Design of Nonlinear PI Controller for Velocity Control of Induction Motor

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Abstract: - This paper presents a robust speed control method of induction motors(IM) using a non-linear PI controller(NPI), NPI is high gain controller in region of small error, and low gain controller in region of large error. So in steady state, system will be robust against variation of load torque. The simulation and experiment results show the validity of proposed control scheme.

Key-Words: - Velocity Control, Nonlinear PI Control, Induction Motor, Vector Control

1 Introduction

The PI (Proportional-Integral) controller is ordinarily used to the speed controller for the induction motor, because its structure is simple and it is easy to implement. However, the necessity of high-performance speed controllers is gradually increasing as the applicable range of induction motors is being widened. The high-performance controller means the controller having rapid torque response speed and high accuracy. To make out such controllers, the vector control that can instantly control torque should be used in the current controller as well as precise speed, the compensation of load disturbance and the parameter of motors and machinery should be secured in the speed controller [1-3]. An outstanding speed controller can be designed on the basis of accurate formulas, but it is impossible to calculate accurate parameter related with the load and also many errors occur as it is different from uses [4-6]. In the present study, a nonlinear PI controller was presented instead of the existing PI controller, and a full-order observer was used in order that it can bear up against load variation. The cases where the speed-state observer is used together with the presented nonlinear PI controller were checked through simulations and experiments, and the results were shown.

2 Designing the Existing PI Speed Con troller

In setting the parameter of PI speed controller, the current controller is regarded as a first order delay filter and the open loop transfer function is worked out. ‘Formula 1’ shows the result.

$$G_{sc}(s) = (K_{sp} + \frac{K_{si}}{s}) \cdot \frac{\omega_{cc}}{s+\omega_{cc}} \cdot \frac{K}{Js} \qquad (1)$$

‘*Wcc*’ designates the bandwidth of a current controller. *Ksp* and *Ksi* designate the proportional gain and the integral gain of a speed controller. On the premise that the bandwidth of a current controller (*Wcc*) is remarkably wider than the bandwidth of a speed controller (*Wsc*), the transfer function of a current controller can be ‘1.’ ‘Formula 2’ shows the cut-off frequency of a PI controller (*Wpi*).

$$\omega_{pi} = \frac{K_{si}}{K_{sp}} \qquad (2)$$

In case *Wpi* is less than one-fifth of *Wsc*, the speed controller can be expressed to ‘Formula 3’ around *Wsc*.

$$G_{sc}(s) = (K_{sp}) \cdot \frac{K}{Js} \qquad (3)$$

In case a formula $\| G_{sc}(j\omega) \| = 1$ is set in ‘Formula 3’, the bandwidth of a speed controller becomes *Wsc*.

$$K_{sp} = \frac{J\omega_{sc}}{K},\ K_{si} = K_{sp} \cdot \omega_{pi} = K_{sp} \cdot \frac{\omega_{sc}}{5} \qquad (4)$$

‘Formula 4’ shows the gain of a speed controller. Through ‘Formula 4’, it is known that the gain of a PI controller is determined by inertia moment(J), torque constant(K) and controller bandwidth(Wsc). In case load disturbance occurs, the bandwidth should be maximized as much as possible so that a controller strong in disturbance can be designed.

3 Nonlinear PI Speed Controller

The purpose of a controller is to minimize errors with time. The following formula compares the steady-state errors of a linear controller and a nonlinear controller. 'Formula 5' expresses the system of which disturbance is W_0.

$$\dot{e} = w_0 + u \tag{5}$$

Ordinary linear controllers are inputted by 'Formula 6', and nonlinear controller is inputted by 'Formula 7'.

$$u = -K \cdot e \tag{6}$$

$$u = -K \cdot |e|^{\alpha} \cdot sign(e) \tag{7}$$

The input of nonlinear controllers is different from the value of 'α.' In case the value of α is 1/2, the steady-state error becomes 0.01; in case the value is 1/3, the error becomes 0.001. In a word, the steady-state error gets smaller as the value of α approaches 0. This is because the error is in inverse proportion to the gain.

The nonlinear PI controller changes gain nonlinearly as to error. In this study, the purpose of nonlinear PI controller is to improve the degradation caused by load variation in case the load of system is changed under steady state. To realize the control stronger than the existing PI controller, the bandwidth should be maximally widened or the load variation should be accurately calculated. The bandwidth should be relatively widened in the part of which error is low but it should be narrowed in the part of which error is high so that the bandwidth can be widened under steady state; in that case, the control gain is heightened and disturbances can be remarkably controlled.

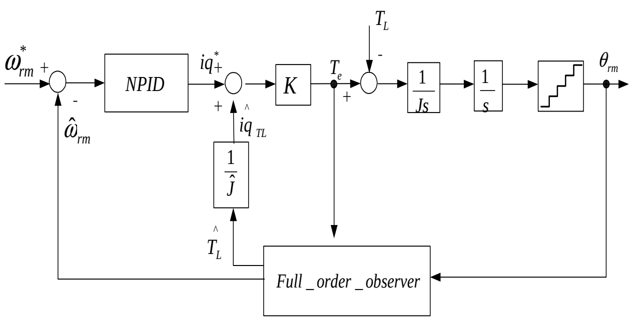

Fig.1 proposed control scheme

'Fig.2' shows what the bandwidth changes as to error in a nonlinear PI controller. It is being in inverse proportion to errors. 'Fig.1' shows the block diagram of system based on a nonlinear PI controller.

$$\frac{\omega_{rm}}{\omega^*_{rm}} = \frac{K(\alpha K_{sp} s + K_{si})}{Js^2 + KK_{sp} s + KK_{si}} \tag{8}$$

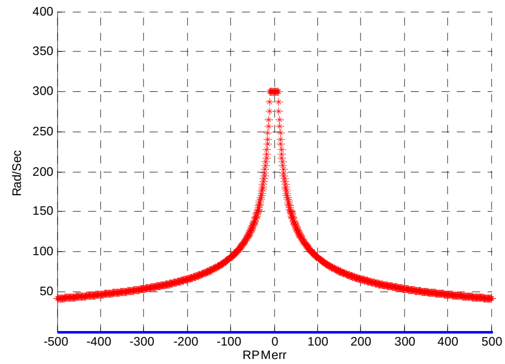

Fig.2 bandwidth change as to error in NPI

'Formula 8' shows the relational expression between command and response speed in a 2-degree-of-freedom PI controller, and 'Formula 9' shows the relational expression between disturbance torque and response speed.

$$\frac{\omega_{rm}}{T_L} = \frac{s}{Js^2 + KK_{sp} s + KK_{si}} = \frac{s}{(s+\omega_c)^2} \tag{9}$$

'Formula 9' means that the controller gets stronger in disturbance when the gain of controller is heightened or the bandwidth is widened. Consequently, the bandwidth was widened at steady state so that the controller can be stronger in disturbance torques. If the bandwidth is remarkably widened, it is necessary to limit the bandwidth because the system gets unstable.

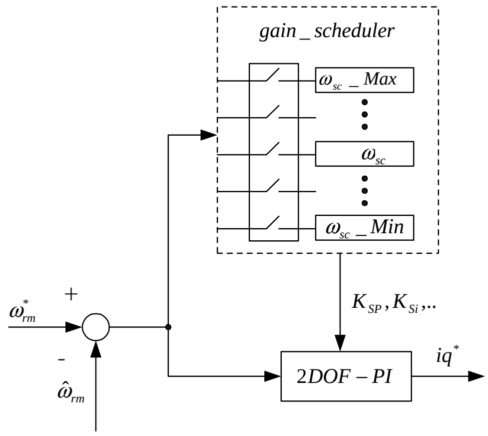

Fig.3 the structure of a NPI

'Fig.3' shows the structure of a nonlinear PI controller presented in this study. Its bandwidth is determined as to speed error in the gain scheduler and the proportional-integral gain is changed as to the determined bandwidth in order that the gain can be modified as to error.

This study proved that this method makes the controller get stronger in load under steady state as well as speed control get stable, through simulations and experiments.

4 Experiment System Configuration

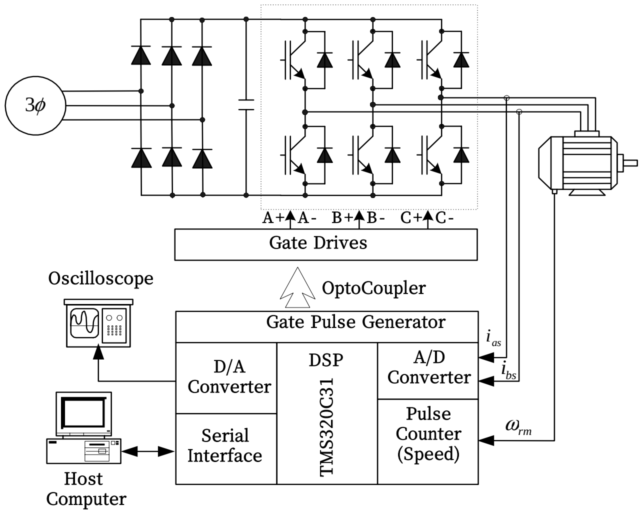

Fig.4 configuration of experiment system

Current control, speed control, magnetic flux estimation and load torque estimation were configured to the software by using Taxas Instrument's DSP, TMS3230C31 (50MHz). The electric current was measured by using Hall sensor and was inputted by a 12Bit A/D converter on the basis of Hall sensor. Likewise, the speed was measured by using an optical encoder (1024 Pulses/Revolution) on the basis of M/T method. A 4-channel D/A converter was used for debugging through an oscilloscope. The power-converting unit was largely configured by PWM IGBT inverter, a 400W induction motor and a 400W DC motor as a load device.

5 Results of Simulation and Experiment

The simulation was carried out by using matlab simulink. 'Fig.5' and 'Fig.6' show the existing 2-degree-of-freedom PI controller and the waveforms of the nonlinear PI controller presented in this study, respectively. The waveform designates speed command, real measurement and command torque. The speed command showed a ramp as it indicated from 0rpm to 1500rpm between 0 and 200ms. Also, it is the waveform in case the load disturbance of $1\,N\cdot m$ is authorized between 1 and 1.4 second.

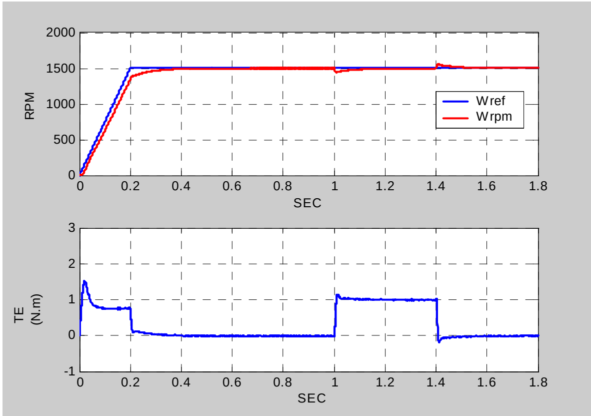

Fig.5 characteristics of existing PI controller(simulink)

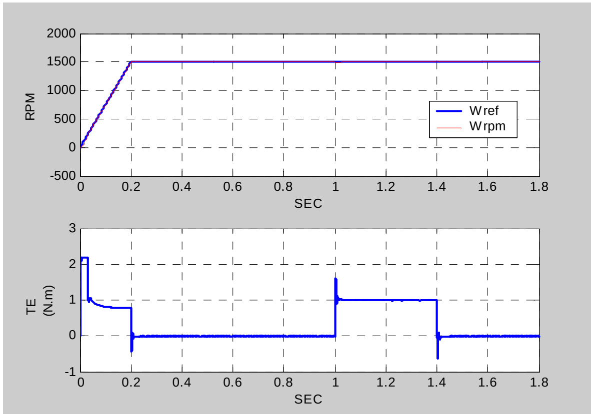

Fig.5 characteristics of proposed NPI controller(simulink)

As compared with the existing PI controller, disturbance torque and command characteristics were remarkably improved.

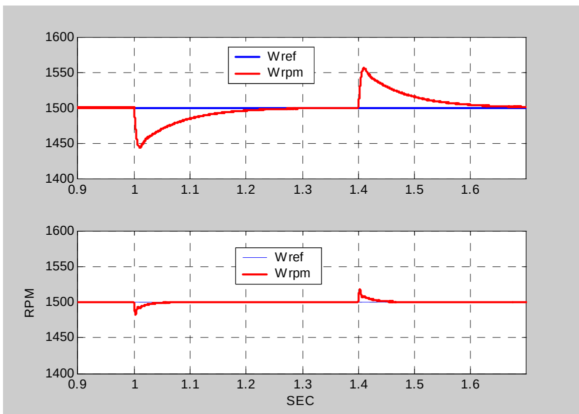

Fig.7 comparison of disturbance characteristics (simulink)

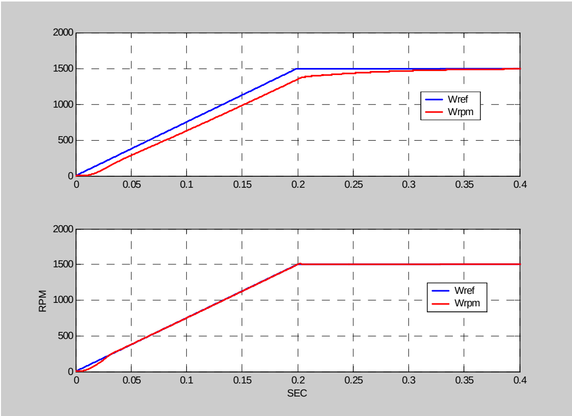

Fig.8 comparison of command characteristics (simulink)

'Fig.7' and 'Fig.8' compare disturbance characteristics with command characteristics respectively. In the two figures, the below waveform shows the result of the presented method; two characteristics were all improved.

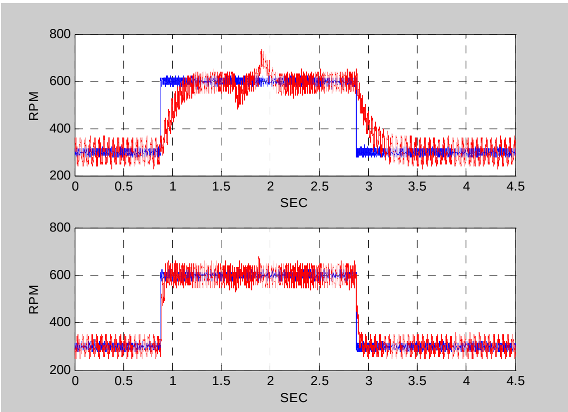

Fig. 9 comparison of experiment result

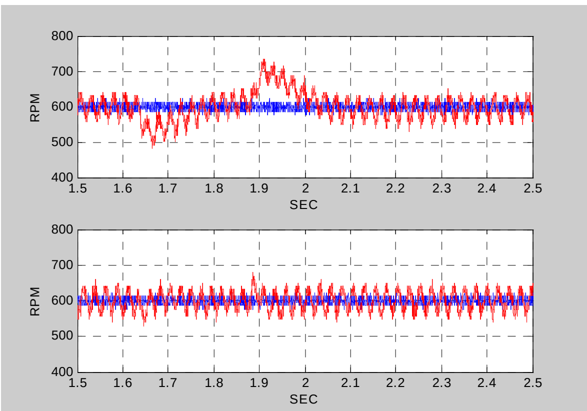

Fig. 10 comparison of experiment result(enlarge)

'Fig.9' and 'Fig.10' show the results of experiment. It showed the same results with the above-mentioned results in matlab simulink. In respect of 2-degree-of-freedom PI controller, the ripple between +100rpm and -100rpm occurred; the recovery time was about 150ms and significant error occurred at the variable-speed section. On the other hand, in the method presented in this study, the ripple was between +50 and -50rpm and the recovery time was about 50ms and also the error in the variable-speed section was remarkably low. On this wise, the superiority of the present method was improved in this study.

6 Conclusion

In the present study, nonlinear PI controllers were researched on purpose to improve the performance of 2-degree-of-freedom PI controllers. Likewise, the performance of the nonlinear PI controller, presented in this study, was proved through simulations and experiments. The instantaneous speed could be estimated by using a full-order observer as well as disturbances could be actively cut off by estimating load torques. Moreover, high gains could be taken under steady state by this nonlinear PI controller and also the influences of disturbances could be remarkably cut off and speed-follow characteristics could be improved.

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