NFL-H$_\infty$에 기준한 SMC 의 안정도 증명 : Part 8

이 상 성° 박종근
서울대학교 전기공학부

이 주 장
한국과학기술원 전기공학과

Stability Proof of NFL-H$_\infty$-based SMC : Part 8

Sang-Seung Lee° and Jong-Keun Park
School of Electrical Engineering
Seoul National University

Ju-Jang Lee
Dept. of Electrical Engineering
K AIST

[Abstract] In this paper, the standard Dole, Glover, Khargoneker, and Francis (abbr. : DGKF 1989) H$_\infty$ controller (H$_\infty$C) is extended to the nonlinear feedback linearization-H$_\infty$-based sliding mode controller (NFL-H$_\infty$-based SMC). A stability proof of the closed-loop stability is done by a Lyapunov function candidate using an addition form of the sliding surface vector and the estimation error.

Keywords : nonlinear feedback linearization-H$_\infty$-based sliding mode controller, Lyapunov function, stability proof

1. Introduction

In this paper, the standard Dole, Glover, Khargoneker, and Francis (abbr. : DGKF 1989) H$_\infty$ controller (H$_\infty$C) [1] is extended to the nonlinear feedback linearization-H$_\infty$-based sliding mode controller (NFL-H$_\infty$-based SMC) [2-18]. The proposed NFL-H$_\infty$-based SMC is obtained by the estimated state variable based on H$_\infty$ estimator state in designing a sliding surface gain to ensure the stability by Lyapunov's method. The closed-loop stability is proved by a Lyapunov function candidate using an addition form of the sliding surface vector and the estimation error.

2. NFL-H$_\infty$-based SMC

The state equations under worst case based on nonlinear feedback linearization (NFL) are [19]

$$z(t) = T(x(t)) \quad (1)$$

$$\dot{z}(t) = Az(t) + B_1 w_{worst}(t) + B_2 u(t) \quad (2)$$

$$p(t) = C_1 z(t) + D_{11} w_{worst}(t) + D_{12} u(t) \quad (3)$$

$$y(t) = C_2 z(t) + D_{21} w_{worst}(t) + D_{22} u(t) \quad (4)$$

The standard H$_\infty$ estimator state equation based on NFL is [1]

$$\dot{\hat{z}}(t) = A\hat{z}(t) + B_2 u(t) + B_1 \hat{w}_{worst}(t) + Z_\infty K_e (y(t) - \hat{y}(t)) \quad (5)$$

where $\hat{w}_{worst}(t) = \gamma^{-2} B_1^T X_\infty \hat{z}(t)$ (6)

$$\hat{y}(t) = \left[C_2 + \gamma^{-2} D_{21} B_1^T X_\infty\right]\hat{z}(t) \quad (7)$$

The controller gain K_c is given by

$$K_c = \tilde{D}_{12}\left(B_2^T X_\infty + D_{12}^T C_1\right) \quad (8)$$

where $\tilde{D}_{12} = \left(D_{12}^T D_{12}\right)^{-1}$ (9)

The estimator gain K_e is given by

$$K_e = \left(Y_\infty C_2^T + B_1 D_{21}^T\right)\tilde{D}_{21} \quad (10)$$

where $\tilde{D}_{21} = \left(D_{21} D_{21}^T\right)^{-1}$ (11)

The term Z_∞ is given by

$$Z_\infty = \left(I - \gamma^{-2} Y_\infty X_\infty\right)^{-1} \quad (12)$$

The controller Riccati equation term X_∞ is

$$X_\infty = Ric\begin{bmatrix} A - B_2\tilde{D}_{12}D_{12}^T C_1 & \gamma^{-2}B_1B_1^T - B_2\tilde{D}_{12}B_2^T \\ -\tilde{C}_1^T\tilde{C}_1 & -\left(A - B_2\tilde{D}_{12}D_{12}^T C_1\right)^T \end{bmatrix} \quad (13)$$

where $\tilde{C}_1 = \left(I - D_{12}\tilde{D}_{12}D_{12}^T\right)C_1$ (14)

The estimator Riccati equation term is

$$Y_\infty = Ric\begin{bmatrix} \left(A - B_1\tilde{D}_{21}D_{21}^T C_2\right)^T & \gamma^{-2}C_1C_1^T - C_2^T\tilde{D}_{21}C_2 \\ -\tilde{B}_1\tilde{B}_1^T & -\left(A - B_1\tilde{D}_{21}^T\tilde{D}_{21}C_2\right) \end{bmatrix} \quad (15)$$

where $\tilde{B}_1 = B_1\left(I - D_{21}^T\tilde{D}_{21}D_{21}\right)$ (16)

The estimated control input based on NFL is

$$u_c(t) = -K_c\hat{z}(t) \quad (17)$$

The closed loop system can be expressed as

$$\begin{bmatrix} \dot{z}(t) \\ \dot{\hat{z}}(t) \end{bmatrix} = \begin{bmatrix} A & -B_2K_c \\ Z_\infty K_e C_2 & A_2 \end{bmatrix}\begin{bmatrix} z(t) \\ \hat{z}(t) \end{bmatrix} + \begin{bmatrix} B_1 \\ Z_\infty K_e D_{21} \end{bmatrix} w_{worst}(t) \quad (20)$$

$$\begin{bmatrix} p(t) \\ y(t) \end{bmatrix} = \begin{bmatrix} C_1 & -D_{12}K_c \\ C_2 & 0 \end{bmatrix} \begin{bmatrix} z(t) \\ \hat{z}(t) \end{bmatrix} + \begin{bmatrix} 0 \\ D_{21} \end{bmatrix} w_{worst}(t) \quad (21)$$

where $A_2 := A - B_2K_c + \gamma^{-2}B_1B_1^TX_\infty$

$$-Z_\infty K_e\left(C_2 + \gamma^{-2}D_{21}B_1^TX_\infty\right) \quad (22)$$

The state equation based on NFL is set to

$$\dot{z}(t) = Az(t) + B_1 w_{worst}(t) + B_2 u(t)$$
$$= \left(A + B_1\left(\gamma^{-2}B_1^TX_\infty\right)\right)z(t) + B_2 u(t) \quad (23)$$

The switching surface vector and the differential switching surface vector can be expressed as

$$\sigma(\hat{z}(t)) = G_{SS}^T\hat{z}(t) \quad (24)$$

$$\dot{\sigma}(\hat{z}(t)) = G_{SS}^T\dot{\hat{z}}(t) \quad (25)$$

where G_{SS}^T is the sliding surface gain.

The Lyapunov's function candidate is chosen by

$$V(\hat{z}(t)) = \sigma^2(\hat{z}(t))/2 \quad (26)$$

$$\dot{V}(\hat{z}(t)) = \sigma(\hat{z}(t))\dot{\sigma}(\hat{z}(t)) = G_{SS}^T\hat{z}(t)G_{SS}^T\dot{\hat{z}}(t)$$
$$= G_{SS}^T\hat{z}(t)G_{SS}^T\Big[\big[A - Z_\infty K_e\left[C_2 + \gamma^{-2}D_{21}B_1^TX_\infty\right]$$
$$+B_1\gamma^{-2}B_1^TX_\infty\big]\hat{z}(t) + B_2\hat{u}^{equal}_{H_\infty-SMC}(t) + Z_\infty K_e y(t)\Big]$$
$$= G_{SS}^T\hat{z}(t)\Big[G_{SS}^T\big[A - Z_\infty K_e\left[C_2 + \gamma^{-2}D_{21}B_1^TX_\infty\right]$$
$$+B_1\gamma^{-2}B_1^TX_\infty\big]\hat{z}(t) + G_{SS}^TB_2\hat{u}^{equal}_{H_\infty-SMC}(t) + G_{SS}^TZ_\infty K_e y(t)\Big]$$
$$\leq 0 \quad (27)$$

From (27), the estimated control input with switching function can be reduced as

$$\hat{u}^+_{H_\infty-SMC}(t) \geq -\left(G_{SS}^TB_2\right)^{-1}\Big[G_{SS}^T\big[A - Z_\infty K_e\left[C_2 + \gamma^{-2}D_{21}B_1^TX_\infty\right]$$
$$+B_1\gamma^{-2}B_1^TX_\infty\big]\Big]\hat{z}(t) + G_{SS}^TZ_\infty K_e y(t)$$
$$for \ G_{SS}^T\hat{z}(t) > 0 \quad (28)$$

$$\hat{u}^-_{H_\infty-SMC}(t) \leq -\left(G_{SS}^TB_2\right)^{-1}\Big[G_{SS}^T\big[A - Z_\infty K_e\left[C_2 + \gamma^{-2}D_{21}B_1^TX_\infty\right]$$
$$+B_1\gamma^{-2}B_1^TX_\infty\big]\Big]\hat{z}(t) + G_{SS}^TZ_\infty K_e y(t)$$
$$for \ G_{SS}^T\hat{z}(t) < 0 \quad (29)$$

The estimated control input with sign function can be reformed as

$$\hat{u}^{sign}_{H_\infty-SMC}(t) = -\left(G_{SS}^TB_2\right)^{-1}\Big[\Big[G_{SS}^T\big[A - Z_\infty K_e\left[C_2 + \gamma^{-2}D_{21}B_1^TX_\infty\right]$$
$$+B_1\gamma^{-2}B_1^TX_\infty\big]\Big]\hat{z}(t) + G_{SS}^TZ_\infty K_e y(t)\Big] \ sign(\sigma(\hat{z})) \quad (30)$$

subject to, $sign(\sigma(\hat{z}(t))) = 1$ for $\sigma(\hat{z}(t)) > 0$, $sign(\sigma(\hat{z}(t))) = 0$ for $\sigma(\hat{z}(t)) = 0$, and $sign(\sigma(\hat{z}(t))) = -1$ for $\sigma(\hat{z}(t)) < 0$.

The equation (30) can be simplified as follows:

$$\hat{u}^{sign}_{H_\infty-SMC}(t) = -\left[WK_1^{equal}\hat{z}(t) + WK_2^{equal}y(t)\right]sign(\sigma(\hat{z}(t))) \quad (31)$$

where, $WK_1^{equal} := \left(G_{SS}^TB_2\right)^{-1}G_{SS}^T\big[A - Z_\infty K_e$

$$\left[C_2 + \gamma^{-2}D_{21}B_1^TX_\infty\right] + B_1\gamma^{-2}B_1^TX_\infty\big] \quad (32)$$

$$WK_2^{equal} := \left(G_{SS}^TB_2\right)^{-1}G_{SS}^TZ_\infty K_e \quad (33)$$

Theorem 1: Consider the state equations and the H_∞ estimator based on NFL for the regulation problem under a worst case

$$\dot{z} = Az + B_1w_{worst} + B_2\hat{u}^{sign}_{H_\infty-SMC}$$
$$p = C_1z + D_{11}w_{worst} + D_{12}\hat{u}^{sign}_{H_\infty-SMC}$$
$$y = C_2z + D_{21}w_{worst} + D_{22}\hat{u}^{sign}_{H_\infty-SMC}$$
$$\dot{\hat{z}} = A\hat{z} + B_2\hat{u}^{sign}_{H_\infty-SMC} + B_1\hat{w}_{worst} + Z_\infty K_e(y - \hat{y})$$

The estimated sliding mode control law with sign function based on NFL that keeps the system stable is guaranteed an *asymptotically stable* for the system (2)

$$\hat{u}^{sign}_{H_\infty-SMC} = -\left[WK_1^{equal}\hat{z} + WK_2^{equal}y\right]sign(\sigma(\hat{z}))$$
$$WK_1^{equal} := \left(G_{SS}^TB_2\right)^{-1}G_{SS}^T\big[A - Z_\infty K_e$$
$$\left[C_2 + \gamma^{-2}D_{21}B_1^TX_\infty\right] + B_1\gamma^{-2}B_1^TX_\infty\big]$$
$$WK_2^{equal} := \left(G_{SS}^TB_2\right)^{-1}G_{SS}^TZ_\infty K_e$$

subject to, $sign(\sigma(\hat{z}(t))) = 1$ for $\sigma(\hat{z}(t)) > 0$, $sign(\sigma(\hat{z}(t))) = 0$ for $\sigma(\hat{z}(t)) = 0$, and $sign(\sigma(\hat{z}(t))) = -1$ for $\sigma(\hat{z}(t)) < 0$.

Proof. Let us define the estimation error equation

$$e = z - \hat{z}$$
$$\dot{e} = \dot{z} - \dot{\hat{z}} = Az + B_1w_{worst} + B_2\hat{u}^{sign}_{H_\infty-SMC}$$
$$-\left[A\hat{z} + B_2\hat{u}^{sign}_{H_\infty-SMC} + B_1\hat{w}_{worst} + Z_\infty K_e(y - \hat{y})\right]$$
$$= Az + B_1w_{worst} - A\hat{z} - B_1\hat{w}_{worst} - Z_\infty K_e y + Z_\infty K_e\hat{y}$$
$$= Az + B_1w_{worst} - A\hat{z} - B_1\hat{w}_{worst}$$
$$-Z_\infty K_eC_2z - Z_\infty K_eD_{21}w_{worst} - Z_\infty K_eD_{22}(-K_C\hat{z})$$
$$+Z_\infty K_eC_2\hat{z} + Z_\infty K_eD_{21}\hat{w}_{worst} + Z_\infty K_eD_{22}(-K_C\hat{z})$$
$$= Az - Z_\infty K_eC_2z - A\hat{z} + Z_\infty K_eC_2\hat{z} + B_1w_{worst}$$
$$-Z_\infty K_eD_{21}w_{worst} - B_1\hat{w}_{worst} + Z_\infty K_eD_{21}\hat{w}_{worst}$$
$$= (A - Z_\infty K_eC_2)z - (A - Z_\infty K_eC_2)\hat{z} + B_1w_{worst} - Z_\infty K_eD_{21}w_{worst}$$
$$-B_1\hat{w}_{worst} + Z_\infty K_eD_{21}\hat{w}_{worst}$$
$$= (A - Z_\infty K_eC_2)z - (A - Z_\infty K_eC_2)(e + z) \quad \because \hat{z} := e + z$$
$$+B_1\gamma^{-2}B_1^TX_\infty z - Z_\infty K_eD_{21}\gamma^{-2}B_1^TX_\infty z - B_1\gamma^{-2}B_1^TX_\infty\hat{z}$$
$$+Z_\infty K_eD_{21}\gamma^{-2}B_1^TX_\infty\hat{z}$$
$$= -(A - Z_\infty K_eC_2)e - B_1\gamma^{-2}B_1^TX_\infty e + Z_\infty K_eD_{21}\gamma^{-2}B_1^TX_\infty e$$
$$= -\left(A - \gamma^{-2}B_1B_1^TX_\infty - Z_\infty K_e\left(C_2 - \gamma^{-2}D_{21}B_1^TX_\infty\right)\right)e$$

Lyapunov's function candidate is chosen by

$$V = \frac{1}{2}\sigma^T\sigma + \frac{1}{2}e^Te$$
$$\dot{V} = \sigma^T\dot{\sigma} + e^T\dot{e}$$
$$= \sigma^T\left(G_{SS}^T\dot{\hat{z}}\right) - e^T\left(A - \gamma^{-2}B_1B_1^TX_\infty - Z_\infty K_e\left(C_2 - \gamma^{-2}D_{21}B_1^TX_\infty\right)\right)e$$
$$= \sigma^TG_{SS}^T\left(A\hat{z} + B_2\hat{u}^{sign}_{H_\infty-SMC} + B_1\hat{w}_{worst} + Z_\infty K_e(y - \hat{y})\right)$$
$$-e^T\left(A - \gamma^{-2}B_1B_1^TX_\infty - Z_\infty K_e\left(C_2 - \gamma^{-2}D_{21}B_1^TX_\infty\right)\right)e$$

$$= \sigma^T G_{SS}^T \Big(A\hat{z} + B_2 \hat{u}_{H\infty-SMC}^{sign} + B_1 \hat{w}_{worst} + Z_\infty K_e y - Z_\infty K_e \hat{y} \Big)$$
$$-e^T \Big(A - \gamma^{-2} B_1 B_1^T X_\infty - Z_\infty K_e \big(C_2 - \gamma^{-2} D_{21} B_1^T X_\infty \big) \Big) e$$
$$= \sigma^T G_{SS}^T \Big(A\hat{z} + B_2 \big(-K_{W-SMC}^{equal} \hat{z} sign(\sigma(\hat{z})) \big) + B_1 \hat{w}_{worst}$$
$$+ Z_\infty K_e C_2 z + Z_\infty K_e D_{21} w_{worst} + Z_\infty K_e D_{22} \big(-K_{W-SMC}^{equal} \hat{z} sign(\sigma(\hat{z})) \big)$$
$$- Z_\infty K_e C_2 \hat{z} - Z_\infty K_e D_{21} \hat{w}_{worst} - Z_\infty K_e D_{22} \big(-K_{W-SMC}^{equal} \hat{z} sign(\sigma(\hat{z})) \big) \Big)$$
$$-e^T \Big(A - \gamma^{-2} B_1 B_1^T X_\infty - Z_\infty K_e \big(C_2 - \gamma^{-2} D_{21} B_1^T X_\infty \big) \Big) e$$

Let $w_{worst} = \gamma^{-2} B_1^T X_\infty z(t)$, and $\hat{w}_{worst} = \gamma^{-2} B_1^T X_\infty \hat{z}(t)$

$$\dot{V} = \sigma^T G_{SS}^T \Big(A\hat{z} + B_2 \big(-K_{W-SMC}^{equal} \hat{z} sign(\sigma(\hat{z})) \big) + B_1 \gamma^{-2} B_1^T X_\infty \hat{z}$$
$$+ Z_\infty K_e C_2 z + Z_\infty K_e D_{21} \gamma^{-2} B_1^T X_\infty z - Z_\infty K_e C_2 \hat{z}$$
$$- Z_\infty K_e D_{21} \gamma^{-2} B_1^T X_\infty \hat{z} \Big)$$
$$-e^T \Big(A - \gamma^{-2} B_1 B_1^T X_\infty - Z_\infty K_e \big(C_2 - \gamma^{-2} D_{21} B_1^T X_\infty \big) \Big) e$$
$$= \sigma^T G_{SS}^T \Big[A - B_2 K_{W-SMC}^{equal} sign(\sigma(\hat{z})) + B_1 \gamma^{-2} B_1^T X_\infty \Big] \hat{z}$$
$$+ \sigma^T G_{SS}^T \Big(Z_\infty K_e \big(C_2 + D_{21} \gamma^{-2} B_1^T X_\infty \big) \Big) (z - \hat{z})$$
$$-e^T \Big(A - \gamma^{-2} B_1 B_1^T X_\infty - Z_\infty K_e \big(C_2 - \gamma^{-2} D_{21} B_1^T X_\infty \big) \Big) e$$
$$= \sigma^T G_{SS}^T \Big[A - B_2 K_{W-SMC}^{equal} sign(\sigma(\hat{z})) + B_1 \gamma^{-2} B_1^T X_\infty \Big] \hat{z}$$
$$+ \sigma^T G_{SS}^T \Big(Z_\infty K_e \big(C_2 + D_{21} \gamma^{-2} B_1^T X_\infty \big) \Big) e$$
$$-e^T \Big(A - \gamma^{-2} B_1 B_1^T X_\infty - Z_\infty K_e \big(C_2 - \gamma^{-2} D_{21} B_1^T X_\infty \big) \Big) e$$

Let $K_{W-SMC}^{equal} := \left(G_{SS}^T B_2 \right)^{-1} \left[G_{SS}^T \left(A + B_1 \gamma^{-2} B_1^T X_\infty \right) \right]$,

$$\dot{V} = \sigma^T G_{SS}^T \Big[A - B_2 \left(G_{SS}^T B_2 \right)^{-1} \left[G_{SS}^T \left(A + B_1 \gamma^{-2} B_1^T X_\infty \right) \right] sign(\sigma(\hat{z}))$$
$$+ B_1 \gamma^{-2} B_1^T X_\infty \Big] \hat{z} + \sigma^T G_{SS}^T \Big(Z_\infty K_e \big(C_2 + D_{21} \gamma^{-2} B_1^T X_\infty \big) \Big) e$$
$$-e^T \Big(A - \gamma^{-2} B_1 B_1^T X_\infty - Z_\infty K_e \big(C_2 - \gamma^{-2} D_{21} B_1^T X_\infty \big) \Big) e$$
$$= \sigma^T \Big[G_{SS}^T A - \Big(G_{SS}^T B_2 \left(G_{SS}^T B_2 \right)^{-1} G_{SS}^T A$$
$$+ G_{SS}^T B_2 \left(G_{SS}^T B_2 \right)^{-1} G_{SS}^T B_1 \gamma^{-2} B_1^T X_\infty \Big) \; sign(\sigma(\hat{z}))$$
$$+ G_{SS}^T B_1 \gamma^{-2} B_1^T X_\infty \Big] \hat{z} + \sigma^T G_{SS}^T \Big(Z_\infty K_e \big(C_2 + D_{21} \gamma^{-2} B_1^T X_\infty \big) \Big) e$$
$$-e^T \Big(A - \gamma^{-2} B_1 B_1^T X_\infty - Z_\infty K_e \big(C_2 - \gamma^{-2} D_{21} B_1^T X_\infty \big) \Big) e$$
$$= \sigma^T \Big[G_{SS}^T A - G_{SS}^T A sign(\sigma(\hat{z})) - G_{SS}^T B_1 \gamma^{-2} B_1^T X_\infty sign(\sigma(\hat{z}))$$
$$+ G_{SS}^T B_1 \gamma^{-2} B_1^T X_\infty \Big] \hat{z} + \sigma^T G_{SS}^T \Big(Z_\infty K_e \big(C_2 + D_{21} \gamma^{-2} B_1^T X_\infty \big) \Big) e$$
$$-e^T \Big(A - \gamma^{-2} B_1 B_1^T X_\infty - Z_\infty K_e \big(C_2 - \gamma^{-2} D_{21} B_1^T X_\infty \big) \Big) e$$
$$= \sigma^T G_{SS}^T A \Big[1 - sign(\sigma(\hat{z})) \Big] \hat{z} + \sigma^T G_{SS}^T B_1 \gamma^{-2} B_1^T X_\infty$$
$$\Big(1 - sign(\sigma(\hat{z})) \Big) \Big] \hat{z} + \sigma^T G_{SS}^T \Big(Z_\infty K_e \big(C_2 + D_{21} \gamma^{-2} B_1^T X_\infty \big) \Big) e$$
$$-e^T \Big(A - \gamma^{-2} B_1 B_1^T X_\infty - Z_\infty K_e \big(C_2 - \gamma^{-2} D_{21} B_1^T X_\infty \big) \Big) e$$

The estimation error is $e \to 0$ as $t \to 0$.

$$\dot{V} = \sigma^T G_{SS}^T A \Big[1 - sign(\sigma(\hat{z})) \Big] \hat{z} + G_{SS}^T B_1 \gamma^{-2} B_1^T X_\infty$$
$$\Big(1 - sign(\sigma(\hat{z})) \Big) \Big] \hat{z} \le 0$$

subject to

if $\sigma > 0$, $\dot{V} = 0$

if $\sigma = 0$, $\dot{V} = 0$

if $\sigma < 0$, $\dot{V} \le -2kG_{SS}^T A \hat{z} - 2kG_{SS}^T B_1 \gamma^{-2} B_1^T X_\infty \hat{z} < 0$,

k is positive constant.

The above condition is satisfied on negative definite, and is *asymptotically stable*. This completes the proof of this theorem. □

Conclusion

A stability proof of a nonlinear feedback linearization-H_∞-based sliding mode controller (NFL-H_∞-based SMC) has been done.

References

[1] J. C. Doyle, K. Glover, P. P. Khargonekar and B. A. Francis, "State-space solutions to standard H_2 and H_∞ control problems", IEEE Trans. on Automatic Control, Vol. 34, No. 8, pp. 831-847, Aug., 1989.

[2] V. I. Utkin, "Variable structure systems with sliding modes", IEEE Trans. on Automatic Control, AC-22, No.2, pp. 212-222, April, 1977.

[3] W. C. Chan and Y. Y. Hsu, "An optimal variable structure stabilizer for power system stabilization", IEEE Trans. on Power Apparatus and Systems, Vol. PAS-102, pp. 1738-1746, Jun., 198

[4] J. J. Lee, "Optimal multidimensional variable structure controller for multi-interconnected power system", KIEE Trans., Vol. 38, No. 9, pp. 671-683, Sep., 1989.

[5] M. L. Kothari, J. Nanda and K. Bhattacharya, 'Design of variable structure power system stabilizers with desired eigenvalues in the sliding mode', IEE Proc. C, Vol. 140, No. 4, pp. 263-268, 199

[6] S. S. Lee, J. K. Park and J. J. Lee, "Sliding mode-MFAC power system stabilizer", Jour. of KIEE, Vol. 5, No. 1, pp. 1-7, Mar., 1992

[7] S. S. Lee and J. K. Park, "Sliding mode-model following power system stabilizer including closed-loop feedback", Jour. of KIEE, Vol. 9, No. 3, pp. 132-138, Sep., 1996

[8] S. S. Lee, J. K. Park et al., "Multimachine stabilizer using sliding mode-model following including closed-loop feedback", Jour. of KIEE, Vol. 9, No. 4, pp. 191-197, Dec., 1996.

[9] S. S. Lee and J. K. Park, "Sliding mode power system stabilizer based on LQR : Part I", Jour. of EEIS, Vol. 1, No. 3, pp. 32-38, 1996.

[10] S. S. Lee and J. K. Park, "Sliding mode observer power system stabilizer based on linear full-order observer : Part II", Jour. of EEIS, Vol. 1, No. 3, pp. 39-45, 1996.

[11] S. S. Lee and J. K. Park, "Full-order observer-based sliding mode power system stabilizer with desired eigenvalue-assignment for unmeasurable state variables", Jour. of EEIS, Vol. 2, No. 2, pp. 36-42, 1997.

[12] S. S. Lee and J. K. Park, "New sliding mode observer-model following power system stabilizer including CLF for unmeasurable state variables", Jour. of EEIS, Vol. 2, No. 3, pp. 88-94, 1997.

[13] S. S. Lee and J. K. Park, "Multimachine stabilizer using sliding mode observer-model following including CLF for unmeasurable state variables", Jour. of EEIS, Vol. 2, No. 4, pp. 53-58, 1997.

[14] S. S. Lee and J. K. Park, "H_∞ observer-based sliding mode power system stabilizer for unmeasurable state variables", Jour. of EEIS, Vol. 2, No. 1, pp. 70-76, 1997.

[15] S. S. Lee and J. K. Park, "Nonlinear feedback linearization-full order observer/sliding mode controller design for improving transient stability in a power system", Jour. of EEIS, Vol. 3, No. 2, pp. 184-192, 1998.

[16] S. S. Lee and J. K. Park, "Nonlinear feedback linearization-H_∞/sliding mode controller design for improving transient stability in a power system", Jour. of EEIS, Vol. 3, No. 2, pp. 193-201, 1998.

[17] S. S. Lee and J. K. Park, "Design of power system stabilizer using observer/sliding mode, observer/sliding mode-model following and H_∞/sliding mode controllers for small-signal stability study", Inter. Jour. of Electrical Power & Energy Systems, accepted, 1998.

[18] S. S. Lee and J. K. Park, "Design of reduced-order observer-based variable structure power system stabilizer for unmeasurable state variables, IEE PROC.-GEN., TRANS. AND DISTRIB., accepted, 1998.

[19] R. Marino and P. Tomei, "Nonlinear control design", Prentice-Hall Press, 1995