Study on Simplified Speed Sensorless Vector Control Systems for Induction Motors

Graduate School of Engineering, Nagasaki University
Glanny Martial Christiaan Mangindaan

Vector control of induction motors(IM) allows high performance control of torque and speed and the method is widely used. In recent years, speed-sensorless vector control is studied and applied to practical uses. Many model reference adaptive system (MRAS) based methods are proposed. Representative speed estimation schemes use flux simulator, full-order observer, reduced-order observer, or sliding-mode full-order observer.

Manipulated design of the observers can improve the stability of the sensorless system even at low speed regenerating operation. However, the configurations of these systems are relatively complicated. It is because the MRAS based methods need state observer and many proportional plus integral (PI) controllers such as d – q currents control, speed control and speed estimation.

On the other hand, some simplified speed sensorless vector control methods are proposed. Simplifying the system configuration by removing the current regulators is proposed, and the stability is improved by adding a flux-stabilizing controller using derivative of magnetic current. However, the stability of regenerating mode is not discussed.

In this thesis, new simplified speed-sensorless vector control methods of IM based on rotor flux linkage are proposed. A flux vector is obtained from voltage model, in which the derivative term is neglected. A flux angle of a current model must be aligned with the flux angle of voltage model. Since the output voltage of d–axis PI current controller is used for the flux angle estimation and speed control (q–axis voltage control), the system is simplified and stabilized at regenerating mode. In conventional simplified methods, this scheme is not reported. A linear model of the proposed system in the state space equation is obtained to study the system stability by showing root loci. By virtue of the stability analysis, we can design the parameters of controller. The nonlinear simulation and experiment results of the proposed system show stable transient responses in both motoring and regenerating modes.

This thesis is divided into five chapters with the arrangement:

In chapter 1, the background and the purpose of this research are explained and the contents of chapters are specified.

Chapter 2 describes a space vector representation of induction motor. A three-phase

mathematical model of induction motor is transformed to a $d - q$ model by using two-axis theory. This chapter introduces a non-linear model and a linear model of induction motor. The linear model of induction motor is derived by considering small perturbations of state variables at a steady state operating point.

In chapter 3, new simplified speed-sensorless vector control methods of IM based on rotor flux linkage are proposed . The two simplified sensorless systems are called as system A and system B. The main difference is the presence (in system A) or the absence (in system B) of q – axis PI current controller and PI speed controller. In system A, the angular frequency of rotor flux is estimated to bring q–axis flux to zero by using PI controller. The q – axis flux is obtained by the output of d – axis PI current controller with a non-interference control. The rotor speed is computed by subtracting a slip speed from the angular frequency. Flux angle is obtained by integrating the angular frequency. When q–axis flux is less than zero and rotor flux is lagging than d – axis, the controller must decrease the value of flux frequency. In system B, the computation of q–axis flux is as same as the system A. The angular frequency of rotor flux is computed by subtracting the value which is proportional to the q – axis flux from the speed command. The q – axis flux is also used to control the rotor speed, by adjusting the q – axis voltage. Non-linear models are derived in both proposed systems A and B. From these non-linear models, linear models of the systems are derived in state space equations. The selection of PI current and speed controllers gains are outlined.

Chapter 4 demonstrates systems stability by showing the root loci obtained by the linear models, the transient responses of simulation results and the stable regions. The performance of both systems A and B are compared by using linear models and non-linear models. Transient responses of linear models and non-linear models are computed and compared. Since both responses are almost same around a steady state operating point, the validity of the linear models are confirmed. By using the proposed methods, not only the motoring operation but also the low speed regenerating operation can be stabilized. Quick torque and speed responses of nonlinear models are obtained in both systems A and B. A digital signal processor based pulse-width modulation (PWM) inverter fed IM system is equipped and tested. It is confirmed that the experimental results are very close to those of simulation. Therefore, the effectiveness of the proposed methods are also demonstrated experimentally. It is considered that the system B is superior to the system A because its simple structure.

Chapter 5 is the main conclusions presented in this thesis.