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Damping Ocillations Control by using TCSC and Comparison with Supplementary Controller

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ABSTRACT

Privacy is one of greatest rubbing focuses that rises when interchanges get interceded in Online Social Networks (OSNs).different groups of software engineering analysts have been surrounded the 'OSN security issue' as one of the observation, institutional or social protection. On account of handling these issues they have likewise treated them as though they were free. The principle contends is that the diverse security issues are snared and that the examination on protection in OSNs would profit from a more all encompassing methodology. In this paper, we first give a prologue to the observation and social security viewpoint stressing the account that then educate them, and their suspicions, objectives and techniques.

Keywords- TCSC, Power system Oscillatons, Linear Models, Eigen Values, PSS, STATCOM, SVC.

1. INTRODUCTION

During the last two decades major, if not revolutionary advances have been made in high power semiconductor devices and sophisticated electronic control technologies. Fast and efficient control, conversion, and conditioning of bulk electric power using solid state power electronics technology has paved the way for the broad application of High Voltage Direct Current (HVDC) transmission and significant impact on ac transmission through the increasing use of thyristor controlled Static Var Systems (SVS). These `compensators can generate variable reactive power rapidly and thereby stabilize transmission line voltage and control power flow under dynamic conditions.

Power flow through A.C transmission lines depends on the line impedance, magnitude of bus voltage and the phase angle between the sending end and receiving end voltages. The electric power transmission systems have been designed with the understanding that these three critical parameters in general cannot be controlled fast enough to handle dynamic system conditions. That is, transmission systems have been designed with fixed or mechanically switched series and shunt reactive compensation, together with voltage regulating and phase shifting transformers to optimize line impedance, minimize voltage variations, and control power flow under steady state or slowly changing load conditions. Appropriate control of any one of these parameters can increase both transient and dynamic stability, and thereby increasing transmittable power. Full utilization of the given transmission system with high degree of operation flexibility may require the simultaneous control of two or all the three of these parameters.

The SVS, which is one of the control elements of FACTS controllers, can achieve this by providing a variable source of reactive power to improve the steady state and dynamic performance of high voltage long distance ac transmission system.

The control of reactive power is as important as the control of active power for maintaining system stability. If the system has to operate close to stability limits, fast reactive power control is essential. In the past, dynamic shunt compensators, such as synchronous condensers and saturable core reactors were used, although the transmission systems were conservatively designed with large stability margins. In recent years, thyristor controlled Static Var. Systems are being used for fast reactive power control [5].

SVS's were originally developed for power factor compensation of changing loads but later were adopted for the voltage regulation of ac transmission lines. They are extremely fast in response. The speed of response coupled with easy controllability of the reactive power makes it possible to devise suitable control strategies for improving system dynamic stability. The ability of SVS to rapidly and continuously vary reactive compensation in response to changing system conditions can result in numerous improvements in transmission system performance depending on the control objectives and strategy adopted.

2. SUPPLEMENTARY CONTROL FOR SVS

Static Var systems are applied by utilities in transmission applications for several purposes. The primary purpose is usually rapid control of voltage at weak points in a network.

CIGRE [2] defines a static Var system (SVS) as a combination of a static var compensator (SVC) and mechanically switched capacitors and reactors, all under coordinated control.

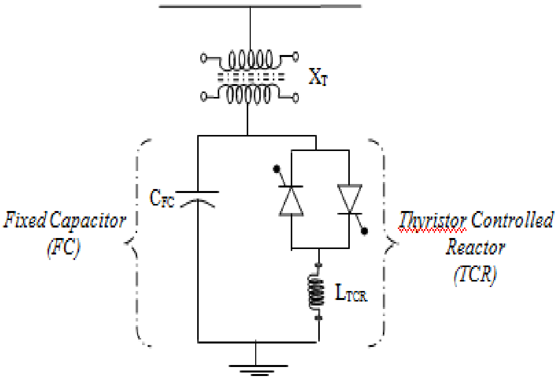

Figure 1. Static Var. System

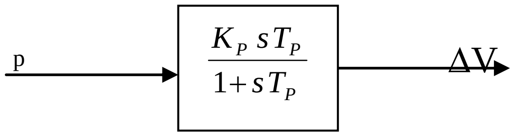

Figure 3. Supplementary Control Block diagram

A. Importance of Supplementary Control

The fixed susceptance is fixed at the midpoint of the transmission line. In order to investigate the effectiveness of the voltage control loop both in excitation system and svc, the gains and time constants of both the voltage control loops are varied. In the case of dynamic response with only fixed susceptance, to a 10% disturbance to mechanical power input, only gains and time constants of Avr are varied. In the case of dynamic response with SVS (variable susceptance) to a 10% disturbance to mechanical power input, gains and time constants of both the voltage control loop (Avr and voltage control loop of SVC) are varied . Hence three cases are made to investigate the effectiveness of the variation gains and time constant with the variation of the operating point(power level). The three cases are given bellow as

For Excitation system:

Case1: K_A=1.0 T_A=0.1 Sec
Case2: K_A=2.0 T_A=0.05 Sec
Case3: K_A=4.0 T_A=0.025 Sec
For SVC :
Case1: K_{svc}=1.0 T_{svc}=0.1 Sec
Case2: K_{svc}=2.0 T_{svc}=0.05 Sec
Case3: K_{svc}=4.0 T_{svc}=0.025 Sec

The power level is varied in steps from Pg = 0.50, 0.60,0.70p.u. etc. At these power levels, a disturbance of 10% increase in mechanical power is created and kept as permanent disturbance, and the variation of machine angle and active power supplied by the machine are plotted.

But from the variation of machine angle for all three loading condition given above, the change in machine angle for CASE1 is higher than the other two. The effect of increasing gains and decreasing time constant makes the voltage control loop more sensitive and reduces the steady state error, but the system becomes more oscillatory. Hence CASE 3 is selected for the design of supplementary controller. It is observed that, as the power level is increased, the deviation in the system steady state is also increasing and takes more time to settle at the new operating point. At Pg= 0.8p.u.(for CASE 1) the system becomes unstable. This shows that, instead of having a fixed susceptance, it may be replaced with a device, which can provide a variable susceptance, which intern can be referred as variable reactive power source.

B. System model with Supplementary Control

In the present analysis active power flow is considered as auxiliary signal for the SVS controller. The auxiliary control consists of a reset filter [1]. The reset filter was installed originally to share the functions of voltage – reactive power control at substations. This filter has a leading effect on synchronizing torque in the power system and then works to improve steady state stability. This filter is equivalent to deriving the derivative of auxiliary signal. The derivative feedback of auxiliary signal has the following effect: it filters off the DC component of the signal and provides a damping torque for generator. In the control terminology, the auxiliary controller is a first order dynamic compensator, which can be modeled as follows. For the purpose of convenience, the block diagram shown in fig.4.1 is re – arranged and shown in fig.4.2. The following equations are derived referring to fig.4.2. The complete block diagram of SVC with supplementary control is shown in fig.4.3.

$$V_{aux_1} = K_P \quad \Delta P_S$$
$$V_{aux} = V_{aux_1} - V_{aux_2}$$
$$\Delta \overset{*}{V}_{aux_2} = \left(\frac{K_P}{T_P}\right)\Delta P_S - \left(\frac{1}{T_P}\right)\Delta V_{aux_2}$$

The above equations are arranged in the form

$$\overset{*}{Z}_2 = P_2\ Z_2 + N_2\, Y_2$$
$$U_1 = H_2\ Z_2 + G_2\, Y_2$$

Where Z_2 = V_{aux2} state variable corresponding to auxiliary control

$Y_2 = \Delta P_S$ auxiliary control signal.
$U_1 = V_{aux}$
$P_2 = -1/T_P$; $N_2 = K_p/T_P$
$H_2 = -1.0$; $G_2 = K_p$

Kp and Tp are the supplementary control parameters.

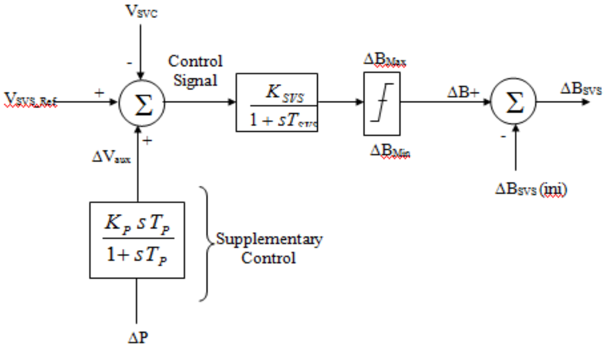

Figure 2. Block diagram of a Static Var. System with Automatic Voltage Regulator andSupplementary Control

3. METHOD OF ANALYSIS AND DESIGN

Static Var compensators are dynamic reactive power compensation devices, conventionally used for voltage control through reactive power modulation, which improve the static power transfer capabilities of long transmission lines and increase stability limit. Increased transmission capability can be achieved through application of locally available signals for auxiliary controller. The high-speed operation of the devices can be effectively utilized to minimize the power oscillations in addition to their conventional voltage control. In the design of SVS stabilizer (supplementary control) the important areas in which a designer has to concentrate are the following:

- Selection of a suitable model for the system
- Location of SVS stabilizer for effectively stabilizing the oscillations.
- Choice of feed back signal.

- Design procedure for the determination of the parameters.

In the previous chapters it has been discussed regarding selection of suitable model for the system, location of SVS stabilizer and choice of feedback signals. Finally, selection of optimal parameters for supplementary controller, are decided based on two methods.

Fist method [10] deals minimal settling time, in (i) deriving Kp-Tp parameter plane (ii) selecting optimal value of controller parameters from a set of controller parameters through minimal settling time.

Second method [8,9] deals with (i) calculation of parameters for a pre-assumed damping ratio.(ii) calculation of performance index of the closed loop system. Based on the performance index the optimal controller parameters are decided. Once sizing and location of each compensator have been selected, the problem still remains of adopting feasible and implementable feedback control strategies for the SVS's. Every approach, which tries to solve successfully this problem, has to take the following points into account:

- Overall system model used for the design should include an appropriate representation of each dynamic component of the system.
- The regulating action of SVS feedback controller has to be suitably co–ordinate.
- The design procedure has to be rigorous and systematic.

As the SVS tries to keep the bus voltage constant, the generator also should be modeled along with its exciter as the exciter tries to keep the generator terminal voltage constant. A model similar to CIGRE admittance model is used to represent the main control of SVS, and the structure of the supplementary controller is fixed appropriately. The complete system is derived in state space form at a particular operating point.

A. Concept of minimal setting time

A Lyapunov function gives a measure of system states at any given instant of time hence it can be considered as a measure of distance of the state. It can be used to estimate the rapidity of the transient response or the rate at which the system comes back to its normal states. Considering the origin as a stable equilibrium state, let

$$J\,min \le \min\{-V(x,t) / V(x,t)\}$$

In some region of the state space, excluding the origin integrating the above equation leads to

$$V(x,t) \le V(Xo, 0)\exp\left(\int_{0}^{inf} (Jmin.\, dt)\right)$$

The above equation gives a measure of, how fast the origin is approached from any initial state Xo. The time constant of the system can be considered as 1/ Jmin. Thus large value of Jmin corresponds to faster response. A large number of Lyapunov functions (V) can be found for a given system. Hence the largest value of Jmin should be considered as a figure of merits for the system. With a negative definite V function as $V(x) = -X^T Q X$

Where P is symmetric positive-definite solution of

$$P\,Ac + Ac^T P = -Q$$

The figure of merit of the linear system is defined as

$$Jmin = \min(X^T Q X)$$

subjected to constraint $\quad X^T PX = 1$

Using the Lagrangian multiplier μ, the Hamiltonian is formed as $\quad H(x, \mu) = X^T Q X + \mu (1- X^T PX)$

Minimization of H leads to

$$X^T (Q - \mu P) X \text{ at } X=Xmin \text{ Or}$$
$$X^T min\, Q\, Xmin = \mu X^T min\, P\, Xmin, \ \mu > 0$$

From above equation μ is the eigenvalue of QP^{-1}. Thus the minimum value of Jmin is the minimum eigenvalue of QP^{-1}. The problem is to find the parameters corresponding to the largest value of Jmin. It is the same as finding the least value of largest eigenvalue of PQ^{-1}

B. Analysis of the design

The single machine connected to infinite bus system with SVS located at the middle of the long AC transmission system as shown in fig.2.1. is studied. From the study of the system with only SVS (i.e., without any supplementary control signal) it is observed that as the power level increases the oscillations also increase. The design is attempted at the following operating point given bellow for CASE 3 (i.e. gain is increased by four times and time constant is reduced by four times for both the voltage control loop,(i.e. for AVR and SVC)).Pg = 0.90 p.u, Qg = 0.55777 p.u., pf = 0.85lag, V_t = 1.0p.u.

For this operating point, B_{SVC} is adjusted in such a way that, infinite bus voltage magnitude is maintained constant. With these operating points for the considered CASE 3, the system matrix A1 (without any supplementary control signal) is formulated. To obtain the optimal auxiliary control parameters, first stable region in the parameter plane is obtained using the algorithm discussed in Appendix C, so that the closed loop system (Ac) is stable with active power as the supplementary signal. This is examined based on eigenvalue of the matrix Ac.

C. Selection of Optimal Controller Parameter From Stability Region of Kp-Tp Parameter Plane

The stability region in the Kp, Tp parameter plane with active power flow over the line as supplementary control signal is determined to know the boundary of parameters, which make the closed loop system stable.The time constant Tp is varied in smaller steps (i.e. 0.01Sec. to 0.1Sec).For each value of Tp the corresponding value of maximum Kp is obtained after which the system becomes unstable .Kp-Tp parameter planes for the operating point considered is shown in fig 5.1 and corresponding values of Kp and Tp are given in Table 1.

From these sets of Kp-Tp, optimal auxiliary control parameter is obtained based on minimal settling time concept[10] . That is, to obtain optimal auxiliary control parameter, so that the response of the system to any disturbance settles down more rapidly than the other set of Kp-Tp values from the Kp-Tp parameter plane.The Q matrix is chosen as an unit matrix. The optimal values of of Kp-Tp are determined by finding the minimum of the largest eigenvalue of PQ^{-1}. Finding largest eigenvalue of PQ^{-1} and selecting the minimum of the largest eigenvalues, instead of the least eigenvalue of QP^{-1} and then selecting maximum of the least eigenvalues, avoids the calculation of inverse for the P matrix each time, and hence saves computation time. The optimal value obtained from the Kp-Tp parameter plane are, Kp=2.0 and Tp=0.9.

D. Simulation of SMIB System with and Without Supplementary Control Signal:

In order to verify the usefulness of the designed supplementary controller using linearized model, the time response of the system is obtained. The simulation is carried out for the following disturbance: (i) Disturbance in Mechanical Power supplied to machine. (10% increase at 5 sec and kept constant up to 35 sec and then decreased by 20% at 35 sec and kept as permanent disturbance for remaining time).

In the case of above disturbance the variation of machine angle, for the system with and without supplementary control signal. This plot indicates that the machine takes a long time to reach steady state when supplementary signal is not used. With supplementary control, system reaches the steady state with negligible oscillations, indicating that the system is close to critically damped. This indicates that stability of the system has been improved.

E. Evaluation of designed Kp and Tp at different Operating Points:

In the previous section the response of certain important variables with the optimum parameters at the operating point Pg = 0.90p.u, Qg = 0.5577p.u., pf = 0.85lag, V_t = 1.0p.u.have been discussed. However it should be quite interesting to analyze the suitability of the designed Kp and Tp at other operating conditions also. For this purpose, the eigenvalues of the closed – loop system with the same parameters at different operating points i.e., Pg= 0.8p.u.and Pg = 0.7p.u. keeping pf and Vt constant are calculated. It is observed that the system is stable but exhibit few oscillations. From this it may be observed that supplementary control signal parameters designed for one operating condition will work satisfactorily for a wide range of operating conditions.

TP	KP
0.01	3.9
0.02	2.8
0.03	2.5
0.04	2.3
0.05	2.2
0.06	2.1
0.07	2.1
0.08	2.0
*0.09	*2.0
0.1	2.0

Table 1. Supplementary Control Signal Parameters within the Stability Region

4. TRANSFER FUNCTION APPROACH BASED ON PERFORMANCE INDEX

The objective of this section is to present a new guideline for the design of SVS supplementary control signal parameters connected at the midpoint for the single machine connected to infinite bus system. As it is well understood that, the rotor mode plays an important role in the dynamic stability of the system, the design of supplementary control signal is concerned with shifting of rotor mode eigenvalues to an acceptable position in the s - plane. In the designs reported in the literature so far, the damping ratio of the rotor mode is arbitrarily selected in the range of 0.2 to 0.5. In this section some new guideline for selection of optimum damping ratio of rotor mode based on performance index [8] is given.

A. Design Of Supplementary Signal Parameters for an Assumed Damping Ratio of Rotor Mode:

The single machine connected to infinite bus system with SVS located at the middle of the long AC transmission system as shown in fig.2.1. is studied. The system state space model excluding the supplementary control signal is given by

$$\overset{*}{X}_1 = A_1 X_1 + B_1 U_1$$

$$Y_1 = C_1 X_1$$

The necessary condition to be satisfied by the closed loop system, in order to have a specified pole (λ) is given by

$$H(s) = \frac{1}{C\,(sI - A)^{-1}\,B}$$

Where s=λ(the value of λ may be real). The derivation of eq.5.12 is given in Appendix D.

$$\frac{Kp\,s\,Tp}{1 + s\,Tp} = \frac{1}{C\,(sI - A)^{-1}\,B}$$

In order to keep synchronizing torque unaltered due to feedback, the open – loop natural frequency of the rotor mode is kept constant. Hence, for a particular value of damping ratio (ξ) of rotor mode and un - damped natural frequency $\omega_{n,}$ the desired eigen- value is $\lambda = \sigma + j\omega = -\xi\omega_n \pm j\,\omega_n\,(1 - \xi^2)^{1/2}$. Corresponding to s = λ, let the right hand side of equation 5.4. be a +j b (H1∠ϕ). Then by substituting s=λ in the left hand side and comparing magnitudes and phase angles, we get Kp and Tp are as follows:

Comparing phase angles

$$Tp = \frac{\omega * a - \sigma * b}{b * (\sigma^2 + \omega^2)}$$

Comparing magnitudes both sides

$$Kp = (((1+\sigma * Tp)^2 + (\omega * Tp)^2)^{1/2} / (\omega^2 + \sigma^2)^{1/2}) * (H1 / Tp)$$

B. Simulation of SMIB System with and Without Supplementary Control Signal

In order to verify the usefulness of the SVS designed using linearized model, the time response of the system is obtained. The simulation is carried out for the following disturbance

Disturbance in Mechanical Power supplied to machine (10% increase for 30 sec and then decreased by 20% and kept as permanent disturbance).

In the case of above disturbance the variation of machine angle, for the system with and without supplementary control signal. This plot indicates that the machine takes a long time to reach steady state when supplementary signal is not used. With supplementary control signal system reaches the steady state value with only few oscillations, which are damped within 5 seconds, i.e., almost critically damped. This indicates that stability has been improved due to improved damping of rotor mode.

For the same disturbance, the response of electrical power output of the machine from this plot, it can be observed that the power oscillations are damped out with in 3sec. and the system is settling at the new steady state operating point with supplementary control signal.

C. Evaluation of designed Kp and Tp at different Operating Points:

In the previous section the response of certain important variables with the optimum parameters at the operating point Pg = 0.9p.u, Qg = 0.55777p.u., pf = 0.85lag, V_t = 1.0p.u have been discussed. However it should be quite interesting to analyze the suitability of the designed Kp and Tp at other operating conditions also. For this purpose, the eigenvalues of the closed – loop system with the same parameters at different operating points i.e., Pg= 0.8p.u.and Pg = 0.7p.u. Keeping pf and Vt as constant are calculated. The time responses correspond to these operating points. It is observed that the system is stable and having very few oscillations. From this it may be observed that supplementary control signal parameters designed for one operating condition will work satisfactorily for a wide range of operating conditions.

Corresponding – Mode	Eigenvalues
Δ Bsvc	-86.9872
Δ V3	-49.0045
Δδ , Δω	-0.0493 ±j4.3264
Δ Eq', Δ Efd	-1.0115, -0.4221

Table 2. Variation of Supplementary Control Signal Parameters and Performance Index with different Damping Ratio's of Rotor Mode

Damping Ratio's	Kp	Tp	Performance Index
0.10	2.3072	0.0392	0.7103
0.15	2.0916	0.0672	0.5025
*0.20	*1.9994	*0.095	*0.4360
0.25	1.949	0.1227	0.4365
0.30	1.9073	0.1504	0.4817
0.35	1.8784	0.178	0.5648
0.40	1.855	0.2055	0.6868
0.45	1.8349	0.2329	0.8395
0.50	1.8172	0.2602	1.0270

Table 3. Performance Index is Minimum and corresponding Kp and Tp are Optimal Parameters

D.R's	ΔBsvc,ΔVaux2 - mode	Δδ,Δω - Mode	ΔV_3 - Mode	ΔEq',ΔEfd-Mode
0.1	-1.3146±j47.0061	-0.4329±j4.3047	-49.1895	-1.0122,-0.4210
0.15	-0.8633±j35.891	-0.6493±j4.2774	-49.1571	-1.0126,-0.4210
0.2	-0.6405±j30.1794	-0.8654±j4.239	-49.1780	-1.0130,-0.4210
0.25	-0.5165±j26.5494	-1.0813±j4.1894	-49.1902	-1.0134,-0.4209
0.3	-0.4363±j23.9597	-1.2979±j4.1271	-49.2044	-1.0139,-0.4209
0.35	-0.3842±j22.0327	-1.5143±j4.0528	-49.2091	-1.0144,-0.4209
0.4	-0.3423±j20.5011	-1.7306±j3.9652	-49.2129	-1.0149,-0.4208
0.45	-0.3126±j19.2526	-1.9468±j3.8637	-49.2162	-1.0154,-0.4208
0.5	-0.2875±j18.2103	-2.1628±j3.747	-49.2190	-1.0159,-0.4208

Table 4. Sensitivity of Eigenvalues with the variation of Damping Ratio's of Rotor Mode

5. RESULTS AND DISUSSION

To obtain the below simulated results, program was simulated using SIMULINK matlab7.9. Consider the data as mentioned in above discussion.

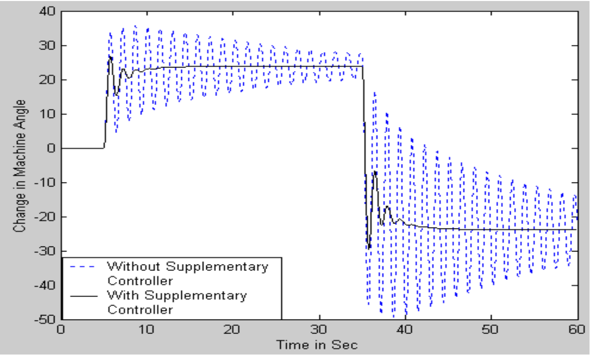

Figure 1. Variation of Machine Angle With 10% Increase and Decrease in Mechanical Power

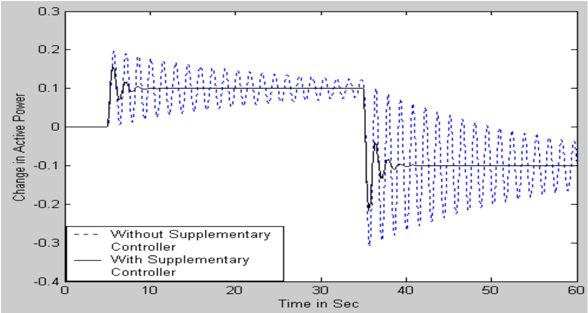

Figure 2. Variation of Active Power With 10% Increase and Decrease in Mechanical Power

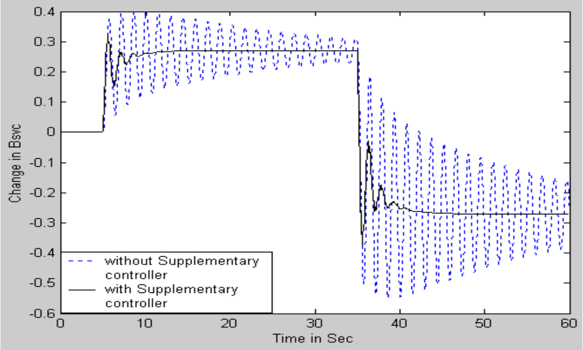

Figure 3. Variation of Bsvc With 10% Increase and Decrease in Mechanical Power

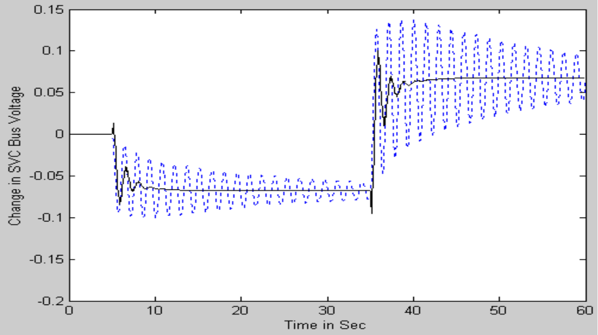

Figure 4. Variation of SVC Bus Voltage With 10% Increase and Decrease in Mechanical Power

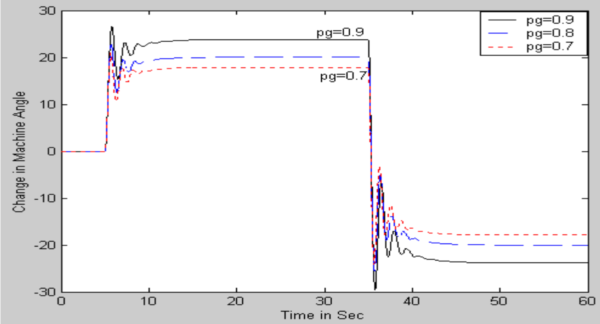

Figure 5. Variation of Machine Angle With 10% Increase and Decrease in Mechanical Power at Different Operating Points for Optimal Kp and Tp

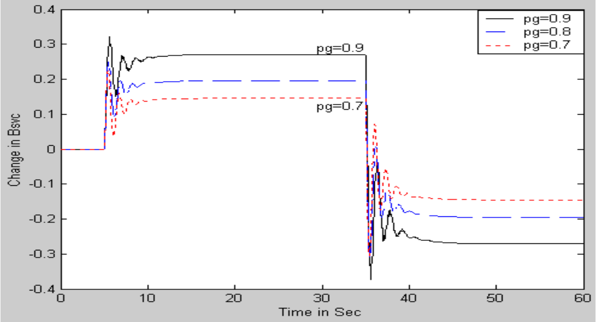

Figure 6. Variation of Bsvc With 10% Increase and Decrease in Mechanical Power at Different Operating Points for Optimal Kp and Tp

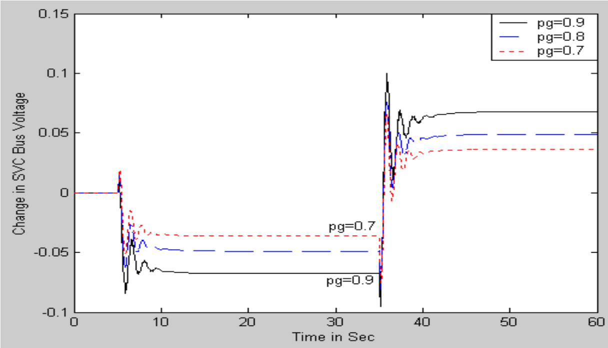

Figure 7. Variation of SVC Bus Voltage With 10% Increase and Decrease in Mechanical Power at Different Operating Points for Optimal Kp and Tp

6. CONCLUSION

In this work an attempt is made to study the effectiveness of the application of SVS at the midpoint of long transmission line connected to infinite bus and the effect of supplementary controller for damping out the power oscillations, minimization of voltage deviations under certain disturbance conditions. Also two design criteria's for the calculations of optimal parameters for the supplementary control signal are discussed.

Transmission of AC electric power from generating plants to distant areas of compensation is severely limited by stability and voltage regulation problems. Among the technical solutions suggested to solve these difficulties and to make long distance AC transmission lines feasible and economically advantageous, shunt compensation with thyristor controlled reactive power devices is finding increasing employment. In this thesis it is implemented first by considering a fixed susceptance at the midpoint of the long transmission line. A disturbance of 10% increase in mechanical power is created and kept as permanent disturbance at different operating points. Also to investigate the effectiveness of the voltage control loop (both for excitation system and SVC), the gain and time constants are varied and three cases are taken depending upon the gains and time constants. From the dynamic response of all three cases to a 10% disturbance (increase) in mechanical power one case is selected for the design of supplementary controller. It has been observed that, as the power level increases, the system becomes more oscillatory. The deviation in the system steady state is also increasing and takes more time to settle at the new operating point and at higher operating points this is not working satisfactorily (i.e., system becomes unstable).

Then the fixed susceptance is replaced with *'Static Var System'*, which has the capability to produce or absorb the reactive power, depending on the system requirement. Having replaced fixed susceptance with SVS (variable susceptance), and the same disturbance as above was created. It has been observed that even at higher power levels the system is becoming stable, but it takes long time to attain the new operating point. Now the objective is to damp out these power oscillations, so that its effectiveness is realized more critically. For effective utilization of static Var compensator capability, an auxiliary controller (supplementary controller) is incorporated, in addition to the voltage regulator

In this work active power flow in the line(entering to SVC bus from generator bus) is taken as supplementary control. Finally, the selection of optimal parameters for supplementary controller is designed based on two approach, (i) 'minimal settling time concept' [10], (ii) 'Transfer function approach based on performance index' [8,9].

In the first method, the supplementary controller parameters are decided as (i) obtaining stability region in Kp-Tp parameter plane by which a set of parameters of the supplementary controller is obtained. (ii) Selecting optimal parameters of the supplementary controller based on minimal settling time concept. Second method deals (i) with calculation of parameters for a pre-assumed damping ratio. (ii) Calculation of performance index of the close loop system. Based on performance index the optimal parameters are decided.

After deciding the optimal parameters, the performance of these parameters at designed operating point and at different operating point is carried out. It has been observed that these parameters are also working satisfactorily for a wide range of operating points.

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