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The estimation of PID controller parameters of vector controlled induction motor using Ziegler-Nichols method

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Abstract
Induction motors (IM) are commonly used in industrial applications due to their superiorities such as low cost, less maintenance requirements, high effiency and high power density in comparison with other electric motors such as dc motors. There are many studies in the literature on IM control. The best known speed control method of the IM is scalar control method (SCM) because of its easy to understand and implement. The another control method which is known as vector control method is the field oriented control method (FOC). Although FOC is more sophisticated than SCM, it is higher performance on control in general. In this study, the mathematical model of IM has used on simulation and FOC method has implemented on it. Then for speed control of IM Ziegler-Nichols method is used.Matlab/Simulink software has used to simulate system.

Keywords: Induction motor; vectrol control; ziegler-nichols method;Simulink

1. Introduction

The use of induction motors is widespread in industry due to their simple structure and simple maintenance compared to other electric drives such as dc motors. With the development on the power electronic technology and control theories by using many control algorithms such as vector control and direct torque control the performance of IM has become more superior [1]. There are many control methods on IM such as SCM and FOC. FOC method has superiorities than SCM due to high performance on control [2]. PID controllers can used to control speed of IM. Although PID controllers have simple structure, many control loops used today are PID controllers [3]. There are a lot of studies about designing PID parameters [4-10]. The most useful method to determine PID controller parameters is Ziegler - Nichols method [4]. In literature there are many studies to improve PID controller parameters which has designed by using Ziegler-Nichols method. In this study it has tried to control speed of three phase induction motor on Matlab/Simulink software. Speed results has shown on figures.

2. Material and Methods

Firstly, to implement FOC to induction motor mathematical model of induction motor has investigated from its equivalent circuit. The equivalent circuit of IM has shown on Figure-1. Equialevent circuit shown on dq axis.From this equialevent circuit this equations has generated.

$$v_{sd} = R_s i_{sd} - w_d \lambda_{sq} + L_{ls}\frac{d}{dt} i_{sd} + L_m \frac{d}{dt}(i_{sd} + i_{rd}) \quad (1.1)$$
$$v_{sq} = R_s i_{sq} - w_d \lambda_{sd} + L_{ls}\frac{d}{dt} i_{sq} + L_m \frac{d}{dt}(i_{sq} + i_{rq}) \quad (1.2)$$

$$v_{rd} = R_r i_{rd} - w_{dA} \lambda_{rq} + L_{lr}\frac{d}{dt} i_{rd} + L_m \frac{d}{dt}(i_{sd} + i_{rd}) \quad (1.3)$$
$$V_{rq} = R_r i_{rq} - w_{dA} \lambda_{rd} + L_{lr}\frac{d}{dt} i_{rq} + L_m \frac{d}{dt}(i_{sq} + i_{rq}) \quad (1.4)$$

EElectromagnetic torque;

$$T_{em} = -\frac{p}{2}\lambda_{rd} i_{rq} = \frac{p}{2}\lambda_{rd}\left(\frac{Lm}{Lr} i_{sq}\right) \quad (1.5)$$

p is the pole number
Rotor d axis winding;

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$$\frac{\mathrm{d}}{\mathrm{dt}}\lambda_{\mathrm{rd}}+\frac{\lambda_{\mathrm{rd}}}{\tau_{\mathrm{r}}}=\frac{\mathrm{L_m}}{\tau_{\mathrm{r}}}\mathrm{i_{sd}} \qquad (1.6)$$

τ_r is called rotor time constant.

Stator Fluxes is written in a vector form

$$\frac{\mathrm{d}}{\mathrm{dt}}\begin{bmatrix}\lambda_{\mathrm{sd}}\\ \lambda_{\mathrm{sq}}\end{bmatrix}=\begin{bmatrix}\mathrm{v_{sd}}\\ \mathrm{v_{sq}}\end{bmatrix}-\mathrm{R_s}\begin{bmatrix}\mathrm{i_{sd}}\\ \mathrm{i_{sq}}\end{bmatrix}-\mathrm{w_d}\underbrace{\begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}}_{\mathrm{Mrotate}}\begin{bmatrix}\lambda_{\mathrm{sd}}\\ \lambda_{\mathrm{sq}}\end{bmatrix} \qquad (1.7)$$

Mechanical rotor of speed;

$$\frac{\mathrm{d}}{\mathrm{dt}}\mathrm{w_{mech}}=\frac{\mathrm{T_{em}}-\mathrm{T_L}}{\mathrm{J_{eq}}} \qquad (1.8)$$

Synchronous speed;

$$\mathrm{w_{syn}}(\mathrm{t})=\mathrm{w_m}(\mathrm{t})+\mathrm{w_{slip}}(\mathrm{t}) \qquad (1.9)$$

θ Angel;

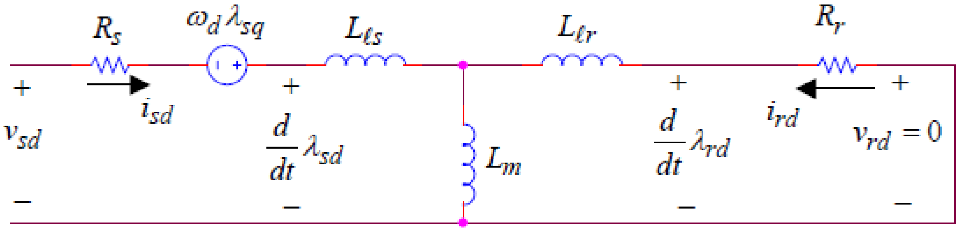
$$\theta_{\mathrm{B_r}}(\mathrm{t})=0+\int_0^{\mathrm{t}}\mathrm{w_{syn}}(\tau).\,\mathrm{d}\tau \qquad (1.10)$$

abc-dq transform;

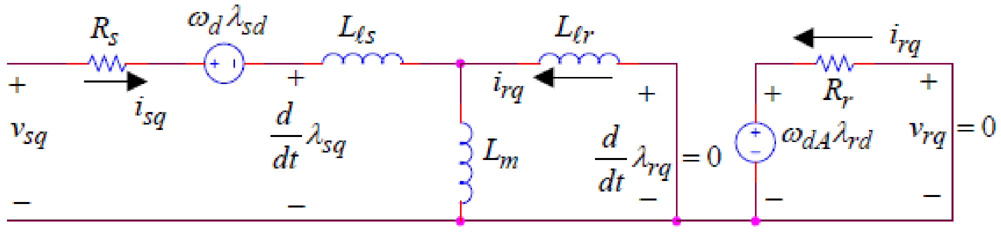
$$\begin{bmatrix}\mathrm{d}\\ \mathrm{q}\end{bmatrix}=\sqrt{\frac{2}{3}}\begin{bmatrix}\cos\theta & \cos\theta-2\frac{\pi}{3} & \cos\theta-4\frac{\pi}{3}\\ \sin\theta & \sin\theta-2\frac{\pi}{3} & \sin\theta-4\frac{\pi}{3}\end{bmatrix} \qquad (1.11)$$

dq- abc transform;

$$\begin{bmatrix}\mathrm{a}\\ \mathrm{b}\\ \mathrm{c}\end{bmatrix}=\sqrt{\frac{2}{3}}\begin{bmatrix}\cos\theta & -\sin\theta & \\ \cos\theta+4\frac{\pi}{3} & -\sin\theta & +4\frac{\pi}{3}\\ \cos\theta+2\frac{\pi}{3} & -\sin\theta+2\frac{\pi}{3} & \end{bmatrix}\begin{bmatrix}\mathrm{d}\\ \mathrm{q}\end{bmatrix} \qquad (1.12)$$



(a) d-axis



(b) q-axis

Figure 1. Equivalent circuit of IM on dq axes.

Simulink model of IM has generated from this equations[11] on Matlab/Simulink software as shown Figure-2.

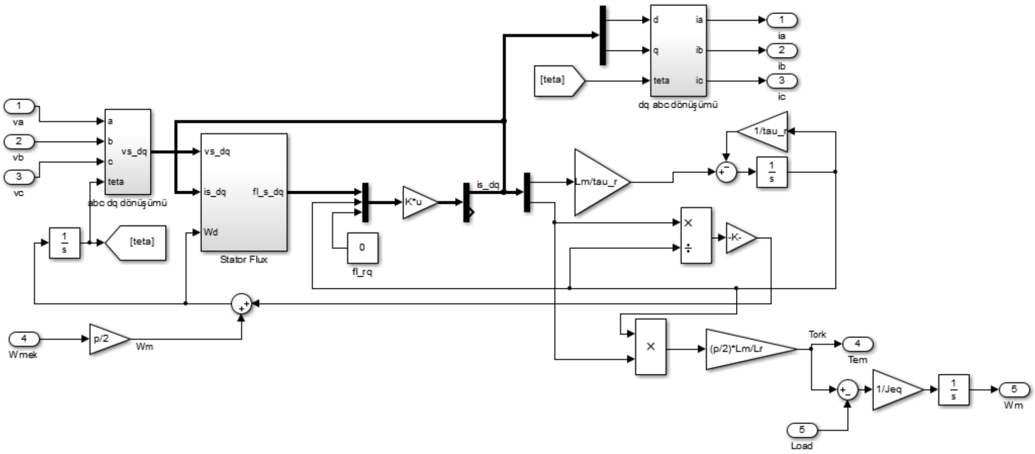


Figure 1. IM model block.

The parameters and nameplates of IM which has simulated here are listed below.

Power : 3 HP/2.4 kW
Voltage : 460 V
Frequency : 60 Hz
Phase: : 3
Tüm Yüklemedeki Çektiği Akım:4A
Tam Yüklemedeki Hızı : 1750 Rpm
Verimliliği : %88.5
R_s : 1.77Ω
R_r : 1.34Ω
X_ls : 5.25Ω
X_lr : 4.57Ω
X_m : 139Ω
J_eq : 0.025kg.m^2

According to field oriented control theory, a reference mechanical speed has given initially to system. Then by PI controlling with which measured from motor. current has obtained. has given 0 initially. and voltages has calculated by controlling reference currents. For controlling three phase induction motor this and voltages has transformed from dq axis to abc axis. voltage has given to induction motor and motor has driven with this three phase voltages. In Figure-3 a classic vector control block scheme has shown. Simulink impelentation of this control method also has shown Figure-4.

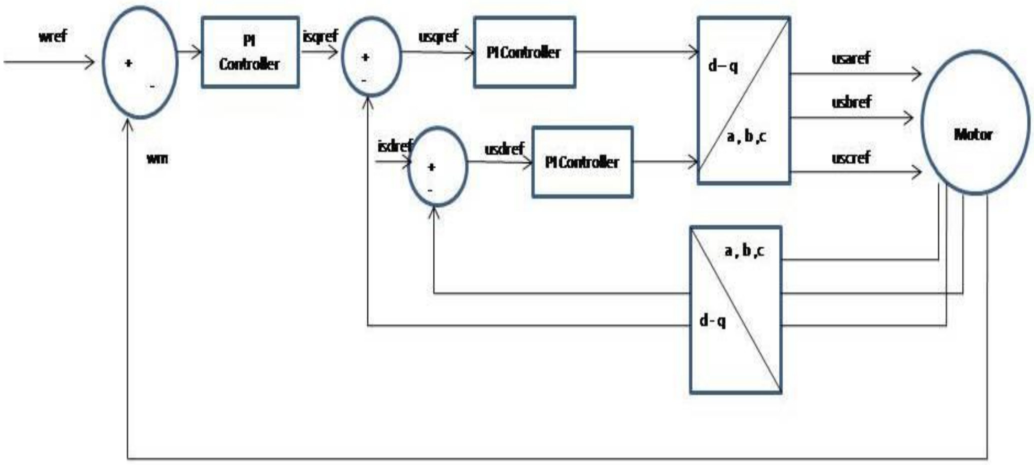


Figure 2 Vector control block scheme.

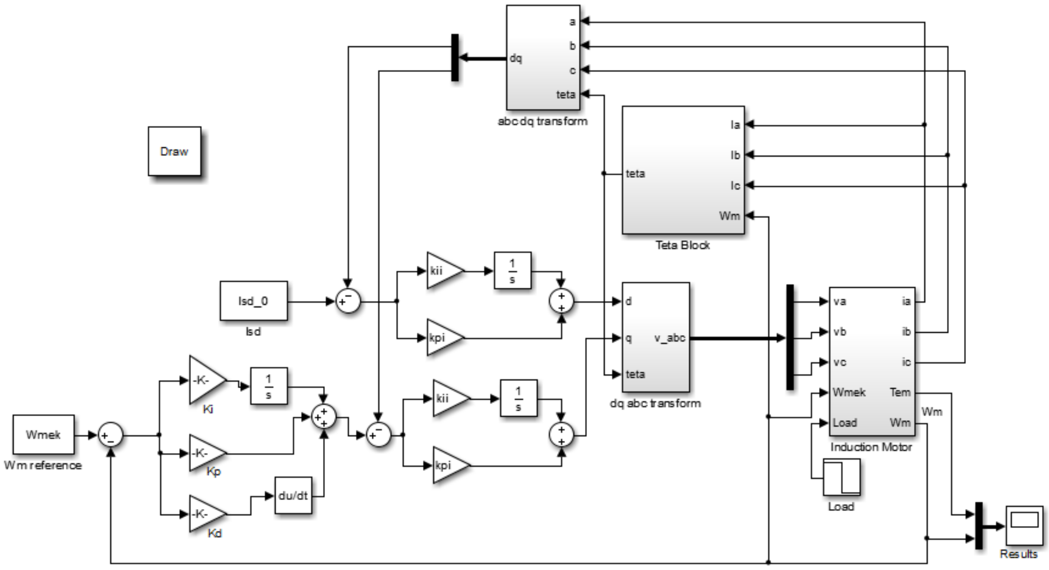


Figure 3 Vector controlled IM simulation.

Ziegler-Nichols method is a technique that tries to find parameters by trial and error. System is driven by using only P controller initially and slowly increased until persistent oscilation is reached. At this point value is marked as and the period between two oscilation is denoted as . In Figure-5 IMs mechanical speed which is reached oscilation by slowly increasing value has shown. At this point and values has founded like below.

$$\tilde{T} = 0,025 - 0,017 = 0,08$$

$$\tilde{K}_p = 26$$

Then, PID controller parameters has calculated according to Ziegler-Nichols parameter calculation method as shown Table-1.

$$K_p = 0.6\tilde{K}_p = 0.6 * 26 = 15.6$$
$$K_i = \frac{\tilde{T}}{2} = \frac{0.008}{2} = 0.004$$
$$K_d = \frac{\tilde{T}}{8} = \frac{0.008}{8} = 0.001$$

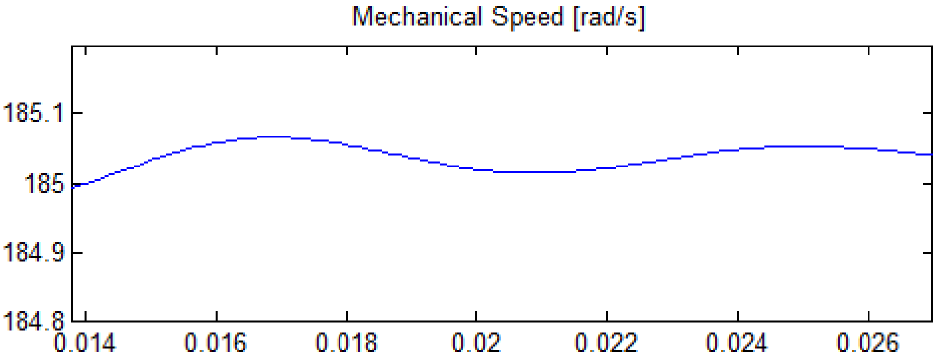


Figure 4 Oscilation state.

Table 1. Ziegler-Nichols method PID parameters calculation

Controller Type	K_p	K_i	K_d
P Controller	$0.5\tilde{K}_p$	∞	0
PI Controller	$0.45\tilde{K}_p$	$\tilde{T}/1.2$	0
PID Controller	$0.6\tilde{K}_p$	$\tilde{T}/2$	$\tilde{T}/8$

3. Results

Calculated K_p, K_i, K_d parameters has used speed control loop of this vector control block of simulation model and the speed graphic of IM has obtained as Figure-6. At the 0.1 time point the load torque has affected to IM and has tried to change IM mechanical speed. In this figures it is shown that speed of IM has controlled by using Ziegler-Nichols method.

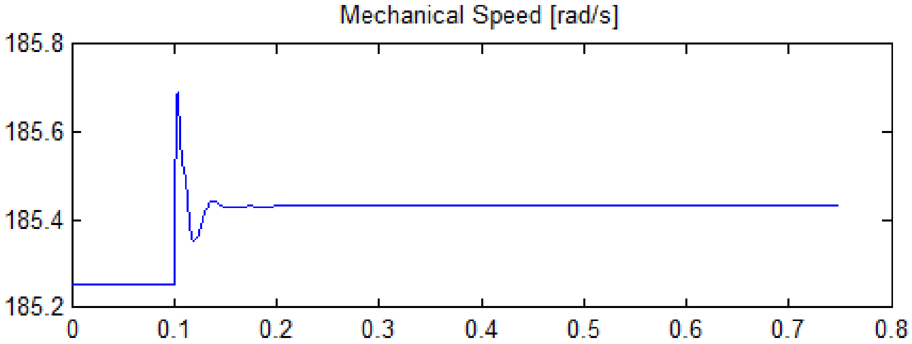


Figure 5 Mechanical speed graph.

4. Conclusion

In this study, speed control of the induction motor has been tried to simulate by using Ziegler-Nichols method on Matlab/Simulink software. Ziegler Nichols method has been successful on designing parameters and controlling IM speed.

Acknowledgement

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