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Analysis of Motor Speed Three Phase Induction Using Harriot and Smith Method

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Abstract: Induction motor is the driving tool needed by the industry but has the drawback that is difficult speed control for induction motor analysis many experimental methods that can be used to describe the plant that resulted in the control engineer must choose the right model at the time of open loop, hence, need to be analyzed on when close loop with hybrid SMC and PID. Based on the simulation shows the Harriot and Smith method when given the controller does not have a significant difference when reaching the desired setpoint, the Harriot Model has a faster setling time of 2.864 sec and the Smith Model has the ability to overcome the more robust interference that is overshoot in the first area of 0.02%, the second 0.03% and third 0.07% without steady state error. In this case on the control with the Harriot and Smith Models depending on the design of the controller.

Key words: Induction motors, rotational speed (RPM), SMC hybrid, PID, Harriot and Smith Models, design

INTRODUCTION

Induction motor is the most motor found in industry when compared with other motor. This is due to the advantages of induction motor. Among its supremacy is its simple construction part, its mechanical robustness, its relatively cheap price and does not require complex maintenance and can also be directly connected to the Alternating Current (AC) resources (Utoro and Pramudijanto, 2014).

But in addition to the advantages of induction motor, not apart from the weaknesses it has. Among the disadvantages is the difficulty of adjusting the speed of this motor because the characteristics of the motor Induction itself is not linear, consequently unable to maintain the speed when the load increases. In order to get a good performance and in accordance with the setpoint provided on the motor induction when performing the operation required a controller that is able to make the motor induction becomes more robust against the disruption given (Nofendra, 2009).

To analyze the behavior of the system is done by simulation but the plant must be changed into mathematical form, one way to get the transfer function is by experimental method. Many forms of experimental methods are used to describe actual system behavior but the weakness of the experimental method has different accuracy levels for each method in an open loop situation, so, it is necessary to test and get the exact method that works with the actual plant. In this case each method must have an equivalent capability in describing a plant therefore it is necessary to analyze on each method used by providing the right controller and a strong controller or able to follow the plant and able to overcome Interference at the time of controlling the speed of three phase induction motor.

Although, the method for describing the plant is different at the time of the open loop but needs to be done close loop analysis by using a sturdy controller. One of the controllers that is able to overcome the parameter uncertainty is Sliding Mode Control (SMC). This controller has the advantage that is strong and able to work on non-linear system that is a system that has uncertainty model or parameter (Nofendra, 2009).

The SMC controller has a disadvantage that lies in uninterrupted chattering that can lead to overshoots, one controlling handler capable of eliminating overshoot is a PID controller. In this research the method used latzel and Smith method with hybrid controller SMC-PID is expected to overcome the experimental method and the disturbance given.

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MATERIALS AND METHODS

In this research, there are several stages which writer do in experimental method analysis at speed of induction motor by using hybrid SMC and PID controller which is done using MATLAB R2013a application.

Three fasa induction motor modeling: This induced induction pad is tested in an open loop and then the result of the plant response read by the rotary encoder is displayed on the computer through the data acquisition process with Mitsubishi PLC (Utoro and Pramudijanto, 2014). After that one sample was applied to an experimental model based on an international research paper written by Jean-Jacques and Li (1991). The results of identification as follows:

The Harriot method (Utoro and Pramudijanto, 2014): In Fig. 1, known input signal X_{ss} = 1000 rpm and output response Y_{ss} = 999.366548, so that, the value obtained $K = Y_{ss}/X_{ss} = 0.991366548$. Searchable value τ_{dH}, $\tau_{H1}+\tau_{H2}$ on equals:

$$\tau_{H1}+\tau_{H2} = \frac{t73}{1.3} \quad (1)$$

Based on Fig. 2-5, we get t73 value. By trial and error method is 4.8136998s:

$$\tau_{H1}+\tau_{H2} = \frac{4.8136998s}{1.3} = 3.702846s \quad (2)$$

Substituted into the equation and obtained:

$$t_i = \frac{3.702846s}{2} = 1.851423 \quad (3)$$

So, we get the value of y_i from t_i in Fig. 1 using trial and error method that is y_i = 290 and can be determined y_i/y_{ss} = 0.292. Furthermore, from Harriot curve got the value of the equation $\tau_{H1}/\tau_{H1}+\tau_{H2}$ is 0.7199999. And substituted the value of $\tau_{H1}/\tau_{H1}+\tau_{H2}$, so that, the value obtained τ_{H1} and τ_{H2}, so that, the transfer function is obtained:

$$G_H(S) = \frac{0.991366548}{2.76415201s^2+3.702846s+1} \quad (4)$$

Smith's method (Utoro and Pramudijanto, 2014): Given input signal X_{ss} = 1000 rpm and output response Y_{ss} = 999.366548. So, we get the value of $K = Y_{ss}/X_{ss}$ = 0.991366548 which will be included in Eq. 14. Figure 2 obtained:

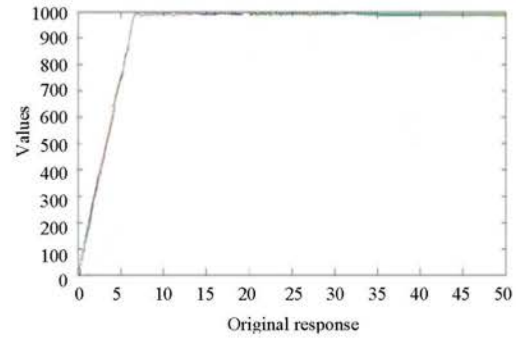

Fig. 1: Step response of three phase induction motor at time ti and t73 (Utoro and Pramudijanto, 2014)

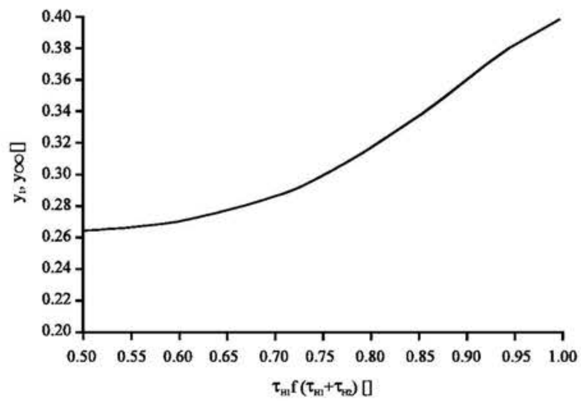

Fig. 2: Harriot curve (Ali, 2004)

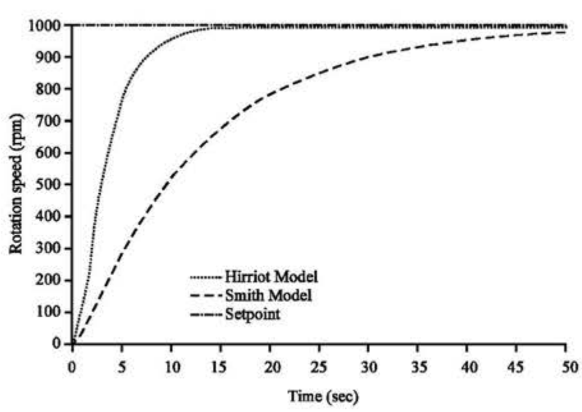

Fig. 3: Response identifies the model approach with Harriot and Smith methods

$$\frac{t_{20}}{t_{60}} = \frac{1.23}{4.22} = 0.291s \quad (5)$$

In Fig. 6, the Smith curve 1, 0.291 = 1.94 ζ and got the value. And in Fig. 7, the Smith curve 1 is obtained: t_{60}/τ = 3.14, sehingga τ = 4.22/1.23 = 4.43:

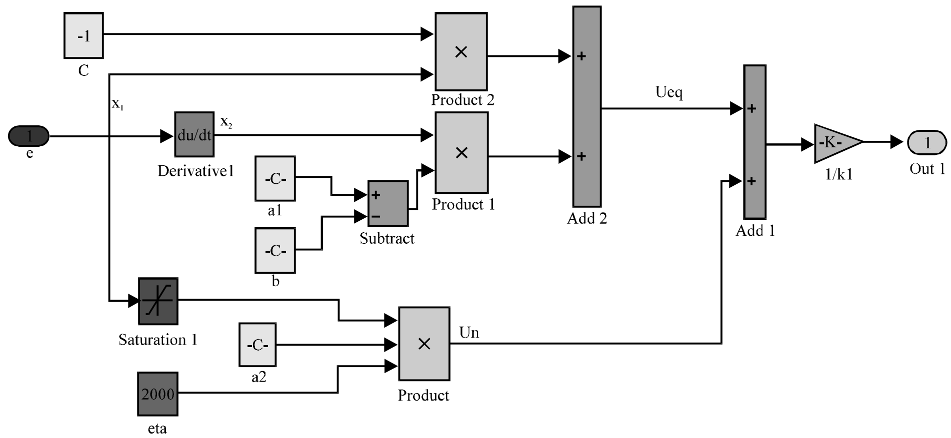

Fig. 4: SMC control block

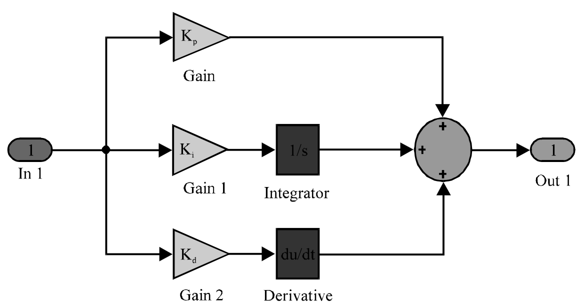

Fig. 5: PID control block

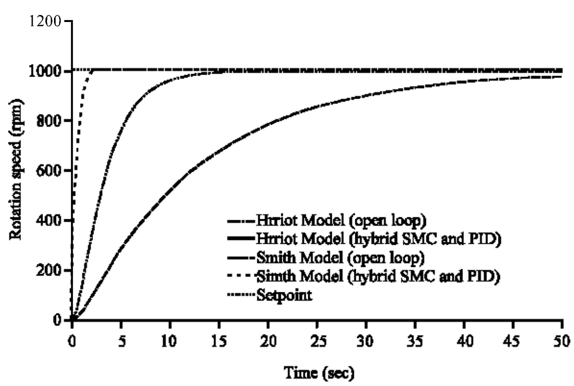

Fig. 6: Comparison of methods in achieving the desired setpoint

$$\tau_{SM1} = \tau\zeta\text{-}\tau\sqrt{(\zeta^2+1)}$$
$$\tau_{SM1} = (3.43\times1.94)+3.34\sqrt{(1.94^2+1)} = 6.6542+5.70 = 12.3542s \quad (6)$$

$$\tau_{SM2} = \tau\zeta\text{-}\tau\sqrt{(\zeta^2+1)}$$
$$\tau_{SM2} = (3.43\times1.94)+3.34\sqrt{(1.94^2+1)} = 6.6542+5.70 = 12.3542s \quad (7)$$

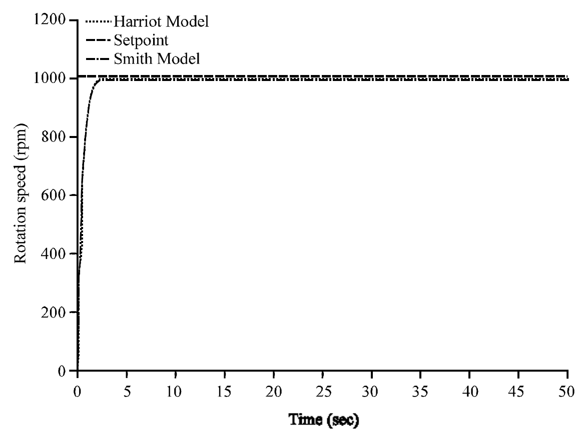

Fig. 7: Comparison of models in overcoming control signal interference

Table 2: Comparison of model approach method

Methods	Mathematical model	ISE
Harriot	0.991366548/(2.7641s+3.7028s+1)	2.253
Smith	0.991366548/(11.7325s²+13.3s+1)	7.194

So, the following transfer function is obtained:

$$G_{SM}(S) = \frac{0.991366548}{(11.7325s^2+13.3s+1)} \quad (8)$$

Table 1 got the identification response model in Fig. 3.

Design of SMC controller for SMC controllers: Transfer function at minimal load will be exemplified as fixed variable to make it easier in designing the controller, so that, the function of conductor of plant is determined by the following equation:

$$G(S)\frac{Y(s)}{U(s)} = \frac{K}{as^2+bs+1} \quad (9)$$

Where:
k = 0.991367
a = 2.644152
b = 3.702846
c = 1

The transfer function can be presented in the form of a differential equation, assuming the initial value is 0:

$$a\ddot{y}+b\dot{y}+cy = Ku \rightarrow a\ddot{y} = -b\dot{y}-cy+Ku$$

Defined:

$$x_1 = y \rightarrow \dot{x}_1 = \dot{y} = x_2 \quad (10)$$

$$x_2 = \dot{y} \rightarrow \ddot{y} = \dot{x}_2 \quad (11)$$

and found:

$$\ddot{y} = -\frac{b}{a}x_2 - \frac{c}{a}x_1 + \frac{k}{a}u \quad (12)$$

Then the error signal is taken as state variable:

$$x_1 = e \rightarrow \dot{x}_1 = \dot{e} = x_2 \quad (13)$$

$$x_2 = \dot{x}_1 = \dot{e} \quad (14)$$

The equation on the error signal is expressed:

$$e = r-y \quad (15)$$

And got:

$$x_1 = e = r-y \rightarrow = r-x_1 \quad (16)$$

Because the system is a regulator then obtained:

$$\begin{aligned} \dot{x}_1 = x_2 = \dot{r}-\dot{y} \rightarrow \dot{y} = \dot{x}_1 \\ \dot{x}_1 = x_2 = \dot{r}-\dot{y} \rightarrow \dot{y} = \dot{x}_1 \end{aligned} \quad (17)$$

Substitute Eq. 17 and 18 in Eq. 13, so that:

$$\dot{x}_2 = -\frac{b}{a}x_1 - \frac{c}{a}(r-x_1) + \frac{k}{a}u \quad (18)$$

$$\dot{x}_2 = -\frac{b}{a}x_2 - \frac{c}{a}x_1 + \frac{k}{a}u \quad (19)$$

So, we get satate-space equation:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{c}{d} & -\frac{b}{a} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{k}{a} \end{bmatrix} \quad (20)$$

Defined a glide surface:

$$\begin{aligned} \dot{\sigma}_s &= 0 \\ S(\dot{x}_1+\dot{x}_2) &= 0 \end{aligned}$$

Then, we can find equivalence control signal with assumption Un = 0:

$$\begin{aligned} & x_2 + \left(-\frac{b}{a}x_2 - \frac{c}{a}x_1 + \frac{k}{a}U \right) = 0 \\ & -\frac{c}{a}x_1 + \left(1-\frac{b}{a} \right)x_2 - \frac{k}{a}U_{eq} = 0 \\ & U_{eq} = \frac{-cx_1+(a-b)x_2}{k} \end{aligned} \quad (21)$$

Having found the equivalent control signal can be searched natural control signal:

$$\begin{aligned} \dot{\sigma}_s &= x_2 + \left(-\frac{b}{a}x_2 - \frac{c}{a}x_1 + \frac{k}{a}U \right) \\ \dot{\sigma}_s &= x_2 + \left(-\frac{b}{a}x_2 - \frac{c}{a}x_1 + \frac{k}{a}(U_{eq}+U_n) \right) \\ \dot{\sigma}_s &= -\frac{k}{a}U_n \end{aligned} \quad (22)$$

Based on the stability requirements lyapunov in Eq. 19 then selected:

$$\begin{aligned} \dot{\sigma}_s &= -\frac{k}{a}U_n \\ -\eta.\ \mathrm{sign}(\sigma) &= -\frac{k}{a}U_n \\ U_n &= \frac{a}{x}\eta.\mathrm{sat}(\sigma) \end{aligned} \quad (23)$$

where, $\eta>0$ (constant positive). Thus, Eq. 18 and 20 are converted to block simulink as follows. In Fig. 4, it is the result of modeling design on SMC control using Simulink MATLAB R2013a.

Design of PID controller: Once designed the SMC controller is then designed PID controller which will be combined. Based on the general form of PID controller in the following Eq. 5:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de}{dt} \quad (24)$$

Then the block diagram of the PID controller is shown in Fig. 5. In Fig. 5, it is a common form of modeling in PID control that is in Eq. 21 which is converted into blocks using Simulink MATLAB R2013a.

RESULTS AND DISCUSSION

Results and analyzes were based on response time (Ogata, 1996).

Comparison of models in achieving setpoints using hybrid SMC and PID: After getting the model response in the state of the open loop then do the control in a close loop on Harriot and Smith Models. On the issue of tuning control parameters are given with different values on each model. The response result with hybrid controller SMC and PID is shown in Fig. 6.

In Fig. 6, the response analysis shows the Harriot and Smith models are able to reach the desired setpoint quickly and have no significant difference when reaching the setpoint in a close loop state or when given a hybrid controller SMC and PID with the timing setling of Harriot 2.864 sec and steady state error 0% while on the Smith Model has a set time of 2.89 sec and a steady state error 0%.

Comparison of models with interference: After Harriot and Smith Models were tested using SMC and PID hybrid controllers, each model was then given a disturbance of control signals in the first region at 13-15 sec with one reinforcement, the second at 20-22 sec with twice the reinforcement and a third area at 35-37 sec with three reinforcements. The simulation results shown in Fig. 7.

Based on Fig. 7, when disturbed in the first and second areas the Harriot Model has an overshoot on the first region of 0.11%, both 0.34% and the third 0.56% while in the Smith Model having overshoot on the first 0.02%, the second 0.03% and the third 0.07% without steady state error.

CONCLUSION

Based on time response analysis obtained: in the simulation results show the Harriot and Smith methods when given the hybrid SMC and PID controllers have no significant difference when reaching the desired setpoint. At the time of simulation Harriot Model have faster time that is time of 2.864 sec setting and 0% steady state error but Smith Model is more solid in overcoming overshoot interference at first area 0.02%, second 0.03% and third 0.07% without steady error state.

Overall experimental method with Harriot and Smith Model can be used in describing a plant well in controlling the speed of the induction motor, in this case on the control of Harriot and Smith's three phase induction motors depends on the design of the controller.

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