Damping Power System Oscillations Using Unified Power Flow Controller

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Abstract - Unified Power Flow Controller (UPFC), is an advanced Voltage-Sourced Converter (VSC) suitable for the power flow management of multilime systems. In recent years, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. In its general form the Unified Power Flow Controller employs number of DC to AC inverters each providing series compensation for a different line. This paper presents a new control method based on Fuzzy Logic technique to control a Unified Power Flow Controller (UPFC) installed in a single-machine infinite-bus power system. The objective of the Fuzzy Logic based UPFC controller is to damp power system oscillations. Phillips-Herffron model of a single-machine power system equipped with a UPFC is used to model the system. The Fuzzy Logic based UPFC controller is designed by selecting appropriate controller parameters based on the knowledge of the power system performance. Simple Fuzzy Logic controller using mamdani-type inference system is used. Two controller structures are considered in this study. Proportional Fuzzy structure and Hybrid Fuzzy structure. The first is a proportional fuzzy logic controller using generator power angle and angular speed as stabilizing signals. The effectiveness of the new controller is demonstrated through time-domain simulation studies. The results of these studies show that the designed controller has an excellent capability in damping power system oscillations.

1. INTRODUCTION

The electrical power industry has gone through tremendous changes since the 1980s. The power demand has increased rapidly which resulted in the huge expansion of generation and transmission facilities, and interconnections of individual systems have never been tighter than today. At the same time the socioeconomic environment has also experienced dramatic changes with the power industry facing a set of social, economic and environmental problems. Increasing public concern about the environment and health, and the cost and regulatory difficulties in obtaining the necessary ‘right of way’ for new projects have often prevented or delayed the construction of new generation facilities and transmission lines. One of the challenges the power industry faces is deregulation: to build up a competitive market ensuring the buyers and sellers can transact through a nondiscriminatory, open access transmission service, which requires the separation of the generation from transmission network. The implementation of deregulation processes challenges to the present power industry: the main economic emphasis of deregulation is to reduce the cost of electricity through competition. This requires a large number of power suppliers in contrast to traditional single-supplier vertically integrated units. The compulsory accommodation of the least expensive power by the transmission network will aggravate the loop-flow problem, possibly resulting in equipment overloading, voltage variation and a decrease of transient stability margin. The traditional solution for the above problems is the addition of new power flow control devices such as phase shifting transformers. When such options do not solve the problem the next option is to add new lines or to reconstruct the transmission systems to re-establish voltage limit and transient stability while maintain the line load within acceptable limits. Apart from the cost, such a large undertaking would be unacceptable under the present environmental and regulatory constraints. The Flexible AC Transmission System (FACTS), relying on large scale application of power electronics based, real time computer-controlled compensators and controllers, provides a technical solution to these problems.

Fuzzy logic provides a general concept for description and measurement. Most fuzzy logic systems encode human reasoning into a program to make decisions or control a system. Fuzzy logic
comprises fuzzy sets, which are a way of representing non-statistical uncertainty and approximate reasoning, which includes the operations used to make inferences in fuzzy logic. This paper presents a new control method based on Fuzzy Logic technique to control a UPFC installed in a multi-machine infinite-bus power system for the purpose of damping power system oscillations. The effectiveness of the developed controllers is demonstrated through time-domain simulations. The results of these simulations show the fuzzy controllers are capable of damping power system oscillations.

2. SYSTEM MODEL

*Power system model*

A Three machine, nine bus interconnected power system is shown in Fig 1. There are two UPFCs in the power system between Bus2, Bus3 and Bus6, Bus7 respectively. The UPFC is a generalized synchronous voltage source (SVS), represented at the fundamental frequency by voltage phasor with controllable magnitude and angle in series with the transmission line. UPFC consists of two voltage source converters. In the parallel branch of UPFC the active power is controlled by the phase angle of the converter output voltage.

![Fig. 1 3-machine, 9-bus interconnected power system model with 4-loads & 2 POD-UPFC & the fuzzy controller.](image-url)

In the series branch of UPFC, the active and reactive power flows in the transmission line are influenced by the amplitude as well as the phase angle of the series injected voltage. Therefore, the active power controller can significantly affect the reactive power flow and vice versa. It is connected to the system through two coupling transformers. The two converters are operated from a common DC link provided by a dc storage capacitor. The UPFC has several operating modes. Shunt converter control and series converter control. Two controls modes are possible for the shunt control:

1) VAR control mode: the reference input is an Inductive or capacitive VAR request.
2) Automatic voltage control mode: the goal is to maintain the transmission line voltage at the connection point to a reference value.

By the control of series voltage, UPFC can be operated in four different ways:
1) Direct voltage injection mode: the reference inputs are directly the magnitude and phase angle of the series voltage.
2) Phase angle shifter emulation mode: the reference input is phase displacement between the sending end voltage and the receiving end voltage.
3) Line impedance emulation mode: the reference input is an impedance value to insert in series with the line impedance.
4) Automatic power flow control mode: the reference inputs are values of P and Q to maintain on the transmission line despite system changes.
3. CONTROL SCHEME

Under a large disturbance, line impedance emulation mode will be used to improve first swing stability. For damping of the subsequent swings, as suggested before, UPFC will be operated in the direct voltage injection mode. In this mode, the UPFC output is the series compensation voltage $V_{se}$. This voltage is perpendicular to the line current $I_{line}$ and the phase angle of $I_{line}$ is ahead of $V_{se}$. By the control of the magnitude of $V_{se}$, the series compensation damping control can be achieved.

4. CONTROLLER DESIGN

A simple fuzzy logic controller based on mamdani type fuzzy logic controller is used in this section to damp power system oscillations in the study system. Two controller structures are considered in this study. The first is a 1951 proportional fuzzy logic controller using generator power angle and angular speed as stabilizing signals. Figure 5 shows the Proportional fuzzy logic UPFC (PF-UPFC) controller structure. Two-input one-output fuzzy logic controller is considered. The membership functions of the input and output signals are shown in Figure 6.

![Figure 2. Proportional fuzzy logic controller structure.](image)

The rules used in this controller are chosen as follows:
- If $\Delta \omega$ is P and $\Delta \delta$ is P then $\Delta mb$ is P.
- If $\Delta \omega$ is P and $\Delta \delta$ is N then $\Delta mb$ is Z.
- If $\Delta \omega$ is N and $\Delta \delta$ is P then $\Delta mb$ is Z.
- If $\Delta \omega$ is N and $\Delta \delta$ is N then $\Delta mb$ is N.

The second controller is a Hybrid fuzzy logic UPFC (HFUPFC) controller. The structure of this controller is similar to the PF-UPFC controller with the addition of a conventional integrator. The HF-UPFC controller structure is shown in Figure 3. The performances of these two controllers are compared with that of a simple unity-feedback proportional UPFC controller (P-UPFC) with the generator angular speed as a stabilizing signal.

![Figure 3. Hybrid fuzzy logic controller structure.](image)

5. SIMULATION RESULTS

The performance of the designed PF-UPFC and HF-UPFC controllers after sudden changes in the reference mechanical power is shown in Figures 5,6. It can be seen from these figures, that the
designed fuzzy logic UPFC controllers significantly damp power system oscillations compared to the P-UPFC. Moreover, comparing two structures, shows that the HF-UPFC controller has the ability to reduce the power angle deviation to zero. This is due to the action of the integral part of such a controller.

![Figure 4](image1.png)

**Figure 4.** Power angle deviation during step change in the mechanical input power for HF-UPFC.

![Figure 5](image2.png)

**Figure 5.** Power angle deviation during step change in the mechanical input power for HF-UPFC.

6. CONCLUSION

In this paper, a complete state space model for a single machine infinite-bus power system equipped with a UPFC is presented to study power system oscillations. Two controllers based on fuzzy logic technique have been developed and investigated.

REFERENCES


