International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 3 Issue 5, August 2019 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Nonlinear Control of Static Synchronous Compensator (STATCOM) for Transmission System

Yadana Aung, Phyu Phyu Win, Moe Phyu Thel

Department of Electrical Power Engineering, Technological University, Mandalay, Myanmar

How to cite this paper: Yadana Aung | Phyu Phyu Win | Moe Phyu Thel "Nonlinear Control of Static Synchronous Compensator (STATCOM) for Transmission System" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-3 | Issue-5, August 2019, pp.2231-2234, **https://doi.org/10.31142/ijtsrd28002**

IJTSRD28002

ABSTRACT

The Static Synchronous Compensator (STATCOM) is a shunt controller, which is a member of FACTS devices. In this paper, an effective and robust controller for STATCOM device on transmission lines, a Single Machine Infinite Bus (SMIB) system is modeled. A state space mathematical model is constructed which considers both electromechanical oscillations and reactive current of the STATCOM at the installation site. Based the obtained third-order model, state feedback linearization and linear quadratic regulation (LQR) approach are applied to obtain a nonlinear control law. The controllers are simulated and tested under different operating conditions comparing with the conventional PI controller.

KEYWORDS: *FACTS; STATCOM; feedback linearization; nonlinear control; PI controller*

I. INTRODUCTION

The power flows in some of the transmission lines are overloaded, which has as an overall situation requires the review of traditional transmission methods and practices, and the creation of new concepts, which would allow the use of existing generation and transmission lines up to their full capabilities without reduction in system stability and security. Series capacitor, shunt capacitor and phase shift are different approaches to increase the power system transmission lines load ability. They are very useful in a steady state operation of power systems but from a dynamical point of view, their time response is too slow to effectively damp transient oscillations.

In the control of electric power systems, reactive power compensation is an important issue. Reactive power compensation is traditionally realized by connecting or disconnecting capacitor or inductor banks to the bus through mechanical switches that are slow and imprecise. With the developments in power electronics, a new kind of compensator was introduced. This compensator is static synchronous compensator (STATCOM), which is the member of FACTS devices [1]. STATCOM is based on self-commutated solid state power electronic devices to achieve advanced reactive power control.

Much work about STATCOM steady state performance control has been done, which is based on steady state vector (phasor) diagram analysis to power system quantities. This kind of control approach, usually a proportional integrated control (PI control) is convenient to the traditional power system analysis method and not necessary to build a special mathematic model for controller design. However, the system response is slow due to the calculation of active and reactive power, that need several periods (T) of the power system, and not effective when the change of power system is rapid[3][4].

As power system becomes more complex and more nonlinear loads are connected, the control of power system transient response is becoming a very critical issue. Therefore, it is necessary to study nonlinear control strategy to control the STATCOM dynamic characteristics and capabilities to improve transient stability [5].

STEADY STATE MODEL

A STATCOM is always connected in shunt with the ac system through some magnetic coupling, namely, the coupling transformer or interface reactor. A typical STATCOM connection is shown in Fig.1; it consists of a voltage source converter (VSC) using either a GTO or IGBT as a switching device, and a capacitor, Cs, on the DC side as an energy-storage device. The resistance Rp in parallel with Cs represents both the capacitor losses and switching losses. The STATCOM is connected to the ac system through magnetic coupling, represented by leakage inductance Ls and resistance Rs. The STATCOM improves the desired power system performance, including dynamic compensation, mitigating the synchronous resonances (SSR) bu modeling the reactive power at the common coupling point, and so forth.

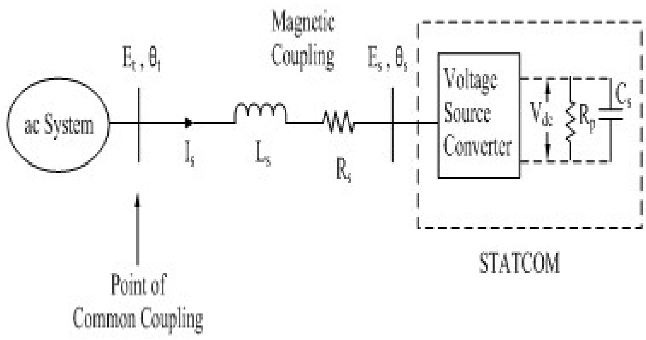

Fig.1 A Typical STATCOM Connection to AC System

MATHEMATICAL EQUATION

A single machine infinite bus system (SMIB) is shown in Fig.2. The STATCOM is placed at the middle of the transmission line which is generally considered to be the ideal site.

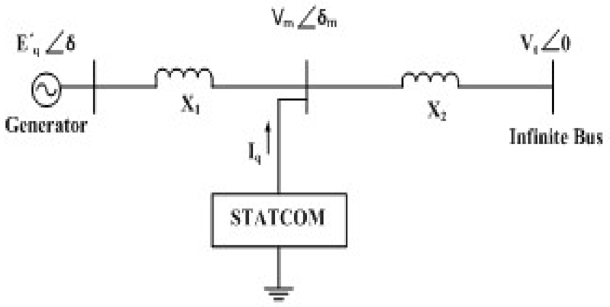

Fig.2 A Single Machine Infinite Bus (SMIB) System with STATCOM

The synchronous generator is represented by the classical second order model. The system dynamics is described by the following equations.

$$\dot{\delta} = \omega - \omega_0 \quad (1)$$

$$\dot{\omega} = \frac{\omega_0}{H}\left[P_m - P_e - \frac{D}{\omega_0}(\omega - \omega_0)\right] \quad (2)$$

$$\text{where } P_e = \frac{E'_q V_m}{X_1}\sin(\delta - \delta_m) \quad (3)$$

The voltage magnitude and angle at bus m can be written as

$$V_m = \left[\frac{X_2 E'_q \cos(\delta-\delta_m) + X_1 V_t \cos\delta_m}{X_1 + X_2}\right] + \left[\frac{X_1 X_2}{X_1 + X_2} I_q\right] \quad (4)$$

$$= V_{mo} + X_{eq} I_q \quad (5)$$

$$\delta_m = \tan^{-1}\left[\frac{X_2 E'_q \sin\delta}{X_2 E'_q \cos\delta + X_1 V_t}\right] \quad (6)$$

When the STATCOM is installed at the transmission line, the STATCOM reacrive output current is given by the STATCOM control theory as

$$\dot{I}_q = \frac{1}{T}(-I_q + Ku) \quad (7)$$

The target of the nonlinear control strategy here is to keep the whole system stable by regulating the reactive power exchange between the STATCOM and ac system. For the system shown in Fig.2, the system stability can be evaluated by checking the absolute value of the relative angle of the generator within 180°. This relative angle is used as a stability index of the connected power systems. After a large disturbance, the smaller the relative angle is, the more stable will be. Therefore, the relative rotor angle of the generator is taken as the output equation for the nonlinear control design.

$$y(t) = \delta \quad (8)$$

Combining equations (1), (2) and (8), obtain the state equation and the output equation of the power system installed with the STATCOM

$$\dot{\delta} = \omega - \omega_0 \quad (9)$$

$$\dot{\omega} = \frac{\omega_0}{H}\left[P_m - P_e - \frac{D}{\omega_0}(\omega - \omega_0)\right] \quad (10)$$

$$\dot{I}_q = \frac{1}{T}(-I_q + Ku) \quad (11)$$

The output equation is

$$y(t) = h(X(t)) = \delta \quad (12)$$

The dynamic equation of a synchronous generator can be written in a state space as

$$\dot{X}(t) = f(X) + g(X)u \quad (13)$$

$$y(t) = h(X) \quad (14)$$

where $X = [\delta\ \omega\ I_q]^T$; u is the control variable of the STATCOM

$$f(x) = \begin{bmatrix} \omega - \omega_0 \\ \frac{\omega_0}{H}P_m - \frac{\omega_0}{H}C_1(V_{m0} + X_{eq}I_q) - \frac{D}{H}(\omega - \omega_0) \\ -\frac{1}{T}I_q \end{bmatrix} \quad (15)$$

$$g(x) = \begin{bmatrix} 0 & 0 & \frac{K}{T} \end{bmatrix}^T \quad (16)$$

$$h(x) = \delta \quad (17)$$

and

$$C_1 = \frac{E'_q}{X_1}\sin(\delta - \delta_m) \quad (18)$$

NONLINEAR CONTROL DESIGN OF THE STATCOM

The development of the feedback linearization techniques provides a powerful tool for the design of controllers for nonlinear systems. The first step in the design procedure is the establishment of the linearization condition for the SMIB system. Hence the SMIB system has relative degree r=3, which is equal to the system order. A nonlinear system in X coordinate can be transferred into the following Z coordination

$$z_1 = \delta \quad (19)$$

$$z_2 = \omega - \omega_0 = \Delta\omega \quad (20)$$

$$z_3 = \dot{\omega} = \frac{\omega_0}{H}P_m - \frac{\omega_0}{H}C_1(V_{m0} + X_{eq}I_q) - \frac{D}{H}\Delta\omega \quad (21)$$

Then the nonlinear system can be transferred into a linear system of the form

$$\dot{Z} = AZ + Bv \quad (22)$$

$$y = CZ \quad (23)$$

where 'v' is the control input of the linear system and

$$Z = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix}, A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \quad (24)$$

$$C = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}, D = [0] \quad (25)$$

The optimal control vector 'v' is

$$v = -K^*Z = -k_1^* z_1 - k_2^* z_2 - k_3^* z_3 \quad (26)$$

$$v = -k_1^*\delta - k_2^*\Delta\omega - k_3^*\dot{\omega} \quad (27)$$

where $k_1^* = 1.0, k_2^* = 7.6, k_3^* = 3.9$

The nonlinear control design for the system using STATCOM is obtained as

$$u = -\frac{\alpha(x)}{\beta(x)} + \frac{1}{\beta(x)}v \tag{28}$$

$$\alpha(x) = \frac{\omega_0}{TH}C_1X_{eq}I_q \tag{29}$$

$$\beta(x) = -\frac{K\omega_0}{TH}C_1X_{eq} \tag{30}$$

$$u = \frac{H}{KC_1X_{eq}}\frac{T}{\omega_0}(k_1{}^*\delta + k_2{}^*\Delta\omega + k_3{}^*\dot{\omega}) + \frac{1}{K}I_q \tag{31}$$

PI CONTROL SCHEME OF STATCOM

The effectiveness of the proposed nonlinear controller in damping power system oscillations is evaluated through a comparison with a conventional PI controller shown in Fig.3. The gains of controller were selected based on a pole placement technique.

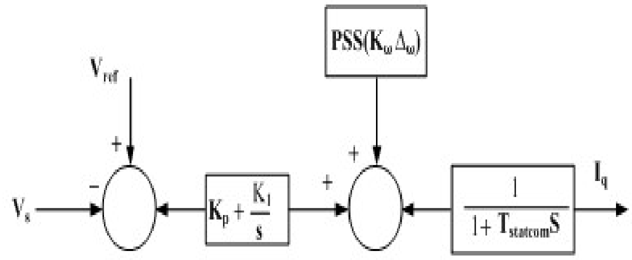

Fig.3 Block Diagram of Conventional PI Control

The method produces an optimum control function for linear system designed for a specific operating point. The transfer function of PI controller is given as

$$G_{PID}(s)=K_P+\frac{K_I}{s} \tag{32}$$

The controller transfer function can be written as

$$G_c(s)=\frac{sT_W}{1+sT_W}\left(K_P+\frac{K_I}{s}\right) \tag{33}$$

Here, K_P and K_I are the gains in proportional and integral loops, T_W is the washout time constant.

SIMULATION RESULTS

The performance of the STATCOM for the stabilization of synchronous generator is evaluated by computer simulation studies. The STATCOM is installed at the middle of the transmission line. The time constant of the STATCOM reactive output current is set to 0.01 sec. The transient performances of the rotor angle are shown in Fig.4 when the generator is loaded at power 0.8 p.u. Fig.5 shows the transient response of the mid-bus voltage. It can be seen that from the simulation results, the nonlinear control is superior over the conventional PI control not only in suppressing the STATCOM bus voltage fluctuation, but also in restraining the power oscillation.

The transient performances of the rotor angle are shown in Fig.6 when the generator is loaded at power 1.0 p.u. Fig.7 shows the transient response of the mid-bus voltage. When the generator load was increased (P=1.0 p.u), STATCOM with conventional PI control are more unstable, but the STATCOM using nonlinear control is effectively damp the system oscillation and completely stable at 7 second. This proved that nonlinear control technology provides new promising way to further improve the operation security and dynamic performance of the system.

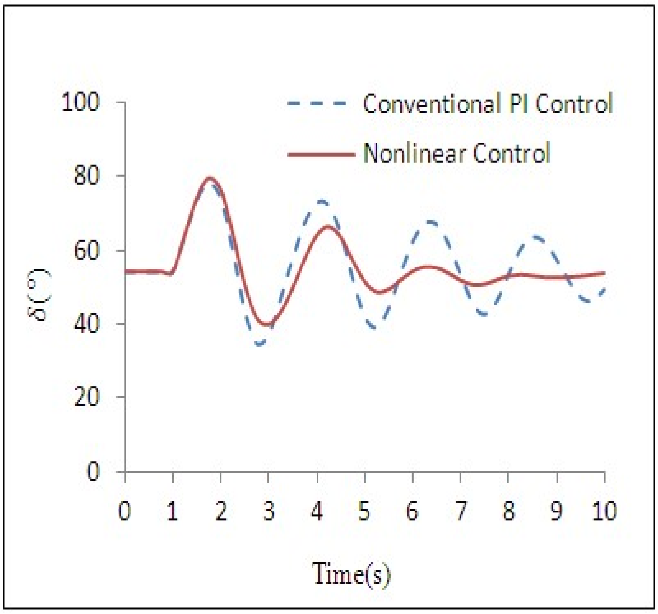

Fig.4 Transient Response of Rotor Angle (Generator was Loaded to P=0.8 p.u)

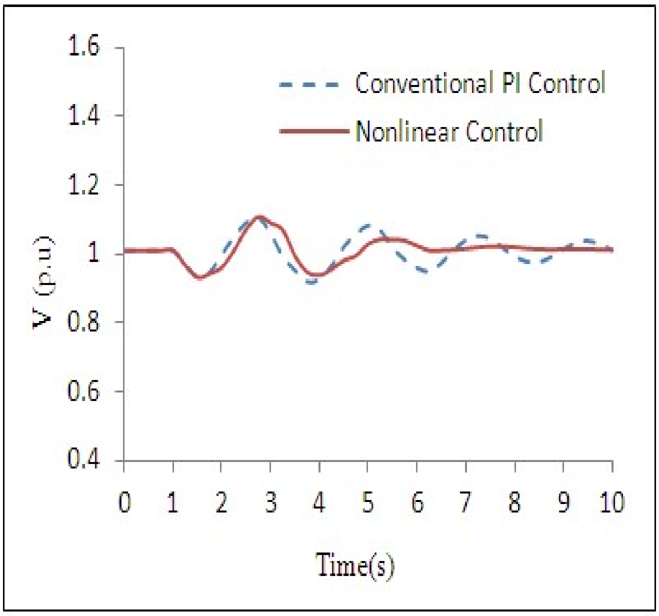

Fig.5 Transient Response of Mid-bus Voltage (Generator was Loaded to P=0.8 p.u)

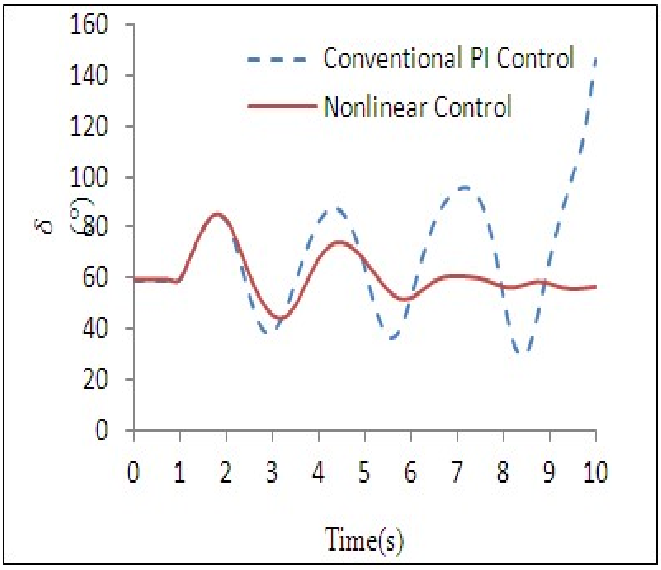

Fig.6 Transient Response of Rotor Angle (Generator was Loaded to P=1.0 p.u)

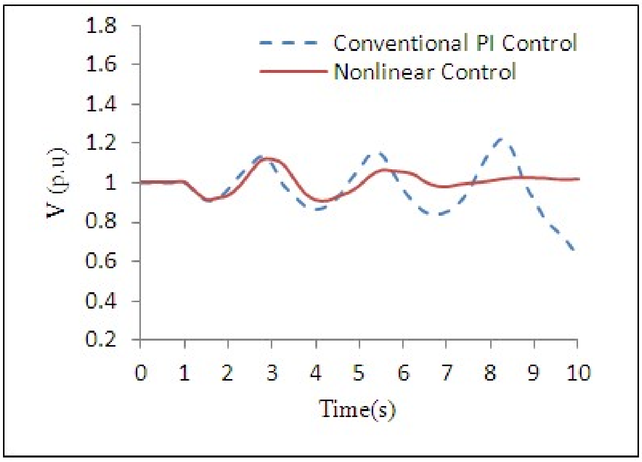

Fig.7 Transient Response of Mid-bus Voltage (Generator was Loaded to P=1.0 p.u)

CONCLUSION

The control strategy of a STATCOM in a single machine infinite bus system was derived to improve system stability and damping power system oscillation. The control of the STATCOM is selected based on the linearized mathematic model of the system by applying nonlinear control. The effectiveness of the proposed control strategy in improving the power system dynamic stability has been verified through nonlinear time-domain simulations under different load conditions. This control approach for STATCOM shows better performance compare with the conventional PI controller.

REFERENCES

[1] N. G. Hingorani, L. Gyugyi, *"Understanding FACTS"* IEEE Press, 2000

[2] A. Hammad, B. Roesle, *"New Roles for Static Var Compensators in Transmission Systems"*, Brown Boveri Review, June, 1986

[3] Dong Shen and P. W. Lehn, "Modeling, Analysis and Control of a Current Source Inverter-Based STATCOM", IEEE Transctions on Power Delivery, Vol.17, No.1, January, 2002

[4] M. A. Abido, Ch. Weindl, G. Herold, "STATCOM-Based Damping Stabilizers for Power System Stability Enhancement", 11th International Power Electronics and Motion Control Conference EPE-PEMC, September 2004.

[5] W. Mielczarski and A. M. Zajaczkowski, *"Multivariable Nonlinear Controller for a Synchronous Generator"* Optimal Control Applications and Methods, Vol. 15,1994

[6] D. I. Kim, I. J. Ha and M. S. Ko *"Control of Induction Motor via Feedback Linearization with Input-output Decoupling"* International Journal of Control,Vol.51, No.4,1990

[7] P. W. Lehn and M. R. Irvani, *"Experimental Evaluation of STATCOM Closed Loop Dynamics", IEEE Transctions on Power Deliver,* Vol.13, No.4, pp.13781384,1998

[8] Alberto Isidori, " Nonlinear Control Systems: an Introduction", Berlin, Springer-Verlag,1989

[9] S. Mori, K. Matsuno, M. Takeda, et al, " Development of a Large Static Var Generator using Self-commutated Inverters for Improving Power System Stbaility", IEEE Transctions on Power Systems,1993

[10] R. Marino, "An Example of a Nonlinear Regulator", IEEE Transctions on Automatic Control, Vol.AC-29,No.3,pp.276-279,1984

[11] O. Akhrif, F. A. Okou, L. A. Dessaint and R. Champagne, " Application of a Multivariablr Feedback Linearization Scheme for Rotor Angle Stability and Voltage Regulation of Power Systems", IEEE Transctions on Power Systems, Vol.14, No.2,PP. 620-628,1999

[12] P. M. Anderson and A. A. Fouad, "Power System Control and Stability", IEEE Press, Newyork,1994