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PERFORMANCE OF SVC WITH POD AND PSS FOR DAMPING OF POWER SYSTEM OSCILLATIONS

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ABSTRACT

This paper presents a systematic approach for designing of Static var Compensator (SVC) based damping controllers for damping of low frequency oscillations in a power system. Detailed investigation have been carried out considering two controllers like Power System Stabilizer (PSS) controller and Power Oscillation Damping (POD) controller under variation of mechanical disturbances (Pm) which provides robust performance for single machine infinite bus (SMIB) power system. The realization of the Phillips-Heffron model has been completely and effectively done on comprehensive and user friendly simulink platform. Here, we have designed simplified transfer function block set model to minimize the simulation time because model designed on another domains while simulation internally converts original model to such simplified block diagram model. Eigen value analysis validates the performance of various controllers.

Keywords: FACTS, SVC, PI, PSS, POD, Damping of oscillations.

1. INTRODUCTION

As is well known several kinds of electromechanical oscillations must be damped in a power system: local oscillations (associated with single generator), inter- machine oscillations involving two generators (each one swinging against the other) and inter area oscillations (involving several generators in one area swinging against the generator of another area). These oscillation generally have quite different frequencies, hence damping all of them is challenge. In addition the characteristic of the network significantly change (due to load variation, a line tripping etc). Hence those oscillations must be damped using robust controllers, i.e. controllers which are still efficient in spite of these uncertainties. SVC is one of the FACTs (Flexible AC transmission system) device, which is used for shunt compensation to maintain voltage magnitude. The application of SVC is concerned with the damping of power system oscillations of synchronous generator as well as to control the system voltage. The Proportional Integral (PI) controller parameter of (SVC) is of the fundamental importance in ensuring it performance adequately. This paper presents a systematic approach for PI controller and design of SVC. To verify the robustness of the proposed method, PI controller design the dynamic response of generator (Speed deviation) due to power fluctuation and disturbance under heavy and light loading condition is considered. The PI controller design results in improved stability of single machine connected to infinite bus with SVC system over without controller. H.F. Wang et al [3] investigated SVC damping control scheme for general single-machine infinite–bus power system by damping and synchronizing analysis on the Phillips-Heffron model. However they have not used damping control scheme for using POD controller, and PSS controller. K.Somsat et al [6] presented graphic–based simulation and optimal PI controller design of SVC. The aim of the proposed method is to find the optimal parameters of these compensators in order to improve the steady state and transient performances and also to improve the system damping over a wide range of operating conditions and system parameters using MATLABs SIMULINK model. But they have not used linear model. Noroozian et al [4] used sensitivity analysis method for general two machine power system model and result has been proved by analysis. However they have not used linearized model controller with different controller. Since linear model establishes user friendly simulink platform with minimum simulation time. Hence task in this project is to develop a linearized Phillips Heffron model of single machine infinite bus system model and design simplified transfer function block set. Since MATLAB is a high performance language for technical computing. Hence it integrates computation, visualization, and programming in an easy to use. The control schemes to be studied will be simulated using software MATLAB 7.1. The results obtained will be compared with that obtained experimentally. Hence this paper presents modeling and simulation of-

(1) Coordinated tuning of SVC with POD for Pm=0.1pu

(2) Coordinated tuning of SVC with PSS for Pm=0.1pu

(3) Coordinated tuning of SVC with POD for Pm=0.15pu

(4) Coordinated tuning of SVC with PSS for Pm=0.15pu.

2. SYSTEM MODEL OF STATIC VAR COMPENSATOR (SVC)

To test the capability of the proposed method, single machine infinite bus power system with SVC is considered as shown in Fig.1.The model consist of generator supplying bulk power to an infinite bus through a transmission line, with SVC located at its terminal. SVC is located via step down transformer. SVC has control characteristic similar to as a synchronous condenser as continuous control action in contrast with existing switched shunt capacitor banks. The SVC consists of Fixed Capacitor (FC) and Thyristor Controlled Reactor (TCR) in parallel.

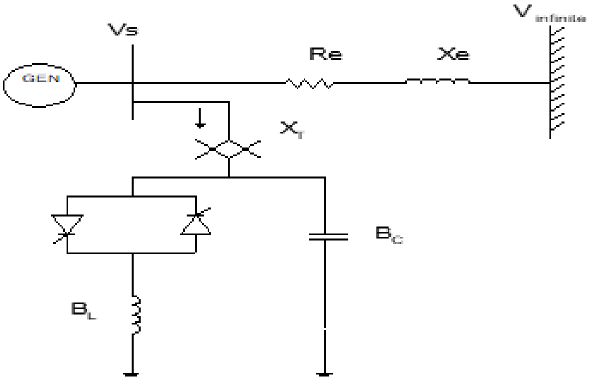

Fig. 1 Single machine infinite bus system model

3. SMIB SYSTEM WITHOUT SVC

A synchronous machine with IEEE type 1 excitation system is connected to an infinite bus through a transmission line has been selected to demonstrate the derivation of simplified linear models of power system for dynamic stability analysis. Fig. 2 shows the control block diagram of simplified linear model for SMIB system. The formula for constants K_1 to K6 is incorporated in Phillips-Heffron model, which govern the system configuration and operation are as follows.-

$K_1=\{E_bE_{qo}\cos\partial_o/(X_e+X_q)\}+\{E_bi_{qo}\sin\partial_o(X_q-X_d')/(X_e+X_d')$ (1)

$K_2=\{iqo(X_e+X_q)/(X_e+X_d')\}$ (2)

$K_3=(X_e+X_d')/(X_e+X_d)$ (3)

$K_4=E_b\sin\partial o(X_d-X_d')/(X_e+X_d')$ (4)

$K_5= \{(-X_qV_{do}E_b\cos\partial_o)/((X_e+X_q)V_{to})\}$

$-\{X_d'V_{do}E_b\sin\partial_o/((X_e+X_d')V_{to})\}$ (5)

$K_6=X_eV_{qo}/[((X_e+X_d')V_{to})]$ (6)

The linearized constant, K_1,K_2 are from the electric torque equation, K_3,K_4 are from field voltage equation and K_5,K_6 are from terminal voltage equation, H is a inertia constant, D is the mechanical damping coefficient and T'_{do} is the transient time constant. K_A and T_A are the exciter amplifier constant and time constant. This simplified model can be described by state space representation as follows:

$$\dot{X} = [A]X + [B]U \quad (7)$$

$$Y = [C]X \quad (8)$$

$$A = \begin{bmatrix} 0 & \omega_R & 0 & 0 & 0 & 0 \\ \frac{-K_1}{2H} & \frac{-D}{2H} & \frac{-K_2}{2H} & 0 & 0 & 0 \\ \frac{-K_4}{\tau'_{do}} & 0 & \frac{-1}{K_3\tau'_{do}} & \frac{1}{\tau'_{do}} & 0 & 0 \\ 0 & 0 & 0 & \frac{-K_E}{T_E} & \frac{1}{T_E} & 0 \\ \frac{-K_AK_5}{T_A} & 0 & \frac{-K_AK_6}{T_A} & 0 & \frac{-1}{T_A} & \frac{-K_A}{T_A} \\ 0 & 0 & 0 & \frac{-K_EK_F}{T_ET_F} & \frac{K_F}{T_ET_F} & \frac{-1}{T_F} \end{bmatrix} \quad (9)$$

Where X, Y and U are the state vector, output and input signal vector respectively. The [A], [B] and [C] are all real constant matrices of appropriate dimension. The state variable in X and the elements in [A] of this simplified model are as above. Subscript Δ are the deviation in the quantity from the initial operating point.

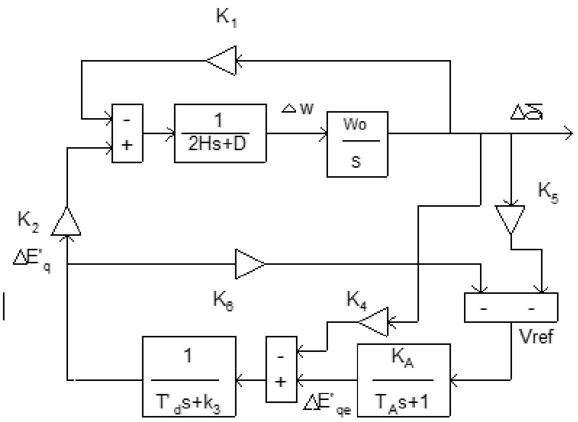

Fig. 2 Phillips-Heffron model of power system

4. SVC-PI CONTROLLER OF SMIB SYSTEM

Static Var Compensator (SVC) is connected to the SMIB power system as shown in Fig.3, in which Kv is a SVC constant, Tv is time constant, B_L is inductive admittance. When Static Var Compensator (SVC) is connected to SMIB system, It depends upon the selection of its controllers. Although there exists many efficient control scheme for compensation. Here Proportional Integral (PI) controller is chosen for study. In Proportional Integral (PI) controller, there are two parameter Proportional controller (Kp) and Integral controller (Ki) must be tuned in order to minimize voltage oscillations in both magnitude and frequency swing. Static Var Compensator (SVC) is basically FACTS device which is used to regulate the voltage magnitude. Additional control function of SVC can be enhanced the system stability and restrain oscillation. The main function of SVC is to regulate the voltage magnitude across the protected load due to reactive power loading. When voltage load variation is detected the SVC will perform the compensation in order to minimize the oscillations.

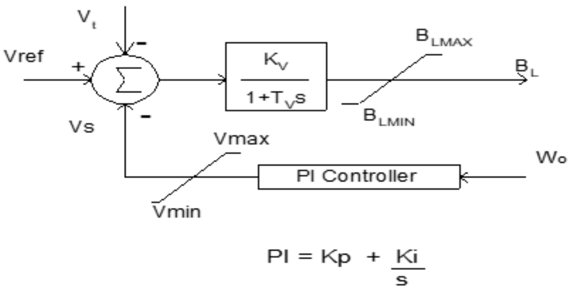

Fig.3 PI controller of SVC system

5. STRUCTURE OF POWER SYSTEM STABILIZER (PSS) AND SVC-BASED CONTROLLER

The objective of designing Power System Stabilizer (PSS) is to increase the power transfer in the network, which would otherwise be limited by oscillatory instability. Thus Power System Stabilizer (PSS) must function properly when system is subjected to the large disturbance. The commonly used lead-lag structure is chosen in this study as PSS and SVC-based controller as shown in Fig. 4. Each structure consists of a Gain Block Ks, and two or three lead-lag Stage Compensation Block. The time constant T_1 to T_6 are chosen to provide a phase lead for the input signal. The phase compensation block provides the appropriate phase lead characteristics to compensate for the phase lag between input and output signals. The power system stabilizer (PSS) can be used to add the damping to the rotor oscillations of the synchronous machine by controlling its excitation. The disturbance occurring in power system induces electromechanical oscillation of electrical generator. This oscillations is called power swing must be effectively damp to maintain the system stability. The output signal of Power System Stabilizer (PSS) is used as an additional input to the excitation system block.

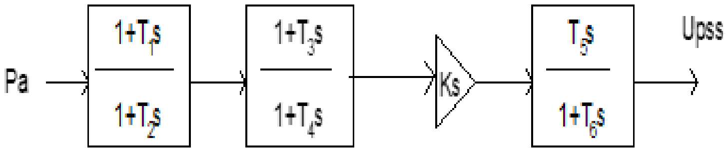

Fig. 4 Structure of Power System Stabilizer

6. POWER SYSTEM OSCILLATION DAMPING (POD) CONTROLLER

Power oscillation damping (POD) controller is provided to improve the damping of power system oscillation as shown in Fig. 5. The damping controller may be considered as comprising two cascade connected blocks. Block 1 is provided to derive the speed deviation signal from the electric power Pe. The total electrical power is measured at SVC location. It is then compared with the set point (mechanical power). The error is integrated and multiplied by 1/2H to derive a speed deviation signal. It may be noted that the speed deviation signal derived used instead of the speed deviation signal which has been measured, since speed deviation signal in general may not be available at static var compensator (SVC) location. The second block comprises a lead-lag compensator. An electric torque in phase with speed deviation is to be produced in order to improve the damping of power system oscillation. The parameters of lead-lag compensator are chosen so as to compensate for the phase shift between control signal and resulting electrical power deviation. In this way an additional electrical power output is obtained in phase with the speed deviation. The gain setting of the damping controller is chosen so as to achieve the desired damping ratio of the electromechanical mode. The output of damping controller modulates the reference setting of the power flow controller.

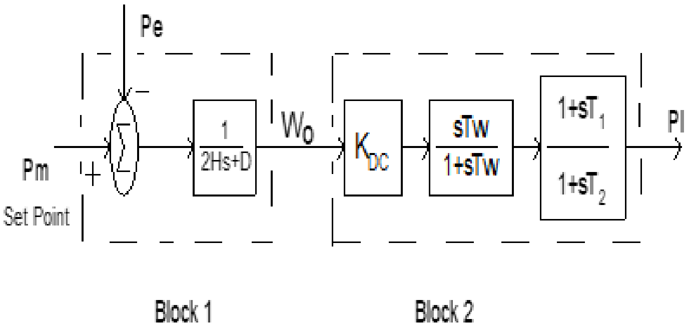

Fig. 5 Structure of Power Oscillation Damping Controller

7. SIMULATION RESULT AND EIGEN VALUE ANALYSIS

Simulation result of the modified Phillips-Heffron model with static var compensator (SVC) coordinated tuning of power system stabilizer (PSS) controller and power oscillation damping (POD) controller under 10% deviation in mechanical power input has been demonstrated.

A.WITHOUT SVC (for Pm = 0.1 pu)

Simulation result of Phillips-Heffron model without SVC is as shown in Fig 6, where peak of speed deviation is 1.4 rad/sec and oscillations are settled in 6 sec.

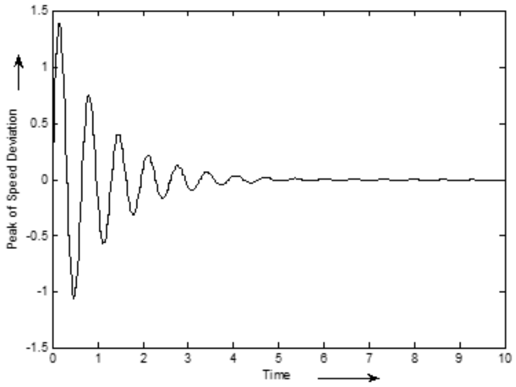

Fig.6 Simulation result of system without SVC

B. COORDINATED TUNING OF SVC-PI (for Pm = 0.1pu)

Response shown in Fig. 7 indicates the satisfied performance of Static var Compensator (SVC), in which peak of speed deviation is 0.46 rad/sec, and settling time is 5.2 sec.

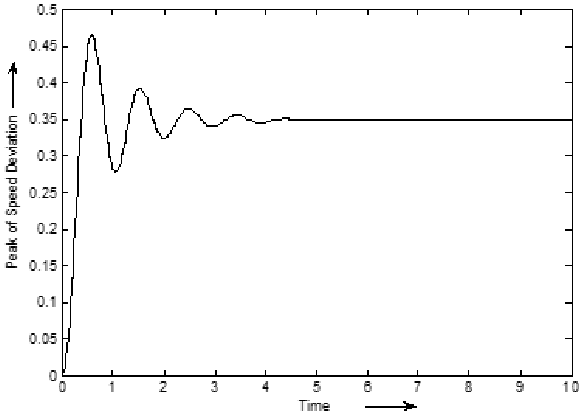

Fig.7. Simulation result of SVC

C. COORDINATED TUNING OF SVC-PSS (for Pm = 0.1 pu)

Result is shown in Fig.8 indicate that with coordinated action of static var compensator (SVC) with Power System Stabilizer (PSS), dynamic performance is improved with settling time 3.2 sec.

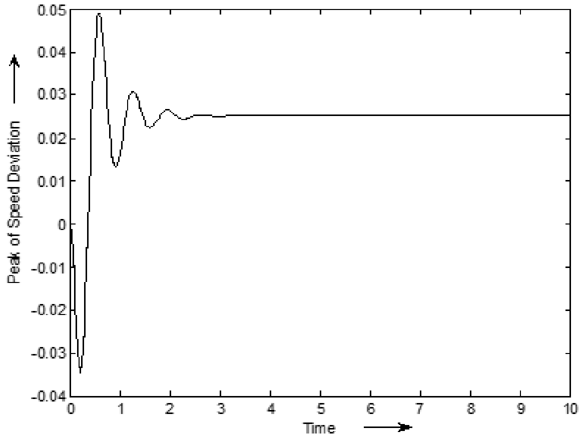

Fig. 8 Simulation result of with SVC-PSS

D. COORDINATED TUNING OF SVC-POD (for Pm = 0.1pu)

The digital simulation is shown in Fig 9, demonstrates the satisfied performance of coordinated effect of static var compensator (SVC) with Power Oscillations Damping (POD) controller which provides the highest improvement in stability in which peak of speed deviation, no. of oscillations are effectively reduced.

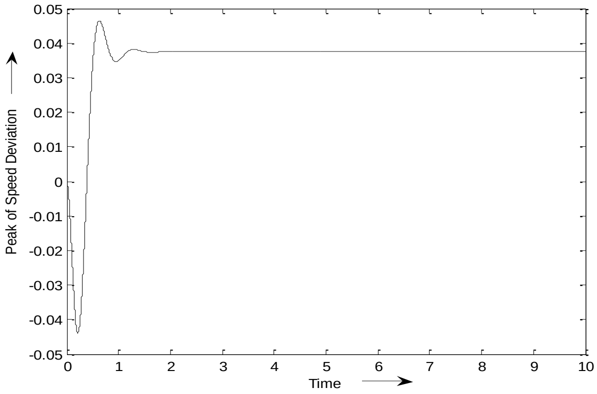

Fig.9 Simulation result of SVC-POD

TABLE NO.1: Comperative Analysis Of Simulation Result Of Svc With Various Controllers

Parameters	Without SVC	With SVC-PI	With SVC-PSS	With SVC-POD
Peak of Speed Deviation	1.4	0.46	0.05	0.048
No. of Oscillations	9	5	4	2
Settling Time	6	5.2	3.2	2

Table 2 indicates the eigen value analysis of all controllers which indicates that all the values are driven into negative part of real axis which shows that the system become stable.

TABLE NO.2: Eigen Value Analysis Of Without Svc, Svc, Svc-Pss, Svc-Pod

S.N.	Without SVC	With SVC	With SVC-PSS	With SVC-POD
1	-16.074 ± 45.82i	-16.108± 45.84i	-4.8332± 12.54i	-18.7709
2	-13.293	-10.3825	-18.2788	-3.456± 9.318i
3	-4.6641	-7.2179	-9.9324± 1.48i	-10.0750
4	0.0806	-0.2057	-0.122 ± 0.308i	-7.7606
5	-0.9955	-0.9952	0.0000	-2.8199
6	-	-0.8723	-0.0500	-0.0995
7	-	-0.8723		-0.0000

SMALL SIGNAL STABILITY ANALYSIS WITH VARIATION OF CHANGE IN MECHANICAL POWER

Simulation result of the modified Phillips-Heffron model with coordinated tuning of PSS controller and POD controller under 15% deviation in mechanical power input has been demonstrated. It has been seen that results are deteriorated with increase in mechanical disturbance (Pm = 0.15 pu).

A. COODINATED TUNING OF SVC AND PSS CONTROLLER (for Pm = 0.15 pu)

Result as shown in Fig.10 indicates that coordinated tuning of SVC and PSS controller shows improvement of transient response. Results are deteriorated with the increasing mechanical power.

Table 3 shows the location of eigen values of the system wherein all the values with coordinated action of PSS controller moves towards left half of the real plane which shows the system become stable.

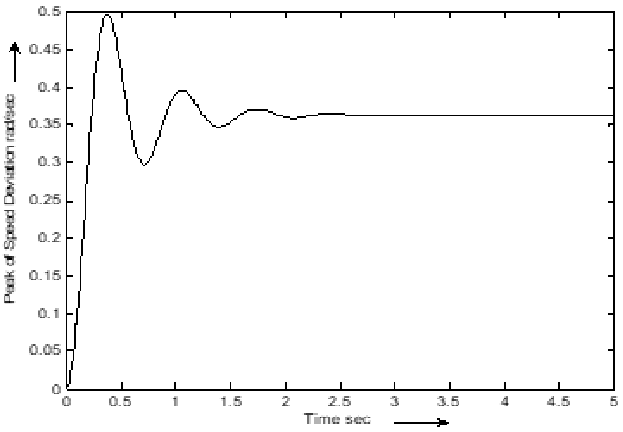

Fig.10) Coordinated tuning of SVC with PSS

TABLE NO.3: EIGEN VALUE ANALYSIS OF SVC AND PSS (for Pm = 0.15 pu)

S.N	Pm = 0.15 pu
1	1.1257
2	-0.1854
3	-0.0210 ± 0.0917i

4	-0.1083
5	-0.0455
6	0.0000
7	0.0000
8	-0.0005

B. COORDINATED TUNING OF SVC AND POD CONTROLLER (for Pm 0.15 pu)

Response shown in Fig.11indicate the optimized POD controller performance is far better than PSS with settling time 1.5 sec.

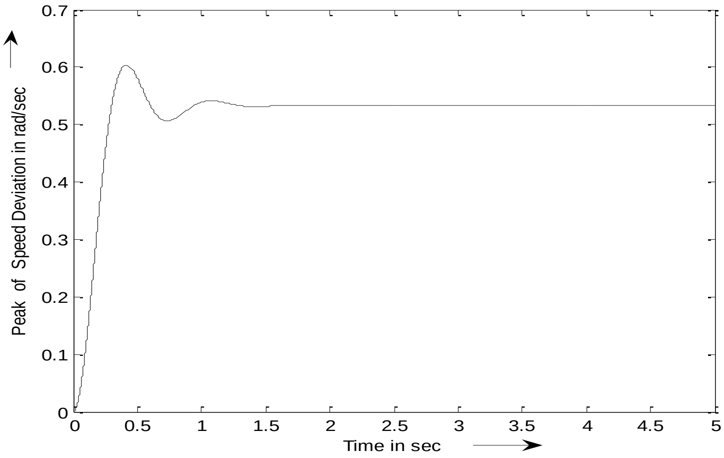

Fig.11) Coordinated tuning of SVC with POD

Above result is verified in Table 4 wherein all the eigen values regarding Power Oscillation Damping (POD) controller migrate towards left hand side of the real plane which indicates the stability of system.

TABLE NO. 4: EIGEN VALUE ANALYSIS OF SVC AND POD for Pm = 0.15 pu

S.N	Pm = 0.15 pu
1	-18.7709
2	-3.4567 ± 9.3181i
3	-10.0750
4	-7.7606
5	-2.8199
6	-0.0995
7	-0.0000

8. CONCLUSION

SVC damping control has been investigated for a general single-machine infinite bus power system by damping and synchronizing analysis on the basis of the Linearized Phillips-Heffron model. A systematic approach for designing Static var Compensator (SVC) based controllers for damping of power system oscillation has been presented. This paper illustrates the utilization of MATLAB’s SIMULINK to optimal PI controller design of static var compensator (SVC), which is connected to infinite bus power system.

Detailed analysis of coordinated tuning of Static var Compensator (SVC) with Power System Stabilizer (PSS) and Power Oscillation Damping (POD) in Single Machine Infinite Bus (SMIB) under variation of mechanical disturbances (Pm=0.1 to Pm=0.15) system has been done. Investigation revels that coordinated tuning of SVC with POD controller is more effective than PSS controller in damping of power system oscillations. Time domain analysis and Eigen value analysis validated the performance of various controllers. Proposed controller fulfils the main objective of this project. Hence proposed work is more effective in damping of power system oscillations.

APPENDIX

SVC:

$K_1=0.5995$, $K_2=0.9263$, $K_3=5.044$, $K_4=0.4319$, $K_5= -0.0878$, $K_6=0.6004$, $T_A=0.05$, $K_A=50$, $\iota'_{do}=5.044$, $Ki=11.9559$, $Kp=1.0167$, $Kv=10$, $Tv =0.15$, $D=4.0$, $H=2.37$, $Wo=314.16$, $X_d=0.146$, $X_d'=0.0608$, $Xq=0.0969$, $Xq'=0.0969$, $V_{to}=1.0$, $Vdo=-0.0412$, $Vqo=1.0392$, $I_{do}=-0.2872$, $Iqo=0.678$, $E_b=1.0$, $\partial o=-85.348^0$, $Xe=0.1$, $Eqo=1.0558$, $Vt=1$, $I_{do}=-0.2872$, $Iqo=0.678$, $E_{do}'=-0.0419$, $Pe=0.2, 0.8, 1.2$, $Xe=0.3, 0.5, 0.65$.

SVC-PSS:

$T_1 = 0.23$, $T_2 = 1.96$, $T_3=20$, $T_4=5$, $T_5 =20$, $T_6 = 20$ $Ks=2.53$

SVC-POD:

$K_{DC}=0.01$, $T_1=0.3235$, $T_2=0.35$ $Tw=10$

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