

Enhancement of Transient Stability with Unified Power Flow Controller-UPFC

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ABSTRACT

UPFC is a Flexible AC Transmission System device whose role is controlling the flow of power in transmission line thus improving the system stability. The configuration of power system includes three generators, three transformers, nine buses, four loads and UPFC. The UPFC along with POD controller helps in enhancing the dynamic performance of the system. UPFC-POD along with fuzzy logic helps in damping the oscillation in the system. Therefore in this paper, a hybrid combination including fuzzy with UPFC and POD control strategy is proposed to damp the oscillation. Simulation is done using Matlab/Simulink software and results are shown with and without hybrid controller. The fault is prepared to occur near generator for 200ms.

KEYWORDS: FACTS, PID, POD, Power System, Controller, UPFC model

I INTRODUCTION

These days the power generation and transmission has been limited severely due to the limited available sources and environmental restrictions. So to overcome the above issue FACTS play a major role [1][2]. Of many FACTS devices, UPFC is the most flexible device and is multifunctional. The power system stabilizer (PSS) were in use for damping oscillations in power system, but could not produce enough damping to inter-area mode, thus FACTS like STATCOM and UPFC came into existence [3][5]. In this paper, UPFC along with fuzzy coordination scheme is utilized to damp oscillations in the system [4]. Gyugi proposed UPFC [6] which is an effective controller to control and optimize flow of power in transmission line [7]. The UPFC is formed by the combination of STATCOM and SSSC, connected by a common DC link [8][9].

To ensure secured system operation, it is always necessary to damp the electromechanical oscillation in the power system. [10] Gives many methods for damping oscillations in

single and multi-machine infinite bus systems using flexible ac transmission system devices. But great results are obtained, when used the concepts of fuzzy logic, neural networks and genetic algorithms [11][12]. In this paper fuzzy based UPFC was used.

Fuzzy control with linguistic information has several advantages like model-free, robustness, universal approximation theorem and rule based algorithm [7][13]. Fuzzy controller are rule based controllers, contains set of rules representing control decision mechanism. FLC's do not need any mathematical model and can handle huge range of operating conditions. UPFC with fuzzy logic can eventually lessen the power oscillation damping in multi-machine systems [14].

The paper is ordered as, Introduction to FACTS, UPFC and FLC was presented in previous paragraphs. Section 2 gives the modeling of 3-machine 9-bus system model. The control strategy containing UPFC and FLC was discussed in Section 3. Section 4 presents the simulation results; finally Section 5 gives the conclusion of the paper.

II. 3-MACHINE, 9-BUS SYSTEM MODEL

In this paper, the system model is developed containing three generators, four loads and nine buses. The models are developed without and with controllers as shown in Figs 1 and 2 respectively. The generator 1 is connected to the bus 1, generator 2 to bus 8 and generator 3 to bus 5. The transformers 1, 2 and 3 are placed near the generator buses for transmitting power either by stepping up or stepping down. As the power system is nonlinear in nature, there is a requirement of mathematical model for modeling and simulating in Matlab/Simulink software. After the process of linearization the total system model is in state space form as

$$\begin{aligned} \Delta \dot{x} &= A \Delta x + B \Delta u \\ \Delta y &= C \Delta x + D \Delta u \end{aligned} \quad (1)$$

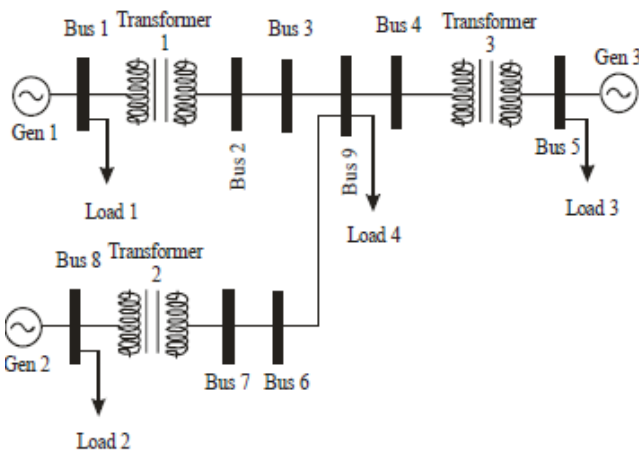


Fig. 1: A system model without the controllers

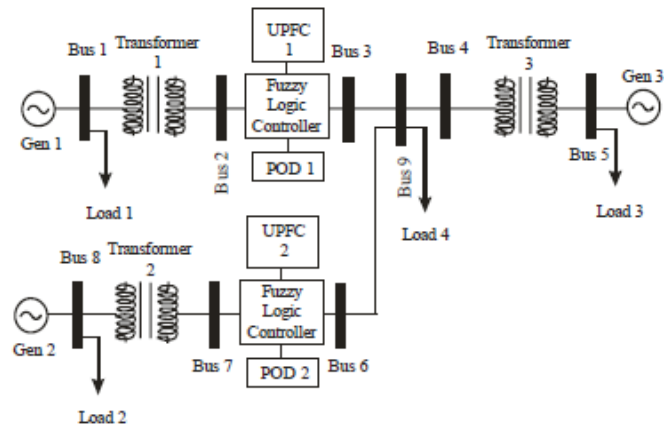


Fig. 2 : A system model with POD-UPFC & the fuzzy controller

Here, $\Delta x, \Delta y, \Delta u$ indicates state vector, output vector and input vector with lengths as n, m and r respectively. A is system state matrix, B is control input vector, C is control input vector and D is feed forward matrix whose sizes are $(n \times n), (n \times r), (m \times n)$ and $(m \times r)$ respectively. The Table I gives the simulation parameters of the system.

TABLE I

Base value	$V_B=220 \text{ KV}, S_B=100 \text{ MVA}$
Generators	$2H_1=2H_2=8s, 2H_3=10$ $D_1=D_2=D_3=0.0,$ $T_{d01}=T_{d02}=4.49s,$ $T_{d03}=6s$ $X_{d1}=X_{d2}=1.56 \text{ (p.u.)},$ $X_{d3}=2 \text{ (p.u.)}$ $X_{q1}=X_{q2}=1.06 \text{ (p.u.)},$ $X_{q3}=1.9 \text{ (p.u.)}$ $X_{d1}'=X_{d2}'=0.17 \text{ (p.u.)},$ $X_{d3}'=0.25 \text{ (p.u.)}$
Transformers	$X_{r1}=X_{r2}=X_{r3}=j0.305 \text{ (p.u.)}$
Transmission lines	$Z_{i1}=Z_{i2}=Z_{i3}=0.0+j0.25 \text{ (p.u.)}$
UPFCs	$V_{Oper}=220 \text{ KV}, V_{semax}=0.1V_{Oper},$ $V_{semin}=-0.1V_{Oper}$
Loads	$L_1=L_2=L_3=0.05 \text{ (p.u.)}, L_4=0.65$ (p.u.)

In the linearized system model, the controller was kept in loop along with the plant model, such that when any disturbance like fault occurs the oscillations are damped quickly within no time [12]. Therefore this system is considered as the closed loop feed control system.

In this system model, controllers are placed in a loop; such that when any disturbances like faults occur, the oscillations are damped quickly with in no time [12].

III CONTROL SCHEME

A controller controls the entire system and provides stability of the system at all the times i.e., even during the fault or disturbance or noise. A UPFC is a FACTS device mostly used in compensating reactive power on transmission network of high voltage. It also regulates magnitude of the voltage, phase angle, line impedance and controls the flow of active and reactive power in transmission line [5]. It also improves steady state and dynamic performance of a system, giving better system stability and voltage control. Furthermore when coordinated with damping controller, the UPFC can further improves the power system performance dynamically.

UPFC is a FACTS device mostly used for reactive power compensation in transmission networks. Fig. 3 shows the block diagram in which 2 voltage source converters (VSC) are presented linked through a common DC link capacitor. There are two transformers in the figure namely boosting transformer and excitation transformer, coupled together by the two converters. One transformer is connected in series and other in shunt to the line. The converters compensate active and reactive power. Whereas the UPFC not only controls the flow of active and reactive power in steady state conditions but also improves the damping of system oscillations by converter voltage modulation.

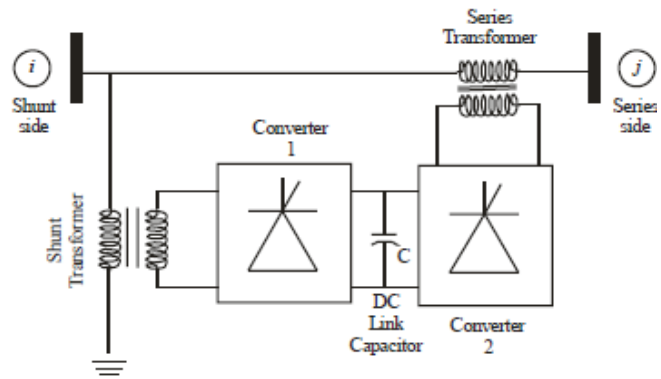


Fig. 3: Block diagram with UPFC scheme used in FACTS

Conventionally FACTS along with POD controller and UPFC were in use, in which the settling time, oscillations and ringing effects of different power system parameters may be more. These can be reduced by the usage of POD and UPFC to coordinate with fuzzy controller. And to obtain more accurate results, POD based UPFC scheme is coordinated with a fuzzy scheme, which is used in this work. The fuzzy controller has lot of merits compared to conventional (POD-UPFC) and classical (P,PI,PID) controllers like simplicity, low cost, high reliability etc. Fig 4 shows the Fuzzy Logic Controller along with POD-UPFC for power oscillation damping.

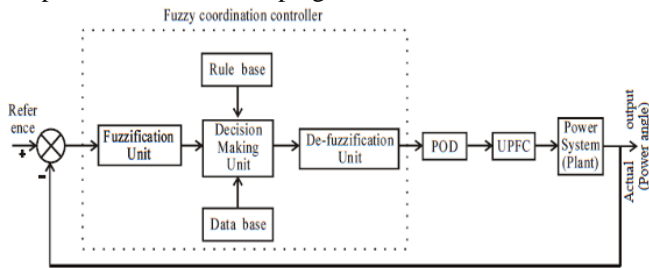


Fig. 4: A diagrammatic view of fuzzy logic controller along with POD-UPFC

In single machine systems, the issues can be solved by POD along with UPFC controllers, but in multi-machine systems, there may be occurrence of large disturbances and faults. In such cases to obtain best coordination among different parameters of POD-UPFC, fuzzy logics play an important role together with POD-UPFC controller in providing the best performance of the system. The advantage of fuzzy controller over classical (P, PI, PID) and conventional (POD-UPFC) are simplicity, low cost, highly reliable, hardware compactness and no requirement of mathematical model in designing.

Fuzzy logic contains linguistic variables, represented by fuzzy sets. In fuzzy sets, an element can partially belong to one or more sets. A fuzzy logic controller works based on fuzzy rules, expressed in conditional statements form. The basic structure that damps out power system oscillations comprises of 3 parts such as fuzzification, knowledge base and defuzzification.

The rule based and data based units are the inputs to the inference system. The crisp data is converted into linguistic variables by the fuzzy unit. The knowledge base takes decision on the linguistic variables by using logical linguistic rules of rule base and relevant data of data base [8][5]. The output is forwarded as input to the next unit i.e., defuzzification unit where the linguistic variables are once more converted into numeric data in crisp form [5] using methods such as center of gravity method, center of singleton method and so on. The Table II shows the rule base used by the decision making unit.

TABLE II

$P_{UPFC1} \rightarrow$		Small set S	Medium set M	Big Set B
$P_{UPFC2} \downarrow$		mf_1	mf_2	mf_3
Small set S	mf_1	B	M	S
Medium set M	mf_2	B	M	S
Big set B	mf_3	M	S	S

The fuzzy coordination unit's output is sent to the POD (Power Oscillation Damping), which is further sent as input to UPFC controller. The POD uses 5 blocks namely amplification block, washout link, 2-stage of lag lead blocks and a limiter. The fuzzy-POD-UPFC finally generates a control signal which is supplied to the multi machine model for damping oscillations. As the fuzzy coordination unit is kept before UPFC-POD, the amplification part of the converter controller is modified by the fuzzy; therefore the power system stability is increased.

IV SIMULATION RESULTS

Figs. 5 and 6 show the Simulink models of a system containing 3 machines, 9 buses with Fuzzy-POD and without controller respectively, in which a line of 220kV and generators of 100MW are used. The simulation is done using Matlab/Simulink software. A fault was happened to occur at the first generator for 200ms and is simulated. The simulation results were observed for without controller, with PID-POD and with Fuzzy-POD. Figs 7-9 show the curves of power angle measured in degrees against time without, with PID-POD, and with Fuzzy-POD respectively. From the results it is shown that the power system with Fuzzy-POD controller gives the improved dynamic performance compared to the one with PID-POD and without controller.

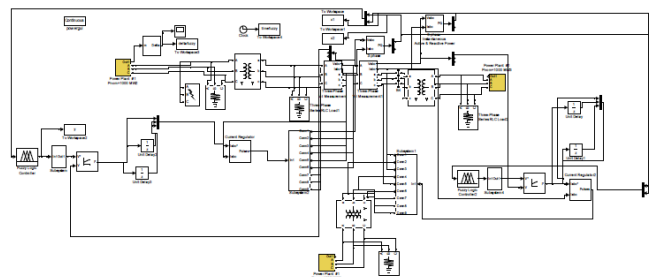


Fig. 5 : The Simulink model system with Fuzzy-POD-UPFC

Also the overshoots and undershoots exhibited by power angle curves is very less when fuzzy controller is used. The damping of power system oscillations was done within short time and reach final steady state value.

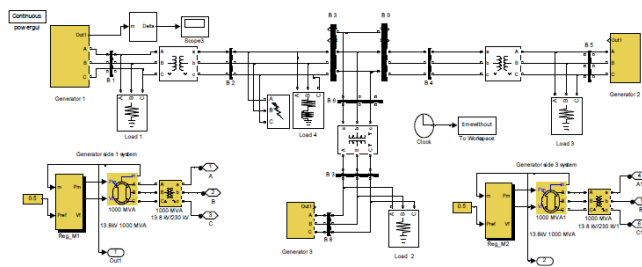


Fig. 6 : The Simulink model of a system without controller

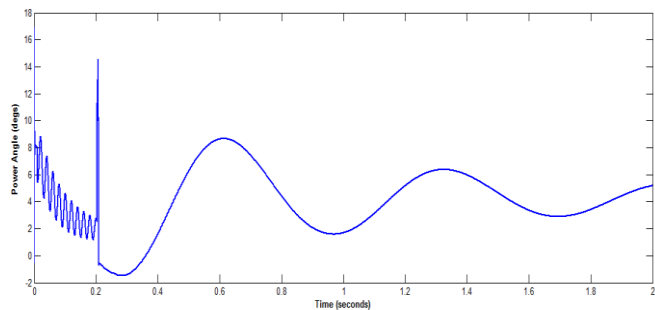


Fig. 7 :Power angle v/s time(without controller)

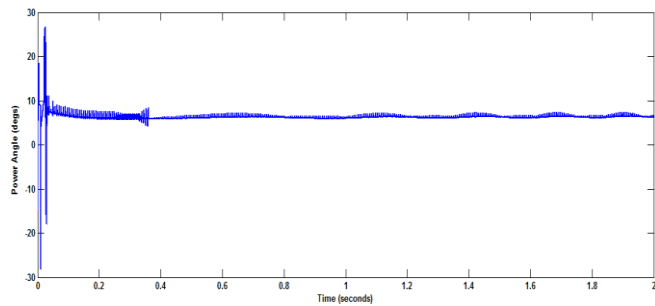


Fig. 8 :Power angle v/s time (withPID-POD)

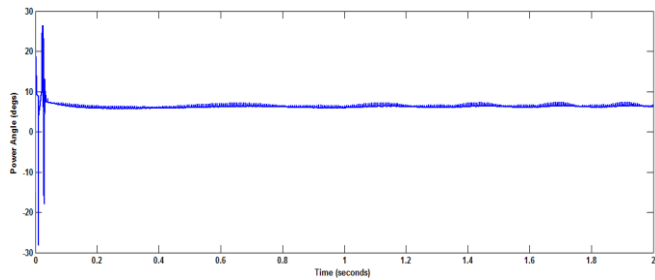


Fig. 9: Power angle v/s time (with Fuzzy control-POD)

V CONCLUSION

In this paper, a system was developed containing three generators, nine buses without and with controller i.e., Fuzzy-POD. The power system stability was greatly improved by the Fuzzy-POD compared to the conventional controller; this is because the fuzzy coordination unit modified the amplification part of the existing controller. The simulation was done using Matlab/Simulink software with and without controller for damping power system oscillations. The simulation results were shown for power angle versus time without controller, with PID-POD and with Fuzzy-POD. From which the efficacy of the developed method is demonstrated and Fuzzy-POD was proved to be the best control method in damping the power system oscillations.

NOMENCLATURE

UPFC	Unified Power Flow Controller
FACTS	Flexible AC Transmission System
POD	Power Oscillation Damping
PSOC	Power System Operation & Control
IEEE	Institute of Electrical & Electronics
SVC	Static Var Compensator
TCSC	Thyristor Controlled Series Compensator
TCPS	Thyristor Controlled Phase Shifter
SSSC	Static Synchronous Series Compensator
STATCOM	Static Synchronous Compensator
DC	Direct Current
AC	Alternating Current
FLC	Fuzzy Logic Control
PD	Proportional Derivative
PID	Proportional Integrator Derivative

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