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Fractional Order PI$^{\lambda}$ Controller Application for Limited Memory System

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Abstract: In this study, the fractional order PI$^{\lambda}$ controller has been realized for induction motor speed control system with using dsPIC microcontroller which has a limited memory device. To computation of fractional order integral, the error function and the weight function data sets has been limited for using only last 50 data. This limitation has provided the fractional order controller to be used in the dsPIC microcontroller. The experiments are realized by using different k_p, k_i and λ values for speed control. The results are presented in tables and figures.

Keywords: fractional order PI control; microcontrollers; induction motors.

Sınırlı Hafızalı Sistem için Kesirli PI$^{\lambda}$ Kontrolör Uygulaması

Özet: Bu çalışmada, asenkron motorun hız kontrolünde kesirli PI$^{\lambda}$ yöntemi, sınırlı hafızaya sahip olan bir dsPIC mikrodenetleyicisi kullanılarak gerçekleştirilmiştir. Kesirli integralin hesaplanması işleminde kullanılan hata fonksiyonu ve ağırlık fonksiyonu veri setleri sadece son 50 veriyi kullanacak şekilde sınırlandırılmıştır. Bu sınırlandırma işlemi kesirli kontrolörün dsPIC mikrodenetleyicisinde kullanılabilmesini sağlamıştır. Farklı k_p, k_i ve λ değerleri için hız kontrolü deneyleri gerçekleştirilmiştir. Sonuçlar tablolarda ve şekillerde sunulmuştur.

Anahtar kelimeler: kesirli PI kontrol; mikrodenetleyiciler; asenkron motorlar.

1. Introduction

Variable-speed drive systems are used in many applications in industry. They are hybrid electric vehicles, air conditioning (HVAC) systems, heating, ventilation, driver controls and automotive controls [1, 2]. In recent years, for variable-speed drive systems, induction machines are preferred in instead of direct current machines due to their low-cost, promising performance at bad environmental conditions, maintenance free, making less fault due to not containing brush and collector [3, 4].

Computer or Digital Signal Processor (DSP) based hardware systems are widely preferred in speed or position control of induction motor. However these systems are expensive for some applications. Microcontrollers are used for these systems that are cheap and have a limited flexibility. Therefore, in this study dsPIC30F4011 microcontroller is chosen for speed control of induction motor. This controller is useful for these applications because it is developed for three phase systems. Integer order proportional integral (IOPI) control method is commonly employed in industrial closed-loop control system applications due to its simple algorithm. However in the recent years, fuzzy logic, sliding mode, fractional order proportional integral (FOPI$^{\lambda}$) etc. control methods are preferred in some industrial applications for some of their advantages [5].

Bu makaleye atıf yapmak için
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Fractional order calculus describes and models a real object more accurately than the classical integer methods [6-8]. FOPI controller is symbolized as PI$^{\lambda}$. Integral order (λ) can be adjust with the proportional and integral constants. The values of λ change between 0 and 1. This also provides more flexibility and opportunity to better adjust the dynamical properties of the control system. The main advantage of Fractional-order controller is to provide more adjustable time and frequency responses of the control system. Therefore, the fractional-order controller always provides better response than integer-order controller if it is properly tuned whatever may be the type of plant (integer or fractional). The fractional order is supposed to offer two advantages that are, FOPI$^{\lambda}$ is less sensitive than IOPI controller If the parameter of a controlled system changes. FOPI$^{\lambda}$ has an extra variable to tune [9].

2. Fractional Order PI$^{\lambda}$ Controller

FOPI$^{\lambda}$ controller equation is defined as follows:

$$u(t) = k_p e(t) + k_i I^{\lambda} e(t) \tag{1}$$

Here, k_p and k_i are the proportional and the integral gains of the controller and t is the time variable. I is the integral function and λ is the order of integral. The error function $e(t)$ is the difference between the reference value $r(t)$ and the system output $y(t)$.

There are different types of fractional order derivative and integral definitions which can be chosen according to the problem structures [10]. In this study, the Grünwald-Letnikov definition is used for the controller. It can be defined as

$${}_0D_t^{\alpha} x(t) = \lim_{h \to 0} \frac{1}{h^{\alpha}} \sum_{k=0}^{[t/h]} (-1)^k \binom{a}{k} x(t-kh) \tag{2}$$

$$\binom{\alpha}{k} = \frac{\Gamma(\alpha+1)}{\Gamma(k+1)\Gamma(\alpha-k+1)} \tag{3}$$

where x is a time dependent function, α is the order of derivative $(n\text{-}1 \le \alpha < n,\ n \in N^{+})$, Γ(.) is Euler's gamma function, h is the time interval, and [t/h] represents the integer parts of t/h. If the order of derivative α is changed with -λ this definition corresponds to the fractional order integral I$^{\lambda}$ in the sense of Grünwald-Letnikov. Advantage of Grünwald-Letnikov definition comes from its ability to discretize system [10]. The Grünwald-Letnikov definition is preferred in this study, because the microcontroller's structure is a discrete-time operation system.

If the limit operation is removed from equation (2), the Grünwald-Letnikov fractional derivative becomes a numerical tool. This approximation is applied to calculate fractional integral I$^{\lambda}$ by dividing the time interval [0,T] to N equal parts where the each parts size h=1/N. The nodes are defined as 0, 1, 2, …, N and the fractional order integral at node M is obtained as follows [7]:

$${}_0I_t^{\lambda} x(t) = {}_0D_t^{-\lambda} x(hM) = \frac{1}{h^{-\lambda}} \sum_{j=0}^{M} w_j^{(-\lambda)} x(hM - jh) \tag{4}$$

$$w_0^{(\alpha)} = 1, \quad w_j^{(\alpha)} = \left(1 - \frac{\alpha+1}{j}\right) w_{j-1}^{(\alpha)}, \quad j = 1, 2, \dots N \tag{5}$$

Then the fractional order PI$^{\lambda}$ controller is discretized as follows:

$$u(Mh) = k_p e(Mh) + k_i \frac{1}{h^{-\lambda}} \sum_{j=0}^{M} w_j^{(-\lambda)} e(Mh - jh) \tag{6}$$

3. dsPIC Based Fractional Order PI$^{\lambda}$ Speed Controller Application for Induction Motor

The fractional order PI$^{\lambda}$ controller has been realized for induction motor speed control system with using dsPIC microcontroller. The system consists of dsPIC30F4011 microcontroller, single-phase rectifier, three-phase inverter, 1.1 kW induction motor, 1024 PPR encoder, LabVIEW software and DAQ card, and 20 Nm electromagnetic Foucault Brake. Figure 1 shows the block diagram of the experimental setup and Figure 2 shows the power circuit of the experimental setup.

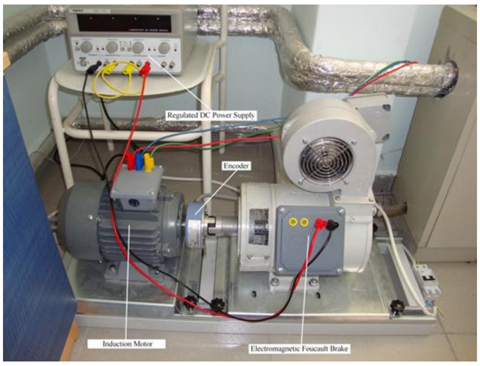

Figure 1. Block diagram of experimental setup

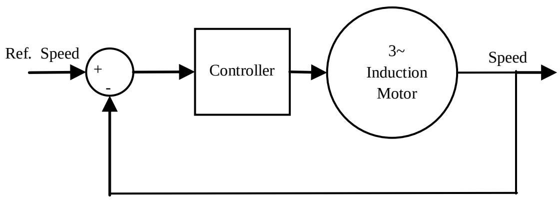

Figure 2. Power circuit of experimental setup

Induction motor parameters are listed in Table 1.

Table 1. Induction motor parameters

Rated voltage	1.1 kW
Rated current	380 V
Frequency	2.7 A
Cosineφ	50 Hz
Stator resistance (Rs)	0.8
Stator inductance (Lls)	6.9 Ω
Rotor resistance (Rr)	0.52 H
Rotor inductance (Llr)	6.5 Ω
Mutual inductance (Lm)	0.52 H
Rotor inertia (J)	0.0088 kg.m^2
Friction factor (B)	0.072 N.m.s
Pole pairs	2

Single-phase rectifier has been used to obtain the DC bus voltage from AC line voltage to supply the inverter circuit. The inverter circuit has been designed to control the amplitude and the frequency of the AC output voltage. dsPIC30F4011 microcontroller has been used as a controller to compare the reference value (reference speed) and the system output (real speed) for obtaining the error information. PI algorithm runs by using this error information. LabVIEW software and NI 6024E DAQ card have been used to obtain the system input (reference speed) and output (real speed) values to save in EXCEL file and displaying them graphically. Interpretation of experimental results can be made easier in this way. A 1.1 kW induction motor has been preferred in this study because its low cost and easy usage in experimental studies. 1024 PPR encoder has been used to minimize the speed measurement error. k_p, k_i and λ coefficients are written in dsPIC and the control signals are generated to driving the inverter circuit. The controller adjusts the amplitude and the frequency of the AC supply voltage of the induction motor by changing the pulse width and frequency of the sinusoidal PWM output. The results of these algorithm applications have been stored in EXCEL file by using the LabVIEW interface. Transferring data to EXCEL file effects the LabVIEW system slightly negative. However, it is useful to analyzing the data and transforming into the graph. The experimental results are given in Figure 3, Figure 4 and Figure 5.

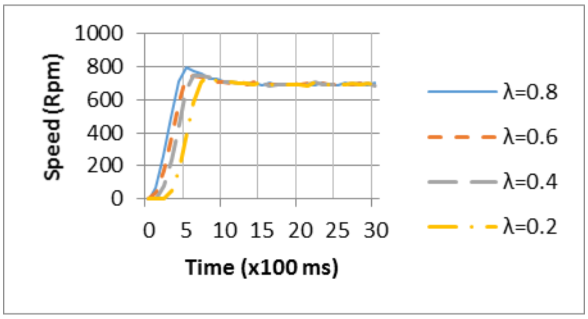

Figure 3. The change of speed for different λ values

As shown in Figure 3, the rising time is shorter but overshoot is bigger for the high λ values. The rising time is longer but overshoot is smaller for the low values of λ. Settling time (T_s) and Maximum overshoot values (M_o) are given for different λ values in Table 2. k_p and k_i values are constant for these λ values . M_o is 14.0% for high value and T_s is 1 second. Mo is 6.9% for low value and T_s is 1.2 second.

Table 2. Settling time and overshoot according for different λ values

k_p	k_i	λ	M_O (%)	T_S (s)
0.5	0.01	0.8	14.0	1.0
0.5	0.01	0.6	6.6	0.9
0.5	0.01	0.4	7.0	1.0
0.5	0.01	0.2	6.9	1.2

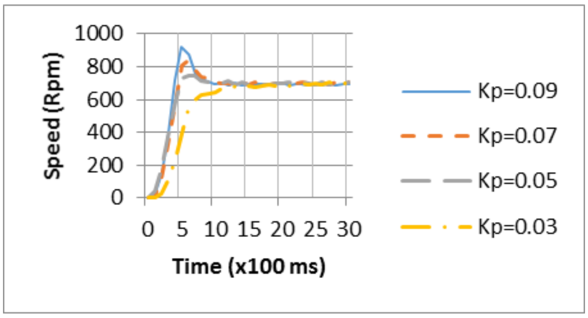

Figure 4. The change of speed for different k_p values

As shown in Figure 4, the rising time is shorter but overshoot is bigger for the high k_p values. The rising time is longer but overshoot is smaller for the low k_p values. Settling time (T_s) and Maximum overshoot values (M_o) are given for different k_p values in Table 3. λ and k_i values are constant for these k_p values. M_o is 31.6% for high value and T_s is 1 second. M_o is 0% for low value and T_s is 2 second.

Table 3. Settling time and overshoot according for different k_p values

k_p	k_i	λ	M_O (%)	T_S (s)
0.9	0.01	0.6	31.6	1.0
0.7	0.01	0.6	19.7	1.0
0.5	0.01	0.6	6.6	0.9
0.3	0.01	0.6	0	2.0

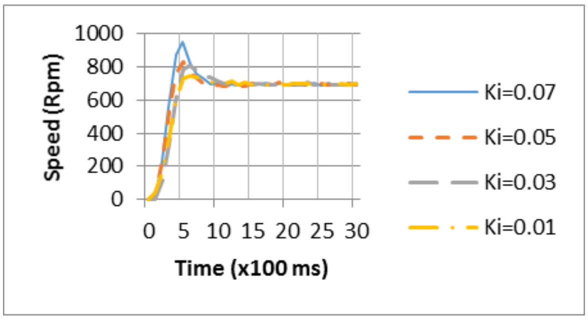

Figure 5. The change of speed for different k_i values

As shown in Figure 5, the rising time is shorter but overshoot is bigger for the high k_i values. The rising time is longer but overshoot is smaller for the low k_i values. Settling time (T_s) and Maximum overshoot values (M_o) are given for different k_i values in Table 4. λ and k_p values are constant for these k_i values. M_o is 36.0% for high value and T_s is 0.9 second. M_o is 6.6% for low value and T_s is 0.9 second.

Table 4. Settling time and overshoot according for different k_i values

k_p	k_i	λ	M_O (%)	T_S (s)
0.05	0.07	0.6	36.0	0.9
0.05	0.05	0.6	18.8	0.9
0.05	0.03	0.6	15.1	1.1
0.05	0.01	0.6	6.6	0.9

5. Conclusion

In this study, a dsPIC based induction motor speed control system has been realized by using the $FOPI^{\lambda}$ controller. No load starting experiment has been done and has been examined for different values of the $FOPI^{\lambda}$ controller gains. Even if the $FOPI^{\lambda}$ controller performance has been decreased by the microcontroller's limited memory, the $FOPI^{\lambda}$ controller has still good performance. In future works, the performance of the $FOPI^{\lambda}$ controller can be seen clearly with the development of high memory capacity industrial controller units. As shown in Figures, the controller gains are must be optimized to obtain the best results by different methods such as genetic algorithm, artificial bee colony, particle swarm optimization.

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References

[1] Arulmozhiyal, R., Baskaran, K., Deverajan, N., Kanagaraj, J. (2010). Real Time MATLAB interface for Speed Control of Induction Motor Drive Using dsPIC 30F4011. *International Journal of Computer Applications*. vol. 1 no. 5, pp. 85-90.

[2] Waskar, S.A., Bombale, U.L., Sonawane, T.B. (2012, June). dsPIC Based SPWM Controlled Three Phase Inverter Fed Induction Motor Drive. *International Journal of Computer Applications*. vol. 47, no. 16.

[3] Bowling, S. (2005). An Introduction of to AC Induction Motor Control Using the dsPIC30F MCU. Microchip.

[4] Toufouti, R., Meziane, S., Benalla, H. (2009). New Direct Torque Neuro-Fuzzy Control Based SVM for Dual Two Level Inverter-Fed Induction Motor. *Journal of Control Engineering and Applied Informatics*, Vol.11, No.2, pp. 3-13.

[5] Efe, M.O. (2011). Fractional Order Systems in Industrial Automation - A Survey. *IEEE Transactions on Industrial Informatics*. vol. 7(4), pp. 582 – 591.

[6] Podlubny, I. (1999). Fractional-order systems and PIλ Dμ controllers. IEEE Transactions on Automatic Control, 44(1), 208–214.

[7] Özdemir, N., İskender, B.B. (2010, April). Fractional Order Control of Fractional Diffusion Systems Subject to Input Hysteresis. *ASME Journal of Computational and Nonlinear Dynamics*. vol. 5.

[8] Zheng, S., Tang, X., & Song, B. (2014). A graphical tuning method of fractional order proportional integral derivative controllers for interval fractional order plant. Journal of Process Control, 24(11), 1691–1709.

[9] Ilten, E., dsPIC based fractional order PI speed control of induction motor. Balikesir University, Institue of Science, Msc. Thesis, 2013.

[10] Petráš, I. (2011). Fractional Order Nonlinear Systems: Modeling, Analysis and Simulation. *Nonlinear Physical Science*.