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PSS and SVC Unified Power Oscillation Damping control for a SMIB model

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Abstract

Many utilities have been using PSS as a way to enhance AVR operation, to increases system damping for low-frequency oscillations and other stability-related phenomena. Modern FACTs are also very effective in damping power system oscillations. Currently, these FACT devices come equipped with supplementary control for Power Oscillation Damping POD. Every one of these controllers has its own location and set of local or remote input measurement, which can be used to recognize power oscillation. The aim of this paper is to inspect the concept of having a single supplementary controller in a location that is close to the generator, acting as PSS while extending its reach to remote FACT device (an SVC).

This study uses a model of single machine infinite bus SMIB with SVC connected at the midpoint of the line. The design technique of the proposed controller is set as an optimization problem in which Genetic Algorithm GA is utilized to search for the ideal parameters of the single unified power oscillation damping UPOD controller.

Keywords: Power system oscillation, LFO, POD, SVC, SMIB, PSS, FACT, GA, optimization, UPOD.

INTRODUCTION

Besides its main function related to dynamic VAR compensation and voltage support, the viability of SVC in damping power oscillation is established [1...3].

When using SVCs and PSSs in the network for damping power oscillation, it is very crucial to note that coordinating them plays a very important role in the process, as it is becoming a vital necessity for operating the system in a safe and reliable manner [4]. This, of course, is not limited to classical systems, as it has been extended to reach modern applications and integration of renewables [5]. In most cases for damping oscillation, the input taken is angular speed deviation $\Delta\omega$. This input can be taken easily in the local plant, where such signals are available. But with a remote SVC is not the case, other local signals can be considered or sending a desired signal to an SVC location this could result in time delay, added to the task of tuning optimal parameters for SVC POD and PSS.

The same in regards to the system shown in Figure 1, the input signal for both controllers PSS and SVC POD can be taken locally. This can be achieved with PSS is fed with angular speed deviation, and the SVC POD controller is fed with other local input signals such as the power of voltage. It is also noteworthy that another scheme applies a remote signal, such as the angular speed deviation of the generator.

According to [6], the stability of the system increases when the proper remote signal is used rather than using another local signal. It has also been noted that the performance using remote signal is barely influenced by the signal delay. In [7] the Simulation results show us that “delay compensation technique” can be used to help in preserving system performance.

However, time delay could diminish with direct fiber-optic communication between the generator and distant SVC. When attempting to improve system damping with these devices coordination, parameter optimization, and controller input should be the core of the design factors.

The proposed system in this study uses a single POD as the unified controller with a small signal output Uf will be sent directly to the SVC susceptance control [8]. Uf can be seen in Figure 3, assuming that there has been no time delay as a result of direct fiber communication.

The proposed system will dismiss the need to coordinate two controllers. It will also help facilitate the optimization process, as the number of parameters becomes less. In this case, the input will be angular speed deviation, being the quantity associated with oscillation.

This study has taken into consideration a variety of scenarios where the loss of small signal Uf is as follows:

- Scenario 1 signal transmitted machine exciter but failed to reach SVC control
- Scenario 2 signal transmitted to SVC control successfully but fail to reach exciter.
- Scenario 3 signal successfully transmitted to SVC & exciter.

Therefore, it is recommended that when assigning the controller parameter, to take this into consideration to guarantee the stability in either case.

System Model

For this study we are going to use a single machine infinite bus mode SMIB. This type of model is widely use in literature [9,10].

The model in Figure.1 show a generator in connected to an infinite bus, the SMIB system is modified by adding an SVC at location l (it is ratio of full length and is set to 0.5).

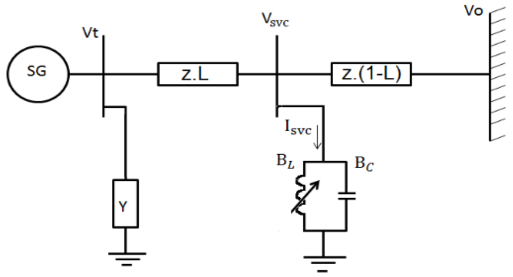

Figure 1: SMIB with SVC connected at distance L P.U from SM

UPOD transfer function

The supplementary input signal is Δω. This input passes through several transfer functions which adjust gain and phase. The supplementary damping control has a common structure as the typical dynamic model of POD. The unified controller will be presented in Figure 2.

High pass filter (Washout filter) will block steady state signals, which in turn allows only transient inputs. It has the general S-domain form as denoted inside the block. Phase compensator “lead-lag" transfer function will compensate for any lead-lag feedback in the response in the controlled [9,10,11].

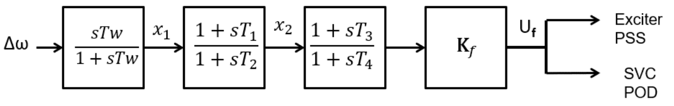

Figure 2: Unified power oscillation damping controller

The model and time domain output signal

$$\dot{U_f} = K_f \frac{T_3}{T_4}\dot{x_2} + \frac{K_f}{T_4}x_2 - \frac{1}{T_4}U_f \tag{1}$$

$$\dot{x_1} = \Delta\dot{\omega} - \frac{x_1}{Tw} \tag{2}$$

$$\dot{x_2} = \frac{T_1}{T_2}\dot{x_1} + \frac{1}{T_2}x_1 - \frac{1}{T_2}x_2 \tag{3}$$

Synchronous Generator Model

For this study the flux linkage of the field winding must be considered, the synchronous generator is represented by Third-Order Model, which is sufficient for simulation. the state equation of the model is the electromechanical swing equation and the generator internal voltage. The IEEE excitation model [12] is used in this study. model equations are:

$$\dot{\omega} = \frac{1}{M}(T_m - T_e - T_D) \cong \frac{1}{M}(P_m - P_e) \tag{4}$$

$$\dot{\delta} = \omega_b(\omega - 1) \tag{5}$$

$$\dot{Eq} = \frac{1}{T\prime do}[E_{fd} - Eq - (x_d - x'_d)i_d] \tag{6}$$

$$\dot{E_{fd}} = \frac{1}{T_A}[K_A(v_{ref} - v_t) - E_{fd}] \tag{7}$$

$$Eq = v_t + jx'_d i_d - jx_q\, ji_q \tag{8}$$

$$\mathrm{T_e} \cong \mathrm{P_e} = \mathrm{i_d v_d} + \mathrm{i_q v_q} \tag{9}$$

Where,

T_m	input mechanical torque
T_e	electrical torque generated in the machine.
M	machine inertia constant
ω_b	base angular speed.
ω	angular speed per unit.
δ	phase difference between internal machine voltage Eq and infit bus
Eq	internal voltage of the machine.
E_{fd}	field voltage.
x_d	d-axis reactance of the generator.
x'_d	d-axis transient reactance of the generator.
i_d	d-axis voltage.
v_d	d-axis current.
i_q	q-axis voltage.
v_q	q-axis current.
v_t	machine terminal voltage.
$T'do$	open-circuit field time constant.
T_A	exciter time constant.
K_A	exciter gain.

SVC model

The illustration of Figure.3 shows the block diagram of SVC susceptance control [8], The feedback loop of SVC is:

$$\dot{BL} = \frac{K_S}{Ts}(Vref - Vsvc + U_f) - \frac{B_L}{Ts} \tag{10}$$

The total susceptance will be

$$Bsvc = Bc - BL \tag{11}$$

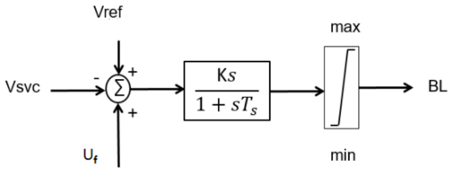

Figure 3: SVC susceptance control

Stability Analysis

The system stability is analyzed using

1. Linearized Model Approach.
2. Nonlinear Time Domain Analysis.

The linearized model approach follows Liapunov's first method of stability in the small for the nonlinear system [11]. If the eigenvalues of linear approximated state matrix [Ac] have the negative real part, then the system is considered asymptotically stable. Using Nonlinear Time Domain Analysis for small signal stability problems has a drawback [11], which is the fact that results can be misleading. Which means that using this approach on its own, does not provide any insight regarding the nature of the issue.

System Linearized Model

The state variables of the system can be written in the following form

$$\dot{x} = A \cdot x + B \cdot U_f = A_C \cdot x \tag{14}$$

Which is in matrix form

$$\begin{bmatrix} \Delta\dot{\omega} \\ \Delta\dot{\delta} \\ \Delta\dot{E}q \\ \Delta\dot{E}fd \\ \Delta\dot{B}svc \\ \dot{x}_1 \\ \dot{x}_2 \\ \dot{U}_f \end{bmatrix} = [A_C] \begin{bmatrix} \Delta\omega \\ \Delta\delta \\ \Delta Eq \\ \Delta Efd \\ \Delta Bsvc \\ x_1 \\ x_2 \\ U_f \end{bmatrix} \tag{15}$$

The augmented system matrix [Ac] is expanded below

$$[A_C] = \begin{bmatrix} 0 & -\frac{K_1}{M} & -\frac{K_2}{M} & 0 & -\frac{K_3}{M} & 0 & 0 & 0 \\ \omega_b & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\frac{K_4}{Tdo} & -\frac{K_5}{Tdo} & \frac{1}{Tdo} & -\frac{K_6}{Tdo} & 0 & 0 & 0 \\ 0 & \frac{-K_A K_7}{TA} & \frac{-K_A K_8}{TA} & \frac{-1}{TA} & -\frac{K_A K_9}{TA} & 0 & 0 & \frac{K_A}{TA} \\ 0 & -\frac{KsK_{10}}{Ts} & -\frac{KsK_{11}}{Ts} & 0 & -\frac{KsK_{12}+1}{Ts} & 0 & 0 & \frac{Ks}{Ts} \\ 0 & -\frac{K_1}{M} & -\frac{K_2}{M} & 0 & -\frac{K_3}{M} & -\frac{1}{Tw} & 0 & 0 \\ 0 & -\frac{K_1 T_1}{MT_2} & -\frac{K_2 T_1}{MT_2} & 0 & -\frac{K_3 T_1}{MT_2} & \frac{1}{T_2} - \frac{T_1}{Tw * T_2} & -\frac{1}{T_2} & 0 \\ 0 & -\frac{K_f T_3 K_1 T_1}{T_4 M T_2} & -\frac{K_f T_3 K_2 T_1}{T_4 M T_2} & 0 & -\frac{K_f T_3 K_3 T_1}{T_4 M T_2} & \frac{K_f T_3 (Tw - T_1)}{T_4 Tw T_2} & \frac{K_f (T_2 - T_3)}{T_2 T_4} & -\frac{1}{T_4} \end{bmatrix}$$

Genetic algorithm GA

Optimization techniques are mainly used for tuning parameters to an optimal value [13…15]. The main advantage of using GA for control system design is the fact that it needs little information. Limits are used for the input parameters and allow the algorithm to operate to fulfill the output of the objective function. Therefore, the design is simply based on input/output relationships only. Subsequently, GA search is mainly used to increase a specific performance by changing the inputs.

Consequently, the GA method provides a more common optimization mythology than any other conventional analytical techniques. Figure 4 shows the main steps linked to Genetic Algorithm.

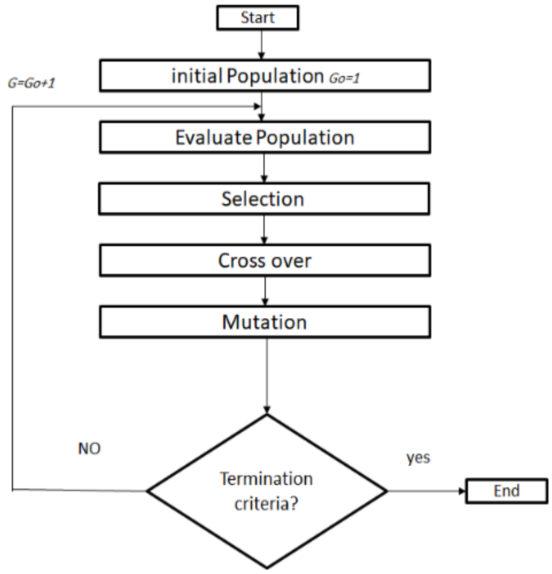

Figure 4: GA steps

Objective Function

When referring to research papers [16...20], we notice that the main objective function is carried out to improve only damping ratio, as we have mentioned before.

Similarly, the objective function here is formulated to shift dominant eigenvalues from relativity unstable region to more stable region achieving sufficient damping over power system oscillations. A Single Objective Function is formulated by focusing the real part of eigenvalues σ that partially ensures system stability for certain operating point/points [21] In this case, the objective function is set to

$$\text{Minimize} \qquad J_{GA} = \text{Max}(\sigma) \qquad (16)$$

RESULTS OF LINEAR ANALYSIS

As mentioned before, the GA approach has been applied to look for the ideal settings of the suggested UPOD controller. With limits is given for each Time constants 0.1…10, while the gain is given a wider range 0. 1..100. The final settings of the optimized parameters for the suggested controller are presented in Table 1.

Table 1: Controller parameter setting

Controller Parameter	Value
Tw	0.7998
T1	0.7013
T2	0.6950
T3	0.7601
T4	1.0676
K_f	58.4358

the results shown in Table 2 reflect the shift of oscillatory modes from an unstable region.

Table 2: Eigenvalue results

Condition	Case 1: No control	Case 2: with controller
Mods	-392.86	-389.3
	0.20895+4.9997i	-15.423
	0.20895-4.9997i	-2.92+6.7248i
	-10.3+2.165i	-2.92-6.7248i
	-10.3-2.165i	-1.4589+0.3183i
		-1.4589-0.3183i
		-1.5945+0.098029i
		-1.5945-0.098029i
Result	Not stable	Stable

Nonlinear simulation

Transient three phase fault was applied to the end of line for 50 ms and the simulation is done in two parts. The first part will simulate the three scenarios mentioned earlier, shown in Figure.5. Second part will simulate two cases with and without controller Figure 6.

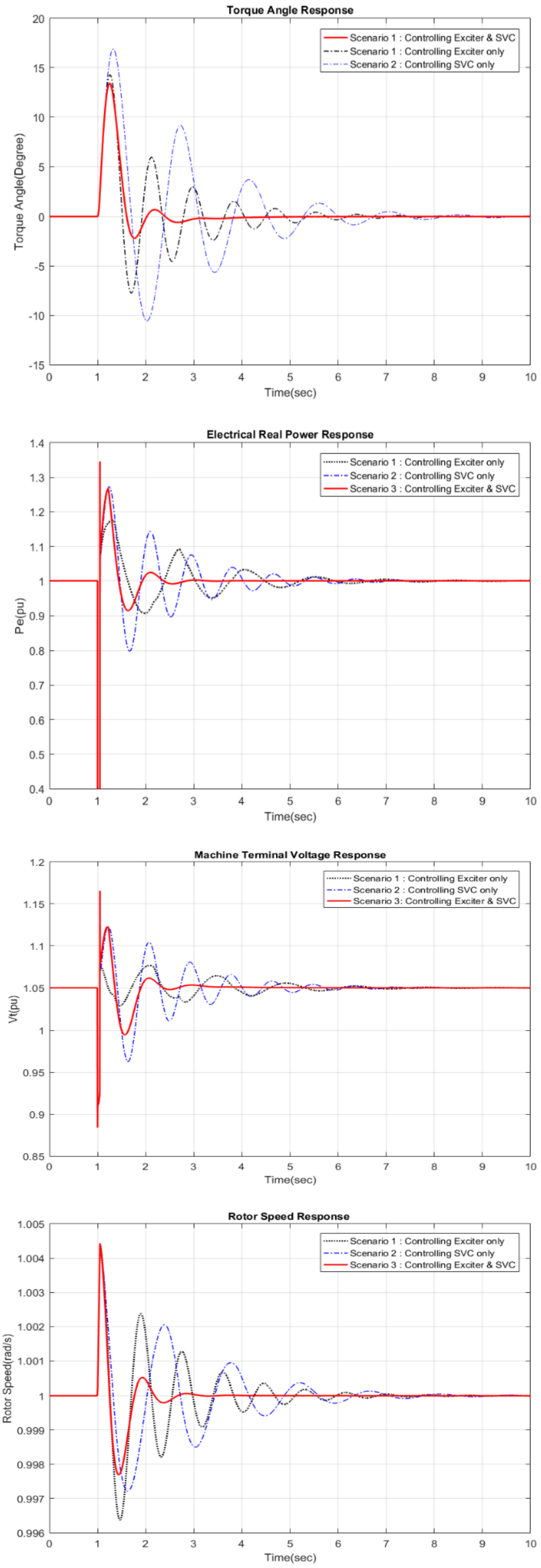

Figure 5: system response for each scenario

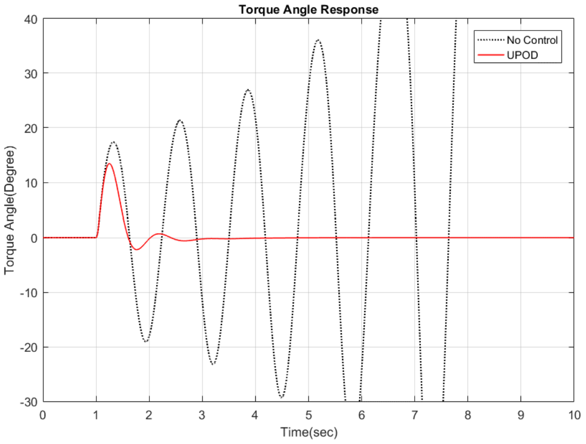

Figure 6: Comparison with and without UPOD

DISCUSSION

Both types of analysis (linearized and nonlinear) show that UPOD controller helps stabilizes the system, the simulation also shows an enhancement in damping.

Simulating the three above-mentioned scenarios shows that the system is stable with only one controlled devices, shown in Figure 5, with a minor advantage acting as PSS for the generator. Taking these scenarios into consideration is very useful, that is, the controller is tuned so that in the likelihood of losing signal to one device either an exciter or SVC susceptance control the system shall remain stable.

The simulation assumes that there is no time delay in transmitting U_f to the SVC control, this is a result of FO connection between the generator control and SVC control, this assumption is true due to SMIB model arrangement, as in a multi-machine system a sensitivity analysis has to be done to determine which PSS and SVC are exhibiting entangled reaction.

CONCLUSION

The suggested UPOD control system has been described along with its requirements. This study has developed Linearized models for eigenvalue analysis and used GA to tune its parameters taking into account different scenarios for loss of signal. Non-linear analysis with scenarios mentioned has also been done to check the stability of each case. In conclusion, it has been shown that the use of UPOD has stabilized the system. The need for coordinated controllers (PSS & SVC UPOD) has been eliminated, with the added benefit that there are fewer parameters to set.

System data

Machine inertia constant $= 9.26\ s$.

d-axis reactance of the generator $x_d = 0.973\ \ p.u.$

q-axis reactance of the generator $x_q = 0.55\ \ p.u$.

d-axis transient reactance of the generator $x'_d = 0.19\ \ p.u.$

Open-circuit field time constant $T'do = 7.76\ \ p.u.$

Line resistance $R = -.034\ \ \ p.u.$

Line reactance $= 0.997\ p.u$.

Shunt conductance $G = 0.249\ \ p.u$.

Shunt susceptance $= 0.262\ \ \ p.u$.

Exciter time constant $T_A = .05\ s$.

Exciter gain $K_A = 50$.

SVC susceptance $B_{SVC} = 0.2\ \ \ p.u.$

Susceptance control time constant $T_s = .05\ s$.

Transfer function gain $K_s = 50$.

machine terminal voltage $v_{to} = 1.05\ \ \ p.u.$.

Machine active power $P_{eo} = 1.0\ \ p.u$.

Machine reactive power $Q_{eo} = .015\ \ p.u$.

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