JPE 2-2-7

Anti-windup Integral-Proportional Controller for Variable-Speed Motor Drives

Jong-Gyu Park, Jae-Ho Chung, and Hwi-Beom Shin*

Dept. of Electrical Engineering, Gyeongsang National University, Korea

ABSTRACT

The windup phenomenon appears and degrades control performance when a controller with integrating action is used and the plant input is limited. An anti-windup integral-proportional (IP) controller is proposed for the variable-speed motor drives and it is experimentally applied to the speed control of a vector-controlled induction motor driven by a pulse width modulated (PWM) voltage source inverter (VSI). The consistency range of the IP controller is firstly derived and the integral state is controlled to satisfy always the consistency range according to whether the controller output is saturated or not. Although the operating condition like motor load or speed command is changed under the limited plant input, it is experimentally verified that the speed response has much improved performance, such as no overshoot and fast settling time, and the maximum plant input is also effectively utilized.

Key Words: Anti-windup integral-proportional control, motor drives

1. Introduction

Most variable-speed motor drives usually employ the current control scheme for fast dynamics and current limitation. The current command generated by the speed controller is practically limited to a prescribed maximum value due to the converter protection, the magnetic saturation, and the motor overheating[1]. Therefore, the speed controller has its output limit like saturation-type nonlinearity.

Since the speed controller is typically designed without considering the controller output limit, the closed-loop control performance will be significantly deteriorated with respect to the expected performance. When a controller with integrating action is used, the windup phenomenon occurs, which causes large overshoot, slow settling time, and, sometimes, even instability in the speed response[2-3].

To overcome the windup phenomenon, a number of the anti-windup techniques for the proportional-integral (PI) controller have been proposed in the literature[2]-[8]. An anti-windup controller based on the conditioning technique is proposed in the presence of the nonlinearity by Hanus et al[6]. and its usefulness is compared with other anti-windup controllers through a computer simulation[2]. While the plant input is different from the PI controller output, a realizable reference, instead of the reference input, is applied to the controller in order to restore the consistency of the integral state. The realizable reference is derived from both the reference input and the difference between the controller output and the plant input. Because the conditioning technique can undergo performance degradation in the presence of both upper and lower restrictive saturation levels, Walgama and et al. have modified this technique by introducing a designer-chosen parameter[7].

Manuscript received March 13, 2002; revised April 29, 2002.

Corresponding Author: hbshin@nongae.gsnu.ac.kr, Tel: +82-55-751-5348, Fax: +82-55-759-2723

The PI controller has been widely used for the variable-speed motor drives by virtue of some desirable features, such as zero steady state error and easy implementation. If the high PI gains are used for fast dynamics, an undesirable high overshoot can, however, occur in the speed response and the settling time becomes very slow by contraries. Since a very high gain cannot be used to obtain fast dynamics, the response to a step command or load disturbance becomes very slow when the system is designed without any overshoot. On the other hand, it has been demonstrated in [9][10] that the integral-proportional (IP) controller can give fast response with minimal or no overshoot and retains the desirable features of the PI controller. The IP controller has been recently applied to the variable-speed motor drives[11]-[13]. In the IP control scheme, integral action is more dominant than proportional action during transient period but it is dominant at steady state in the PI control scheme. Therefore, the windup phenomenon is more serious in the IP controller than in the PI controller if the plant input is limited.

Unfortunately, the anti-windup technique for the IP controller has not been developed yet. To overcome the windup phenomenon, an anti-windup IP (AIP) controller is proposed in this paper. The asymptotic stability condition of the maximum plant input and the consistency range of the IP controller are firstly derived and the integral state is controlled to satisfy always the consistency range according to whether the controller output is saturated or not. With the proposed control scheme, it is expected that the control performance, such as no overshoot and fast settling time, can be much improved while the maximum plant input is effectively utilized. The proposed AIP controller is applied to the speed control of a vector-controlled induction motor driven by a PWM-VSI and its usefulness is verified experimentally.

2. Consistency range of IP speed controller

It is usually designed that dynamics of the current controller is much faster than that of the speed controller. If a fast current control scheme is employed, the current dynamics can be neglected and the variable-speed motor drive can be considered as a first-order system given by:

$$\dot{\omega}_r = -\frac{1}{\tau_m}\omega_r + k_t\upsilon - T_l \tag{1}$$

where, $k_t = k_T / J$, $T_l = T_L / J$ and υ denotes the plant input, namely, the torque-producing current command. It is assumed that the plant input υ is limited by saturation-type nonlinearity as:

$$\upsilon = \begin{cases} u & \text{if } |u| \le U_m \\ U_m \cdot sgn(u) & \text{if } |u| > U_m \end{cases} \tag{2}$$

where, $sgn(\cdot)$ denotes a sign function and u represents the speed controller output. In the following, it will be called as a linear region and a saturation region when $u = \upsilon$ and $u \neq \upsilon$, respectively.

2.1 Maximum plant input for asymptotic stability

Fig. 1 shows block diagram of IP controller. The output of IP speed controller without anti-windup, u, can be expressed as:

$$u = -k_p\omega_r + k_i q \tag{3}$$

When the plant input has no prescribed limit in (2), the integral state q is given by:

$$\dot{q} = e \tag{4}$$

where, $e = \omega_r^* - \omega_r$. For a step speed command ω_r^*, the error equation in the linear region can be expressed, from (1), (3), and (4), as:

$$\dot{e} = -\left(\frac{1}{\tau_m} + k_p k_t\right)e - k_t k_i q + \left(\frac{1}{\tau_m} + k_p k_t\right)\omega_r^* + T_l \tag{5}$$

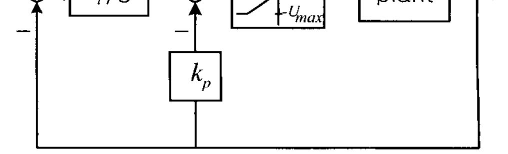


Fig. 1. Block diagram of IP controller.

To obtain the asymptotic stability condition, consider the Lyapunov function such as:

$$V(e,q)=\frac{1}{2}\frac{1}{k_t}e^2+\frac{1}{2}k_i(q-q_{ss})^2 \tag{6}$$

where, k_i is a positive gain and q_{ss} denotes a steady state value of the integral state q. Then, the time derivative of the Lyapunov function can be written, from (4) and (5), as:

$$\begin{aligned}\dot{V}(e,q)=&-\frac{1}{k_t}\left(\frac{1}{\tau_m}+k_tk_p\right)e^2+\\&e\frac{1}{k_t}\left\{\left(\frac{1}{\tau_m}+k_tk_p\right)\omega_r^*+T_l-k_tk_iq_{ss}\right\}.\end{aligned} \tag{7}$$

For some stable values of k_p and k_i, the integral state will have a suitable value q_{ss} given by:

$$q_{ss}=\frac{1}{k_tk_i}\left\{\left(1/\tau_m+k_tk_p\right)\omega_r^*+T_l\right\} \tag{8}$$

The asymptotic stability condition such that $\dot{V}(e,q)\le 0$ will be satisfied for the unlimited plant input[8]. However, the integral state should satisfy the following condition in steady state so that the IP controller with the limited plant input may operate in the linear range:

$$\frac{1}{k_i}\left(-U_m+k_p\omega_r^*\right)\le q_{ss}\le\frac{1}{k_i}\left(U_m+k_p\omega_r^*\right) \tag{9}$$

Therefore, Substituting (8) into (9) yields the maximum plant input for assuring asymptotic stability, in worst case, as:

$$U_m\ge\frac{1}{k_t}\left(\frac{1}{\tau_m}|\omega_r^*|+|T_l|\right) \tag{10}$$

and it can be rewritten as:

$$U_m\ge\frac{1}{k_T}\left(B|\omega_r^*|+|T_L|\right) \tag{11}$$

Therefore, the error dynamics becomes asymptotically stable if the operating condition satisfies the inequality in (11). It is noted that the maximum plant input is not dependent upon the IP controller gains.

2.2 Consistency range of IP controller

The IP controller output may be saturated if the speed command is given a large step change or high gains are used. When this happens, the controller output is different from the plant input, namely the IP controller operates in the saturation region. The integral state is not consistent with the plant input and becomes very large, which causes the windup phenomenon. Therefore, in order to overcome the windup phenomenon, the integral state should be properly controlled for assuring consistency between the plant input and the integral state and it is important to know the consistency range. In this paper, the consistency range is defined as the possible range of the integral state, corresponding to the plant output error, so that the IP controller may always operate in the linear region.

The IP controller output in (3) can be rewritten as:

$$u=k_pe+k_iq-k_p\omega_r^* \tag{12}$$

If the plant input limit in (2) is considered, a consistency range can be found from (12) as shown in Fig. 2 where the upper and lower boundaries of the consistency range are expressed as:

$$B_U:\ q=-\frac{k_p}{k_i}e+\frac{1}{k_i}\left(U_m+k_p\omega_r^*\right) \tag{13}$$

$$B_L:\ q=-\frac{k_p}{k_i}e+\frac{1}{k_i}\left(-U_m+k_p\omega_r^*\right) \tag{14}$$

The IP controller operates in the saturation region when the integral state has a value outside of the consistency range but it operates in the linear region when the integral state takes a value in the consistency range. The width and

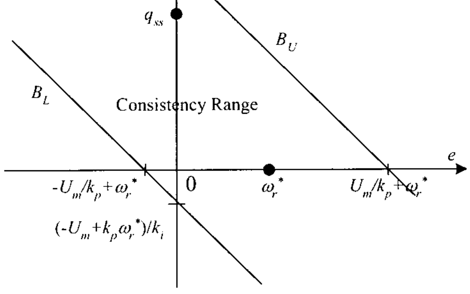


Fig. 2. Consistency range of IP speed controller in phase plane

height of the consistency range along the error axis and the integral state axis are given as, respectively,

$$W_e = 2U_m / k_p \tag{15}$$

$$H_q = 2U_m / k_i \tag{16}$$

It is noted that the consistency range has the following characteristics: 1) as the maximum plant input U_m increases, the area of the consistency range becomes wider; 2) as the proportional gain k_p increases, the consistency range becomes narrower with the center of the speed command ω_r^* along the error axis; 3) as the integral gain k_i increases, the consistency range becomes narrower along the integral state axis; 4) therefore, the high IP gains are likely to make the controller operate outside of the consistency range. If the IP controller operates in the consistency range, the integral state has a proper value and the plant error will follow the trajectory designed with the IP controller. Otherwise, the integral state becomes very large and the plant error may behave regardless of the IP controller.

3. Anti-windup IP speed controller

3.1 Phase plane plot of IP speed controller with and without input limitation

The transfer function of the IP speed control system composed of (1) and (3) is expressed as a prototype second-order system such that[14]

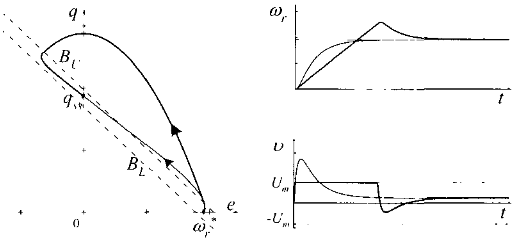
$$\frac{\Omega_r(s)}{\Omega_r^*(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \tag{17}$$

where, the natural frequency ω_n and the damping ratio ζ can be written as:

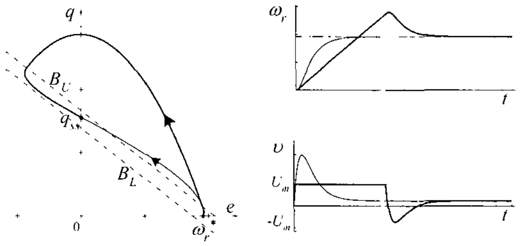
$$\omega_n = \sqrt{k_t k_i}\,, \quad \zeta = \left(1/\tau_m + k_t k_p\right) / 2\omega_n \tag{18}$$

Since there is no zero in the transfer function of the IP control system, the speed will respond to a step command with the designed specifications such as overshoot and settling time if the plant input has no limit. However, the PI control system introduces a zero in the transfer function and a higher overshoot may occurs for a step change in the speed command[9-10]. Because this is an undesirable effect of PI controller, derivative action is usually added and there are some methods for determining the controller gains like Ziegler-Nichols method[3]. In case of the IP control system, the natural frequency depends on the integral gain only and the damping ratio is directly related to the proportional gain. Therefore, if the desired natural frequency and damping ratio are given, the IP gains can be easily calculated from (18).

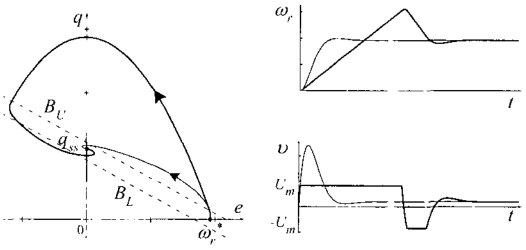
Fig. 3 shows the phase plane plots and time responses of the IP control system with and without plant input limitation according to various damping ratios under a constant natural frequency.



(a) overdamped ($\zeta = 1.2$)



(b) critically damped ($\zeta = 1$)



(c) underdamped ($\zeta = 0.707$)

Fig. 3. Phase plane plots and time responses of IP speed controller with and without limitation (solid line: without limit, bold line: with limit).

When the controller output is not limited, the system response behaves with the designed specifications as shown in time responses of Fig. 3. As the damping ratio is smaller, the integral state is more largely deviated from the consistency range and the larger plant input is required. Therefore, the controller output is more apt to exceed a prescribed limit. When the controller output is limited, the response has large overshoot as shown in Fig. 3 (a) even though the designed control system is overdamped. If the control system is underdamped, the integral state is very largely deviated from the consistency range, which causes very high overshoot and even undershoot as shown in Fig. 3 (c). In some case, the control system may be instable. When the plant input has a prescribed limit, the conventional IP control system cannot use high gains for fast response and the maximum plant input cannot be effectively utilized. Therefore, it is practically important to develop the anti-windup IP controller for the control systems with the limited plant input.

3.2 Proposed anti-windup IP speed controller

In order to overcome the windup phenomenon, the trajectory of the integral state should be kept inside the consistency range. Therefore, the integral state is separately controlled, according to whether the IP controller output is limited or not. If the controller output is saturated, the integral state is set to a boundary value of the consistency range corresponding to a plant error. Otherwise, the conventional IP control is activated while the integral state accumulates the plant error. An AIP controller is proposed as:

$$u = -k_p \omega_r + k_i q \tag{19}$$

where, the integral state q is given by:

$$\begin{cases} \dot{q} = e & \text{if } u = \upsilon \\ q = \dfrac{1}{k_i}\left(\upsilon + k_p \omega_r\right) & \text{if } u \neq \upsilon \end{cases} \tag{20}$$

If the plant input satisfies the condition in (11) and the desired specification is given, the proposed AIP controller can be easily designed by using (18) without considering the plant input limitation. The speed response will also have no overshoot because the integral state in (20) always operates in the consistency range and the response with fast settling time can be obtained corresponding to the designed natural frequency because the maximum plant input will be effectively utilized. Furthermore, the AIP controller can be designed with high gain, so that the speed response will be robust against the load torque disturbance.

4. Experimental results

The proposed anti-windup IP control scheme is applied to the speed control of an induction motor driven by a PWM-VSI and it is compared with the conventional IP controller without anti-windup. The parameters of a 1-hp induction motor are listed in Table 1 and the motor load is a powder brake with a controller. Fig. 4 shows the block diagram of an experimental system. In the vector control method[15-16], the induction motor is controlled like a separately excited dc motor. The control algorithm is fully implemented in software with a TMS320C31 DSP board. The three-phase currents are controlled to settle within 1.5 ms by using a synchronous PI regulator[17] and the rotor flux is controlled to settle within 0.04 s. The PWM frequency is 10 kHz and the sampling times of current and speed control loops are 0.1 and 1 ms, respectively. The shaft encoder has 1,000 pulses per revolution.

Table 1. Parameters of induction motor.

1[hp], 220[V], 4[pole], 60[Hz], 1730[rpm]		
$R_s = 1.985[\Omega]$	$R_r = 1.730[\Omega]$	$X_m = 38.43[\Omega]$
$X_s = 40.38[\Omega]$	$X_r = 41.35[\Omega]$	$V_{dc} = 310[V]$
$J = 7.1 \times 10^{-3}[kgm^2]$	$B = 5.04 \times 10^{-3}[kgm^2 / s]$	

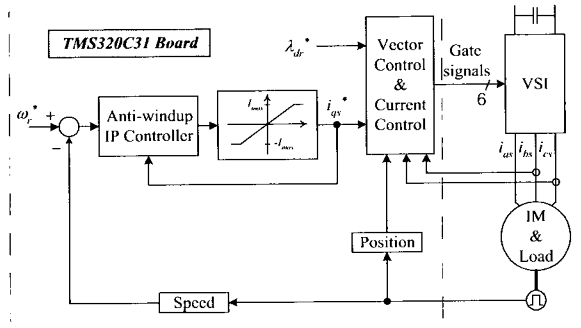


Fig. 4. Block diagram of vector-controlled induction motor drive using anti-windup IP speed control.

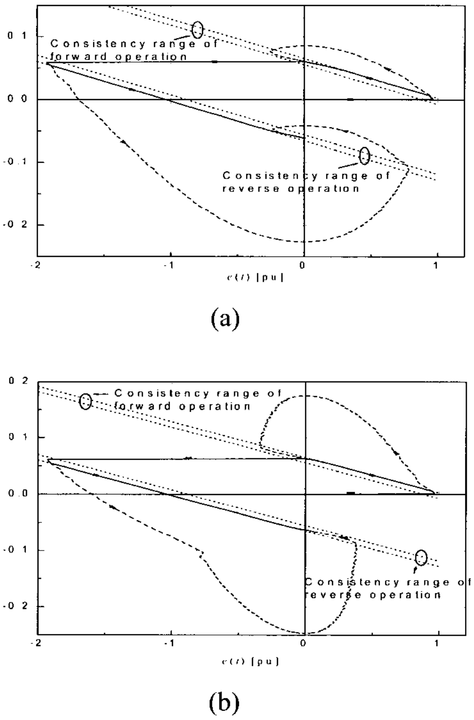


Fig. 5. Phase plane plot of IP and AIP speed controllers when $\zeta=1$, $\omega_n=10\pi$ rad/s: (a) no load (b) full load (dash: IP, solid line: AIP).

Fig. 5 shows the phase plane plots of the IP and AIP speed controller at no load and full load conditions. The speed command is initially zero and 0.96 pu at $t = 0.04$ s and –0.96 pu at $t = 2.04$ s. The consistency range given in (13) and (14) is different according to the speed command. It can be seen that the integral state of the IP controller is largely deviated from the consistency range, which causes large overshoot and slow settling time. However, the integral state of the AIP controller is always kept in the consistency range and the speed response with no overshoot and fast settling time can be obtained.

Fig. 6 shows the experimental results for the IP and AIP speed controllers at no load condition when $\omega_r^* = 0.96$ pu (1730 r/min) at $t = 0.04$ s and $\omega_r^* = -0.96$ pu at $t = 2.04$ s. The IP gains are chosen from (18) to satisfy the specifications such as $\zeta=1$ and $\omega_n=10\pi$ rad/s. The torque-producing current command in Fig. 4 is limited to $I_{max} = 2.5$ pu. Under this condition, the current command from the speed controller is saturated to a prescribed value as shown in Fig. 6 (c) when the motor is started up and the direction is changed. During these transient periods, the integral state of the IP controller is not consistent with the plant input, so that the integral state becomes large regardless to the IP controller output as shown in Fig. 6 (b). The superfluous integral state causes a large overshoot in the speed response and it prolongs the duration of the saturation region, which results in very slow settling time in the speed response as shown in Fig. 6 (a). This phenomenon becomes more serious when the motor direction is changed. On the other hand, because the integral state of the proposed AIP controller governed by (20) always operates in the consistent range as shown in Fig. 5 (a), the speed response has no overshoot corresponding to the designed damping ratio ($\zeta = 1$).

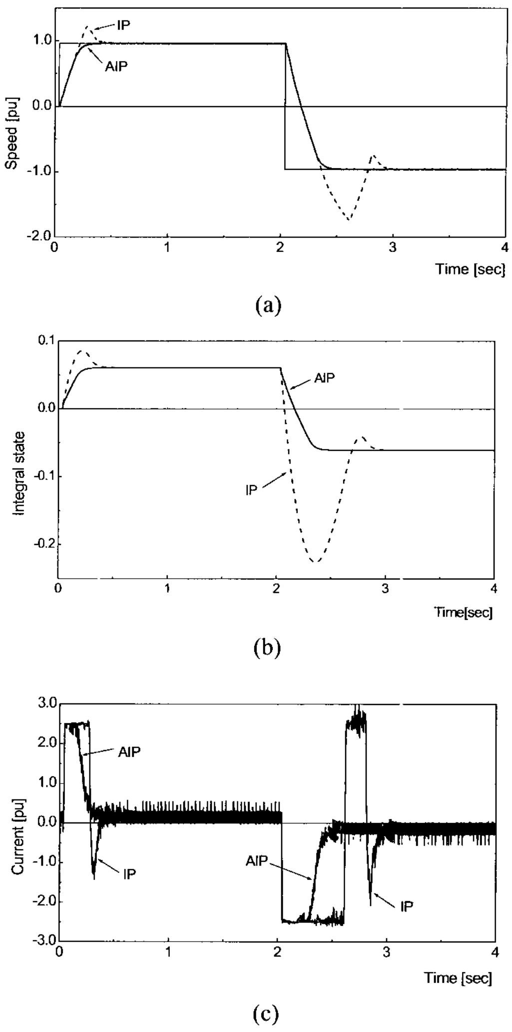


Fig. 6. Experimental responses of IP and AIP speed controllers at no load condition when $\zeta=1$, $\omega_n=10\pi$ rad/s.

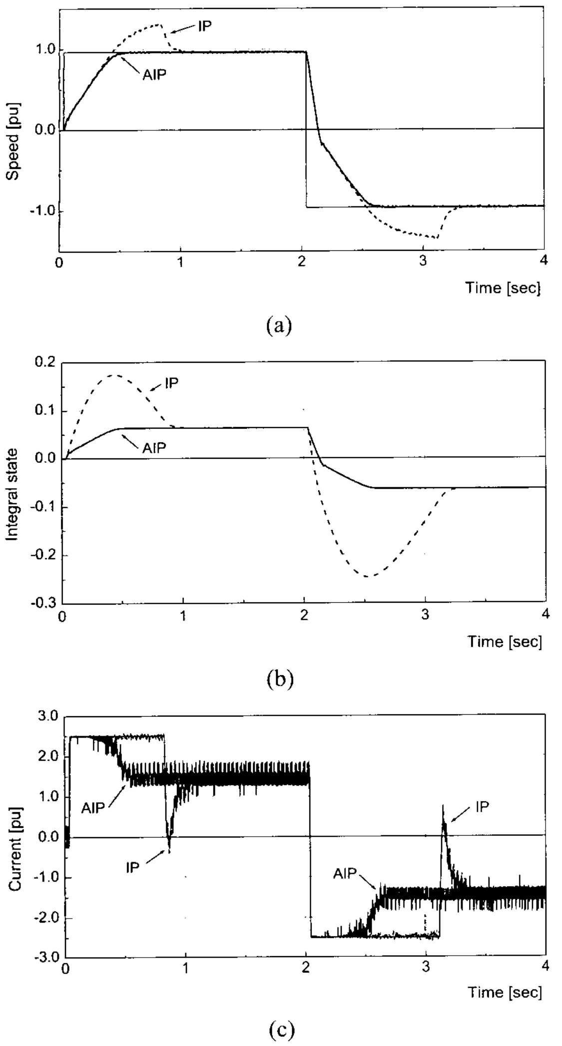


Fig. 7. Experimental responses of IP and AIP speed controllers at full load condition when $\zeta = 1$, $\omega_n = 10\pi$ rad/s.

Although the duration of the maximum input is shorter than that in the IP controller, the response has faster settling time. Therefore, as shown in Fig. 6, it can be seen that the proposed AIP control scheme has the much improved control performance at no-load condition.

Fig. 7 shows the experimental results for the IP and AIP speed controllers at full load condition. Since the motor load is a powder brake, the slope of the speed response in forward direction is different from that in reverse direction when the speed command is changed from 0.96 pu to – 0.96 pu. In case of the IP controller, the integral state becomes larger as shown Fig. 7 (b) and the speed response has large overshoot and slow settling time as shown in Fig. 7 (a).

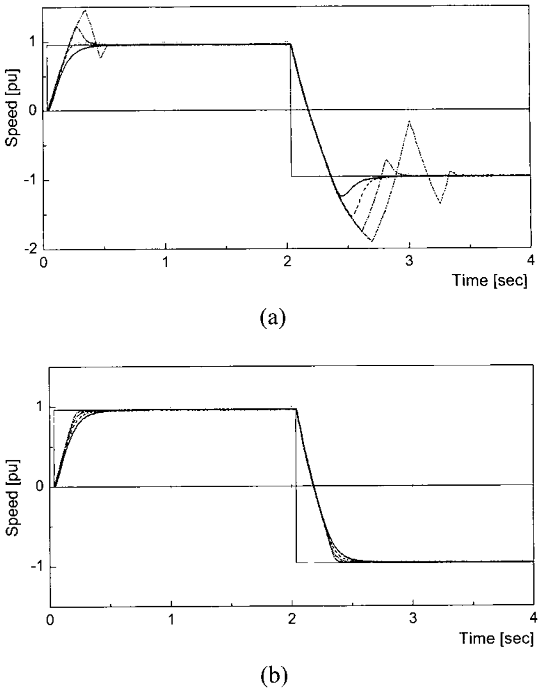


Fig. 8. Speed responses according to different gains at no load: (a) IP control (b) AIP control (solid: $\omega_n = 5\pi$, dash: $\omega_n = 6.8\pi$, dash dot: $\omega_n = 10\pi$, dash dot dot line: $\omega_n = 20\pi$ rad/s).

The percent overshoots at both no load and full load conditions are different. The proposed AIP controller has no overshoot regardless to load condition as shown in Fig. 6 (a) and 7 (b), and has fast settling time.

Fig. 8 and 9 show the experimental comparisons of the speed responses according to various natural frequencies at no load and full load conditions, respectively, while the damping ratio is unity. In the IP control scheme, as the IP gains increase for fast response, the overshoot becomes higher as shown in Fig. 8 (a) and 9 (a), and the unexpected undershoot occurs largely at light load as shown in Fig. 8(a). Therefore, the control performance, such as percent overshoot and settling time, is largely deteriorated from the designed one. On the other hand, the proposed AIP control scheme shows the desirable speed responses as shown in Fig. 8 (b) and 9 (b). As the IP gains increase, the speed response becomes faster without overshoot even though the controller output is limited.

As a result, the IP controller does not operate corresponding to the chosen gains in the saturation region and the control performance may be much degraded due to

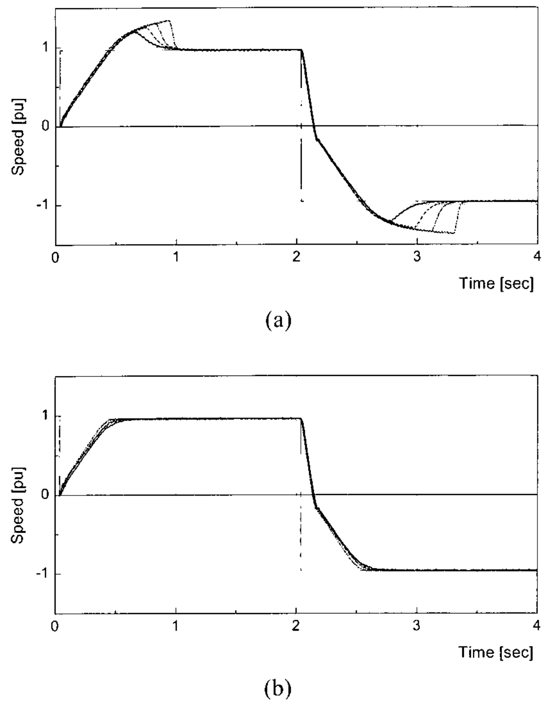


Fig. 9. Speed responses according to different gains at full load: (a) IP control. (b) AIP control (solid: $\omega_n = 5\pi$, dash: $\omega_n = 6.8\pi$, dash dot: $\omega_n = 10\pi$, dash dot dot line: $\omega_n = 20\pi$ rad/s).

the operating conditions as motor load and speed command. On the other hand, the proposed AIP control scheme shows much improved performance, such as no overshoot and fast settling time, in a way that it operates as the IP controller in the linear region and the integral state is modified to satisfy the consistency range in the saturation region. Although the plant input has a prescribed limit and the speed command is changed, the speed responses corresponding to the chosen gains can be obtained and the limited plant input can also be effectively utilized.

5. Conclusions

An anti-windup IP control scheme for the variable-speed motor drives has been proposed in order to overcome the windup phenomenon that occurs in the IP controller with the limited plant input. The condition of the maximum plant input has been derived for asymptotic stability and an easy method for choosing the IP gains has been presented from the prototype second-order system. With the derived consistency range of the IP controller, the integral state of the proposed AIP controller is separately controlled corresponding to whether the plant input is limited or not. The proposed control scheme has been applied to the speed control of a vector-controlled induction motor driven by a PWM-VSI and its usefulness has been experimentally verified.

The experimental results show that the proposed AIP control has much improved performance, such as no overshoot and fast settling time even though the plant input is limited. It is considered that the proposed AIP controller can be applied to other applications.

Nomenclature

B : Friction coefficient.
J : Moment of inertia of total system.
k_p : Proportional gain of IP speed controller.
k_T : Torque constant.
q : Integral state of IP speed controller.
T_L : External load torque.
ζ : Damping ratio of prototype second-order system.
τ_m : Mechanical time constant ($= J/B$).
u : Output of IP speed controller.
U_m : Limitation of plant input.
υ : Plant input, i.e. torque-producing current command.
ω_r : Motor speed.
ω_r^* : Motor speed command.
ω_n : Natural frequency of prototype second-order system.

Acknowledgement

This work was supported by grant no. (1999-30200-001-2) from the University-Industry Collaborative Research program of the Korea Science & Engineering Foundation.

References

[1] Boldea and S. A. Nasar, "Vector Control of AC Drives", Bocan Raton, FL: CRC Press, 1992.

[2] Y. Ping, D. Vrancic, and R. Hanus, "Anti-windup, bumpless, and conditioned transfer techniques for PID controllers", *IEEE Control Systems*, vol. 16, no. 4, pp. 48~57, 1996.

[3] K. J. Astrom, and T. Hagglund, "Automatic Tunning of PID Controllers", Instrument Society of America, Research Triangle Park, NC, 1988.

[4] N. J. Krikelis and S. K. Barkas, "Design of tracking systems subject to actuator saturation and integral wind-up", *Int. J. Control*, vol. 39, no. 4, pp. 667~682, 1984.

[5] I. H. Suh, S. H. Hwang, and Z. Bien, "A design and experimental of speed controller with PI-plus bang-bang action for a DC servomotor with transistorized PWM drives", *IEEE Trans. Ind. Electron.*, vol. 31, no. 4, pp. 338~345, 1984.

[6] R. Hanus, M. Kinnaert, and J. L. Henrotte, "Conditioning technique, a general anti-windup and bumpless transfer method", *Automatica*, vol. 23, no. 6, pp. 729~739, 1987.

[7] K. S. Walgama, S. Ronnback, and J. Sternby, "Generalization of conditioning technique for anti-windup compensators", *IEE Proceedings part D*, vol. 139, no. 2, pp. 109~118, 1992.

[8] H. B. Shin, "New antiwindup PI controller for variable-speed motor drives", *IEEE Trans. Ind. Electron.*, vol. 45, no. 3, pp. 445~450, June 1998.

[9] P. K. Nandam and P. C. Sen, "Analog and digital speed control of DC drives using proportional-integral and integral-proportional control techniques", *IEEE Trans. Ind. Electron.*, vol. 34, no. 2, pp. 227~233, May 1987.

[10] P. K. Nandam and P. C. Sen, "A comparative study of proportional-integral (P-I) and integral-proportional (I-P) controllers for dc motor drives", *INT. J. Control*, vol. 44, no. 1, pp. 283~297, 1986.

[11] D. C. Lee, S. K. Sul, and M. H. Park, "Comparison of AC current regulators for IGBT inverter", in *Conf. Rec. PCC '93*, pp. 206~212, Yokohama, Japan, 1993.

[12] F. J. Lin, R. J. Wai, C. H. Lin, and D. C. Liu, "Decoupled stator-flux-oriented induction motor drive with fuzzy neural network uncertain observer", *IEEE Trans. Ind. Electron.*, vol. 47, no. 2, pp. 356~367, April 2000.

[13] K. Ogata, "Modern Control Engineering", 3rd ed., Upper Saddle River, NJ: Prentice-Hall, pp. 669~709, 1997.

[14] B. C. Kuo, "Automatic Control Systems", 7th ed., Englewood Cliffs, NJ: Prentice-Hall, pp. 387~402, 1995.

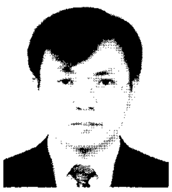
[15] D. W. Novotny and R. D. Lorenz, "Introduction to Field Orientation and High Performance AC Drives", New York: IEEE Press. 1986.

[16] B. K. Bose, "Power Electronics and AC Drives", Englewood Cliffs, NJ: Prentice-Hall, 1986.

[17] T. W. Rowan and R. J. Kerkman, "A new synchronous current regulator and analysis of current regulated PWM inverters", *IEEE Trans. Ind. Appl.*, vol. 22, no. 4, pp. 678~690, July/Aug. 1986.

Jong-Gyu Park received the B.S. and M.S. degrees in electrical engineering from Gyeongsang National University, Korea, in 1995 and 1997, respectively. He is presently working toward the Ph.D. degree. His research interests are in the areas of power electronics, ac machine drives, and micro controller-based control applications. He is a member of the Korea Institute of Power Electronics.

Jae-Ho Chung received the B.S. and M.S. degrees in electrical engineering from Gyeongsang National University, Korea, in 1992 and 1994, respectively. He is presently working toward the Ph.D. degree. His research interests include motor drive system and power electronics. He is a member of the Korea Institute of Power Electronics.



Hwi-Beom Shin received the B. S. degree in electrical engineering from Seoul National University, Seoul, Korea, in 1982, and the M. S. and Ph. D. degrees in electrical engineering from Korea Advanced Institute of Science and Technology (KAIST), Seoul, Korea, in 1985 and 1992, respectively.

He was with Hyundai Electronics Industries Co. Ltd. as chief engineer from 1990 to 1992. Since 1993, he has been with Department of Electrical Engineering, Gyeongsang National University, Gyeongnam, Korea, where he is an Associate Professor and a researcher of Research Institute of Industrial Technology. His research interests are in the areas of power electronics and control, electric vehicle and industrial drives.

Prof. Shin is a member of the Korea Institute of Power Electronics, Korea Institute of Electrical Engineering, IEEE Power Electronics, Industry Applications and Industrial Electronics Societies.