Damping of power system oscillations using SVC with HPF control

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Abstract—In large power systems, low frequency electro-mechanical oscillations often follow the electrical disturbances. Generally, power system stabilizers (PSS) are used in conjunction with Automatic Voltage Regulators (AVR) to damp out the oscillations. However, during some operating conditions this device may not produce adequate damping and other effective alterations are needed in addition to PSS. That can be achieved with shunt FACTS device designed with auxiliary controllers. Static Var Compensator (SVC) is a shunt type FACTS device which is used in power system primarily for the purpose of voltage and reactive power control it has also the capability of damping oscillations with suitable controllers. A new Hybrid PID with fuzzy logic controller is designed and studied the performance. The results are obtained using nonlinear simulation in MATLAB. The results showed that Hybrid PID with fuzzy (HPF) controller is more effective in damping power system oscillations.

Keywords— HPF, SVC, Transient stability, SMIB, PID controller.

I. INTRODUCTION

The transient following a system perturbation is oscillatory in nature; but if the system is stable, these oscillations will be damped toward a new quiescent operating condition. These oscillations, however, are reflected as fluctuations in the power flow over the transmission lines. If a certain line connecting two groups of machines under goes excessive power fluctuations, it may be tripped out by its protective equipment there by disconnecting the two groups of machines. This problem is termed the stability of the tie line, even though in reality it reflects the stability of the two groups of machines.

A statement declaring a power system to be “stable” is rather ambiguous unless the conditions under which this stability has been examined are clearly stated. This includes the operating conditions as well as the type of perturbation given to the system. The same thing can be said about tie-line stability. Since we are concerned here with the tripping of the line, the power fluctuation that can be tolerated depends on the initial operating condition of the system, including the line loading and the nature of the impacts to which it is subjected. These questions have become vitally important with the advent of large-scale interconnections. In fact, a severe (but improbable) disturbance can always be found that will cause instability. Therefore, the disturbances for which the system should be designed to maintain stability must be deliberately selected [1]. Dynamic voltage support and reactive power compensation have been identified as a very significant measure to improve the transient stability of the system. Flexible AC Transmission Systems (FACTS) devices with a suitable control strategy have the potential to increase the system stability margin [2,3]. Shunt FACTS devices play an important role in reactive power flow in the power network. In large power systems, low frequency electro-mechanical oscillations often follow the electrical disturbances. Generally, power system stabilizers (PSS) are used in conjunction with Automatic Voltage Regulators (AVR) to damp out the oscillations [3]. However, during some operating conditions this device may not produce adequate damping and other effective alterations are needed in addition to PSS [4,5]. Another means to achieve damping is to use the same shunt. FACTS device Static Var Compensator (SVC) designed with auxiliary controllers [6]. Therefore SVC is more effective and if accommodated with supplementary controller, by adjusting the equivalent shunt capacitance, SVC will damp out the oscillations and improves the overall system stability [7]. The system operating conditions change considerably during disturbances. Various approaches are available for designing auxiliary controllers in SVC. In [8] a proportional – integral – derivative (PID) was used in SVC. It was found that significant improvements in system damping can be achieved by the PID based SVC. Although PID controllers are simple and easy to design, their performances deteriorate when the system operating conditions vary widely, large disturbances occur. Fuzzy logic control approach is an emerging tool for solving complex problems whose system behavior is complex in nature. An attractive feature of fuzzy logic control is its robustness in system parameters and operating conditions changes [9, 10]. Fuzzy logic controllers are capable of tolerating uncertainty and imprecision to a greater extent [11]. This paper presents a method based on fuzzy logic control for SVC controller which damp out the oscillations at a faster rate. Global input signals such as machine speed (ω) and
electrical power (Pe) are given as input to the fuzzy controller. Simulation results for a Single Machine Infinite Bus System (SMIB) and a Multi machine system (WSCC system) are presented and discussed. Finally a comparative study has been carried out between the PID controller and fuzzy controller.

II. MODELING AND CONTROL OF SVC

The Static Var Compensator is basically a shunt connected variable Var generator whose output is adjusted to exchange capacitive or inductive current to the system. One of the most widely used configurations of the SVC is the FC- TCR type in which a Fixed Capacitor (FC) is connected in parallel with Thyristor Controlled Reactor (TCR). The magnitude of the SVC is inductive admittance \( B_L(\alpha) \) is a function of the firing angle \( \alpha \) and is given by

\[
B_L(\alpha) = \frac{2\pi - 2\alpha + \sin 2\alpha}{\pi X_L^2}
\]

For \( \pi/2 \leq \alpha \leq \pi \) where \( X_L^2 = \frac{V_s^2}{Q_L} \), \( V_s = \) SVC bus bar voltage

and \( Q_L = \) MVA rating of reactor. As the SVC uses a fixed capacitor and variable reactor combination (TCR- FC), the effective shunt admittance \( B_s = B_L(\alpha) - \frac{1}{X_C} \) is given by

\[
B_s = \frac{1}{X_C} - B_L(\alpha)
\]

where \( X_C = \) Capacitive reactance.

An SVC with firing control system can be represented, for the sake of simplicity by a first order model characterized by a gain \( K_{SVC} \) and time constants \( T_1 \) and \( T_2 \) as shown in Fig.1. The controller sends firing control signals to the thyristor switching unit to modify the equivalent capacitance of the SVC. The fuzzy controller provides an auxiliary control, which is in addition to the voltage feedback loop.

Fig.1 Block representation of SVC control

The auxiliary control loop of the SVC uses stabilizing signals, such as speed, frequency, phase angle difference etc... to improve the dynamic performance of the system.

III. FUZZY LOGIC

Fuzzy set theory provides an excellent means for representing uncertainty due to vagueness in the available data or unknown behavior of a system. It can represent the human control processes and also allows experimental knowledge in adjusting the controller parameters.

A. Fuzzy sets:

A fuzzy set is a collection of distinct elements with a varying degree of relevance or inclusion. If \( X \) is a set of elements, then a fuzzy set \( A \) in \( X \) is defined to be a set of ordered pairs, \( A = \{ (x, \mu_A(x)) | x \in X \} \) where \( \mu_A(x) \) is called the membership function of \( x \) in \( A \). This membership function can take \( \mu_A(x) \) denotes the degree to which \( x \) belongs to \( A \) and is normally limited to values between 0 and 1. A high value of \( \mu_A(x) \) implies that it is very likely for \( x \) to be in \( A \).

B. Fuzzy if–Then Rules:

In the fuzzy model the knowledge relating the input features and the output class are represented by the fuzzy if – then rules of the form \( R_j: \text{if } x_{pl} \text{ is } A_{j1} \text{ and } x_{pn} \text{ is } A_{jn}, \text{ then class } C_j \text{ with } CF_j \) where \( A_{j1}, \ldots, A_{jn} \) are antecedent fuzzy sets in the unit interval \([0,1]\), \( C_j \) is one of the class codes and \( CF_j \) is the grade of certainty of the rule. A collection of such statements replace the usual mathematical model of system theory. The knowledge required to generate the fuzzy if – then rules can be derived from an expert operator and a design engineer or by an off–line simulation.

C. Fuzzy interface system:

With cause effect relationship expressed as a collection of fuzzy if – then rules, in which the preconditions use linguistic variables and the consequent have class labels, qualitative reasoning is performed to infer the results. In our model Mamdani inferene system with product t-norm and max t-co norm is used. Here the set of sensor input is matched against the if part of each if – then rule, and the response of each rule is obtained through fuzzy implication operation. The response of each rule is weighted according to the extent to which each rule fires. The response of all the fuzzy rules for a particular output class are combined to obtain the confidence with which the sensor input is classified to that fault class.

D. Defuzzification:

The output of a fuzzy rule based system is generally imprecise and fuzzy. As a fuzzy set cannot
directly be used to take the decisions, the fuzzy conclusions of rule based systems have to be converted into precise quantity. This is called Defuzzification. There are various methods like centroid method, weighted average method and max-membership method etc… for this purpose.

IV. HPF BASED DAMPING CONTROLLER DESIGN

Fig. 2 shows the schematic diagram of a SVC along with Hybrid PID Fuzzy logic based damping controller. Generator speed deviation (Δω) and (ΔP) are taken as the input signals of the fuzzy controller.

The number of membership functions for each variable determines the quality of control which can be achieved using fuzzy logic controllers. In the present investigation, five membership functions are defined for the input and output variables. Fig. 3 shows the membership functions defined. The mentioned membership functions are used to specify a set of rules called a rule base. The rules developed are based on the knowledge and experience. With two inputs and five linguistic terms, 25 rules were developed which is given in Table 1. In the inference mechanism all the rules are compared to the inputs to determine which rules apply to the current situation. After the matching process the required rules are fired. The controlled output $B_{svc}$ is determined for the different input conditions. The defuzzification produces the final crisp output of HPF with the fuzzified input. Centroid method is employed where the output will be calculated as:

$$O/P = \frac{\sum_{i=1}^{5} b_i \int \mu_i(t)}{\sum_{i=1}^{5} \int \mu_i(t)}$$  \hspace{1cm} (3)$$

V. SIMULATION RESULTS

To assess the effectiveness of the proposed controller, simulation studies are carried out for the most severe fault conditions and overload conditions in both SMIB system and Multi machine system. The details of the simulation are presented here.

A. SMIB system:

A SMIB system, equipped with Generator, Transmission line and SVC at the midpoint of the line is shown in Fig. 4. The SVC with its HPF controller is placed at the midpoint of the transmission line. The HPF damping controller for the SVC is developed using MATLAB / SIMULINK and its block diagram is shown in Fig. 5. A three phase fault is simulated at the load end at $t=0.1$ sec. and cleared after 0.05 sec. The system response without SVC is oscillatory and leads to instability.
When the SVC with conventional PID controller is placed at bus 1 and the same fault condition is simulated, it is observed that the damping is improved but still oscillations are present. With the HPF based SVC the oscillations are fully damped out and the system comes back to original steady state. Figs 6 and 7 show the dynamic response of the variation in rotor angle and angular speed deviation, under fault conditions with different controllers.

B. Multimachine system:

The same SVC controller with FLC is implemented in the 3 machine nine bus system (WSCC system). The one line diagram of WSCC system is given Fig.8

Power system data is given in [8]. Power system stabilizers with IEEE type DC1 exciter are equipped with the generators.

The FLC based SVC is installed at bus 8 near the generator 2. With the initial power flow conditions, a three phase to ground short circuit was simulated near bus 7. In Figs 9 to 11 the variation of rotor angle \( \delta \), angular speed deviation and the susceptance \( B_{svc} \) of SVC with PID controller and with Fuzzy controller and HPF controller are plotted. In this study case, fault condition at 0.1 seconds, existing for the period of 0.3 second and cleared at 0.4 seconds is shown in
Fig. 9. It is clear that the rotor angle damping using HPF controller is more effective than Fuzzy and PID controller. The settling time of both controllers is found to be same, but the amplitude of rotor angle is reduced in HPF controller.

From Fig. 10, it is acknowledged that the angular speed deviations are quickly reduced using HPF controller.

From Fig. 11, the injection of BSVC during fault condition is demonstrated. When the fault occurs, the susceptance injected due to the firing angle control through HPF, it was immediately thrown off to inductive effect from capacitive effect.

VI. CONCLUSION

This paper presents the application of a Hybrid PID with Fuzzy logic based supplementary control for an SVC to damp out the power system oscillations. The proposed HPF for SVC is proved to be very effective and robust in damping power system oscillations and thereby enhancing system transient stability. Fuzzy rules are easily derived from the signals like line active power flow, and remote generator speed deviation. The performance of various controllers is then compared for both SMIB system and multimachine system results which are shown in Fig. 6 to 11. The design results are confirmed with nonlinear simulations. Among these the performance of the proposed HPF controller is found to be better and damp out the system oscillations rapidly at faster rate. The total HPF SVC simulations were performed using MATLAB/SIMULINK software.

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