SVC Additional Damping Controller Design Using Prony Identification

Yong Lin, MingChao Xia, Edward W.C. Lo

***Abstract*—The paper presents an identification method based SVC damping controller parameters tuning method. The most detailed SVC structure is modeled, the Prony identification method is introduced to get the controlled system, the SVC damping controller is tuned in the optimal programming and the control design result is validated in IEEE 14- bus system. Due to the research work is established on the most detailed SVC structure module and system identification idea proposed method can be practical to use.**

***Index Terms*—SVC, power system identification, Prony analysis, low frequency oscillation damping**

I. INTRODUCTION

THE low frequency oscillation is becoming the major problem of the inter-connection power systems. This problem lowered the transmission limits and the dynamic stability level. In China the problem is even significant as gigas of power electric is transmitted from the West to the East through both HVAC and HVDC lines. Several approaches are studied or applied for solving this problem, including the PSS tuning on the generation side, the HVDC modulation and the FACTs damping controller design on the transmission side. SVC as the one of the typical representatives of the FACTs family is installed world wide. The SVC installation is mainly for the voltage regulation and reactive power compensation. But the SVC additional control function can solve the oscillation problem and improve the small signal stability of the system[1].

This paper selects Prony identification to get the order reduced control system module and uses optimal controller design method for the SVC damping parameter tuning..

II. PRONY IDENTIFICATION

Prony method is a fast system identification method, it directly gives the initial amplitudes and attenuation coefficients of the oscillation modes, based on the damping controllers design using nonlinear constrained optimization[2].

The whole identification and SVC damping controller design approach can be illustrated as Fig.1.

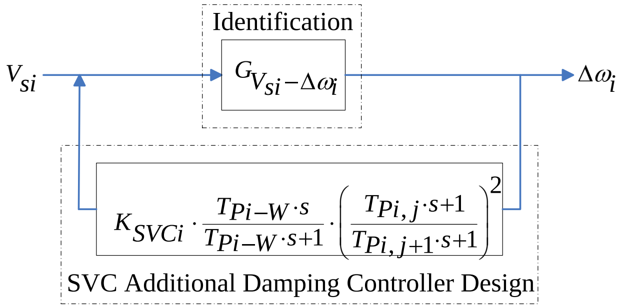

Fig. 1. Identification and controller design principle

We apply the prony identification to get the reduced order linear description of the power system, and then select the input and output channels to add the SVC to get the closed loop. Thus, by tuning the SVC controller parameters the power system can be controlled and the oscillation can be damped.

For n order LTI dynamic system, after the initial state $X(t0) = X(0)$, the system can be described as follows:

$$\dot{X} = AX \tag{1}$$

where X is the state variable.

Let λ_i, p_i, q_i^T be the eigenvalues, right eigenvectors and left eigenvectors of the matrix A, then the solution is:

$$\begin{aligned} X(t) &= \sum_{i=1}^{n}\left(q_i^T X_0\right) p_i \cdot \exp(\ddot{e}_i t) \\ &= \sum_{i=1}^{n} R_i X_0 \cdot \exp(\lambda_i t) \end{aligned} \tag{2}$$

where $R_i = p_i q_i^T$ is the residues matrix.

Assume the output is:

$$y(t) = CX(t) \tag{3}$$

Using the formula to fit the output, and get the parameters of eigenvalues and residues:

$$y(t) = \sum_{i=1}^{n} d_i \exp(\ddot{e}t) \tag{4}$$

Prony analysis gives the eigenvalues λ_i and residues R_i :

$$\begin{cases} \lambda_i = \alpha_i + j\beta_i \\ R_i = m_i + jn_i \end{cases} \tag{5}$$

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where $R_i, m_i, n_i \in R^{M\times 1}, i = 1, 2, \cdots, p$.

The eigenvalue λ_i and residue R_i of $G(s)$ have the following relations:

$$G(s) = \sum_{i=1}^{p} \frac{R_i}{s-\lambda_i} = \sum_{i=1}^{p/2} \frac{2m_i s-(2\alpha_i m_i+2\beta_i n_i)}{s^2-2\alpha_i s+(\alpha_i^2+\beta_i^2)} \qquad (6)$$

By prony analysis the transfer function of the controlled system with U_{SVC} as input and speed deviation as output can be achieved in Fig.2.

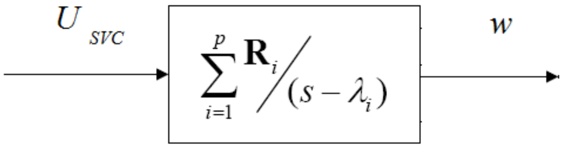

Fig. 2. The transfer function of SVC

III. SVC DAMPING CONTROL

As one of the typical FACTs devices, SVC has the advantages in technical maturity and low costs. The SVC is mainly developed for the voltage regulation and reactive compensation[3]. Recently many attentions have been paid to use the SVC for the oscillation damping so as to improve the small signal stability and increase the transfer limits.

To install the SVC is one of the efficient ways of damping the low frequency oscillation, and the control strategy is the key to success. To achieve different control targets, there are types of control strategies as voltage control, reactive control, constant admittance control, and so on. And the additional damping control is a supplementary control strategy aiming at damping the speed and power angle deviation under the disturbance[4].

IV. THE SUPPLEMENTARY DAMPING CONTROL PRINCIPLE

As mentioned above, the SVC can not only provide the voltage support to the system, but can also supply the additional damping to the system if the supplementary strategy is properly added[5].

The principle of SVC damping function can be illustrated by single infinite system shown in Fig.3. The SVC is installed in the midpoint of the transmission line.

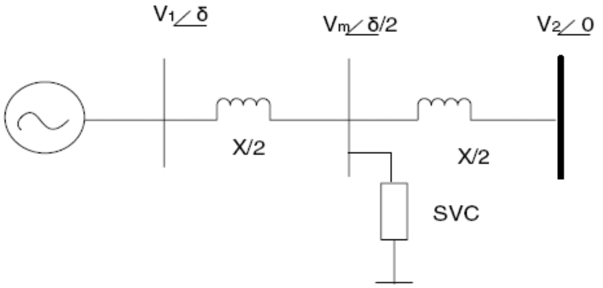

Fig. 3. Single machine infinite system with SVC damping.

The voltage at the generator side is V_1, the voltage at the end is V_2, and the voltage at the midpoint is V_m. They have the following relations:

$$\begin{cases} V_1 = |V_1| \sin(\omega t + \delta) \\ V_2 = |V_2| \sin \omega t \\ |V_1| = |V_2| = V \\ V_m = |V_m| \sin(\omega t + \delta / 2) \end{cases} \qquad (7)$$

The transmission power is:

$$P_E = \frac{VV_m}{0.5X} \sin\frac{\delta}{2} \qquad (8)$$

Linearization is:

$$\Delta P_E = \frac{\partial P_E}{\partial V}\Delta V + \frac{\partial P_E}{\partial V_m}\Delta V_m + \frac{\partial P_E}{\partial \delta}\Delta\delta \qquad (9)$$

And easy to get:

$$M\frac{d^2(\Delta\delta)\partial P_E}{dt^2} + \frac{\partial P_E}{\partial V_m}\Delta V_m + \frac{\partial P_E}{\partial \delta}\Delta\delta = 0 \qquad (10)$$

We can see if

$$\Delta V_m = K\frac{d(\Delta\delta)}{dt} \qquad (11)$$

Namely, if the voltage V_m at the midpoint is changing linearly with the power angle deviation $\Delta\delta$, then SVC can has the effect of damping the oscillation.

The supplementary damping control strategy is shown as Fig.4. There are four factors included, proportional factor KSVC wash out factor sTw/(1+sTw), lead and lag factor $(1+sT_2)^2/(1+sT_3)^2$ and mass factor $1/(1+sT_1)$.

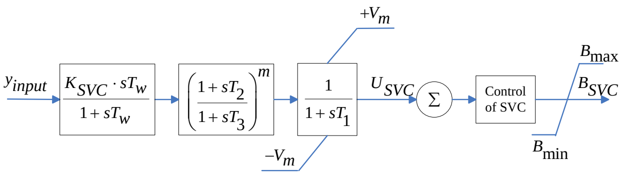

Fig. 4. The supplementary damping control strategy.

As mentioned, the transfer function of the controlled system $G(s)$ can be got by Prony identification, the input of which is voltage of the SVC(V_{SVC}) and the output of which is the speed deviation of the different generators w. Getting the $G(s)$ SVC controller parameters can be tuned accordingly. If the parameters of V_{SVC}, T_w , T_1, T_2, T_3 are properly tuned, then the SVC design work can be done.

The SI unit for magnetic field strength *H* is A/m. However, if you wish to use units of T, either refer to magnetic flux density *B* or magnetic field strength symbolized as $\mu_0 H$. Use the center dot to separate compound units, e.g., "A·m^2."

V. CONTROLLER DESIGN METHOD

There are approaches for the control parameters design, like pole placement eigenvalue assignment optimal linear design or optimal programming.

In the paper we select the optimal programming, as the method has the following advantages:

The tuning procedure is dependent of the problem. It is not changing as the problem of the controllers change. More constrains can be set for the future special control needs. By defining the different objective function more control object other than oscillation damping can be achieved like economic or other stability requirements.

$$K_{SVC} = 0.1$$

$$T_w = 0.5$$

$$T_1 = 0.003$$

$$T_2 = 0.22$$

$$T_3 = 0.25$$

VI. CASE STUDY

A. *System of case study*

The proposed method is validated in IEEE 14-bus system shown as Fig.5, and the simulation environment is chosen to PSCAD.

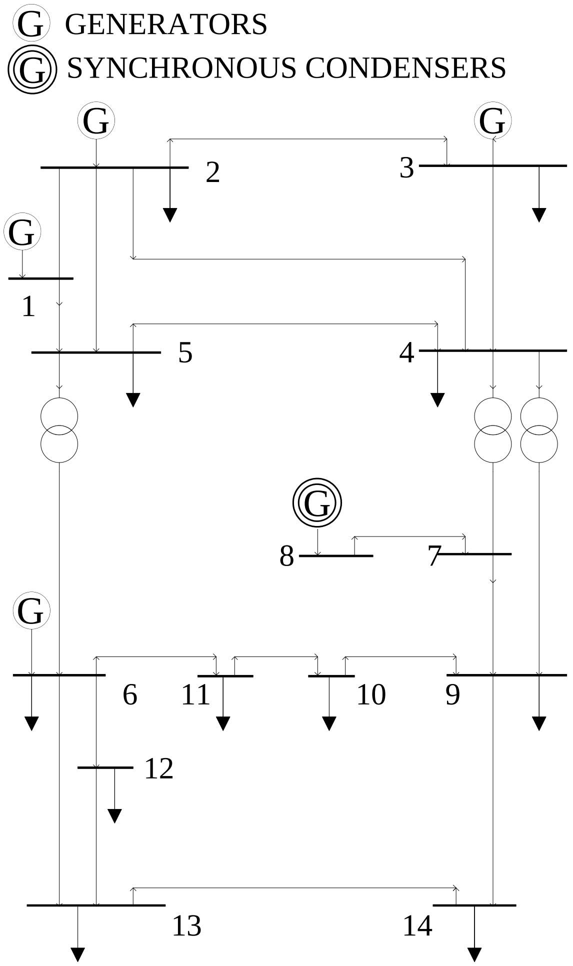

Fig. 5. Case study- IEEE 14-bus system.

The typical three phases to the ground fault is applied at node 9 to test the control effect. The fault is set at 2s and is cleared at 2.3s. The SVC is installed at node 14 to damp the oscillation.

The speed deviation between generator 3 and 4 is selected as the feed back signal of the system.

B. *Time domain analysis*

The following Fig.6 shows the time domain damping effect when applying the supplementary control strategy compared with traditional SVC compensation.

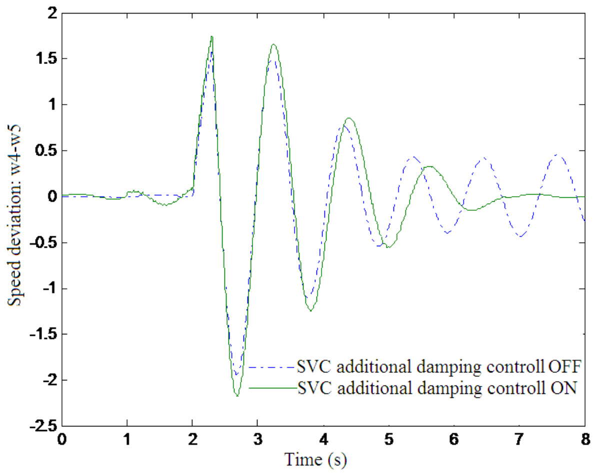

Fig. 6. The time domain damping effect compare.

The reactive power output is shown in Fig.7. The original signal output of the SVC in voltage regulation mode is the steady component the value is at around 60Mvar, and the modulation output signal is add upon the steady component.

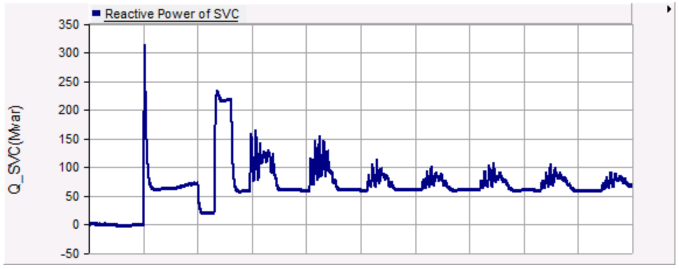

Fig. 7. SVC reactive power output.

The line voltage output at the installation node is shown in Fig.8. The original signal output of the SVC in voltage regulation mode is the steady component the value is at around 35kV, and the modulation output signal is add upon the steady component.

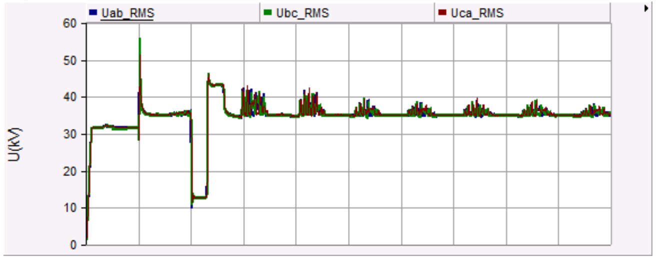

Fig. 8. The line voltage output at the installation node

C. *Frequency domain analysis*

The supplementary control strategy can move the dominant eigenvalues of the system leftward shown as Fig. 9, thus increasing the small signal stability of the system.

The main oscillation modes of the system without SVC installation by Prony Analysis results as in Table I.

TABLE I
TSAT WITHOUT PRONY ANALYSIS RESULTS

Magnitude	Phase (deg)	Frequency (Hz)	Damping (%)	Real (1/s)	Imaginary (rad/s)
3.8384	86.899	0.938	4.272	-0.2521	5.896
1.2642	43.619	1.207	66.974	-6.8371	7.581
0.9251	94.165	1.060	6.930	-0.4628	6.662
0.8527	-111.836	0.755	3.044	-0.1484	4.873
0.8440	-99.049	1.712	42.144	-4.9989	10.757

The main oscillation modes of the system with SVC installation by Prony Analysis results as in Table II.

TABLE II
TSAT WITH PRONY ANALYSIS RESULTS

Magnitude	Phase (deg)	Frequency (Hz)	Damping (%)	Real (1/s)	Imaginary (rad/s)
2.2146	100.185	0.915	14.455	-0.8403	5.572
0.6760	-177.300	0.758	5.465	-0.2607	4.763
0.1068	0.000	0.000	100.000	-4.0789	0.000
0.0979	101.042	17.954	18.844	-21.6451	112.808
0.0938	143.160	1.654	13.012	-1.3636	10.390

The dominant eigenvalues of the SVC before and after the additional damping control is applied are distributed shown in Fig.9.

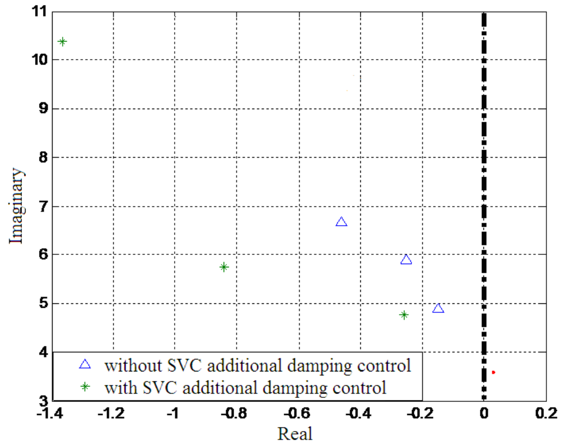

Fig. 9. The dominant eigenvalues of the SVC before and after the additional damping control

It's obvious that the dominant eigenvalues of the SVC could be shifted left on the complex coordinate.

VII. CONCLUSION

In this paper the authors discussed the SVC supplementary control strategy to damp the oscillation. The Prony analysis is introduced to get the controlled system model for the SVC damping controller tuning. The IEEE 14-bus case study with most practical and detailed SVC model installed shows the control results. Through the time domain analysis with installing the SVC the power oscillation can be damped significantly. And through the frequency analysis the dominant oscillation modes can be moved leftward after the SVC installation. The author modeled the most detailed and widely used SVC control system and control strategies for the supplementary controller design and parameters tuning. Thus the simulation results can be accuracy and trusted. The works of the paper can be adopted improve performance of system, such as wind farm, which is sensitive to oscillation.

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