Fast Response Three Phase Induction Motor Using Indirect Field Oriented Control (IFOC) Based On Fuzzy-Backstepping

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Abstract

Induction Motor in Electrical drive system at a accelleration speed for example in electric cars have a hard speed setting is set on a wide range, causing an inconvenience for motorists and a fast response is required any change of speed. It is necessary for good system performance in control motor speed and torque at low speed or fast speed response, which is operated by Indirect Field Oriented Control (IFOC). Speed control on IFOC methods should be better to improving the performance of rapid response in the induction motor. In this paper presented a method of incorporation of Fuzzy Logic Controller and Backstepping (Fuzzy-Backstepping) to improve the dynamically response speed and torque in Induction Motor on electric car, so we get smoothness at any speed change and braking as well as maximum torque of induction motor. Test results showed that Fuzzy-Backstepping can increase the response to changes speed in electric car. System testing is done with variations of the reference point setting speed control system, the simulation results of the research showed that the IFOC method is not perfect in terms of induction motor speed regulation if it's not use speed control. Fuzzy-Backstepping control is needed which can improve the response of output, so that the induction motor has a good performance, small oscillations when start working up to speed reference.

Keywords: Fuzzy-Backstepping, IFOC, induction motor.

1. INTRODUCTION

The induction motor has more benefits then dc motor, because it is robust and relatively cheap. It is also mostly used to electrically drive a car in constant speed, big inertia, and no need regular maintenance [1], in the otherside induction motor have a weakness in complicated speed control.

And now the advance technology in electrics makes this complication easy to applicate.

Meanwhile an induction motor has a multi-variable nonlinear coupled structure of which its acceleration is difficult to control and dc motor has a structure that is decoupled so that its acceleration is easier to control. The control operation of ac motor driver generally needs complicated algorithm implemented in an accurately real time signal process. By using the advance technology of power electronics and electric control, the task for complicated control can be implemented. To do this job, the induction motor is made linear by operating the method of Indirect Field Oriented Control [2][3].

In the development of Indirect Field Oriented Control, the method is known to have characteristics that is similar to the dc motor induction of which the current magnetic field and anchor current are mutually upright.[4][5].

In this paper, Fuzzy-Backstepping is designed to control the speed of mover of the induction motor. This paper presents combine controller from fuzzy logic controller and Backstepping controller became Fuzzy-Backstepping in speed controller for IFOC methode on induction motor drive system. By using fuzzy control, system error while starting work can be minimized. Use of Backstepping will make the steady state error value to be small and result in the best output performance.

2. RELATED WORKS

Theory of fuzzy was first proposed and investigated by Prof. Zadeh in 1965. And then Mamdani is make a fuzzy inference system was presented to control a steam engine and boiler combination by linguistic rules. Fuzzy logic is expressed by means of if-then rules with the human language. In the design of a fuzzy logic controller, the mathematical model is not necessary. Therefore, the fuzzy logic controller is good for robustness. Rene Jager (1995) use Fuzzy logic techniques attempt to simulate human thought processes, even in technical environments. In doing so, the fuzzy logic approach allows the designer to handle efficiently very complex closed-loop control problems [7]. Fuzzy logic has been mainly used in industrial automation for relatively slow processes. Fuzzy control supports non-linier design theqniques that are now being exploited in motor control applications, Jerry M. Mendel (1995) [8]. B.Subudhi, Anish Kumar, IEEE (2009) presented that induction motor deficiencies can be corrected with fuzzy, they are used a fuzzy logic based vector control approach to speed control of an induction motor [2]. The focus of the paper is to analyze the real-time implementation issued for realizing a vector control in a laboratory. In 2012 Divya Ray presented speed control based on fuzzy logic technique to achieve maximum torque and efficiency. A rule based Mamdani type fuzzy logic controller is applied to closed loop induction motor model. Scalar control (volt-hertz) method is used for controlling speed [4].

This paper presents combine controller from fuzzy logic controller and Backstepping controller became Fuzzy-Backstepping in speed controller for IFOC methode on induction motor drive system. By using fuzzy control, system error while starting work can be minimized. Use of Backstepping will make the steady state error value to be small and result in the best output performance. with the addition of backstepping, the system will be more reliable due to the characteristics of backstepping itself that can create a virtual control to maintain system stability.

3. ORIGINALITY

Induction motors play a vital role in the industrial sector especially in the field of electric drives & control. Without proper controlling of the speed, it is virtually impossible to achieve the desired task for a specific application. AC motors, particularly the squirrel-cage induction motors (SCIM), enjoy several inherent advantages like simplicity, reliability, low cost and virtually maintenance-free electrical drives. However, for high dynamic performance industrial applications, their control remains a challenging problem because they exhibit significant nonlinearities and many of the parameters, mainly the rotor resistance, vary with the operating conditions [1]. Indirect Field orientation control (IFOC) or vector control of an induction machine achieves decoupled torque and flux dynamics leading to independent control of the torque and flux as for a separately excited DC motor. IFOC methods are attractive, but suffer from one major disadvantage, viz., they are sensitive to motor parametric variations such as the rotor time constant and an incorrect flux measurement or estimation at low speeds or respose on Induction Motor [7].

Indirect Field Oriented Control (IFOC) is known to produce high performance in induction Motor (IM) drives by decoupling rotor flux and torque producing current components of stator current. The decoupling control between the rotor flux and the torque is no longer achieved in terms of stator current components considering core loss into account. IFOC is more connecting in d-q parameter performs. In this paper proposes a combine of control methodology that is based on Fuzzy Logic Controller added by Backstepping Controller to became a 'Hybrid' control in IFOC speed control. Backstepping methode is created for designing stabilizing controls for a special class of nonlinear dynamical systems. These systems are built from subsystems that radiate out from an irreducible subsystem that can be stabilized using some other method. Because of this recursive structure, the designer can start the design process at the known-stable system and "back out" new controllers that progressively stabilize each outer subsystem. In result if we use a speed control using Fuzzy_Backstepping on IFOC it can be make a good respon and the d-q parameter is can be fast to stable on good torque and stability of speed.

And the originality of this research is that research on backstepping mostly discussed the position of the actuator control. whereas in this study

more emphasis on speed control combined with fuzzy so get optimal control system for an induction motor. Many of the studies backstepping not able to apply directly to the hardware, whereas in this study it can be realized.

4. SYSTEM DESIGN
4.1. METHOD
4.1.1. Indirect Field Oriented Control (IFOC)

The field-oriented control technique has been widely used when high-performance rotary machine drive is required, especially the indirect field oriented control (IFOC) which is one of the most effective vector control of IM due to the simplicity of designing and implementation [1]. Advent of high switching frequency PWM inverters has made it possible to apply sophisticated control strategies to AC motor drives. The most fundamental difference between IFOC and FOC is, the FOC field and torque measurement carried out directly on the system, it is of course make its own complexities in the calculation results. IFOC while the measurement is done indirectly by taking the parameters of the rotary encoder as readers of the rotational speed of the rotor as a reference for changes in the amount field (equation 1).

The principle of indirect field-oriented control system of an induction motor is that the d-q coordinate's reference frame is locked to the rotor flux vector, this results in a decoupling of the variables so that flux and torque can be separately controlled by stator direct-axis current *isd*, and quadrature-axis current *isq*, respectively, like in the separately excited dc machine. To perform the alignment on a reference frame revolving with the rotor flux requires information on the modulus and position of the rotor flux.
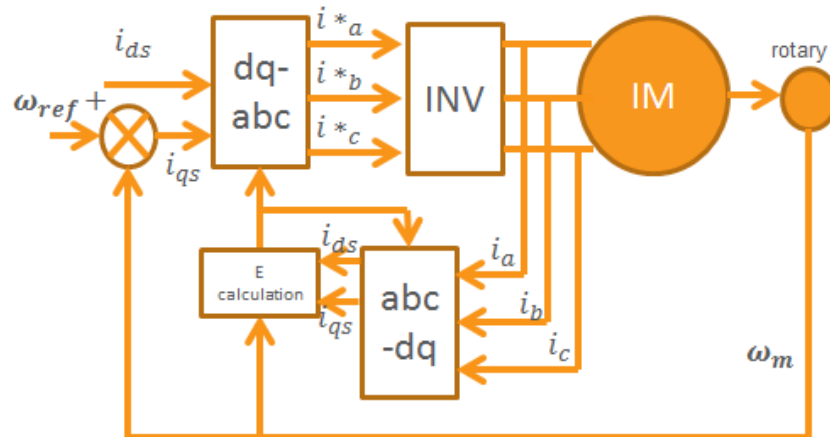

Figure 1. Block diagram induction motor speed control with IFOC.[12]

Rotor flux and torque can be separately controlled by stator direct-axis current (ids) and quadrature-axis currents (iqs) in sequence. Large quadrature-axis current reference (i * qs) can be calculated by reference torque Te * using the following equation,

$$i_{qs}^* = \frac{2}{3} * \frac{2}{P} * \frac{L_r}{L_m} * \frac{T_e^*}{\lambda_r^*} \tag{1}$$

Lr is the rotor inductance, Lm is the mutual inductance, and λr is the estimate of the rotor flux linkage, which is obtained from the following equation,

$$\lambda_r = \frac{L_m i_{ds}}{1 + \tau_r S} \tag{2}$$

with $\tau_r = \frac{L_r}{R_r}$ is a rotor time constant.

The magnitude of the direct-axis stator current reference i_{qs}^* is dependent on the input flux reference λ_r^* :

$$i_{ds}^* = \frac{\lambda^*}{L_m} \tag{3}$$

Rotor flux angle θe for coordinate transformation is obtained from the calculation of the speed of rotation of the rotor speed ωm and slip ωsl, with the equation,

$$\theta_e = \int (\omega_m + \omega_{sl}) \, dt \tag{4}$$

slip velocity is obtained from the calculation of the stator current reference i_{qs}^* with parameters of motor,

$$\omega_{sl} = \frac{L_m}{\lambda_r^*} * \frac{R_r}{L_r} * i_{qs}^* \tag{5}$$

Reference current i_{qs}^* dan i_{ds}^* converted into a reference-phase flow i_{as}^*, i_{bs}^*, i_{cs}^* which will be the input current regulator. Then the flow regulator will process the reference phase current into a signal which triggers will control the inverter.

4.1.2. Fuzzy Logic Control

Fuzzy logic system introduced by L.A. Zadeh in 1965, to develop a set of binary logic theory. Binary logic knows only two kinds of conditions that "1" and "0", so that there are strict limits. L.A. Zadeh then modify the set theory in which every member has a continuous valued membership degrees between 0 to 1 or written [0 1], as shown below.
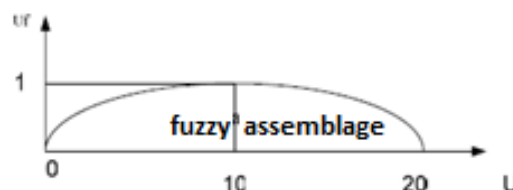

Figure 2. The set of Fuzzy

Systems that utilize fuzzy conclusion fuzzy if-then rules can model the qualitative aspects of human knowledge and reasoning processes without giving utilize appropriate quantitative analysis. There are some basic aspects of this approach which requires a better understanding, in detail :

1. There is no standard method for downloading transform human knowledge or experience into the rule base (rule base) and a database of fuzzy inference system.
2. There is a need for an effective method to organize (tuning) the membership function (MF) to minimize the output error measure or maximize the achievement index.

Fuzzy controller performance depends on membership functions, distribution and fuzzy rules that describe the control algorithm. There is no formal method for accurately determining the controller parameters. FLC tuning is an iterative process that requires modification of the membership functions and control rules. Adaptation can be done by considering the response of the system regulator and modify the fuzzy set of input variables (e and de / dt) and output variables (du / dt) until the desired response is obtained.
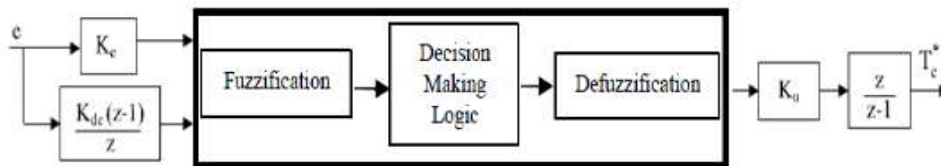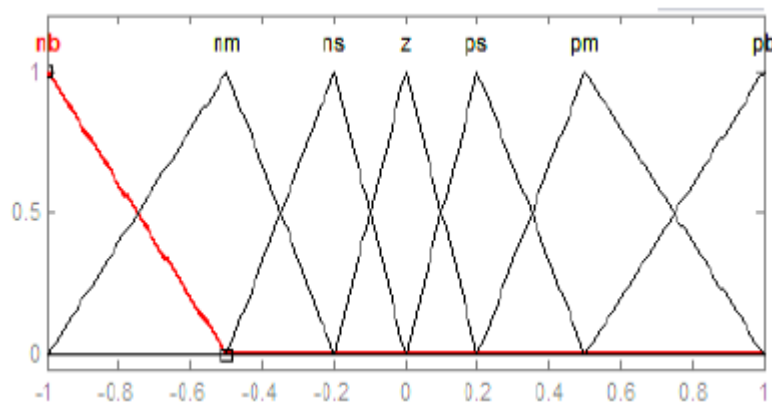

Figure 3. Fuzzy structure
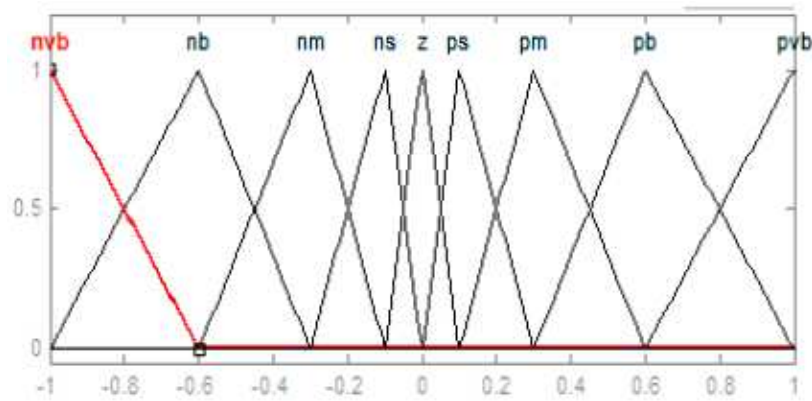

Figure 4. input 'e' and 'de'

Figure 5. output Fuzzy

Fuzzification process produces fuzzy variable 'e' and 'de' using a set of crisp. variables are then processed by the fuzzy inference mechanism based on a set of control rules contained in the rule base table. The variables used as {NVB (very large negative), NB (negative big), NM (negative medium), NS (negative small), Z (zero), PS (positive small), PM (positive medium), PB (positive large), PVB (very large positive)} (Y.Miloud et al, 2000). Fuzzy rules are expressed using IF-THEN rules. the set of crisp output of FLC obtained using the MAX-MIN inference algorithms and approaches the center of gravity of defuzzyfication.

Fuzzy controller performance depends on membership functions, distribution and fuzzy rules that describe the control algorithm. There is no formal method for accurately determining the controller parameters. FLC tuning is an iterative process that requires modification of the membership functions and control rules. Adaptation can be done by considering the response of the system and modifying the fuzzy set of input variables (e and de / dt) and output variables (du / dt) until the desired response is obtained.

4.1.3. Backstepping Control

In a control theory, Backstepping is a technique developed circa 1990 by *Petar V. Kokotovic* and others for designing stabilizing controls for a special class of nonlinear dynamical systems. These systems are built from subsystems that radiate out from an irreducible subsystem that can be stabilized using some other method. Because of this recursive structure, the designer can start the design process at the known-stable system and "back out" new controllers that progressively stabilize each outer subsystem. The process terminates when the final external control is reached. Hence, this process is known as *Backstepping.*

Before we present the Standard Backstepping Method we need to define the Lyapunov function and how to use it in the stability analysis and controller design for simple 1st order systems. In the theory of : ordinary differential equations (ODEs), Lyapunov functions are scalar functions that may be used to prove the stability of an equilibrium of an ODE. Named after

the Russian mathematician Aleksandr Mikhailovich Lyapunov, Lyapunov functions are important to stability theory and control theory.

Informally, a Lyapunov function is a function that takes positive values everywhere except at the equilibrium in question, and decreases (or is non-increasing) along every trajectory of the ODE. The principal merit of Lyapunov function-based stability analysis of ODEs is that the actual solution (whether analytical or numerical) of the ODE is not required.

Consider the following 1st order differential equation

$$\dot{x} = -x \tag{6}$$

Let the candidate Lyapunov function is

$$V = \frac{1}{2}x^2 \tag{7}$$

where V is a positive definite function,

$$V > 0, \forall x \neq 0 \ and \ V\,(0) = 0 \tag{8}$$

By differentiating VV with time, we get

$$\dot{V} = \frac{dV}{dx}\frac{dx}{dt} = x\dot{x} = x(-x) = -x^2 \tag{9}$$

Since $\dot{V}$ is negative definite the system is asymptotically stable

4.1.4. Full design by using backstepping

Backstepping control method is to create a virtual control ($\dot{V}$).Virtual control is intended to make the system more stable so that the real value is getting close to the desired reference.

The application backstepping on this system are :

step 1 : if we have a general system (in Figure 6)

Figure 6. Imagery general system

first We define the equation error on the system. Error can be defined:

$$e_1 = v_{ref} - v_r \tag{10}$$

Terms stable in Lyapunov equation if

$$\dot{V} = -V(x) \tag{11}$$

So for error equation (1) we sent down into :

$$\dot{e}_1 = \dot{v}_{ref} - \dot{v}_r \tag{12}$$

For virtual control signals that we use is $\dot{v}_r$

And to determine the equation of $\dot{v}_r$ can be found after the dynamic equation

of induction motors we diferensialkan be:

$$\frac{di_{ds}}{dt} = -\frac{1}{\sigma L_s}\left(R_s + \frac{R_r L_m^2}{L_r^2}\right)i_{ds} + \omega_s i_{qs} + \frac{1}{\sigma L_s}\left(\frac{R_r L_m^2}{L_r^2}\right)\phi_{dr} + \frac{1}{\sigma L_s}v_{ds} \tag{13}$$

$$\frac{di_{qs}}{dt} = -\omega_s i_{ds} - \frac{1}{\sigma L_s}\left(R_s + \frac{R_r L_m^2}{L_r^2}\right)i_{qs} - \frac{1}{\sigma L_s}\left(\frac{L_m}{L_r}\right)\omega\phi_{dr} + \frac{1}{\sigma L_s}v_{qs} \quad (14)$$

$$\frac{d\phi_{dr}}{dt} = \frac{L_m.R_r}{L_r}i_{ds} - \frac{R_r}{L_r}.\phi_{dr} + (\omega_e - \omega_r)\phi_{qr} \quad (15)$$

$$\frac{d\phi_{qr}}{dt} = \frac{L_m.R_r}{L_r}i_{qs} - \frac{R_r}{L_r}.\phi_{dr} - (\omega_e - \omega_r)\phi_{dr} \quad (16)$$

$$\omega_{sl} = \frac{L_m}{T_r}\frac{i_{sq}}{\phi_{dr}} \qquad\qquad T_e = K_t i_{qs} \quad (17)$$

where σ is a loses factor and the equivalent is :

$$\sigma = 1 - \frac{L_m^2}{L_s L_r} \quad (18)$$

L_s, L_r, L_m is the stator, rotor and mutual inductance
R_s, R_r is the resistance of a stator dan rotor
ω_e, ω_r is the electromagnetic speed and rotor speed
ω_{sl} is the value of slip $(\omega_e - \omega_r)$
τ_r, P is the rotor time constant and nominal of pole in induction motor
Broadly speaking, vector control, in this case the Indirect Field Oriented Control make the same linear induction motor control with DC motor control. Basically is to control torque and flux, this can be solved by dq rotational reference frame or commonly known as clark transformation (transformation from frame 3 phase to 2-phase stasionari frame) and the transformation of the park (transformation that changes the phase stasionari frame 2 frame into 2 phases rotational). So that would be obtained equation :

$$\phi_{qr} = \frac{d\phi_{qr}}{d_t} = 0 \quad (19)$$

$$\phi_{dr} = \phi_r = \text{konstan} \quad (20)$$

By using these equations then for the value of the electromagnetic torque (T_e) is :

$$T_e = \frac{3}{2}\frac{P.L_m}{L_r}.\phi_r.i_{qs} \quad (21)$$

and the nominal of slip (ω_{sl}) can be write :

$$\omega_{sl} = \frac{1}{\tau_r}\frac{i_{qs}^*}{i_{ds}^*} \quad (22)$$

And if if is substituted into the dynamic equations of the induction motor becomes :

$$\frac{di_{ds}}{dt} = -\left(\frac{R_s}{\sigma L_s} + \frac{1-\sigma}{\sigma\tau_r}\right)i_{ds} + \omega_s i_{qs} + \frac{L_m}{\sigma L_s L_r \tau_r}\phi_{dr} + \frac{1}{\sigma L_s}v_{ds} \quad (23)$$

$$\frac{di_{qs}}{dt} = -\left(\frac{R_s}{\sigma L_s} + \frac{1-\sigma}{\sigma\tau_r}\right)i_{qs} + \omega_s i_{ds} + \frac{L_m}{\sigma L_s L_r \tau_r}\phi_{dr} + \frac{1}{\sigma L_s}v_{ds} \quad (24)$$

$$\frac{d\phi_r}{dt} = \frac{L_m}{\tau_r}i_{ds} - \frac{1}{\tau_r}.\phi_{dr} \quad (25)$$

$$\frac{d\omega_r}{dt} = \frac{3}{2}\frac{P^2 L_m}{JL_r}.i_{qs}\phi_{dr} - \frac{f_c}{J}\omega_r - \frac{P}{J}T_l \quad (26)$$

With $\dot\omega = \dot v_r$ and then we can find equation of $\dot v_r$ is :

$$\dot v_r = \frac{3}{2}\frac{P^2 L_m}{JL_r}.i_{qs}\phi_{dr} - \frac{f_c}{J}\omega_r - \frac{P}{J}T_l \quad (27)$$

Then :

$$\dot e_1 = \dot v_{ref} - \frac{3}{2}\frac{P^2 L_m}{JL_r}.i_{qs}\phi_{dr} - \frac{f_c}{J}\omega_r - \frac{P}{J}T_l \quad (28)$$

Before the equation :
$$\dot{e}_1 = \dot{v}_{ref} - \dot{v}_r \qquad (29)$$
Then we design stability function with Lyapunov methode, can be written :
$$\propto_{\omega 1} = -c_{\omega 1}e_1 + \dot{\omega}_r \qquad (30)$$
Where $c_{\omega 1}$ is a positive constant and $\propto_{\omega 1}$ is a stability function. Then Lyapunov function can be written : $V_{\omega 1} = \frac{1}{2}e_1^2$

Then we can define a new variable of (e_2) then we subtitution (21) into a new variable :
$$e_2 = \dot{\omega}_{ref} - \propto_{\omega 1} = \dot{\omega}_{ref} - (-c_{\omega 1}e_1 + \dot{\omega}_r)$$
$$e_2 = \dot{\omega}_{ref} + c_{\omega 1}e_1 - \dot{\omega}_r$$
Then by taking the differential of $V_{\omega 1}$ and subtituting (20), (21) and (23), into it, we can obtain :
$$\dot{V}_{\omega 1} = e_1 e_2 - c_{\omega 1}e_1^2$$
To design a controller, which has the ability to track commands and to reject load disturbance, we add the related terms of d into $V_{\omega 1}$ to obtain a new Lyapunov function as :
$$V_{\omega 2} = V_{\omega 1} + \frac{1}{2}\frac{1}{\gamma_\omega}\tilde{d}^2$$
Where d is the error between the value of d and its estimated value d, and γ_ω is a positive constant. By taking the differential of $V_{\omega 2}$ and subtituting (23) and (24) into the differential result, then :
$$\dot{V}_{\omega 2} = \dot{V}_{\omega 1} + \frac{1}{\gamma_\omega}\tilde{d}\dot{\tilde{d}} = -c_{\omega 1}e_1^2 + e_1[\dot{\omega}_{ref} + c_{\omega 1}e_1 - \dot{\omega}_r] - \frac{1}{\gamma_\omega}\tilde{d}\left(\dot{\hat{d}} - \gamma_\omega e_1\right)$$
The Lyapunov function, explain that the value of $\dot{V}$ is always devenitive negative then we chose a new function to chance the value of $\dot{V}_{\omega 2}$ is always devinitive negative, it can be written :
$$\dot{V}_{\omega 2} = \dot{V}_{\omega 1} + \frac{1}{\gamma_\omega}\tilde{d}\dot{\tilde{d}} = -c_{\omega 1}e_1^2 - \frac{1}{\gamma_\omega}\tilde{d}\left(\dot{\hat{d}} - \gamma_\omega e_1\right) + 0$$
Then we chose $e_1[\dot{\omega}_{ref} + c_{\omega 1}e_1 - \dot{\omega}_r]$:
$$e_1[\dot{\omega}_{ref} + c_{\omega 1}e_1 - \dot{\omega}_r] = 0$$
Became :
$$\dot{\omega}_{ref}e_1 + c_{\omega 1}e_1^2 - \dot{\omega}_r e_1 = 0$$
$$\dot{\omega}_r = \dot{\omega}_{ref} + c_{\omega 1}e_1$$
Then $\dot{\omega}_r$ became :
$$\frac{3}{2}\frac{P^2 L_m}{J L_r}.i_{qs}\phi_{dr} - \frac{f_c}{J}\omega_r - \frac{P}{J}T_l = \dot{\omega}_{ref} + c_{\omega 1}e_1$$
We change $\frac{3}{2}\frac{P^2 L_m}{J L_r}.i_{qs}\phi_{dr}$ into the new variabel T_e, :
$$T_e - \frac{f_c}{J}\omega_r - \frac{P}{J}T_l = \dot{\omega}_{ref} + c_{\omega 1}e_1$$
$$-\frac{f_c}{J}\omega_r - \frac{P}{J}(-T_e + T_l) = \dot{\omega}_{ref} + c_{\omega 1}e_1$$
We chose T_e is the control input :

$$\frac{P.T_e}{J} = \dot{\omega}_{ref} + c_{\omega 1}e_1 + \frac{P.T_l}{J} + \frac{f_c.\omega_r}{J}$$

Then we can obtain the backstepping controller :

$$T_e = \frac{J}{P}\left(\dot{\omega}_{ref1} + c_{\omega 1}e_1 + \frac{P.T_l}{J} + \frac{f_c.\omega_r}{J}\right)$$

Then the backstepping controller can be design :

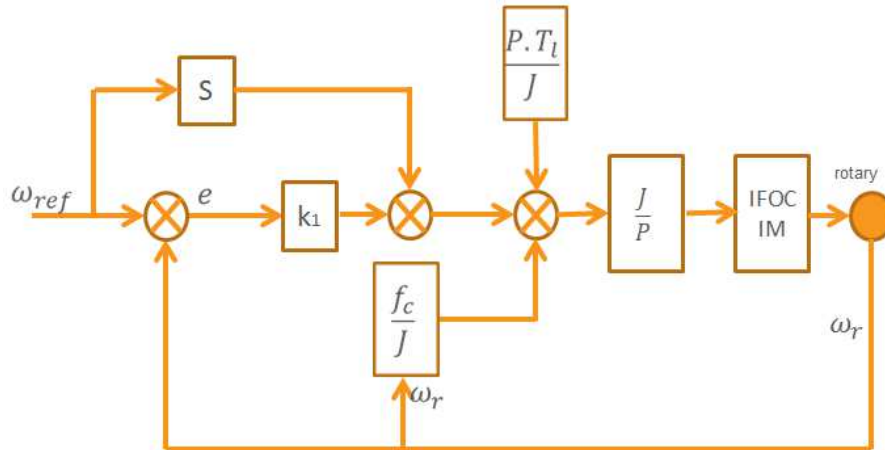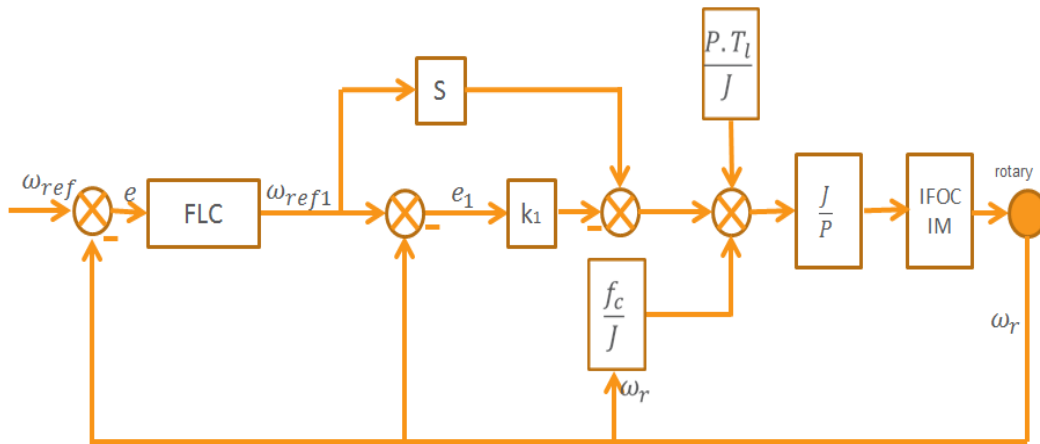**Figure 7.** Blok diagram of Backstepping controller

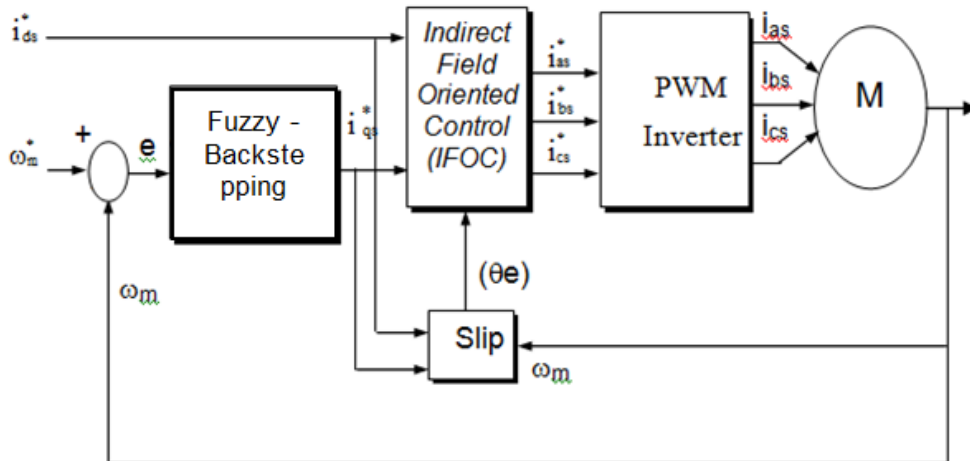**Figure 8.** Final Design of Fuzzy-Backstepping controller

4.2. Design of All System

Figure 9. Blok Design System

In the chart above, we can see that the direct-axis stator currents (i^*_{ds}) used for reinforcement made constant flux which is then used as a parameter for IFOC and constant comparison to the slip. In IFOC d-q coordinate reference frame is locked to the rotor flux vector, this results in a decoupling of the variabels so that flux and torque can be separately controlled by stator direct axis current (i^*_{ds}) and quadrature axis current (i^*_{qs}), respectively like in the separately dc machine. on IFOC field measurement can be done indirectly, ie by observing large changes in the value of the speed of rotation of the rotor. Actual rotational speed of the rotor is continuously read by the sensor is then compared with the speed of the rotor speed reference. Value of the difference between the actual and reference rotor speed is used as the error value to be processed by the adaptive fuzzy backstepping output a quadrature-axis current value (i^*_{qs}). Stator current direct-axis (i^*_{ds}) and quadrature-axis current value (i^*_{qs}) with the current method stasioner IFOC transformed into reference ($i^*_{as}, i^*_{bs}, i^*_{cs}$) processed by the PWM inverter into current to drive a 3 phase induction motor 3 phase. Fuzzy PI function is to fixed error.

Table 1. parameter of induction motor

No.	Parameter	Value
1.	Nominal power	3730 VA
2.	Voltage line-line	460 V
3.	Frequency	60 Hz
4.	Rotor resistance	0.816 ohm
5.	Mutual inductance	69.31e-3 H

4.3. IFOC Simulation
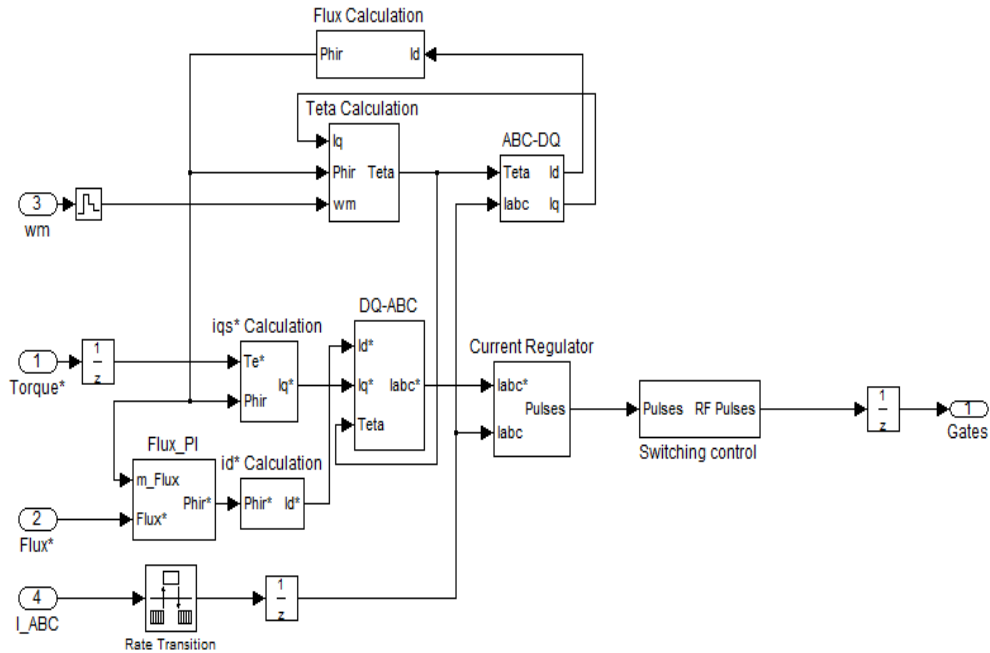
Figure 10. Blok proces of IFOC

In this picture (Figure 10), we can se the transformation to change the stationer frame into rotational frame. First we use clark transformation. Clark transformation is the transformation function to change the stationary 3 phase equation (ia,ib,ic) to 2 fasa equation stationary (iα,iβ). Then we use the park transformation. Park transformation is the transformation function to change the stationary 2 phase equation (iα,iβ), to equation 2 phase moving (id,iq), with id as direct-axis stator current and iq as quadrature-axis currents
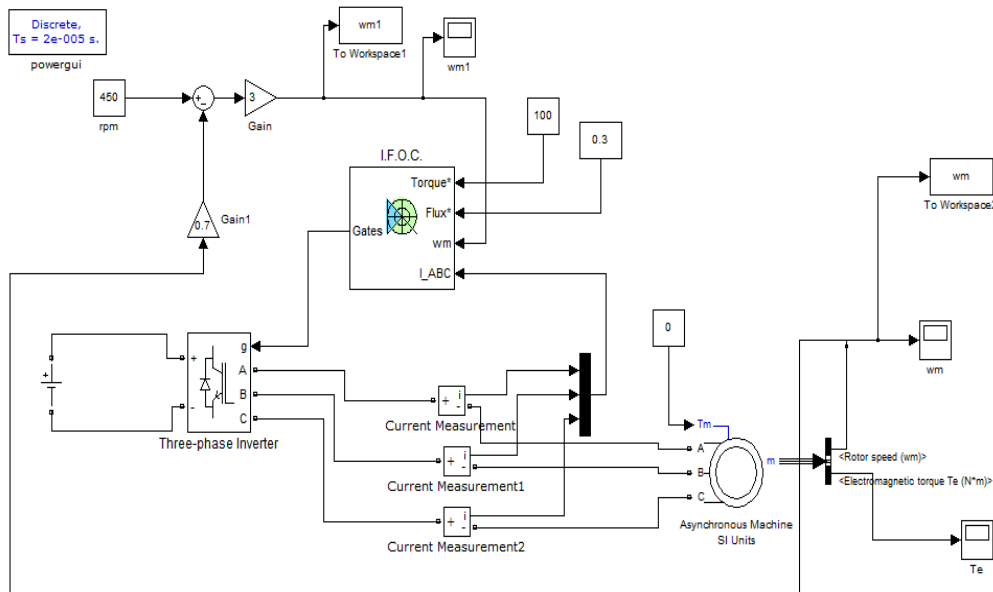
Figure 11. Simulink model 3 phase induction motor with IFOC

4.4 IFOC and Speed Control Using Fuzzy-Backstepping Simulation
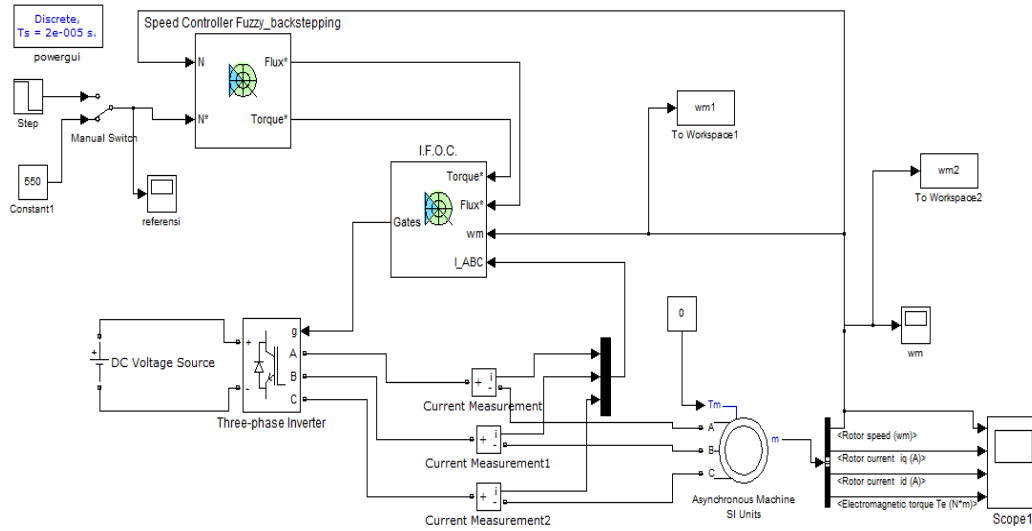
Figure 12. Simulink model 3 phase induction motor with IFOC and Speed control using Fuzzy_Backstepping

4.5 IFOC and Speed Control Using Fuzzy-Backstepping Simulation with dynamic load
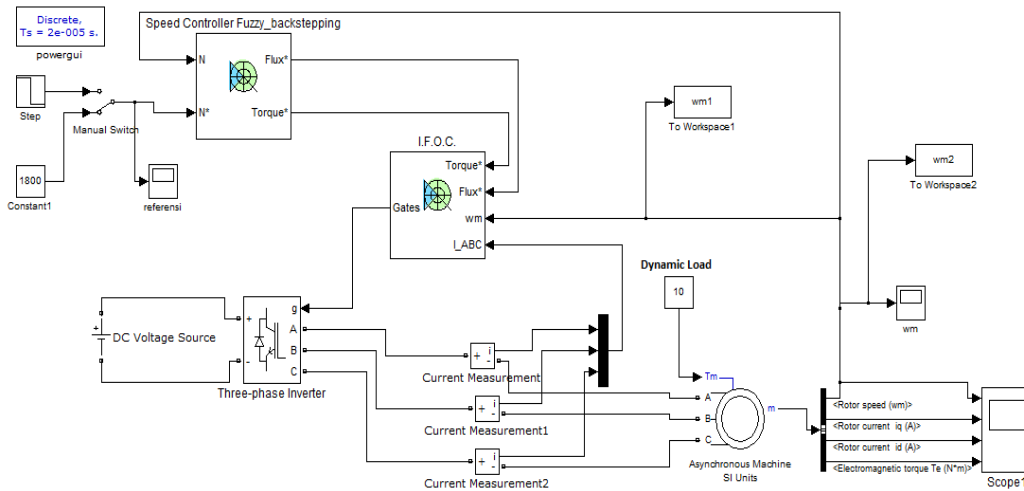
Figure 13. Simulink model 3 phase induction motor with IFOC and Speed control using Fuzzy_Backstepping with dynamic load

5. EXPERIMENT AND ANALYSIS
5.1. Simulation only with IFOC
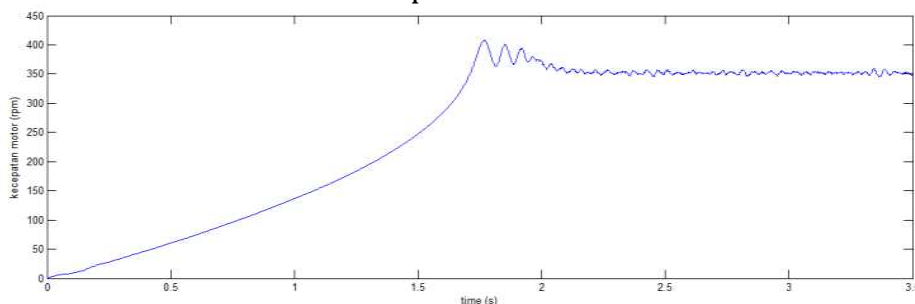Speed rotor with reference = 150 rpm
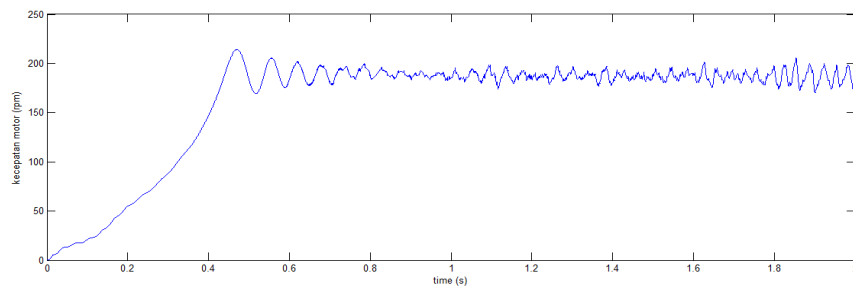
Figure 14. Speed rotor with reference = 150 rpm

In Figure 14, we can see oscillations occur at start, time from the start to reach the reference value takes about 0,5s.

Speed rotor with reference = 200 rpm
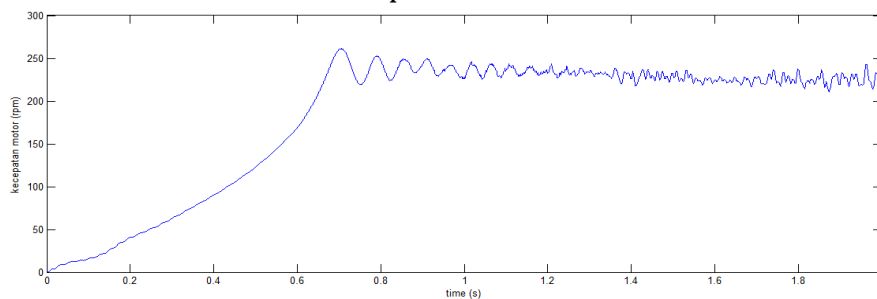
Figure 15. Speed rotor with reference = 200 rpm

In Figure 15, we can see oscillations occur at start, time from the start to reach the reference value takes about 0,7s. the system is very unstable with oscillation error value is large enough, especially when the system will reach a value of reference, the error value undershot overshoot and error is very large. it adversely affects system performance

Speed rotor with reference = 350 rpm

Figure 16. Speed rotor with reference = 350 rpm

In Figure 16, we can see oscillations occur at start, time from the start to reach the reference value takes about 1,7s. The system is unstable with slow system response ranging from starting the beginning until it reaches the reference value. when it reaches the reference value, the system has an error

value overshoot but pretty good compared with previous experiments. When the system reaches the reference value there is little value oscillation error.
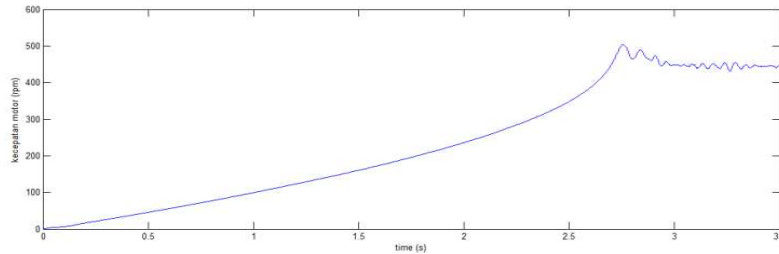
Speed rotor with reference = 450 rpm

Figure 17. Speed rotor with reference = 450 rpm

In Figure 17, we can see oscillations occur at start, time from the start to reach the reference value takes about 2,7s. System response is very slow, when it reaches the reference there is an error overshoot of 50rpm. The time has reached the reference value, there are still error value oscillation.

In Figure 18, demonstrate the use of speed controller with fuzzy control, combined with Backstepping control (Fuzzy-Backstepping). The speed controller is used to set the value of flux and torque ideal which will then be used as input parameters in IFOC used to adjust the motor speed according to the speed reference value changes. With the use of the speed controller, the better the output response with oscillations of diminishing value.
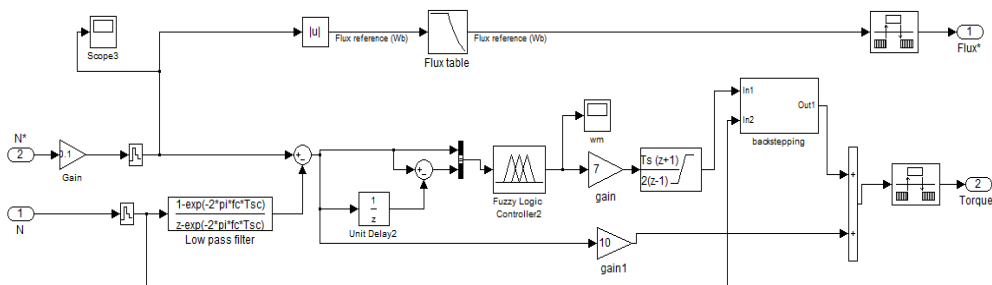

Figure 18. Speed control with Fuzzy-Backstepping

In Figure 18, shows the inside of the speed controller. The use of fuzzy control, combined with backstepping control can alter the response of output to be much better, than if not using a controller on IFOC (see Figure 10-13). Backstepping Control used is placed after Fuzzy Control because output rule in Fuzzy is determined by adding the function of backstepping . To obtain the value of the data retrieval is done many times in order to obtain the ideal combination to improve the value of transient and oscillations when the system starts working. for the design of control backstepping control, has been presented at Figure 4.

5.2. Simulation with speed control using Fuzzy-Backstepping

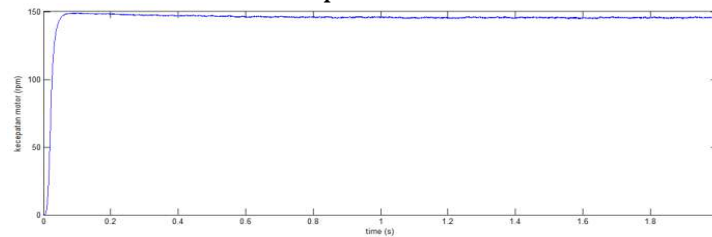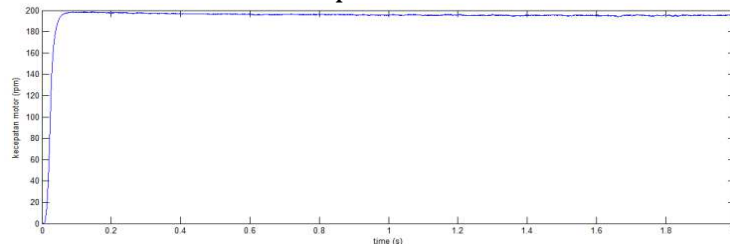Speed rotor with reference = 150 rpm

Figure 19. Speed rotor with reference = 150

In Figure 19, we can see increased system response is very fast, and when it reaches the reference there is no overshoot error and error undershot, oscillations occur at start, time from the start to reach the reference value takes about 0,005s. Value oscillations in the current system works extremely small.

Speed rotor with reference = 200 rpm

Figure 20. Speed rotor with reference = 200 rpm

In Figure 20, we can see oscillations occur at start, time from the start to reach the reference value takes about 0,005s. Oscillation does not occur on the system at start. the system works with a very small response time, indicates that the system has been qualified in the category of fast response. when it reaches the reference value is no overshoot and undershoot.
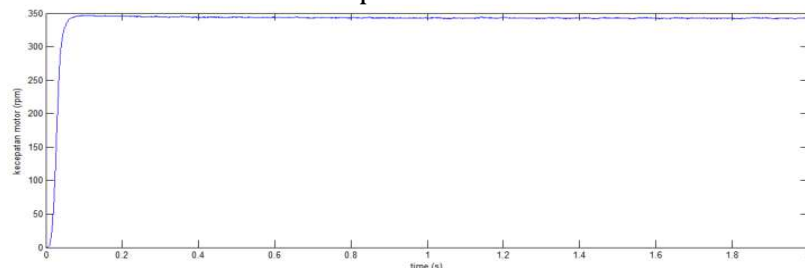
Speed rotor with reference = 350 rpm

Figure 21. Speed rotor with reference = 350 rpm

In Figure 21, we can see oscillations occur at start, time from the start to reach the reference value takes about 0,005s. the system works very well, when the real speed has reached the reference value, not shown any error

overshoot and undershoot. error steady state value is also very small, about 10rpm.

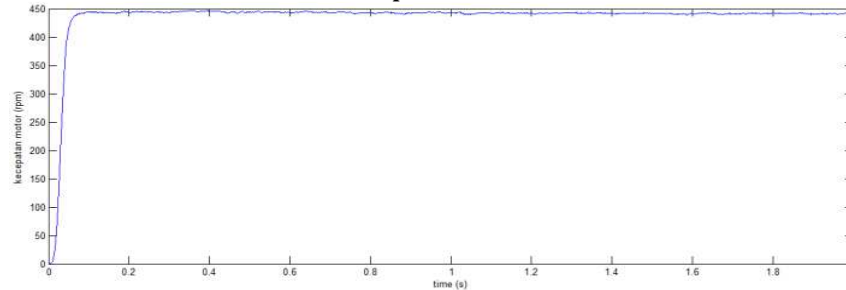Speed rotor with reference = 450 rpm

Figure 22. Speed rotor with reference = 450 rpm

In Figure 22, we can see oscillations occur at start, time from the start to reach the reference value takes about 0,005s. Values are very small oscillation, occurs after the motor speed approaching the reference.

    In figure 18-21, in the picture we can see a significant improvement in the system, which is not the discovery of oscillations error, error overshoot and error undershot. the system has a better response if menggungakan Fuzzy-backstepping than if only relying on IFOC alone, and when it reaches a steady state reference error can be minimized.

5.2. Simulation speed control using Fuzzy-Backstepping with dynamic load

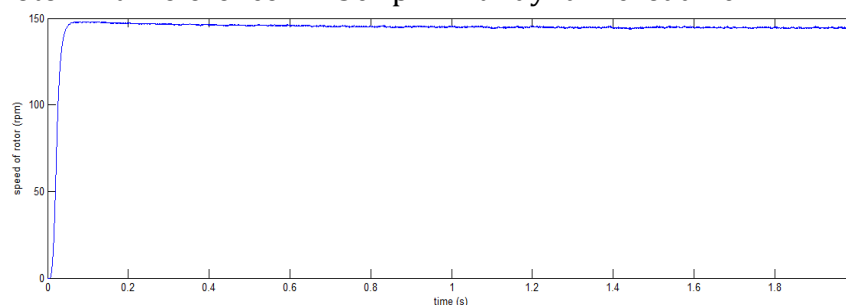Speed rotor with reference = 150 rpm with dynamic load 10Nm

Figure 23. Speed rotor with reference = 450 rpm with dynamic load 10Nm

on experiments loaded with a load torque of 10Nm, we can see that the addition of the load does not directly affect the system. the system is quite stable with a fast enough response time (0,005s) and there are no errors oscillations when the system reaches the reference value.
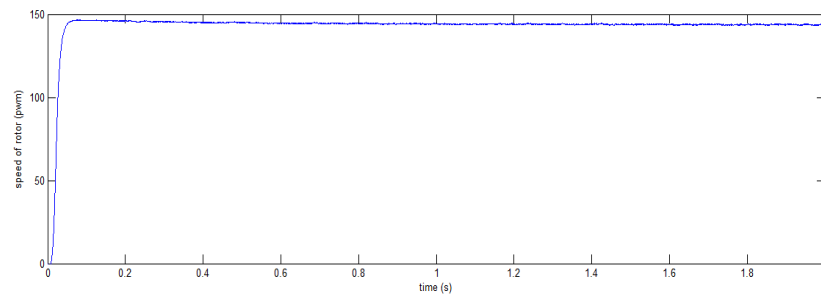Speed rotor with reference = 150 rpm with dynamic load 25Nm

Figure 24. Speed rotor with reference = 150 rpm with dynamic load 25Nm

in addition 25Nm load invisible peruibahan significant, the system is still quite stable in the absence of the error value overshoot and undershoot error when the system reaches reference. Looks very little difference between the load 10Nm and 25Nm, which is currently weighted 25nm system there is very little difference between the reference and real (4.5 rpm).

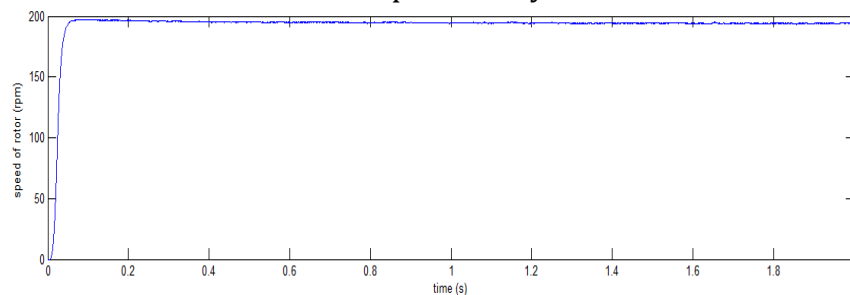Speed rotor with reference = 200 rpm with dynamic load 10Nm

Figure 25. Speed rotor with reference = 200 rpm with dynamic load 10Nm

in figure 25 we can see a fairly stable system response with a response time that is short enough of the system to pursue the reference value. there is no overshoot error when it reaches the system.

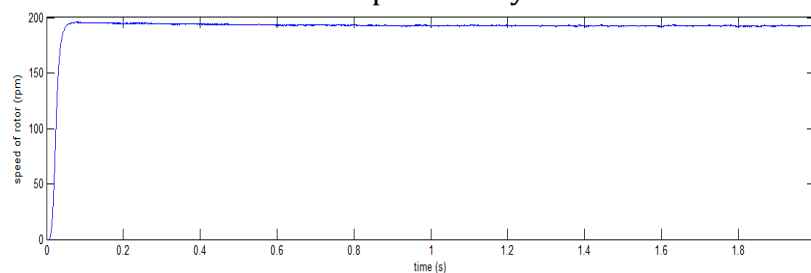Speed rotor with reference = 200 rpm with dynamic load 25Nm

Figure 26. Speed rotor with reference = 200 rpm with dynamic load 25Nm

in Figure 26 we can see a fairly stable system response with a response time that is short enough of the system to pursue the reference value. there is no overshoot error when it reaches the system.

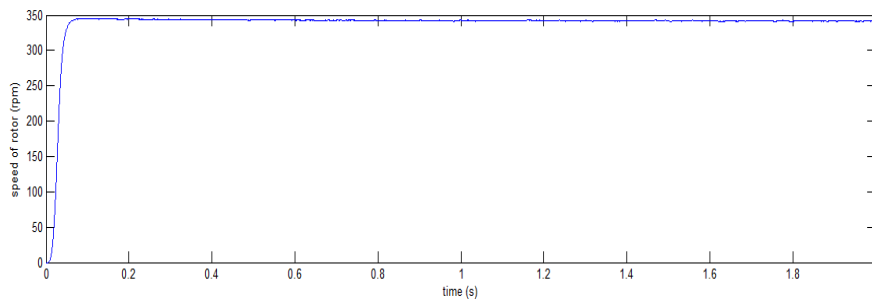Speed rotor with reference = 350 rpm with dynamic load 10Nm

Figure 27. Speed rotor with reference = 350 rpm with dynamic load 10Nm

seen that the effect of the load is not too significant impact on the system, even siste tend to be stable up to when it reaches the reference value.

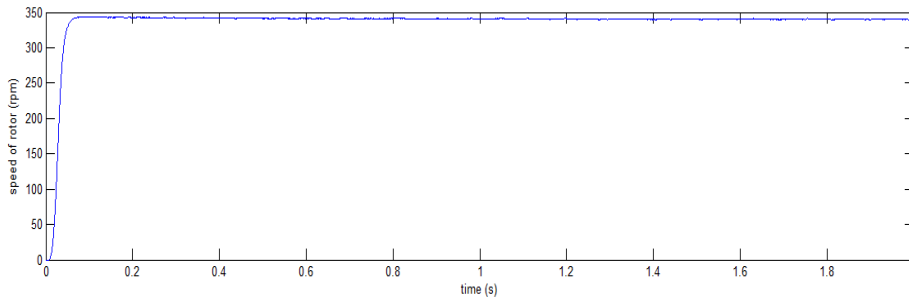Speed rotor with reference = 350 rpm with dynamic load 25Nm

Figure 28. Speed rotor with reference = 350 rpm with dynamic load 25Nm

seen that the effect of the load is not too significant impact on the system, even siste tend to be stable up to when it reaches the reference value. but in addition the burden of 25nm, there is a difference between the current value will reach the reference speed of 2.3 rpm.

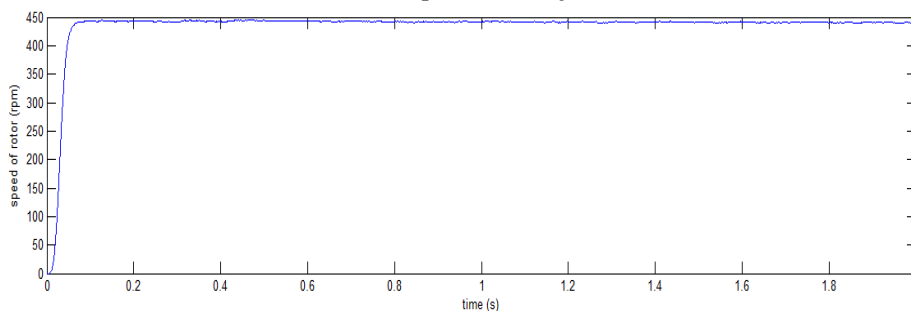Speed rotor with reference = 450 rpm with dynamic load 10Nm

Figure 29. Speed rotor with reference = 450 rpm with dynamic load 10Nm

on experiments loaded with a load torque of 10Nm, we can see that the addition of the load does not directly affect the system. the system is quite stable with a fast enough response time (0,005s) and there are no errors oscillations when the system reaches the reference value.
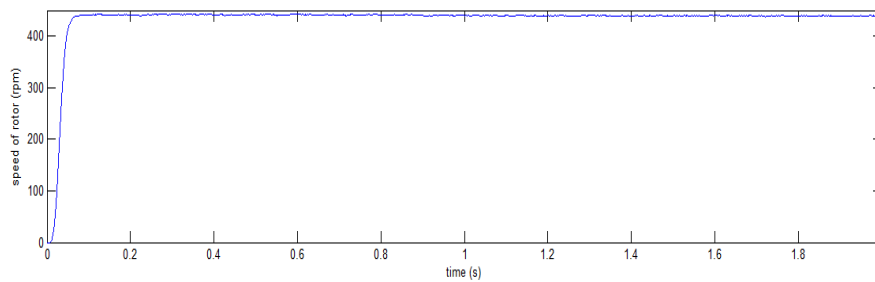Speed rotor with reference = 450 rpm with dynamic load 25Nm

Figure 30. Speed rotor with reference = 450 rpm with dynamic load 25Nm

seen that with the addition of the load, only a very small effect on the system. systems tend to be stable with a very small value of steady state error. With fuzzy-backstepping system will be more robust than interference or external load. With the addition of this method on speed control, it will further improve system performance both in improving the response capacity and to minimize the error value.

5.3. Analysist
On the graph it can be seen that the analysist simulation results:
1. Using IFOC can be used as an approach in terms of induction motor speed control. In this case the approach taken by IFOC only serves to change the nonlinear parameters (ac motor parameters) to the linear parameters (resembling a dc motor), so that if the parameters of the induction motor that was non-linear can be converted into a linear parameter, then the speed of the induction motor itself is easier fish to be controlled according to the desired reference. In the simulation it can be seen that the motor starting current to near reference requires a long time (0-2,7s) which resulted in the current oscillation will reach the reference value. When speed rerefensi 150 and 200 rpm, the actual speed exceeds the reference value with a slightly overshot quite a lot.
2. Using Fuzzy-Backstepping can help get better output response with a very short response time (<0,1s) to reach the reference value. Oscillation at start does not happen so that when the reference is not going to achieve a high oscillation, different if only IFOC using only. The better system response, evidenced by an increase in the actual response rate reached value of reference. Overshot the value is not the case with the value of the steady state error is very small.
3. Backstepping method is use to compare the rule base of output in Fuzzy controller. Bacause of that the output on fuzzy is not only value of the rate error and delta error, but the rule of output fuzzy is added by the equetion of backstepping.
4. Backstepping help us in solving a problem of stability in the system. Because equation of backstepping describe the overall system with the changes in the variables error. With Lyapunov function makes the system can be generalized globally, ranging from variable to variable error that the effect is not too significant as inertia of the system.

6. CONCLUSION

1. In the induction motor speed control use IFOC alone is not able to generate good performance, so the need for a controller that can provide good feedback input response, resulting in a good output with very small oscillation value and fast response.
2. IFOC only be used as a model that can make the system 3-phase induction motor is non linear becomes nearly linear with the separation of controlling torque and terrain make it easier to control induction motors such as DC motors
3. The use of control Fuzzy_Backstepping very well used due to the presence of Backstepping control, error rate can be minimized and fuzzy improve the response reference input so that achievement can be done quickly and with a degree of error is relatively smaller.
4. The use of fuzzy bacstepping very appropriate to make the system robust against interference or external load, this is due to the nature of the fuzzy backstepping improve system response and which minimize the output error.

Acknowledgements

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