American J. of Engineering and Applied Sciences 2 (4): 812-816, 2009
ISSN 1941-7020

An Eigenstructure Assignment for a Static Synchronous Compensator

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Abstract: Problem statement: Power flow through an AC transmission line is influenced by three basic electrical parameters, which are line impedance, magnitudes and phase-shift angle between the sending and receiving voltages. Therefore, the change in any of the three basic parameters means a change in the power flow through the transmission line. The aims of this research paper are: increase the power transfer capability of transmission systems, minimize the transmission losses, support a good voltage profile and retain system stability under large disturbances. Study the use of eigenstructure techniques for state feedback control of the power system static compensator. Therefore, the mathematical analysis was performed for eigenvector assignment, power flow transmission line and for the static compensator analysis based on the transformation of the three-phase into d-q frame. **Approach:** A novel control method for regulating the power system in case of abnormal conditions was carried out. The system considered is a static synchronous compensator. The study includes a detailed mathematical analysis of the impact of the shunt compensator on the power flow; investigation of the system constraints and their effects on the static compensator control; in addition simulation of static compensator to control a transmitted active power flow on the transmission line. The conducted method provides a way of constructing the state feedback gain matrix to satisfy a certain prescribed performance. **Results:** The solutions of the obtained equation were conducted using the computer simulation method for both open-loop and static compensator techniques. The result shows fast tracking of the power flow transient response when using the static compensator technique comparing with open-loop technique. However, the same trend of the behavior was observed for all cases. **Conclusion:** A new method for developing a parameterized feedback matrix that assigns a closed-loop prespecified set of eigenvalues was obtained. It improves the overall system performance and yields a class of controllers contributing uniformly to the assignment process. The voltage could be kept constant independent of the loads with static compensator. The results show clearly the applicability of the proposed control scheme which is acceptable for the static compensator.

Key words: Load Flow Power Transmission, FACTS, open-loop system, transient response

INTRODUCTION

The operation of an AC transmission system is generally constrained by limitations of one or more network parameters (such as line impedance) and operating variables (such as voltages and currents). As a result, the power line is unable to direct power flow among generating stations. To achieve these objectives, i.e., to increase the power transfer capability of transmission systems, to minimize the transmission losses, to support a good voltage profile and to retain system stability under large disturbances, the concept of power electronics with the control technology can provide a promising solution[1-8].

The transmission lines will be operated close to their thermal limits and transmission systems can have a dramatic effect. We need modern control equipment called Flexible AC Transmission Systems (FACTS)[1,2].

Recently, an increasing amount of attention has been paid to the various problems of design and control of electric power systems[11,12]. However, with the advent of cheap microprocessors and the ever decreasing cost of computing, these problems have started to achieve significant solutions. Due to the extreme complexity of power systems, in depth investigations into the application of these facilities and methodologies are required. Hence, it is necessary to have suitable control strategies which return the system to its desired operation[9]. However, it is known that the eigenstructure of a system determines its dynamic properties, since the speed of response is governed by the eigenvalues and the shape of the system response by its eigenvectors[13,14]. Therefore, linear state feedback design via the desired eigenstructure assignment would result in the desired system response. Also, in general, giving the desired closed-loop eigenvelues does not uniquely define the closed-loop configuration[10]. The non-uniqueness transient response s is attributable to the freedom offered by state feedback beyond eigenvalue assignment in selecting the associated eigenvectors.

In this study, the impact of the shunt compensator on the power flow is analyzed. The system constraints and their effects on the STATCOM control are investigated. Also, this study deals with the simulation of STATCOM to control a transmitted active power flow on the transmission line. The objective of this study is to study the use of eigenstructure techniques for state feedback control of the power system static compensator "STATCOM".

MATERIALS AND METHODS

The mathematical analysis for eigenvector assignment , power flow transmission line and for the static compensator based on the transformation of the three-phase into d-q frame was performed as follows:

Consider a linear time-invariant, completely controllable system:

$$\begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) \end{aligned} \qquad (1)$$

Where:

$x(t) \in R^n$ = The state vector
$u(t) \in R^m$ = The input vector
$y(t) \in R^p$ = The output vector
A, B and C = Real constant matrices of compatible dimensions, m<n, rank (B) = m

When a linear constant gain state feedback control law is implemented, a closed-loop system is constructed as:

$$u(t) = K\,x(t) \qquad (2)$$

$$\begin{aligned} \dot{x}(t) &= Ax(t) + B\,K\,x(t) \\ x(t) &= A_c x(t) \end{aligned} \qquad (3)$$

where, $A_c = A + B\,K$.

The eigenstructure assignment problem under consideration is as follows: Given the open-loop system in Eq. 1, develop a parametric form for the real $m \times n$ gain matrix K of the state feedback control in Eq. 2, such that the closed-loop system in Eq. 3 is assigned an arbitrary pre-specified set of eigenvalues $\lambda = [\lambda_i]$.

The solution of the problem is obtained under the condition that the set of closed-loop eigenvalues λ and the set of open-loop eigenvalues (of the matrix A) have no elements in common. Now begins the assignment of the m-eigenvalues, the closed-loop characteristic polynomial is expressed in view of Eq. 3 as the nth order determined:

$$\Delta(\lambda) = |\lambda I_n - A - BK| \qquad (4)$$

which can be rewritten in terms of the open-loop characteristic polynomial:

$$\begin{aligned} \Delta(\lambda) &= |(\lambda I_n - A) - BK| \\ &= \Delta_o |I_m - K\phi(\lambda)B| \end{aligned} \qquad (5)$$

Where:

$$\phi(\lambda) = [\lambda I - A]^{-1} \qquad (6)$$

is the resolvent of the open-loop system matrix A. To assign λ_i to the closed-loop Eq. 3, it must be satisfied, for i = 1,2,…,m, that:

$$|I_m - K\phi(\lambda)B| = 0 \qquad (7)$$

If and only if, the columns of the matrix $|I_m - K\varphi(\lambda)B|$ are linearly dependent (the determinant in Eq. 7 vanishes), that is, for some (non-null) m-dimensional vectors F_i, then:

$$\begin{aligned} &[I_m - K\varphi(\lambda)B]F_i = 0 \\ &\text{or} \\ &K\varphi(\lambda)F_i = F_i \end{aligned} \qquad (8)$$

This implies that:

$$K\,[\varphi\,(\lambda_1)BF_1 \;\; \varphi\,(\lambda_2)BF_2 \;...\; \varphi\,(\lambda_n)BF_n] = [F_1\; F_2\; ...F_n\;] \qquad (9)$$

Where:

F_n = An $m \times n$ parameter matrix whose columns are the right parameter vectors $F_{ij}^{(k)}$
V_n = An $n \times n$ matrix whose columns are functions of $F_{ij}^{(k)}$

The gain matrix K is immediately obtained as:

$$KV_n = F_m$$
$$K = F_m V_n^{-1} \tag{10}$$

The STATCOM, which is a short name for STATic synchronous COMpensator, is a second generation FACTS, which is classified as a shunt compensator. The need for a shunt-connected compensator is to emulate a variable inductor or capacitor in shunt with a transmission line. This emulated inductive or capacitive reactance, in turn, regulates the line voltage at the point of coupling.

The basic STATCOM circuit is shown in Fig. 1. It consists of a Voltage Source Converter (VSC) and a dc storage capacitor, the VSC converts ac voltage to dc voltage on the dc side[1-6].

The capacitor voltage can be adjusted by controlling the phase angle difference between the line voltage and the voltage source converter. The STATCOM has the ability to either generate or absorb reactive power by suitable control of the shunt voltage $V_{sh}\angle\varphi_{sh}$ with respect to the AC voltage $V_{stat}\angle\varphi_{stat}$ as shown in Fig. 2.

A non-linear model based on switching functions is developed to obtain the STATCOM model. Based on such switching functions model, a state-space representation in the abs-reference frame is deduced.

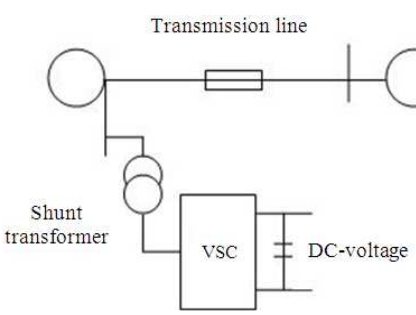

Fig. 1: Basic scheme of STATCOM

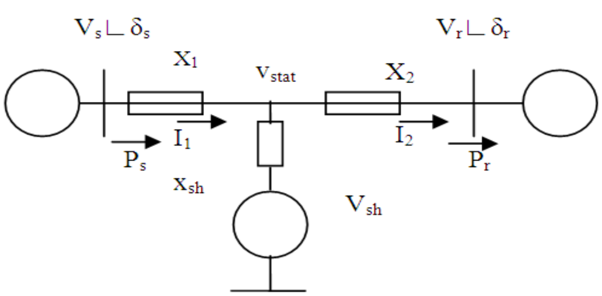

Fig. 2: Diagram the STATCOM

Taking into account six-pulse converter consists of two three-pulse midpoint converters connected in series, as shown in Fig. 3. The currents that flow in the neutral line are equal and opposite and as a result, the neutral line becomes redundant.

The equations of the STATCOM shown in Fig. 2 in the d-q frame which model the STATCOM are as follows:

$$\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & 0 & 0 \\ 0 & -\frac{R}{L} & 0 \\ 0 & 0 & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} v_a - e_a \\ v_b - e_b \\ v_c - e_c \end{bmatrix} \tag{11}$$

By applying Park's transformation, a three-phase system can be transformed into an equivalent d-q system. The transformation matrix for a symmetrical system is given by:

$$T_{d-q} = \frac{2}{3}\begin{bmatrix} \cos wt & \cos(wt-120) & \cos(wt+120) \\ \sin wt & \sin(wt-120) & \cos(wt+120) \end{bmatrix} \begin{bmatrix} T_{abc} \end{bmatrix} \tag{12}$$

Therefore, the d-q representation of a STATCOM is:

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \\ V_{dc} \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & \omega & \frac{s_d}{L} \\ -\omega & -\frac{R}{L} & \frac{s_q}{L} \\ \frac{s_d}{C} & \frac{s_q}{C} & 0 \end{bmatrix} \begin{matrix} i_d \\ i_q \\ V_{dc} \end{matrix} + \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{L} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} \tag{13}$$

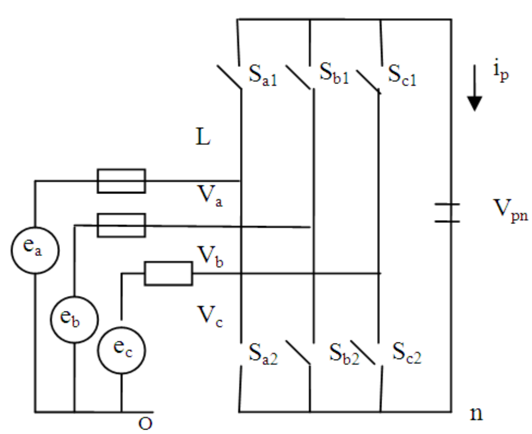

Fig. 3: STATCOM switching pattern

RESULTS AND DISCUSSION

The solutions of the obtained equation were conducted using the computer simulation. The data for the power system are given:

$$\bar{V}_S = 1.055 < 10, \quad \bar{V}_r = 1 < 0$$

L = 3 mH, R = 2 Ω, C = 1000 µF

Case 1: Assume that:

$$V = \begin{bmatrix} 1 & 2 & 1 \\ 1 & 1 & 3 \\ 1 & 1 & -1 \end{bmatrix}$$

Then

$$F = \begin{bmatrix} -0.0059 & 0.0927 & 1.902 \\ -0.6324 & -1.8112 & 2.3488 \end{bmatrix}$$

Hence

$$K = \begin{bmatrix} 2.4519 & -1.0029 & -0.4521 \\ 2.4548 & -0.9998 & -1.088 \end{bmatrix}$$

Case 2: Assume that:

$$V = \begin{bmatrix} 1 & 2 & 1 \\ 2 & 2 & 0 \\ 1 & 1 & -1 \end{bmatrix}$$

Then

$$F = \begin{bmatrix} -0.059 & 0.1854 & 1.9012 \\ -0.6334 & -0.1974 & 2.5438 \end{bmatrix}$$

Hence

$$K = \begin{bmatrix} -1.8173 & 1.71 & -1.8085 \\ -1.6144 & 1.7131 & -2.4452 \end{bmatrix}$$

The results were presented graphically in Fig. 4-6. Figure 4-6 show the variation of the sending-end voltage as a function of the transient response of the power system with open-loop (Fig. 4) and with STATCOM (Fig. 5 and 6).

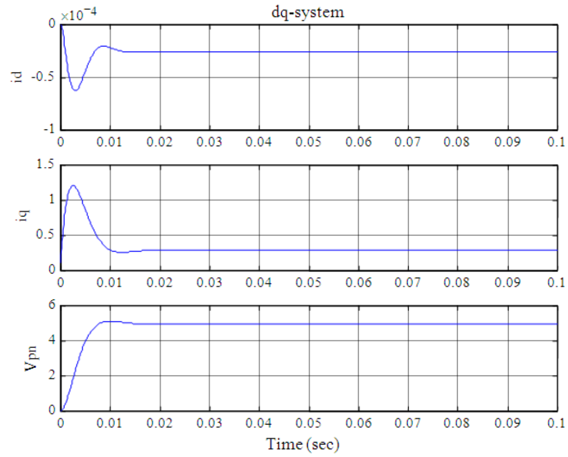

Fig. 4: Open-loop transient response

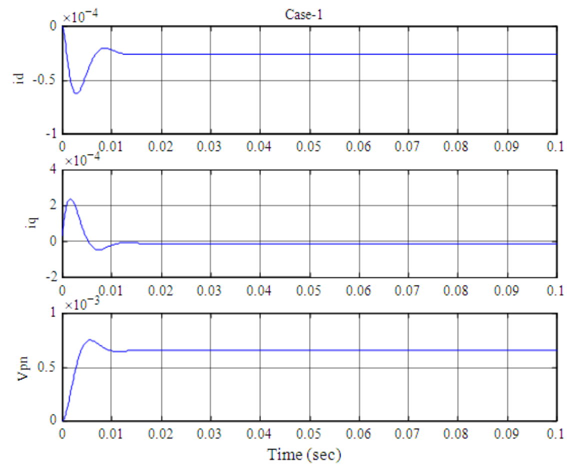

Fig. 5: Transient response using eigenstructure case1

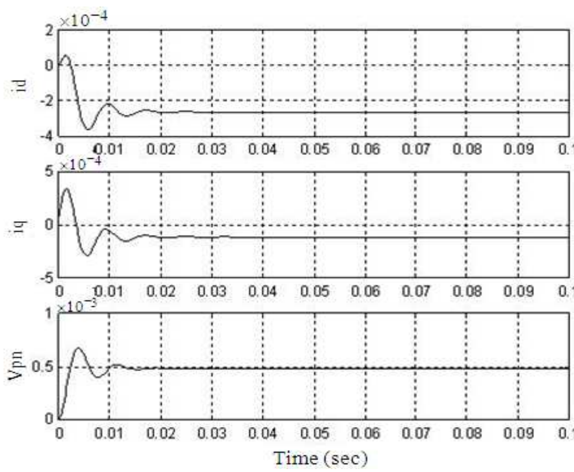

Fig. 6: Transient response using eigenstructure case 2

In general, the same trend of the behavior was observed for all cases. However, comparing the transient response when using the open-loop with STATCOM technique, one can be seen from the response that the STATCOM guarantees the fast tracking of the power flow to the desired reference using this technique.

Finally, it is very interesting to note the change in the transient performance of the STATIC compensation with eigenstructure using the approximation model.

CONCLUSION

In this study, the impacts of the STATCOM control variables on the transmitted power system have been analyzed. It has been shown that power transmission systems are generally sensitive to the magnitude of the terminal voltages, the sending and receiving-end voltages, the phase angle between them and the line impedance. It is evident that with STATCOM, the voltage could be kept constant independent of the loads. Shunt compensation is used to regulate the voltage at a given bus against load variations.

The results clearly show the applicability of the proposed control scheme which is acceptable for the STATCOM. In this study, a new development of a feedback gain matrix that assigns a preselected set of eigenvalues has been given.

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