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Start Up Current Control of Buck-Boost Convertor-Fed Serial DC Motor

Buck-Boost Çeviriciden Beslenen Seri DC Motorunun Bulanık Mantıkla Kalkınma Akımının Denetimi

Yusuf SÖNMEZ [a,*], Mahir DURSUN [a], Uğur GÜVENÇ [a] and Cemal YILMAZ [b]

[a] Gazi University, Technical Education Faculty, Department of Electrical Education, 06500, Ankara

[b] Düzce University, Technical Education Faculty, Department of Electrical Education, 81100, Düzce

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ABSTRACT

Generally, DC motors are given preference for industrial applications such as electric locomotives, cranes, goods lifts. Because of they have high starting moment; they initially start with high current. This high start-up current must be decreased since it may damage windings of the motor and increases power consumption. It could be controlled by an appropriate driver system and controller. The nature of fuzzy logic control has adaptive characteristics that can achieve robust response to a system with uncertainty, parameter variation, and load disturbance. In this paper, fuzzy logic based control of start-up current of a Buck-Boost Converter fed serial DC motor is examined through computer simulation. In order to see the advantages of fuzzy logic control, classical PI control has applied to the same motor, under same circumstances and has been compared. C++ Builder software has been used for the simulation. According to the simulation results, plainly, fuzzy logic control has stronger responses than classical PI control and uses lower current at starting moment.

Keywords : *Fuzzy logic controller, PI controller, Serial DC motor, Buck-boost converter, Current control.*

ÖZET

DA motorlar genellikle elektrikli tren, vinçler, yük asansörleri gibi endüstriyel uygulamalarda tercih edilirler. yüksek kalkınma momentine sahip olduğundan dolayı başlangıçta yüksek akımla kalkınırlar. Bu yüksek kalkınma akımı motor sargılarına zarar verdiğinden ve güç tüketimini artırdığından dolayı mutlaka azaltılmalıdır. Bu işlem uygun bir sürücü ve denetleyici sistemiyle gerçekleştirilebilir. Bulanık mantık denetleyici uyarlanabilir özelliklere sahip olduğundan; belirsizliklere, değişken parametrelere ve yük dağılımına sahip sistemlerde güçlü sonuçlar üretebilmektedir. Bu çalışmada Alçaltıcı-Yükseltici Çeviriciden (Buck-Boost Converter) beslenen seri bağlı bir DA motorun bulanık mantık hız denetimi bilgisayar simülasyonu yoluyla incelenmiştir. Bulanık mantık denetimin üstünlüğünü görmek amacıyla aynı motora aynı durumlar altında klasik PI denetimi uygulanmış ve bir karşılaştırma yapılmıştır. Simülasyon için C++ Builder yazılımı kullanılmıştır. Simülasyon sonuçlarına göre bulanık mantık denetimin klasik PI denetime göre daha güçlü cevap verdiği ve motorun kalkınma anında daha düşük akım çektiği gözlenmiştir.

Anahtar kelimeler : *Bulanık mantık denetleyici, PI denetleyici, Seri da motor, Buck-boost çevirici, Akım denetimi.*

* Yazışılan yazar/Corresponding author. E-posta adresi/E-mail adress: ysonmez@gazi.edu.tr (Y. Sönmez)

1. INTRODUCTION

DC motors are given preference in many industrial applications by reason of some advantages provided by their working characteristics. It is easy to perform a sensitive control through DC motor systems in a broad range of rpm (rotate per minute) (Linares-Flores and Sira-Ramirez, 2004). DC motors which are used in applications such as electrical locomotive, electric-powered domestic devices, cranes, goods lifts require velocity controllers in order to discharge their duties. Firstly, in 1981, Ward Leonard performed velocity control of DC motors by voltage control. In parallel with the improvements of power electronics, switching power supplies has been developed and has become more important for velocity control of DC motors (Aydemir et al., 2004).

As explained above, serial DC motors use in many industrial areas. But, there is a problem/disadvantage the usage of these motors; that is the high start-up current. Thus, the high start-up current must be decreased since it may damage windings of the motor and increases power consumption.

This high start-up current of serial DC motors should be controlled by an appropriate driver circuit and the controller.

There are several control models in literature;

Classical Models (PI, PID i.e.),

Artificial Intelligence (Fuzzy Logic, Neural Networks, Genetic Algorithm).

According to conclusions of studies in literature, it is seen that artificial intelligence models better than classical models and it provides system to give strong responses.

Classical control models can be used for a good operating system in well identified systems. But controlling the system by such a model requires the mathematical model of the whole system. On the contrary, the structure of fuzzy logic controller has adaptable properties. So, when it is used for controlling systems with uncertainties, variable parameters and load distributions, it provides system to give strong responses. Fuzzy logic or fuzzy set theory has firstly been presented by Zadeh (Akcayol, et al., 2002). Since the formation of the fuzzy logic concept, many researchers have studied modeling of ill-defined and non-linear systems. Fuzzy logic controllers have successfully been applied in the domain of DC electric machines' driver systems (Khoei et al., 1998; Navas-Gonzalez, 2000).

In this paper, fuzzy logic based start-up current control of a Buck-Boost Converter-fed serial DC motor has been examined through computer simulation. In order to see the advantages of fuzzy logic control, classical PI control has applied to the same motor under same circumstances and been compared. For the simulation, C++ Builder software has been used. According to simulation results, plainly, fuzzy logic control has stronger responses than classical PI control and uses lower current at starting moment.

2. MODELING OF BUCK-BOOST CONVERTER-FED DC MOTORS

Figure 1 shows Buck-Boost Converter-fed DC motor load. It is assumed that power switch at the converter circuit is ideal; there is no inductance and capacitor loss and while input source of DC, Vg, is an ideal source of voltage; it has also no internal resistance.

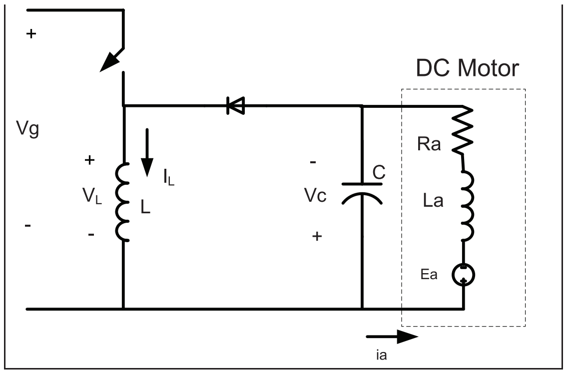

Figure 1. Buck-Boost Converter-fed DC motor load.

By the light of assumptions mentioned above, state variables of system in Figure 1 can be written in matrix form as:

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

In equation 1, $i_L(t)$ is converter inductance current, $v_C(t)$ is converter capacitor voltage, $i_a(t)$ is DC motor current, Vg is converter input DC voltage and $s \in \{0,1\}$ states the state of power switch.

DC motor equation which is composed of mechanical and electrical components is:

$$L_a \frac{di_a(t)}{dt} = v_C(t) - R_a.i_a - K_e.w_s$$

$$J\frac{dw_s}{dt} = -B.w_s + Kt.i_a - T_L \qquad (2)$$

In equation 2, L_a is armature windings' inductance, R_a is armature windings' resistance, i_a is armature current, w_s is angular velocity of motor shaft, J is moment of inertia, B is viscous coefficient of friction, T_L is load torque, Ke and Kt are respectively coefficients based on number of windings and poles of the motor.

Formulas in Equation 1 and 2 can be solved by Euler's method and converter inductance current i_L, capacitor voltage v_C, motor armature current i_a and angular velocity w_s can easily be calculated. In this paper equations have been solved by Euler's methods.

3. CONTROL OF THE SYSTEM

In DC-DC converters the state of power switches are generally determined by Pulse Width Modulation (PWM) method. Also in this study PWM method has been used.

In switching with PWM of constant switching frequency, switch control signal which determines whether the switch is turn on or off, is obtained by comparison between the control voltage at signal level (Vk) and the repetitive waveform (V_{st}) shown in Figure 2.

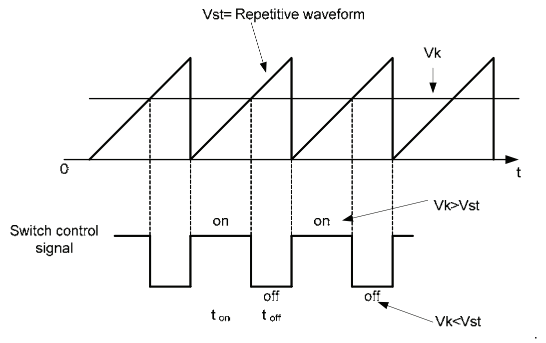

Figure 2. Pulse Width Modulation (PWM).

The frequency of the repetitive waveform (V_{st}) with a constant peak value and which is shown to be saw tooth, establishes switching frequency. In case of controlling with PWM, this frequency value can be fixed and set to a value between a few kilohertz or a few hundreds of kilohertz.

When amplified error signal, which varies very slowly with time relative to the switching frequency, is greater than the saw tooth waveform, the switch control signal becomes high, causing the switch to turn on. Otherwise, the switch is off (Mohan et al., 1989). As this principle considered, converter's switching is being modeled within the frame of the reason shown below.

$$s = \begin{cases} 0 & V_k <= V_{st} \quad \text{off} \\ 1 & V_k > V_{st} \quad \text{on} \end{cases}$$

Control of the motor is performed by setting the DC input voltage of the motor. The input voltage of the motor is on the other hand, the output voltage of converter.

The output voltage of converter is performed by setting of the control voltage, Vk value. In this paper, in order to set the Vk value, PI and fuzzy logic control have been used and the results of both of the control systems have been compared.

3. 1. System Control by PI

Block diagram of system controlled by PI is shown in Figure 3. In order to reach the desired value of motor's angular velocity in PI control (w_{sref}), error e(t), and error change de(t), are calculated. These variables are the inputs of PI control. Error e(t) and error change de(t) are calculated as shown in Eq. 3.

$$e(t) = w_{sref} - w_s(t)$$
$$de(t) = e(t) - e(t-1) \qquad (3)$$

PI controller has two components. These components are named as Proportional (Kp) and Integral (Ki) and each are expressed a coefficient. In PI controller, output of the system is brought about to desired value, setting appropriate Kp and Ki coefficients. Mathematical model of the PI controller is shown in Eq. 4.

$$Vk = Kp.e(t) + Ki\int_0^t e(t)dt \qquad (4)$$

3. 2. System Control by Fuzzy Logic

Fuzzy logic controlling unit is composed of input and output variables, fuzzification, fuzzy inference and defuzzification units. The intended uses of these components in the system are explained below.

3. 2. 1. Defining Input and Output Variables of Fuzzy Logic

In the designed fuzzy logic control unit, input variables are error (velocity; rad/s) and error change (velocity; rad/s). Output variable is Vk (control voltage; volt). Input variables are calcu-

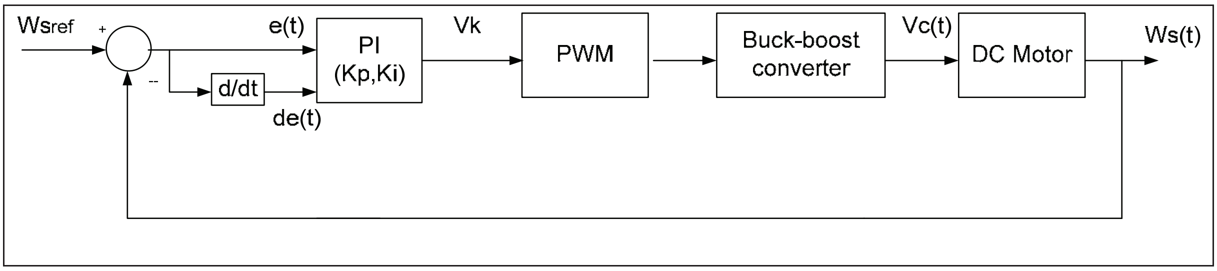

Figure 3. System Control by PI.

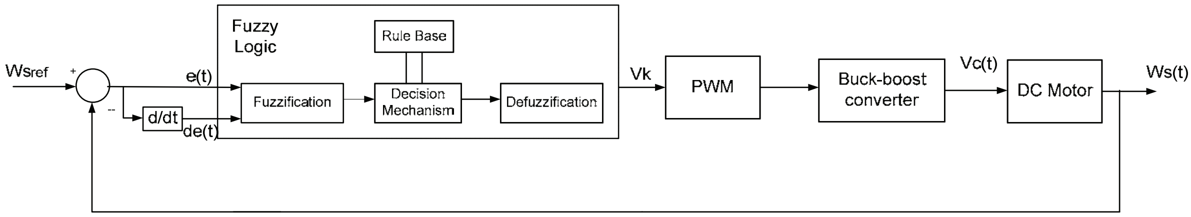

Figure 4. System control by fuzzy logic.

lated as described in Eq. 3.

Output variable is the information of control voltage (Vk; volt) which controls the converter that is responsible for motor's input voltage. Through this information power switches (on, off) related to converter can be controlled. According to this, the output variable Vk, of fuzzy logic control unit is obtained by:

$$V = f(e, de) \tag{5}$$

Block diagram of the expressions mentioned above is shown in Figure 4.

3. 2. 2. Fuzzification

In fuzzification process, numerical input and output variables are converted in to emblematic values (Elmas, 2003).

For input variables of Fuzzy logic control unit, as error (e) and error change (de), there are 7 defined fuzzy sets. Labels and change ranges of these sets are;

Table 1. Input values.

NB:	Negative Big	[-999, -0.5]
NM:	Negative Middle	[-0.8, -0.2]
NS:	Negative Small	[-0.5, 0]
Z:	Zero	[-0.2, 0.2]
PS:	Positive Small	[0, 0.5]
PM:	Positive Middle	[0.2, 0.8]
PB:	Positive Big	[0.5, 999]

Table 2. Output values.

NB:	Negative Big	[0.05]
NM:	Negative Middle	[0.25]
NS:	Negative Small	[0.4]
Z:	Zero	[0.5]
PS:	Positive Small	[0.6]
PM:	Positive Middle	[0.75]
PB:	Positive Big	[0.95]

If it is for the output variable of Fuzzy logic control unit Vk (voltage) then; [0.1,0.5] values here, state that, converter will work as reducer, [0.5,0.9] intermediate values here, state that, converter will work as raiser.

In this system for both input and output variables, fuzzy sets are defined as triangle type membership functions. The membership functions of input and output variables are shown below.

Change ranges of input values Fuzzy error (e) and error change (de) are;

$-0.8 \leq e \leq 0.8$

$-0.8 \leq de \leq 0.8$

According to these ranges, the membership functions of input variables are shown in Figure 5.

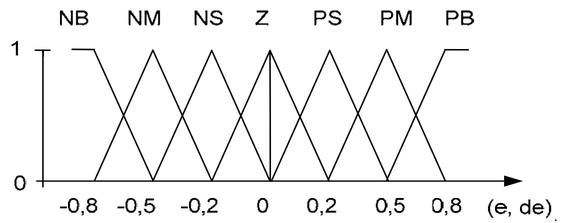

Figure 5. The graph of membership functions of input variables.

The change range of fuzzy output variable Vk is; $0 \le Vk \le 1$

According to these ranges, the membership function of output is shown in Figure 6.

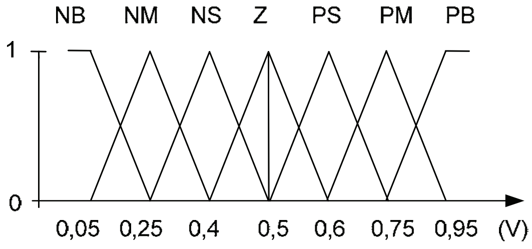

Figure 6. The graph of membership function of output variable.

3. 2. 3. Fuzzy Inference

Expressions that are obtained by the fuzzy logic application on fuzzy rules are called fuzzy inference. Fuzzy inference is the most important part of the fuzzy logic control unit. It is because, in this part data base and decision making logic are being used. There are 49 fuzzy control rules which are used in the designed fuzzy logic control unit and the table of fuzzy rules is shown in Table 3.

3. 2. 4. Defuzzification

Information obtained from the output of fuzzy logic control unit is fuzzy information. Conversion of this fuzzy information into numerical information requires defuzzification process. In defuzzification process, for each rule, membership weight values of error (e) and error change (de) are found and for these two values minimum membership weight and related output membership (Vk) values are confirmed. In the designed fuzzy logic unit, for defuzzification process, generally, frequently used center of gravity method has been performed and defuzzificated output (voltage) value has been calculated by the formula below;

$$U = \frac{\sum_{i=1}^{n} u_i * \mu(u_i)}{\sum_{i=1}^{n} \mu(u_i)} \tag{6}$$

Table 3. Fuzzy rules.

de/e	NB	NM	NS	Z	PS	PM	PB
NB	NB	NM	NM	NS	NS	NS	Z
NM	NM	NM	NS	NS	NS	Z	PS
NS	NM	NS	NS	NS	Z	PS	PS
Z	NM	NS	NS	Z	PS	PS	PS
PS	NS	NS	Z	PS	PS	PS	PM
PM	NS	Z	PS	PS	PS	PM	PM
PB	Z	PS	PS	PS	PM	PM	PB

4. SIMULATION RESULTS

Table 4 shows the motor parameters that are used in simulation.

Table 4. DA Motor parameters.

Armature Resistance (Ra)	1.1Ω
Armature Inductance (La)	0.09 H
Inertia Moment (J)	0.053 kg.m^2
Friction Constant (B)	0.01 N.m/rad/s
Motor Constants (Ke,Kt)	Ke=0.97 Kt=1.4
Load Torque (T_L)	5 N.m

According to the parameters declared at Table 2, PI and Fuzzy logic control results, which are obtained from the simulation, are shown in Figures 7, 8, 9, 10 and 11. For both graphs, green colored lines represent PI controlled system outputs; and red colored ones represent fuzzy logic controlled system outputs. In Figure 7, output voltage of buck-boost converter v_C, in Figure 8, motor current i_a, in Figure 9, induced torque of the motor Te, in Figure 10, motor speed in term of rpm n, and finally in Figure 11, control voltage of the converter Vk can be seen. Simulation takes 8 seconds for 500 rpm of motor reference speed.

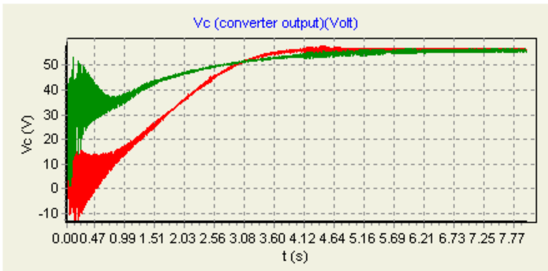

Figure 7. Converter output voltage (volt).

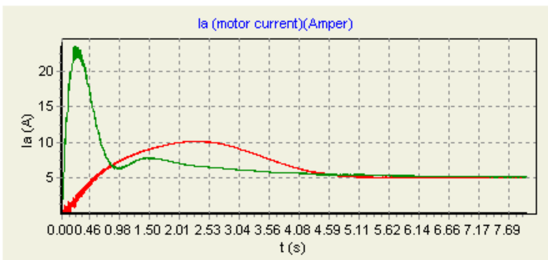

Figure 8. Motor current Ia (A).

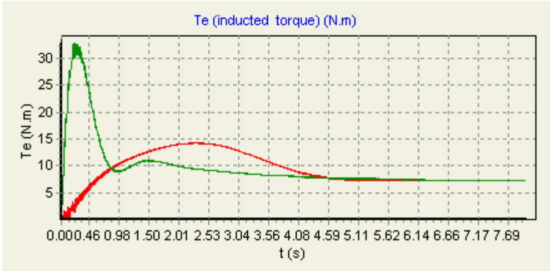

Figure 9. Inducted tork Te (Nm).

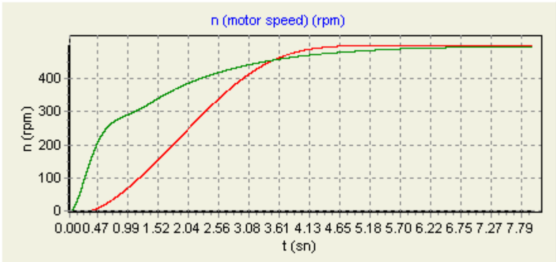

Figure 10. Motor speed n (rpm).

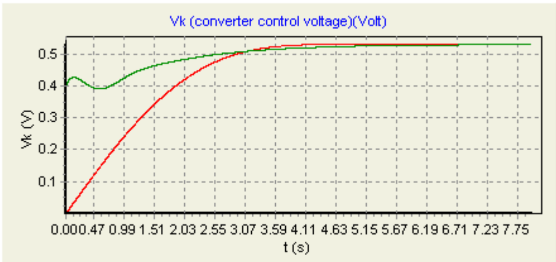

Figure 11. Converter control voltage Vk (volt).

According to the graphs, at the starting moment, fuzzy logic control system uses lower current than PI control; it has lower induced torque fluctuations, its motor velocity is same as reference velocity and it has reached reference velocity in a shorter time period. Therefore fuzzy logic control has made system to, have more efficient results than classical PI control.

5. CONCLUSIONS

DA motors' wide area of usage in the domain of industry requires a productive supervision. In the domain of electric motor controls, fuzzy logic controlled systems, draw attention with their successful applications. In this study, fuzzy logic control simulation of a Buck-Boost Converter-fed serial DA motor has been performed. The obtained results have been compared with the results of the same system worked by PI control. According to these results, it is observed that fuzzy logic control has made system to, use lower current at starting moment and have more efficient results than classical PI control. Thus, disadvantages that occurred by high start-up current is annihilated.

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