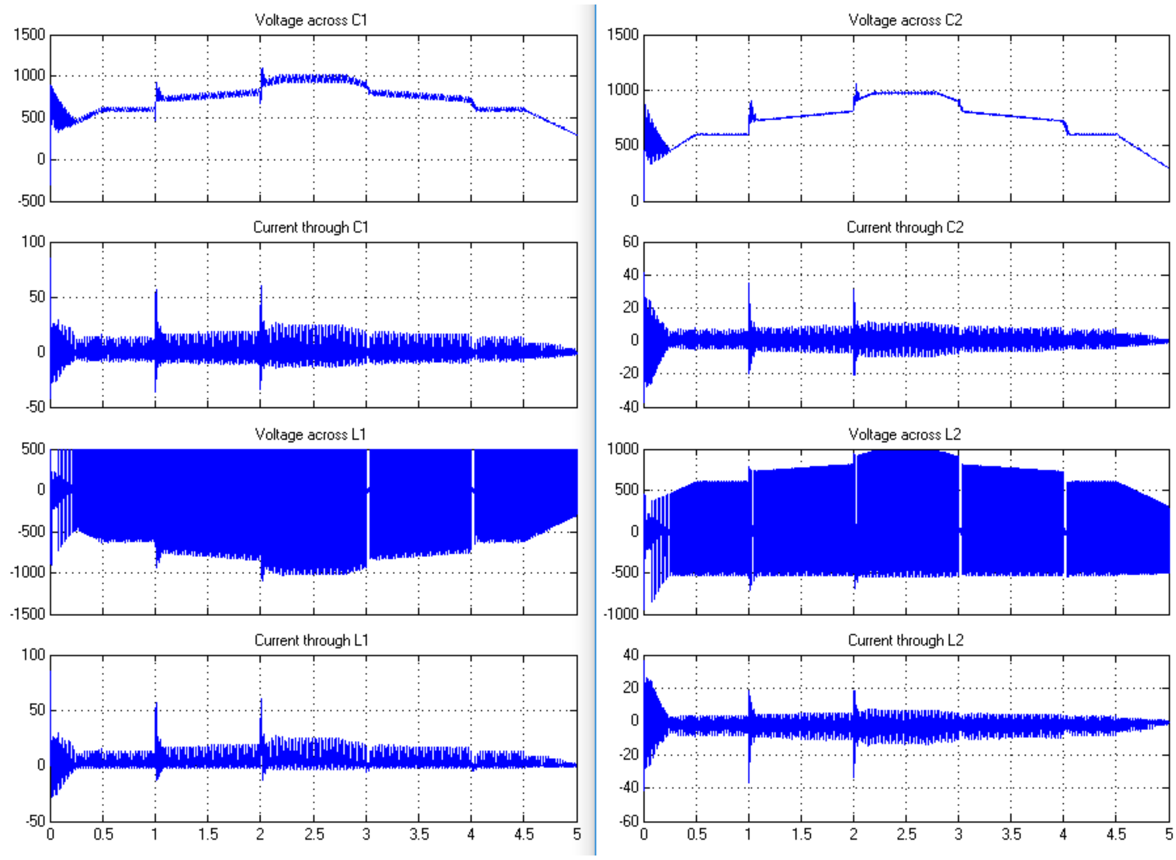

Figure 14. Current and voltage changes of L_1, L_2, C_1 and C_2 elements in the zeta converter circuit.

3.3. CASE 3: Zeta Converter with Fuzzy-Tuned PI Controller

Figure 15 shows the variation of the output voltage v_o with the given reference sine of the Fuzzy-Tuned PI controlled Zeta Converter. In Figure 16, v_o output voltage, w motor speed, i_A motor current and T_e torque value of the motor are given over time. Figure 17 also shows the current and voltage variations of the L_1, L_2, C_1 and C_2 elements in the Zeta converter circuit.

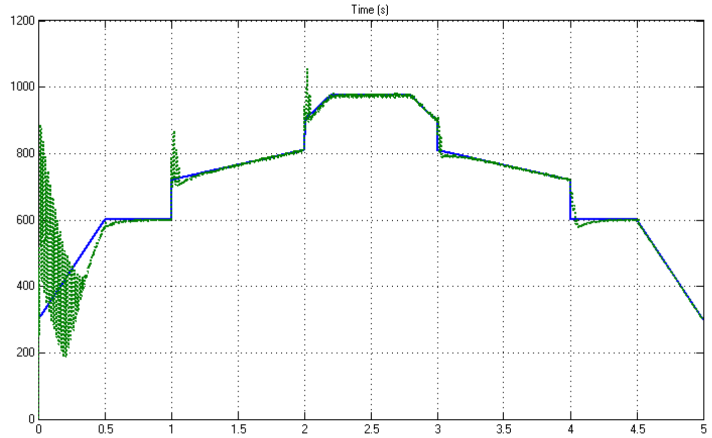

Figure 15. Variation of the output voltage vo over time with the reference signal of the Zeta converter with Fuzzy-Tuned PI Control.

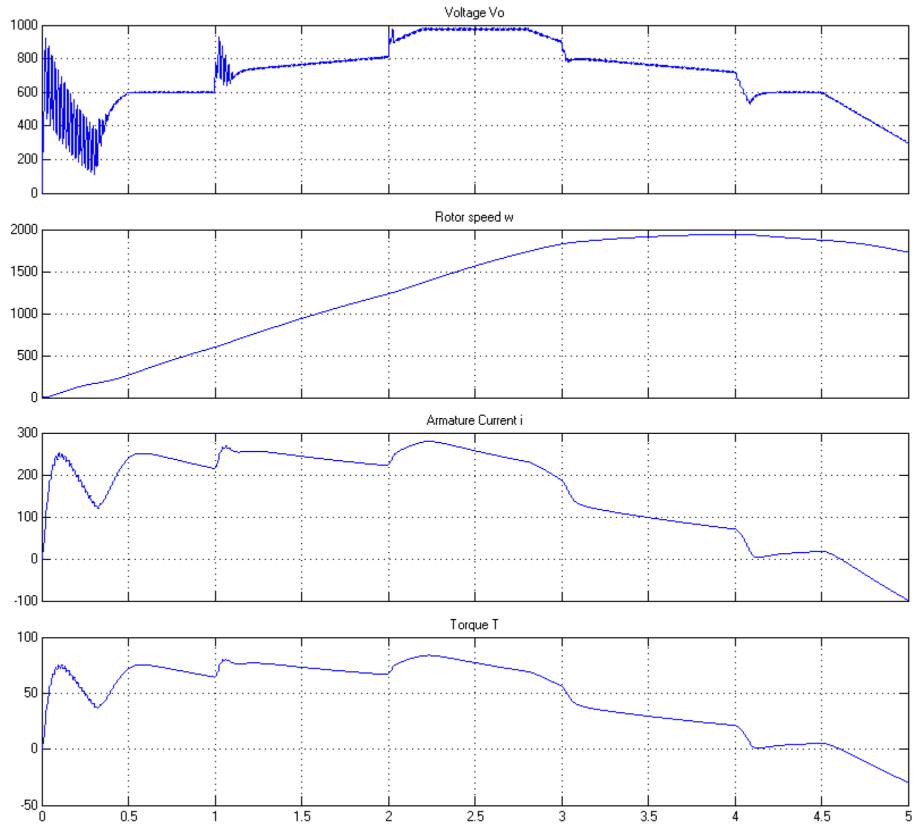

Figure 16. Variation of the output voltage v_o, w motor speed, i_A motor current and T_e torque value of the motor with time controlled by Fuzzy Logic controlled Zeta Converter.

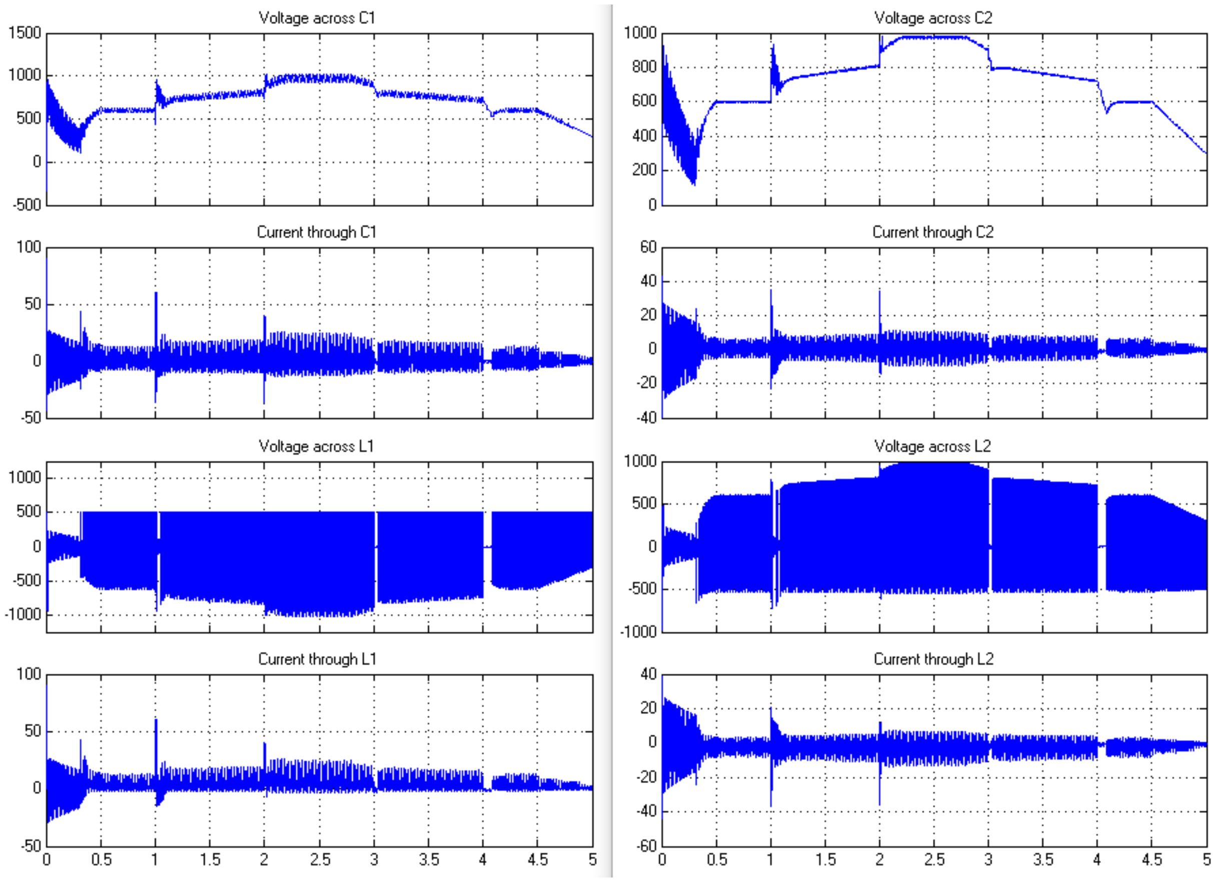

Figure 17. Current and voltage changes of L_1, L_2, C_1 and C_2 elements in the zeta converter circuit.

4. Conclusions and Recommendations

The data of the four points with the largest amplitude current fluctuations during the simulation are given in Table 2 to examine the effects of the Serial DC Motor connected to the system on the starting current.

Table 2. Effects of Different Type Controllers on Motor Starting Currents

Time (s)	PI Controller	Fuzzy Logic Controller	Fuzzy-Tuned PI Controller
0,1500	239,250 A	244,300 A	250,010 A
0,5800	244,100 A	248,040 A	250,550 A
1,0655	263,600 A	265,250 A	268,961 A
2,2390	278,000 A	276,280 A	279,465 A

In this study, electrical performance of a power system connected to a zeta converter is examined using different controller structures. The main load of the system is a series connected DC motor that draws a lot of current. The ON-OFF signals provided to the power electronics-based switch of the zeta converter, which is a power converter in the system, are provided to generate signals with the PWM pulse width required to follow the desired reference variable. These variable pulses are connected to the zeta converter via control elements based on PI, Fuzzy Logic and

Fuzzy-Tuned PI, respectively. The results are quite successful. However, Fuzzy Logic and PI based controllers were more effective than Fuzzy Adjusted PI controllers when their effects on development flow were examined. In the 5 second simulation of these three controllers, data were obtained from four points, the largest amplitude current fluctuations. There is no striking difference between the current amplitudes at these points. However, the classical fuzzy-based controller (FLC) performed slightly better than the others at its largest overrun. With all this in mind, Fuzzy Logic (FL) is the most successful of the controllers used for this system.

Acknowledgements

The MATLAB/SIMULINK data used to support the findings of this study are included within the supplementary information file.

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