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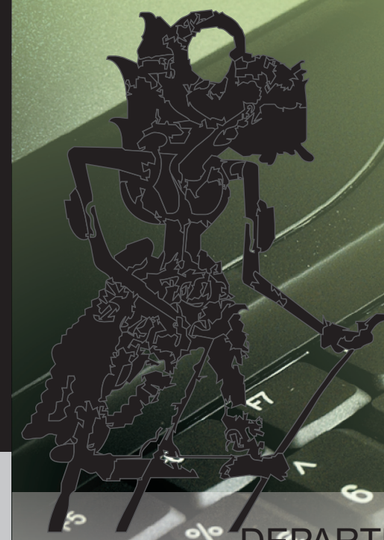
PROCEEDINGS OF

THE FIRST INTERNATIONAL CONFERENCE ON GREEN COMPUTING

AND

THE SECOND AUN/SEED-NET REGIONAL CONFERENCE ON ICT



DEPARTMENT OF ELECTRICAL ENGINEERING
AND INFORMATION TECHNOLOGY
FACULTY OF ENGINEERING
GADJAH MADA UNIVERSITY

Proceedings of The First International Conference on Green Computing and The Second AUN/SEED-Net Regional Conference on ICT

2010

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and Information Technology
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DEPARTMENT OF
ELECTRICAL ENGINEERING AND INFORMATION TECHNOLOGY
FACULTY OF ENGINEERING
GADJAH MADA UNIVERSITY

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Foreword

With the number of human population is getting higher and higher, the ability of our environment to support human life is gaining its importance. Sustainable development, or development that meets the needs of the present without sacrificing the future, has since then been adopted by many countries and institutions at all levels.

In supporting sustainable development, the field of information and communication technology (ICT) has coined the term “green ICT” or “green computing”, which describes the study and practice to use computing resources efficiently. As a contemporary issue, green computing becomes an important concern for big industries, small companies, and even government institutions since their success criteria are no longer based on a single measure.

Unfortunately, green computing has not been widely understood, yet practiced effectively. Not many technological options have been explored, and still it is mainly viewed from technological and engineering perspectives only. The challenges are thus twofold: exploring technological advances to achieve better ICT utilization, and how technology products/solutions can be applied effectively to meet the specified success criteria. These challenges are even more relevant to developing countries, since they are less exposed to scientific frontiers and have shorter tradition and less experiences of ICT utilization. On the other hand, these countries bear heavier burdens due to digital divide phenomenon which may block the road to the fulfillment of Millenium Development Goals in 2015. Therefore it is considered important to pave roads towards green computing, especially its application in developing countries. Many aspects have to be explored, considered, and discussed in an interdisciplinary manner, and this becomes the purpose of this conference.

The First International Conference on Green Computing (ICGC 2010) is an event organized by the Department of Electrical Engineering and Information Technology, Faculty of Engineering, Gadjah Mada University. This year, ICGC 2010 is held in conjunction with the AUN/SEED-Net’s Regional Conference on ICT 2010 (RC-ICT 2010). AUN/SEED-Net is a network of engineering education higher institutions in ASEAN countries. The event also commemorates the 64 years of Faculty of Engineering, Gadjah Mada University, as well as celebrates the inauguration of the new name of Department of Electrical Engineering and Information Technology.

It is expected that ICGC 2010 and RC-ICT 2010 can serve as a forum for sharing knowledge and experiences in the ICT field under the ASEAN spirit. Hosting 82 papers from Thailand, Vietnam, Laos, Cambodia, Myanmar, Malaysia, Philippines, India, Japan, and Indonesia, including speakers from government and industry, the conference is expected to yield fruitful outcomes for the benefit of all participating researchers, institutions, and countries.

Finally, as the Chairman of the Organizing Committee, I would like to express my deep appreciation to ASEAN Foundation, JICA, AUN/SEED-Net, King Mongkut’s Institute of Technology Ladkrabang, for invaluable support and assistance. My big thanks also go to all members of the Organizing Committee who have devoted their time and energy for the success of the event.

For all participants, I wish you an enjoyable conference in this colourful city of Yogyakarta.

Dr. Lukito Edi Nugroho
Chairman of the Organizing Committee

Table of Contents

Inner Cover i
Organizing Committee ii
Foreword iii
Schedule v
Table of Contents ix

Part 1: SPECIAL LECTURE

Lec #1 Energy Efficiency: A Mandatory Driver for a Changing World 1
Aris Dinamika

Lec #2 Experimental Platform in 5-GHz Band Wireless Communication Using an 80-MHz Bandwidth MIMO-OFDM System 13
Singo Yoshizawa, Shinya Odagiri, Yasuhiro Asai, Takashi Gunji, Takashi Saito, Yoshikazu Miyanaga

Lec #3 Virtual Reality and Augmented Reality and their Applications to Medical Diagnosis and Green Computing 17
Kazuhiko HAMAMOTO

Lec #4 Ubiquitous Sensor Networks for Monitoring the Environment: Adaptive Sensing Based on Profiles 23
Yoshiteru Ishida

Lec #5 Hierarchical Consensus for Large Scale Networked Dynamical Systems 28
Shinji Hara

Lec #6 Filter Multicast: A Communication Support for Dynamic Vehicle Platoon Management 34
Hiroshi Shigeno and Ami Uchikawa

Part 2: TECHNICAL PAPERS

CAM #1 Analysis of Single-Phase Passive and Active EMI Filter Performance for Induction Motor Drive 41
Chanthea Khun, Werachet Khan-gnern, Masaaki Kando

CAM #2 Dynamic Modeling and Control of a SEPIC Converter in Discontinuous Conduction Model 45
Vuthchhay Eng and Chanin Bunlaksananusorn

CAM #3 Prototype of Sound-based News on Demand Application in Mutli-languages for partial/fully illiterates 52
Annanda Thavymony RATH

INA #1 Experiences in Implementing General-Purpose Applications on CUDA 56
Achmad Imam Kistijantoro

IND #1 Epitomizing Green Computing 60
P.U. Bhalchandra , Dr.S.D.Khamitkar , N.K.Deshmukh , S.N.Lokhande

JPN #1 Range-Free Localization Algorithm Using Distance Deviation Weighted Factor in Wireless Sensor Network 68
Thida Zin Myint, Tomoaki Ohtsuki

JPN #2 Stereo-Based Ground Plane Estimation: A Reliable Approach for Low Texure Stereo Images 74
Sach Thanh LE, Kazuhiko HAMAMOTO, Kiyoaki ATSUTA, Shozo KONDO

LAO #1 3D Reconstruction from X-ray Fluoroscopy using Exponential Opacity Setting for Differential Volume Rendering 82
Khamphong Khongsomboon, Phoumy Indarak, Saykhong Saynasine, Kazuhiko HAMAMOTO, Shozo KONDO

Sura #5	Optimization of Size and Location of Capacitor Banks on Distribution Systems Using an Improved Adaptive Genetic Algorithm *Patria Julianto, Imam Robandi*	285
Sura #6	Position Control of Manipulator's Links Using Artificial Neural Network with Backpropagation Training Algorithm *Thiang, Handry Khoswanto, Tan Hendra Sutanto*	290
Sura #7	Maximum Power Point Tracker Using Buck-Boost Converter as Variable Resistance *Vita Lystianingrum, Hendra Hardiansyah, Mochamad Ashari*	295
Sura #8	Filtering of normal, and laryngectomiced patient voices using ANFIS: A Preliminary evaluation of ANFIS algorithm compared to LPF, median, and average Filter *Andy Noortjahja, Tri Arief Sardjono, MH Purnomo*	299
Sura #9	Compression and Reconstruction of Digital Dental Image on Fuzzy Transform *Ingrid Nurtanio, I Ketut Eddy Purnama, Mauridhi Hery Purnomo*	304
Sura #10	Simulation of Desicion Support System for Pricing Grid Enterprise in Renderring Farm Using Neural Network *Lilik Anifah, Tommy Alma marif, Haryanto, Buddy Setiawan, Darda Insan Alam, I Ketut Edi Purnama, Mochammad Hariadi, Mauridhi Hery Purnomo*	308
Sura #11	Backpropagation Neural Network based Reference Control Modeling for Mobile Solar Tracker on a Large Ship *Budhy Setiawan, Mochamad Ashari, Mauridhi Hery Purnomo*	314
Sura #12	Design and Performance Analysis of Speed Controller in Induction Motor with Sliding Mode Control *Mardlijah, Lusiana Prastiwi, M Hery Purnomo*	320
Sura #13	High Performance of Nonlinear DC Motor Speed Control using Backpropagation Neural Network *Saidah, Mohamad Ashari, Mauridhi Heri Purnomo*	325
AAU #1	Knowledge Sharing in Knowledge-Growing-based Systems *Arwin Datumaya Wahyudi Sumari, Adang Suwandi Ahmad, Aciek Ida Wuryandari, Jaka Sembiring*	329
AAU #2	Savings Time Execution Prima Numbers Generator Using Bit-Array Structure *Rakhmat Hidayat, A. Rida Ismu Windyarto, Herdjunanto, Samiadji, Himawan, H*	334
ISTA	Design and Implementation of M-Learning for Increasing Flexibility of Learning System *Gatot Santoso, Edy Sutanta, Rifianto Suryawan*	340
UNY #1	Providing User Quality of Service Specification for Communities with Low Connectivity *Ratna Wardani, F. Soesianto, Lukito Edi Nugroho, Ahmad Ashari*	345
UNY #2	ElectroLarynx, Esopahgus, and Normal Speech Classification using Gradient Discent, Gradient discent with momentum and learning rate, and Levenberg-Marquardt Algorithm *Fatchul Arifin, Tri Arief Sardjono, Mauridhi Hery*	351
UNY #3	Analysis of Green Computing Strategy in University: Analytic Network Process (ANP) Approach *Handaru Jati*	358
UNY #4	Website Quality Evaluation Comparison: An Empirical Study in Asia *Handaru Jati*	365
TETI #11	Adaptive LMS Noise Cancellation of Wideband Vehicle's Noise Signals *Sri Arttini Dwi Prasetyowati, Adhi Susanto, Thomas Sriwidodo, Jazi Eko Istiyanto*	372
TETI #12	Design of Power Plant Boiler Temperature Monitoring Application using Sound Card as ADC and Data Acquisition Device *Udayanto Dwi Atmojo, Gotama Edo Priambodo, Umar Sidiq An Naas, Suharyanto, Avrin Nur Widyastuti*	379

Design and Performance Analysis of Speed Controller in Induction Motor with Sliding Mode Control

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Abstract— ***Sliding Mode Control*** **(SMC) is implemented in this research to control the speed of induction motor. The robust superiority of SMC in anticipating disturbance uncertainty and non linear characteristic of induction motor is achieved by first designing a sliding surface and computing the related control signal that are current, flux and speed. An addition of a boundary layer is used to wash out the chattering phenomena. As a result, beside robust performance against disturbance at various operating conditions, the controller proposed here has fast response following induction motor speed dynamics under investigation.**

Keywords-induction motor; sliding mode controlt; speed controller; disturbance uncertainty.

I. INTRODUCTION

Induction motor has many applications in industries because of its simple construction, cheap, easy in maintenance, reliable and high efficiency. Unfortunately it has several drawbacks such as speed control which is not as simple as DC Machine and also its efficiency changes with load and speed variety [1].

Modern industry require high performance of induction machine especially accurate speed variation following to variable load and should also robust against disturbance dynamics[2]. Therefore a controller is needed to regulate the speed according to the demand while keeping good efficiency performance.

In this paper sliding mode control will be implemented to design the speed controller by choosing a sliding surface in the form of state space inside a specific closed loop system dynamics. Switching and control law function were designed in a way so that the state trajectory achieve and move on the surface. The superiority of this method is its robustness against disturbance and model uncertainty and also more less information is needed compared to the classical controller. Because of those superiority, it is especially useful when implemented for very non linear system [3,5,7].

II. BASIC THEORY

In general, induction motor speed controller block diagram is as follows:

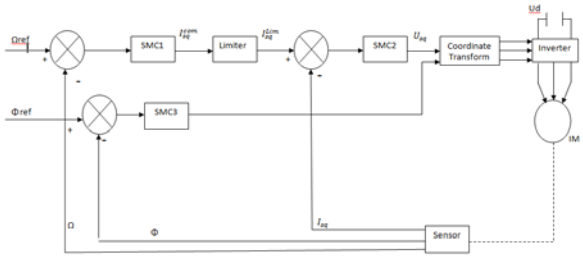

Figure 1.Blok Diagram Induction Motor Speed Controlled

A. Induction Motor Dynamic Model

Three Phase Squirrel Cage Induction Motor Dynamic Model in the d-q axis assuming $\Phi_{rd} = \Phi_r$ dan $\Phi_{rq} = 0$ can be expressed as follows [1,6]:

$$\dot{I}_{sd} = -\gamma I_{sd} + \omega_s I_{sq} + \frac{K}{T_r}\Phi_{rd} + \frac{1}{\sigma L_s}U_{sd} \quad (1)$$

$$\dot{I}_{sq} = -\omega_s I_{sd} - \gamma I_{sq} - P\Omega K\Phi_{rd} + \frac{1}{\sigma L_s}U_{sq} \quad (2)$$

$$\dot{\Phi}_{rd} = M_{sr} I_{sd} - \frac{1}{T_r}\Phi_{rd} \quad (3)$$

$$\dot{\Phi}_{rq} = \frac{M_{sr}}{T_r} I_{sq} - (\omega_s - P\Omega)\Phi_{rd} \quad (4)$$

$$\dot{\Omega} = \frac{PM_{sr}}{JL_r}(\Phi_{rd} I_{sq}) - \frac{C_r}{J} - f\Omega \quad (5)$$

with:

$$T_r = \frac{L_r}{R}; \sigma = 1 - \frac{M_{sr}^{\ 2}}{L_s L_r};$$

$$K = \frac{M_{sr}}{\sigma L_s L_r}; \quad \gamma = \frac{R_s}{\sigma L_s} + \frac{R_r M_{sr}^{\ 2}}{\sigma L_s L_r^2}$$

Φ_{rd}, Φ_{rq} is rotor flux component ; U_{sd}, U_{sq} is stator voltage component; I_{sd}, I_{sq} is stator current component; σ is leak factor; p is pole number; R_s and R_r are stator and rotor resistances; L_s and L_r are stator and

rotor induktances; M_{sr} is mutual induktance; T_e is electromagnetic torque; C_r is load torque, J is induction motor inertia moment; Ω is mechanic speed; ω_s is stator pulsation; f is damping coefisien and T_r is rotor time constant.

B. Sliding Mode Control

Sliding Mode is a technique to regulate the feedback by firstly defining a surface. Controlled system (variables) will be moved to the surface and system motion is directed to equilibrium point desired.

Look at to a dynamic system [4]:

$$x^{(n)} = f(x) + b(x)u \quad (6)$$

where u is a control input, and $x = \left[x \quad \dot{x} \quad \ldots \quad x^{(n-1)}\right]^T$ is a space vector while f(x) and b(x) are limited functions. If x_d is the desired , then its tracking error is:

$$e = x_d - x \quad (7)$$

Sliding surface is defined as [5,8]

$$S(x,t) = 0 \quad (8)$$

with

$$S(x,t) = (\frac{d}{dt} + \lambda)^{n-1} \quad (9)$$

λ is positive coefficient and *n* is system orde. The above equations are used to result system output that converge to the desired output.

Then a control law :

$$u = u_{eq} + m\,\mathrm{sgn}(S) \quad (10)$$

is determined as new control input with equivalent control signal u_{eq} was gained from $\dot{S} = 0$. Control gain *m* was determined from sliding condition:

$$S\dot{S} \langle \eta |S| \quad (11)$$

III. METHOD

A. Speed Controller Design

Tracking error of the speed state is

$$e_1 = \Omega_d - \Omega$$

and

$$\dot{e}_1 = \dot{\Omega}_d - \dot{\Omega}$$

For speed state, (9) result switching function S_1

$$S_1 = \Omega_d - \Omega \quad (12)$$

Because the sliding surface $S_1 = 0$, then (12) can be written as

$$\Omega_d - \Omega = 0 \quad (13)$$

From (13), the first derivative of S_1 can be written as

$$\dot{S}_1 = \dot{\Omega}_d - \frac{PM_{sr}}{JL_r}\Phi_{rd} I_s \quad (14)$$

and

$$I_{sq}^{eq} = \frac{JL_r}{PM_{sr}\Phi_{rd}}(\dot{\Omega}_d + \frac{c_r}{J} + \frac{f}{J}\Omega) \quad (15)$$

To reduce the chattering, the following control term is used.

$$I_{sq}^{n} = m_1 sat(\frac{S_1}{\varphi_1}) \quad (16)$$

with

$$\varphi_1 = 1$$

From (15) and (16) a new control input value was resulted as follows:

$$I_{sq} = \frac{JL_r}{PM_{sr}\Phi_{rd}}(\dot{\Omega}_d + \frac{c_r}{J} + \frac{f}{J}\Omega) + m_1 sat(\frac{S_1}{\varphi_1}) \quad (17)$$

B. Current Controller Design

This controller is designed to limit the possibility of current overshoot. Current limitation is defined [1]:

$$I_{sq}^{\lim} = I_{sq}^{\max} satI_{sq}^{com}$$

Switching function for current controller is

$$S_2(I_{sq}) = I_{sq}^{\lim} - I_{sq} \quad (18)$$

and

$$\dot{S}_2(I_{sq}) = \dot{I}_{sq}^{\lim} - \dot{I}_{sq} \quad (19)$$

Substitute (2) into (15) :

$$\dot{S}_2(I_{sq}) = \dot{I}_{sq}^{\lim} + \omega_s I_{sd} + \lambda I_{sq} + P\Omega K\Phi_{rd} - \frac{1}{\sigma L_s}U_{sq} \quad (20)$$

The resulted equivalent control U_{sq}^{eq} :

$$U_{sq}^{eq} = \sigma L_s(\dot{I}_{sq}^{\lim} + \omega_s I_{sd} + \gamma I_{sq} + P\Omega K\Phi_{rd}) \quad (21)$$

Control term for current controller is

$$U_{sq}^{n} = m_2 sat(\frac{S_2}{\varphi_2})$$

with

$$\varphi_2 = 1$$

Then

$$U_{sq} = U_{sq}^{eq} + U_{sq}^{n} \quad (22)$$

C. Rotor Flux Controller Design

Tracking error for *state* Φ_{rd} is

$$e_3 = \Phi_{rd}^{ref} - \Phi_{rd}$$

The derivative of $\dot{e}_3$ is

$$\dot{e}_3 = \dot{\Phi}_{rd}^{ref} - \dot{\Phi}_{rd}$$

Switching function S_2 can be derived as follows

$$S_3 = \dot{\Phi}_{rd}^{ref} - \dot{\Phi}_{rd} + \lambda\Phi_{rd}^{ref} - \lambda\Phi_{rd} \quad (23)$$

Because Φ_{rd}^{ref} is constant then $\dot{\Phi}_{rd}^{ref} = 0$ and $\ddot{\Phi}_{rd}^{ref} = 0$ and the equivalent control can be determined as:

$$U_{sd}^{eq} = \sigma L_s \dot{I}_{sd} - \sigma L_s \omega_s I_{sq} - \frac{\sigma L_s K}{T_r}\Phi_{rd} + \frac{\sigma L_s(\frac{1}{T_r} - \lambda)}{T_r}\dot{\Phi}_{rd} \quad (24)$$

From control law at (10), the value of new input control U_{sd} is

$$U_{sd} = \sigma L_s \dot{I}_{sd} - \sigma L_s \omega_s I_{sq} - \frac{\sigma L_s K}{T_r}\Phi_{rd} + \frac{\sigma L_s(\frac{1}{T_r} - \lambda)}{T_r}\dot{\Phi}_{rd} + m_3 sat(S_3)$$

The values m_1, m_2, and m_3 are designed to fulfill sliding condition at (11)

$$S\dot{S} \leq -\eta|S|$$

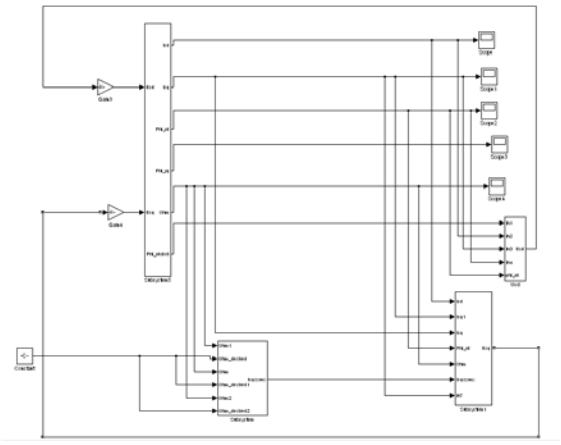

Figure 2. Block diagram of induction motor plant with SMC controller in Simulink Matlab

IV. RESULT

Block diagram of SMC controller together with induction motor plant in Simulink is shown at Fig. 2. Induction motor used has the specification of 0.75 kW, 220 V, 50 Hz. Simulation was conducted using the following parameter values: R_s = 0.63Ω; R_r =0.4Ω; L_s = 0.105H; L_r = 0.094H; M_{sr} = 0.094H; J = 0.0256 Kgm^2; f = 0.001 Nms/rad [1].

Fig. 3 is the response of machine flux before being controlled and without internal disturbance. Flux State has delay time 1.3 s and rising time 2.85 s. Flux stable at 0.15 Wb at 4 s. It is shown that flux response is stable enough with negligible overshoot.

Fig. 4 show the response of induction motor speed before being controlled and without internal disturbance. Speed state has a final value about 3.31 rpm, delay time 1.45 s and rise time 0.78 s. There is an overshoot with peak time 2.3, maximum overshoot 2.31 and settling time 4.36 s.

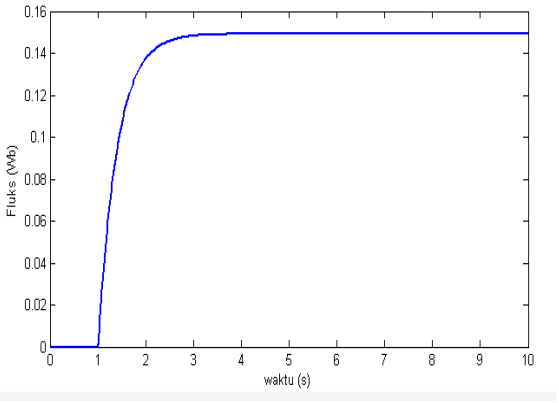

Figure 3. Flux response

When SMC controller installed and it is desired that the flux has a value of 0,9 Wb without any internal disturbance then the resulting simulation of flux response are like at Figure 5.

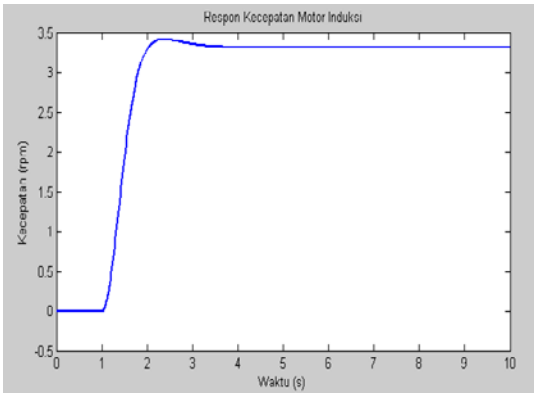

Figure 4. Speed response

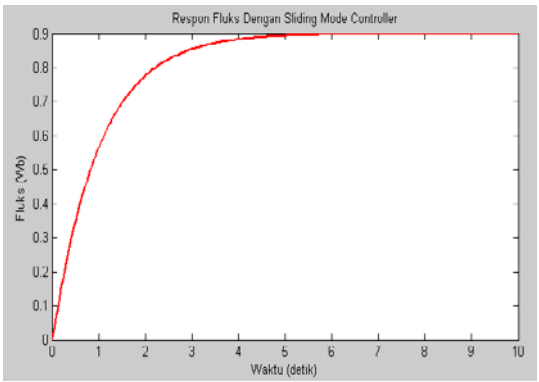

Figure 5. Flux Response with SMC

Fig. 5 shows flux response after being controlled. It is seen that flux state has no overshoot with settling time 5.5 s, rise time 7 s, and delay time 0.7 s which 0.5 s faster compared with before being controlled.

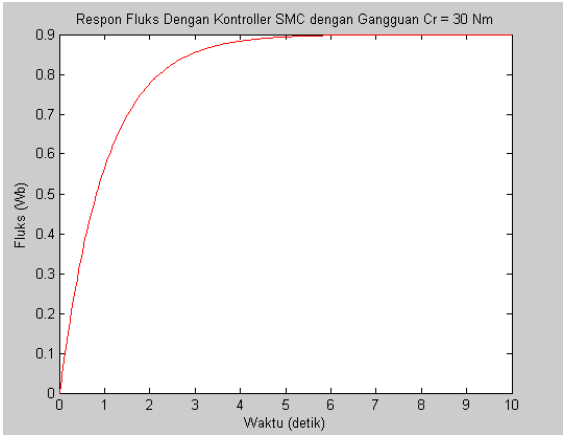

Figure 6. Flux Response with SMC Under Cr=30Nm

Fig. 6 shows the response of flux after being controlled under 30 Nm disturbances. It is shown that the *delay time* now is 0.7 s same with the result before being controlled. The rise time is 7.75 s which is 0.75 s slower compared to the condition before being controlled. The settling time is 7.75 s, 2.25 s slower compared with the result before being controlled. From the transient result, it can be concluded that the disturbance make the system speed response slower.

Another simulation result without internal disturbance with reference speed at 1000 rpm give the results of speed as shown at Fig. 7.

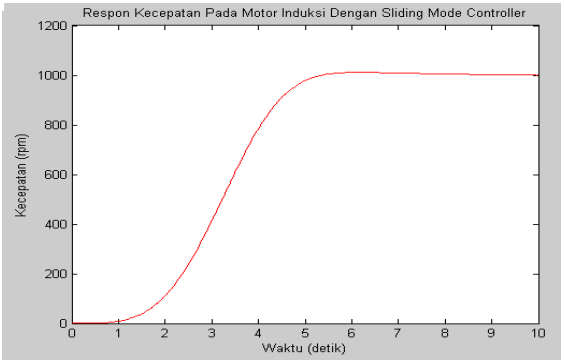

Figure 7. Speed Response on Induction Motor Speed with SMC Without Any Disturbance

The result of controlled speed response at Fig. 7 shows a delay time of 3.24 s, rise time 2.9 s, settling time 6 s, with negligible overshoot.

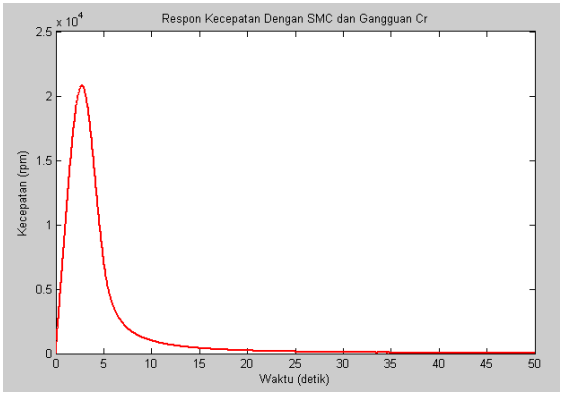

Figure 8. Speed Response With SMC and Disturbance Cr 30 Nm

Fig. 8 shows the speed response of the SMC controlled system under internal disturbances Cr= 30 Nm. It can be seen the disturbance cause significant overshoot. High overshoot caused by high disturbance. In the real application the disturbance value about 3 Nm is quite normal. It also shows the results of peak time 2.75 s, delay time 0.05 s, rising time 10.475 s, and settling time 10 s. It can be concluded that the existence of the disturbance cause slower convergence.

The robustness of the proposed Sliding Mode Control is tested by changing the rotor resistance value to be 0.36 Ω. The simulation result for flux response under this condition is shown at Fig. 9. From the figure, the delay time is 0.7 s, rise time 6 s, settling time 6 s and the system is stable. It can be concluded from the simulation that the uncertainty of the parameter until 10% can be adopted by the controller.

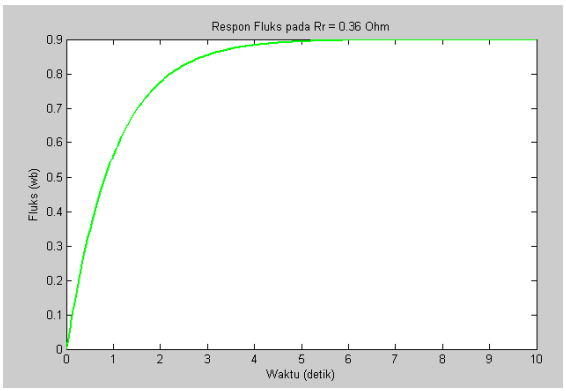

Figure 9. Induction Motor Speed Response with R_r

V. CONCLUDING REMARK

The Proposed SMC Controller can be implemented for controlling the flux and speed of non linear modeled induction motor under parameter uncertainty until 10%.

The use boundary layer inside the SMC was proved to be useful in reducing the chattering phenomena.

Beside the robustness under 10 % parameter changes, the proposed controller speed performance gives faster response until 40 % compared with the condition without controller.

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