ERJ
Engineering Research Journal
Faculty of Engineering
Minoufiya University

A ROBUST CONTROL STRATEGY FOR COORDINATED TCSC AND SVC TO DAMP ELECTROMECHANICAL OSCILLATIONS IN A MULTI-MACHINE POWER SYSTEM

Dr. A. A. Nour Eldeen   Dr. Ahmed H. Elassal
Alaa1958@hotmail.com   Ah_elassal@yahoo.com
Department of Electrical Engineering, Faculty of Engineering
Helwan University of Helwan, Cairo, 11792, Egypt

Abstract

This paper examines the enhancement of power system stability properties via using thyristor controlled series capacitors (TCSCs) and static VAR compensators (SVCs). A control strategy is developed to enhance the damping of the electromechanical oscillations using Linear Quadratic Gaussian technique (LQG). Using this control strategy each device (TCSC and SVC) will contribute to the damping of electromechanical power oscillations. The power system is examined over a wide range of operation conditions and different fault locations. Simulation results showed that the proposed controller with TCSC and SVC provides good damping for the power system and consequently the dynamic performance is improved. The adopted controller gives a better response compared to the conventional thyristor controlled series capacitors and static VAR compensator.

يقدم هذا البحث دراسة وتصميم متحكم مركزي للمعوضات المتناسقة والمكثفات المتوالية المتناسقة المتحكم فيها عن طريق الموحد المحكوم. فلقد ظهر حتى الآن عدد كبير من الأبحاث التي تستخدم معوض القدرة غير الفعالة وكذلك المكثفات المتوالية المتحكم فيها عن طريق الموحد المحكوم في نظم القوى متعددة المكنات. وذلك لان معوضات القدرة غير الفعالة مع المكثفات المتوالية تساعد على المحافظة على جهد الشبكة داخل حدود معينة وكذلك تدعيم هذا الجهد وأيضا تعمل على تحسين عزم المضاءلة واتزان الشبكات وتحسين حالة الاستقرار. ولذلك فأن نظم القوى متعددة المكنات لابد وأن تشمل على معوض القدرة غير الفعالة والمكثفات المتوالية. ونظرا للتعقيد في نظم القوى الكهربية فأن هذه المعوضات والمكثفات المتوالية لابد وان تكون متناسقة للتقليل من عدد هذه المكونات. لكن عند حدوث أخطاء في نظم القوى أو تغير نقطة التشغيل وتحت ظروف تشغيل حرجة يحدث تشويه لاداء هذه المعوضات والمكثفات المتوالية المتناسقة. ولذلك كان من الضروري استخدام متحكم مركزي للتغلب على هذه المشكلة.

المتحكم المقترح يقلل من التغيرات الكبيرة في قيم الجهد و يحسن من حالة الاستقرار. يقدم هذا المتحكم الأسلوب المناسب للتحكم في المكونات المتفرقة من معوضات والمكثفات المتوالية عن طريق استخدام صيغة ملائمة من صيغ التحكم الأمثل باستخدام المعادلات التربيعية الخطية مع الحفاظ على هذه المكونات المتفرقة بدون تغيير. تم تطبيق المتحكم المقترح على شبكة كهربية مكونة من تسعة قضبان ذات سبعة وحدات لتوليد القوى الكهربية عند التعرض لاخطاء أو عند تغيير نقط التشغيل لمعرفة تأثير هذا المتحكم. و توضح هذه النتائج أن استخدام هذا النوع من المتحكمات يعطى تحسينات ملحوظة في أداء النظام العابر والمستقر و كذلك زيادة معامل المضاءلة لإخماد ذبذبات النظام مع الحفاظ على الجهود في الحدود الآمنة.

Keywords: Power System Control, TCSC control, SVC Control

I. INTRODUCTION

Damping of electromechanical oscillations and maintaining constant voltage at all busses have been recognised as important issues in electric power system operation. In principle, a thyristor controlled series capacitors (TCSC) and static VAR compensator (SVC) could provide fast control of active power as well as reactive power through a transmission line and load busses. SVCs are mainly used to perform voltage or reactive power regulation. However, there has been a growing trend to used SVCs to enhance system stability. In general, a compensator maintaining constant terminal voltage is not effective in power oscillations damping. To overcome such defect, addition of a TCSC to a power system is proposed [1, 2, 3]. The rapid response feature of SVC and TCSC also provide many other opportunities for improving power system performance. The SVC and TCSC are used to increase the system damping for undesirable large oscillations under certain critical situations like load-changes and line-outages.

Some conventional methods have been used in previous research for designing a supplementary damping controller such as energy function method

Engineering Research Journal, Vol.27, No. 1, Jan 2004, PP 25-29
© Faculty of Engineering, Minoufiya University, Egypt

[4], damping torque analysis [5], μ synthesis technique [6], adaptive control [7], etc. All of these methods are based on a normal operating point that is selected from a wide range of operating condition. However, the high degree of nonlinearity of power systems and presence of uncertainty, such as change of operating conditions or unknown system parameters, make it very difficult to achieve a good controller design using only one single nominal operating point. Controllers designed for the optimal performance at some operating conditions do not guarantee the system stability and performance under other operating conditions.

This paper examines the enhancement of multi-machine power system stability via coordination between SVCs and TCSCs. Such coordination is based on linear programming, the participation factor and eigenvalues analysis techniques. The coordination method is used to determine the minimum units of SVCs and TCSCs required for the power system in order to damp electromechanical oscillations and maintaining constant voltage at all busses [8]. Also, this paper developed a control strategy for these devices based on Linear Quadratic Gaussian technique (LQG) in order to improve power system stability properties in an effective and robust manner. Local signals are considered as input signals, [9, 10].

To prove the effectiveness of employing SVCs and TCSCs with the proposed control scheme, non-linear simulation has been applied to a 9-bus system including seven generating units [3]. The results show significant improvements in the transient and steady state voltage performances.

II. POWER SYSTEM STRUCTURE

Fig. (1) shows the one line diagram of a multi-machine power system with SVCs and TCSC. Briefly it consists of seven generating units (five steam, one hydro and one nuclear). Each generator is represented by a seventh order non-linear mathematical model based on Park's equations [11]. Both the speed governing system and the automatic voltage regulator of each generator are represented by a third order model [8]. Thus, the overall system is represented by a 91 nonlinear differential equations (without SVC and TCSC).

The first step in the digital simulation of the multi-machine power system is to obtain complete information on the network by using Gauss-Siedel iterative method. Then the initial values of all system variables are computed through the complex power and voltages at the busses. The differential equations of the machines, the SVC and TCSC are solved using the Rung-Kutta fourth order method.

To achieve the satisfactory improvements in dynamic and steady state system performances by power system compensators with control strategy, a direct procedure for guiding coordination of these compensators is used to determine their optimal locations. Firstly, the best locations of the SVCs are determined by using steady state stability, voltage control and total power loss indices. Also, a linear programming technique was used to determine the minimum number of SVCs [8]. Secondly, the participation factor method and eigenvalue analyses are employed to identify the best locations of TCSCs with SVCs [8]. In the present paper, this study has shown that, the minimum number of compensators required in the power system considered here are two SVC located at busses 8 and 9 and one TCSC located at the mid point of transmission line (3-7).

The data of the network is given in [3] and block diagrams of automatic voltage regulators and speed governing systems are given in [8]. The block diagram TCSC and SVC are given in Appendix.

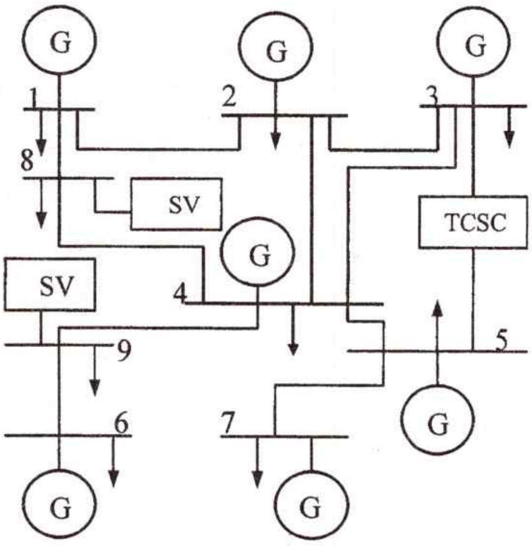


Fig. 1 One-line diagram of the 9-bus power system with SVC and TCSC

III. PROPOSED ROBUST CONTROLLER

Let the system to be controlled be as follows

$$x^{\bullet}(t) = Ax(t) + Bu(t)$$
$$y(t) = Cx(t) \qquad (1)$$

Where x and y are vectors with dimension n, m respectively and the LQ regulator cost functional can be defined as:

$$J = \int_{0}^{\infty}[x(t)^{T} Qx(t) + u(t)^{T} Ru(t)]dt \qquad (2)$$

Where **Q** is a positive semi-definite state-weighing matrix and **R** is a positive definite control-weighting matrix. If all state variables can be measured, the problem not only find the control law which minimizing the cost function (2) under constraint (1) but also find the feedback gains u(t) for all conventional controllers, SVC and TCSC as centralized controllers, form which can be realized as:

$$u(t) = -Gx(t), \qquad G = -R^{-1}B^TK \qquad (3)$$

Where **K** is the unique positive definite solution of the following control equation:

$$KA + A^TK + Q - KBR^{-1}B^TK = 0 \qquad (4)$$

It is well known that measuring of all state- and output-variables is not an easy task and may not be accessible. Output feedback overcame this problem. One way to do so is to perform design via utilization of an **LQG** method. When output variables are measured only with the above design plant model (1), a model based compensators is constructed with the following dynamics:

$$\dot{z}(t) = Az(t) + bu(t) + Hy - Cz(t)$$
$$u(t) = -Gz(t) \qquad (5)$$

In LQG method, the plant is assumed to have the following form:

$$\dot{x}(t) = Ax(t) + Bu(t) + L\xi(t)$$
$$y(t) = Cx(t) + Du(t) + \varphi(t) \qquad (6)$$

Where **ξ(t)** is a white Gaussian process noise with the intensity matrix **Γ**, and **ϕ(t)** is a white Gaussian measurement noise. Let the covariance of the state estimation error be Σ, then, the optimal estimation problem is to find the optimal feedback gain matrix **H** that minimizes the state estimation error as follows:

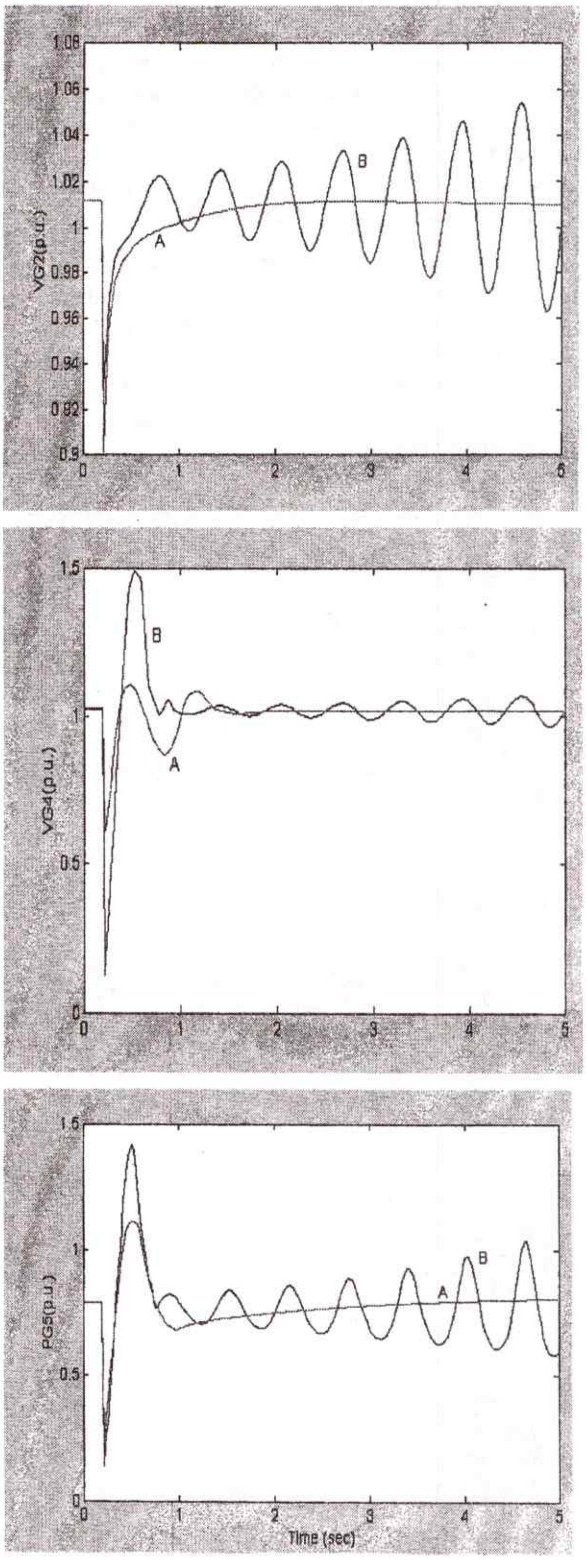
$$A\Sigma + \Sigma A^T + L\Gamma^T - \Sigma C^T - \Sigma C^T\Theta^{-1}C\Sigma = 0 \qquad (7)$$

And the feedback gains matrix **H** can be compute as follows:

$$H = \Sigma C^T\Theta^{-1} \qquad (8)$$

IV. SIMNLATION RESULTS

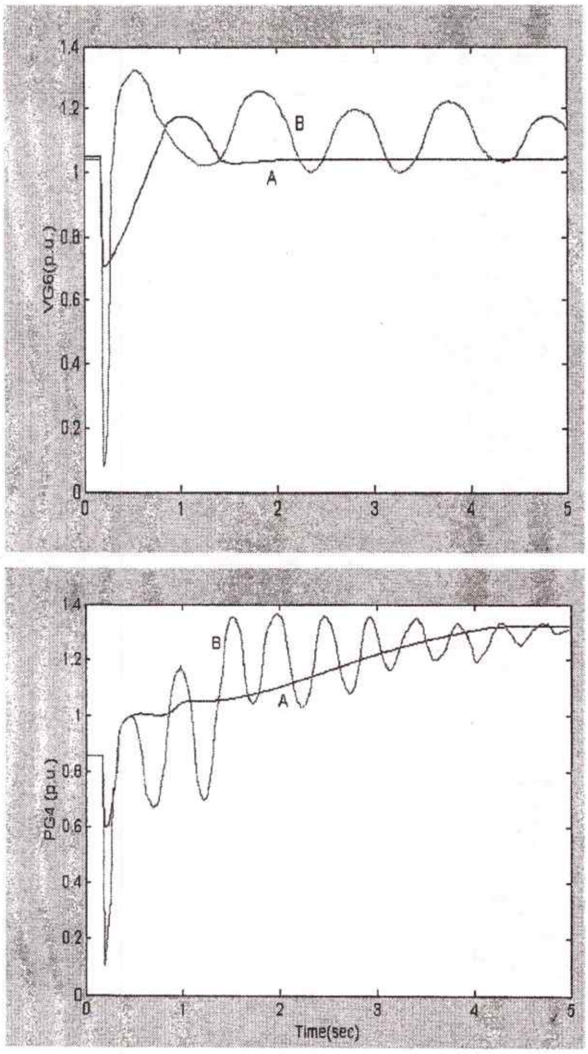
The proposed control strategy is tested under several fault conditions using a full order nonlinear model of the power system shown in Fig. (1). In the first test, the system is subjected to a solid three-phase short circuit fault at bus 9 for a period of 120 msec. After this period, the system restores its original structure. Fig. (2) depicts the system response to this fault without control (curve B) and with the proposed control (curve A). In case of no control, the system shows unstable performance. The response in this case is considered as a dynamic low-frequency-signal is superimposed on a high-frequency-carrier. This causes the system to hunt, which is an unacceptable situation.



I- compensators with controller
II-compensators without controller
Fig. 2 System response to a three phase

Applying the proposed control scheme, the system gets rid of this undesired dynamics and shows a good performance and the system dynamics vanishes completely in a very short time. The added damping cause the system to receive short dynamics time as a result of the robust coordination and clarifies the validity of the proposed control scheme in handling the fault. Minimizing the time of transients avoids the system from getting into tripping conditions that take place in a short time causing blackouts.

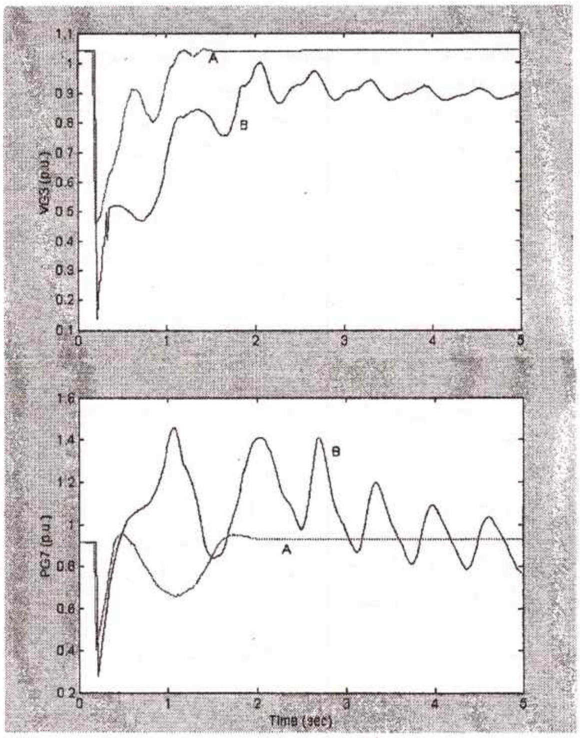
In order to examine the effectiveness of these compensators with the proposed controller, the operating condition of the network is disturbed. Fig. (3) shows the system response to a 50 % sudden increase in load powers (active and reactive) at busses 1, 6, and 4 forcing the system to a new operating condition.



A- compensators with controller

B- compensators without controller

Fig. 3 System transient response to a sudden increase of 50 % in load powers at busses 1,6, and 4.



A- compensators with controller

B- compensators without controller

Fig. 4- System transient response to a complete line outage between buses 2 and 5.

From the responses, it can be ascertained that using these compensators with the proposed controller damps the electromechanical oscillations very quickly and the system units have reached their new operating point very quickly.

In the second test, the power system is subjected to a line outage fault between busses 2 and 4. Figure 4 shows the system response to the line outage fault. The test results showed that the proposed control scheme has accelerated the system to approach steady state much faster compared to case of no control. This results in much power savings and low heating loss in the conductor of the power networks and consequently avoids the over current switching. It is obvious that compensators with this controller provide an effective way to improve the power system performance, where the transient and steady state voltage responses of all buses are significantly improved.

The simulation results showed, in general, the effectiveness of the proposed control strategy where the system restores its operating point smoothly.

V. CONCLUSION

This paper has developed LQG control of SVC and TCSC for maintaining constant terminal voltage at all busses and damping multi-machine power system oscillations. The proposed control strategy based upon LQG can be used for SVC and TCSC to damp the power swing. The performance of such a controller is robust with respect to network structure, fault location and system loading. The simulation results showed that SVCs and TCSCs with this controller can improve the power system performance as it is capable of providing sufficient damping to the system oscillations.

VI. REFERENCES

[1] G. N. Taranto and J. H. Chow, "A Robust Frequency Domain Optimization Technique for Tuning Series Compensation Damping Controllers", IEEE Trans. on Power Systems, Vol. 10, No. 3, August 1995.

[2] M. Noroozian and G. Andersson, "Damping of Power System Oscillations by Controllable Components", IEEE Trans. on Power Delivery, Vol. 9, No. 4, Oct. 1994.

[3] C. A. Canizares and Z T. Faur, "Analysis of SVC and TCSC Controllers in Voltage Collapse", IEEE Trans. on Power Systems, Vol. 14, No. 1, February 1999.

[4] M. Noroozian, M. Ghandhari, G. Andersson, J. Gronquist, and I. Hiskens, "A Robust Control Strategy for Shunt and Series Reactive Compensator to Damp Electromechanical Oscillations", IEEE Trans. on Power Systems, Vol. 16, No. 4, Oct 2001.

[5] K.R.Padiyar and R.K.Varma, "Damping Torque Analysis of Static Var System Controllers", IEEE Trans. on Power Systems, Vol. 6, No. 2, May 1991.

[6] X.Yu, M.Khammash and V.Vittal, "Robust Design of a Damping Controller for Static Var Compensators in Power Systems", IEEE Trans. on Power Systems, Vol. 16, No. 3, Aug. 2001.

[7] J.R. Smith, D.A. Pierre, I. Sadighi, M.H. Nehrir, and J.F. Hauer, "A Supplementary adaptive VAR unit Controller for Power System Damping", IEEE Trans. on Power Systems, Vol. 4, No. 3, Aug. 1989.

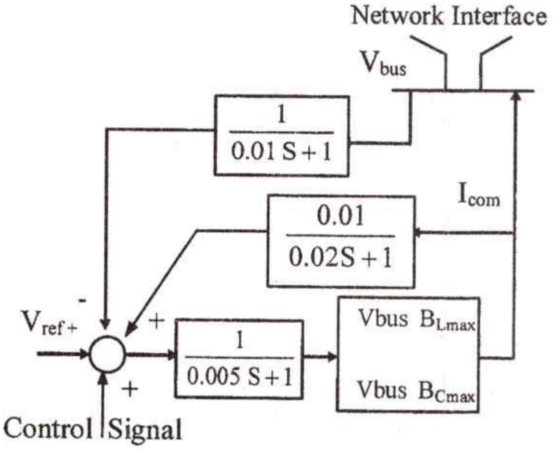
[8] A.A. Nour Eldeen, W.M. Refaey and O.H. Abdullah, "Coordination of Compensators in a Multimachine power System", Sixth International Conference Middle East power System Conference, March 2000.

[9] J.R. Smith, D. A. Pierre, D. A. Rudberg, and A. P. Johnson, "An enhanced LQ adaptive VAR unit controller for power system damping", IEEE Trans. on Power Systems, Vol. 4, No. 2, May 1989.

[10] K. M. Son and J. K. Park, "On the Robust LQG Control on TCSC for Damping Power System Oscillations", IEEE Trans. on Power Systems, Vol. 15, No. 4, Nov. 2000.

[11] O. H. Abdalla, S. A. Hassan and N. T. Tweig, "Coordinated Stabilization of a Multimachine Power System", IEEE Trans. on Power Systems, Vol. PAS-103, No. 3, pp. 483-494, 1984.

VII. APPENDIX



Vbus B_{Lmax} = Max. Inductive admittance,
Vbus B_{Cmax} = Max. Capacitive admittance.

Fig. A.1 - Static VAR Compensation.

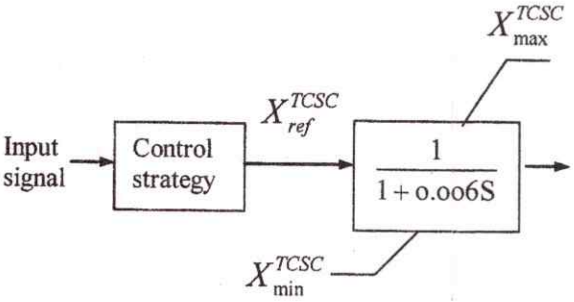


Fig. A.2 - TCSC model as damping controller.