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Simulation and Analysis of Fuzzy Logic based Unified Power Flow Controller connected to Transmission Line

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Abstract

The Unified Power Flow Controller (UPFC) is used to control the flow of power in the transmission systems by controlling the impedance, voltage magnitude and phase angle. The Unified Power Flow Controller (UPFC) is the most versatile and complex power electronic equipment that has emerged for the control and optimization of power flow in electrical power transmission system. Installing the UPFC makes it possible to control an amount of real power flow through the line. This controller offers advantages in terms of static and dynamic operation of the power system. It also brings in new challenges in power electronics and power system design. FACTS devices are mostly used to control the flow of power, to increase the transmission capacity and to optimize the power system stability. The most widely used FACTS device is Unified Power Flow Controller (UPFC). The controller used in the considered system has a significantly effects on improving the real power and compensating the reactive power. In this paper, the capability of UPFC is observed for the transmission line based on PI and fuzzy logic controllers (FLC).

Keywords: FACTS, AC transmission system, power flow control, STATCOM, SSSC, FLC, and Unified power Flow Controller (UPFC).

Introduction

The development of the power systems in the future will rely on increasing the capability of existing transmission systems rather than building the new transmission lines and the power stations for an economical and an environmental reasons. The requirement of the new power flow controllers, which is capable of increasing the transmission capability and controlling the power flow through the predefined corridors, will certainly increase due to the deregulation of the electricity markets. In the late 1980s the Electric Power Research Institute (EPRI) has introduced a new technology known as Flexible AC Transmission System (FATCS) [1-2]. The main scheme behind this program is to increase controllability and optimize the utilization of the offered power system capacities by replacing mechanical controllers with reliable and high speed power semiconductor devices. The most recent generation of FACTS controllers is based on the concept of the solid state synchronous voltage sources (SVSS) introduced by L. Gyugyi in the late 1980s [3-4]. The SVS can be used as shunt or series compensator in FCATS network. If it operated as a reactive shunt compensator it is called static condenser (STATCOM), if it operated as a reactive

series compensator it is called static synchronous series compensator (SSSC). The special arrangement of two SVSSs, one connected in series with the ac system and the other is connected in shunt, with common dc terminals is called Unified Power Flow Controller (UPFC). The Steady state model referred as an injection model is described in [5]. UPFC is modeled as a series reactance in concert with the dependent loads injected at each end of the series reactance. The model is simple and helpful in understanding the UPFC impact on the power system. However, the amplitude modulation and phase angle control signals of the series voltage source converter have to be adjusted physically in order to find the desired load flow solution. A new fuzzy inference system described in matrix form is anticipated and used to develop the dynamic control of real and reactive power [6]. The power-feedback control format is used in the control method of UPFC [7]. The power instability is damped readily and the value of reactive power is reduced as possible by using numerous time constants. The control method of variable interval-fuzzy-mutual is used in the control mechanism of UPFC [8]. The real and reactive power of the transmission line can be

restricted with help of UPFC [9]. The concept of FLC is to utilize the qualitative familiarity of a system to design a realistic controller [10]. In this paper a fuzzy logic based UPFC connected to a transmission system that includes both the shunt converter and series converter has been simulated using MATLAB and the results are compared and evaluated.

Unified Power Flow Controller

The UPFC is a combination of STATCOM and a SSSC, which are coupled through a common DC link. This DC link allows a bi-directional flow of real power among the shunt output terminals of the STATCOM and the series input terminals of the SSSC. This real power is restricted to provide concurrent real and reactive series compensation without an exterior electric energy source. The active power for the series converter is obtained from the line via the shunt converter STATCOM. It is also used for voltage phase and amplitude to control its reactive power. This is a complete controller for controlling the active and reactive power through the line, as well as line voltage controller. The basic circuit of UPFC is shown in Figure 1.

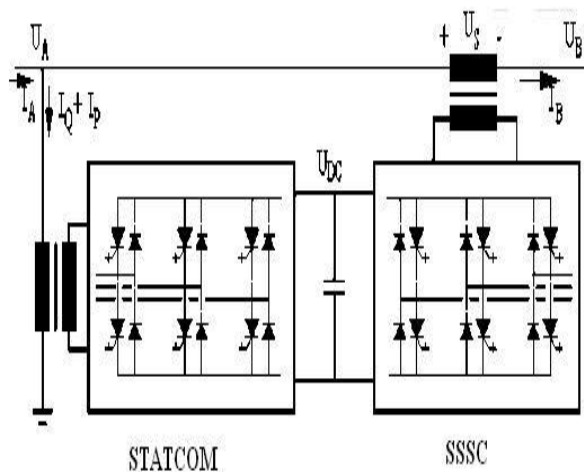


Fig .1.Basics of VSCs and PWM Technique

A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate voltage dips. It is made of six valves each consisting of a gate turn off device (GTO) paralleled with a reverse diode, and a DC capacitor. An AC voltage is generated from a DC voltage through sequential switching of the GTOs. The DC voltage is unipolar and the DC current can flow in either direction. The real power flows from the DC side to AC side if the converter output voltage is controlled to lead the AC system voltage. If the converter output

voltage is made to lag the AC system voltage the real power will flow from the AC side to DC side. When sinusoidal PWM technique is applied turn on and turn off signals for GTOs are generated comparing a sinusoidal reference signal v_r of amplitude A_r with a sawtooth carrier waveform v_c of amplitude A_c . The fundamental frequency of the converter output voltage is determined by the frequency of the reference signal. Controlling the amplitude of the reference signal controls the width of the pulses. The amplitude modulation index is defined as, $m = A_r/A_c$. For $m \leq 1$ the peak magnitude of the fundamental frequency component of the converter output voltage can be expressed as $V = m \frac{V_{dc}}{2}$.

VAR Control Method: According to the system situation, the reference input signal is an inductive or capacitive VAR request. The controller takes the reactive reference to translate into a corresponding shunt current request and adjusts the gating of the converter to establish the desired current. A feedback signal representing the dc bus voltage and the current feedback signals is taken by the controller obtained from current transformers (CTS) and V_{dc} is also required.

Automatic Voltage control Mode. The shunt reactive current of converter is automatically regulated to keep the transmission line voltage at the point of shunt converter connected to a reference value. The actual value of the injected voltage can be obtained in several ways.

Direct Voltage Injection Mode: The reference inputs are directly the magnitude and phase angle of the series voltage.

Phase Angle Shifter Emulation mode: The reference input is phase displacement between the sending end voltage and the receiving end voltage.

Line Impedance Emulation mode: The reference input is an impedance value to insert in series with the line impedance

Automatic Power Flow Control Mode: The reference inputs are values of P and Q to maintain on the transmission line despite system changes.

Controllers for UPFC

UPFC is combined with STATCOM and SSSC. These parts are coupled together with common DC link (capacitor) to allow the real power flow between the series and shunt converter output terminals bi-directionally, and to provide real and reactive line compensation without an external energy source. UPFC is able to control the series voltage injection ($\Delta V \perp \theta$) by the means of unconstrained angle.

a. Proportional controller (P)

In P-control, the output of the controller (control signal) is directly proportional to the error signal. Simple P controller used in control mechanism is shown in Fig.2.

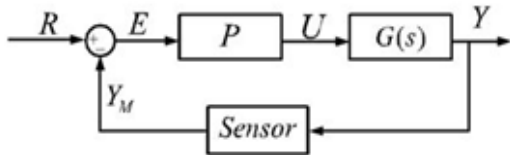


Fig.2. Basic scheme of P Controller

b. Proportional Integral Controller (PI):

In PI-controller, there is another term in the controller equation shown in Fig.3.

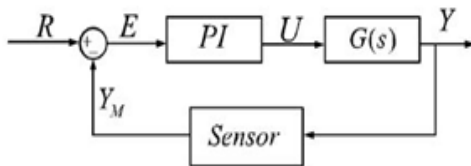


Fig.3. Basic scheme of PI Controller

$$U = K_e(t) \frac{1}{T_1} \int_0^t (e(t)dt)$$

If the controller is tuned to be fast and, T_1 is small, then both terms (P and I) affect the control signal all the way from the beginning. The system becomes faster, but the output signal might oscillate.

c. Proportional Integral Derivative Controller (PID)

The equation of PID-controller has three terms. These are P, I and D-terms. Simple PID controller used in control mechanism is shown in Fig.4.

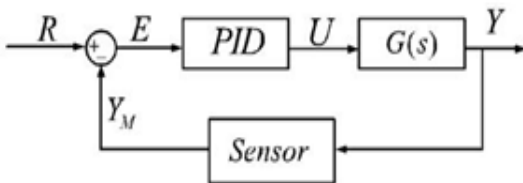


Fig.4. Basic scheme of PID Controller

$$U = K_e(t) \frac{1}{T_1} \int_0^t e(t)dt + T_d \frac{de(t)}{dt}$$

Where T_d is derivation time constant. The derivation term acts like predictor, because the speed of change of the error signal affects the control signal. The derivation term has a large effect in systems where disturbances are present, because disturbances are often fast.

d. Fuzzy Controller:

The simple rule based on *if x and then z* approach is incorporated to a solving control problem rather than attempting to model a system mathematically by FLC. The proposed method does not contain any transformations. The error signal obtained from comparison of sending end voltage and

their reference voltages are directly processed into FL controller to improve the response time of UPFC. In this paper, the number of rules is increased from 1 to 49 to achieve better performance. The effects of UPFC on the power system are increased by the proposed fuzzy controller. The input signals are fuzzified and represented in fuzzy set symbols by membership functions. The output (actuating) signals are produced by defined *If ... then ...* rules and these signals are defuzzified as analog control signals to compare with a carrier signal. The obtained signals are used to control the PWM converter. The error and error rate are described as linguistic variables such as large negative (LN), medium negative (MN), small negative (SN), very small (VS), small positive (SP), medium positive (MP) and large positive (LP). These variables are characterized by memberships in this simulation study.

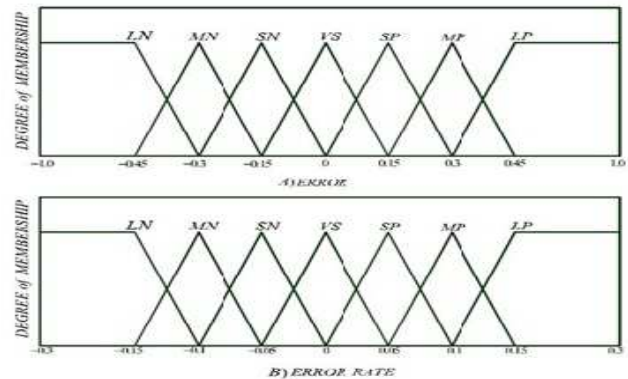


Fig.5. The error and error rate of fuzzy membership functions

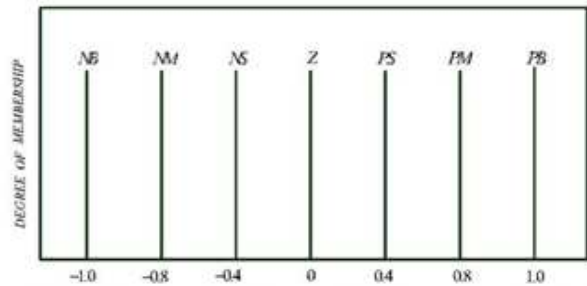
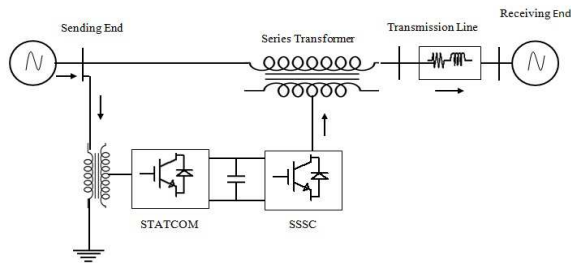


Fig.6. The output of fuzzy membership functions

The seven membership functions are defined as an each input of the fuzzy system which is shown in Fig.6. In the fuzzy controller used in this paper, the symmetric AC variables which possess both positive and negative half-waves are used in order to get the effective control accuracy and the simple based rule. The rules are created by taking into account both positive and negative half-wave polarity of the system variables.

Simulation Setup of UPFC



The phase variation is between sending end and receiving end generators in the transmission lines. The power flow occurs according to the quantity of phase variation. Some FACTS devices are used to utilize more effectively from the power flow in the transmission line. The UPFC is the most beneficial in these FACTS devices. Generally, the power and voltage ratings are in MVA, KV, respectively in the transmission line. These power and voltage ratings could not be achieved in laboratory environment. Regarding this situation, the experimental cases are studied in references and the power and voltage ratings used in the experimental systems are smaller than the real transmission line ratings. The test system has same ratings as used in references in this thesis. In the case studies, the two generators having the same properties are used as a sending end and receiving end generator. The phase variations at the receiving end generator are formed systematically to analyze the performance of UPFC with controllers on power flow. In all case studies, the generators have the same properties and the transmission line impedances use same quantities. The effects of each controller are compared to show the performance of these controllers on power flow in the line transmission.

Simulation Results

In case 1, the receiving end generator is retarded from sending end generator, and the power flow of the line with UPFC and without UPFC is observed. The amounts of real and reactive power are 0.4 KW and 0.0021 KVAR, respectively when the system is worked without UPFC. In the same way, the real and reactive powers are 0.4889 KW and 0.00352 KVAR, respectively, when UPFC is activated in the line.

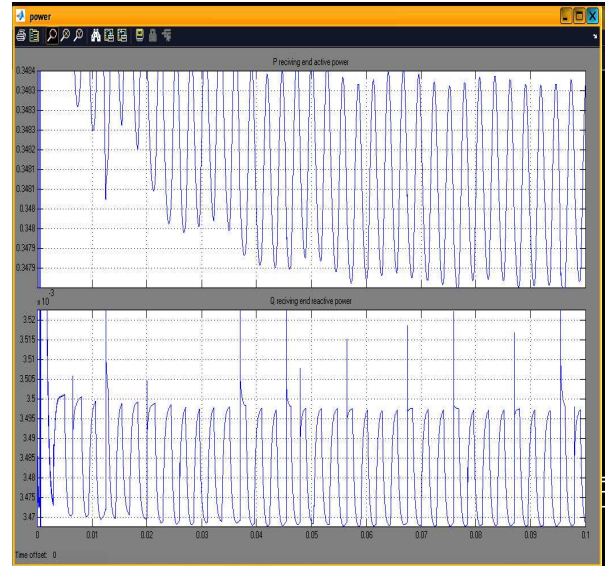


Figure 5. 2 Real & Reactive power quantities of the line with UPFC

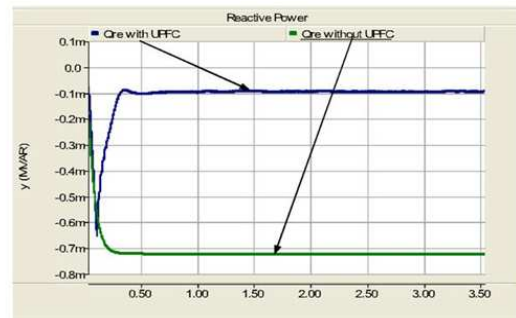


Figure 5. 3 Reactive power quantities of the line with and without UPFC

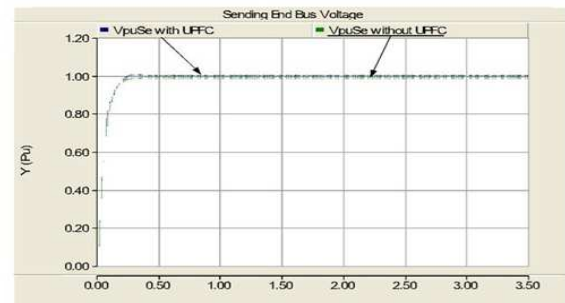


Figure 5. 4 Sending end bus voltage with and without UPFC in the line

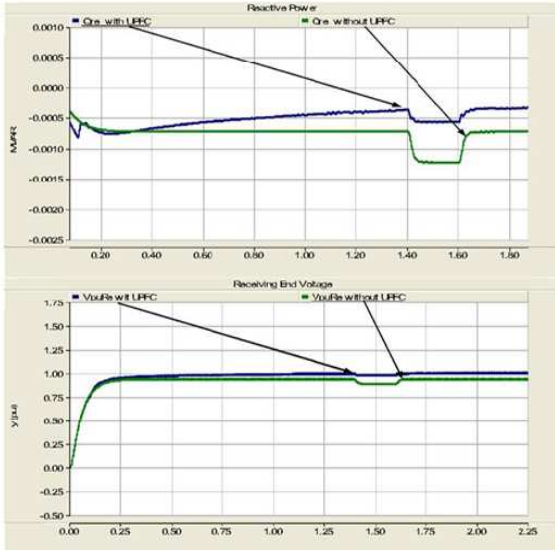


Figure 5.23 The P controller results when fault was occurred

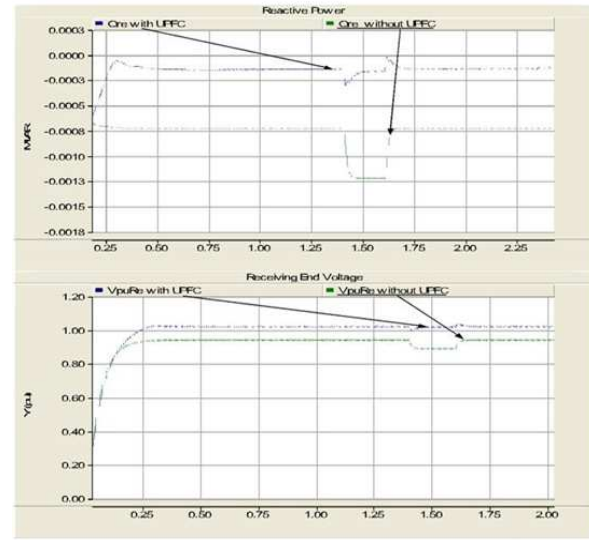


Figure 5.25 The fuzzy controller results when fault was occurred

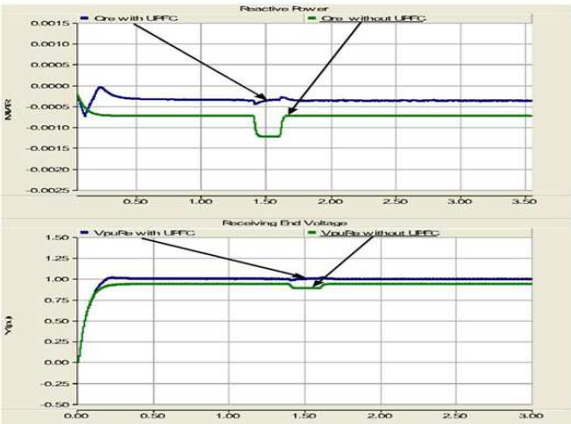


Figure 5.24 The PI controller results when fault was occurred

In case 2, when UPFC senses fault, it immediately activates the electronic bypass to protect the series converter. The results of reactive power quantities and receiving end bus voltage are compared graphically by using in figure 5.23 to 5.25. Considering the results, the P controller has not effect on reactive power compensation and bus voltage control when the fault occurs. The PI, PID and fuzzy controllers arc more effective than P controller when the fault appears in the line. The fuzzy controller is the most effective on power flow in these controllers.

Conclusions

The simulation results show that the when there is small disturbance in the power system, the UPFC with proposed fuzzy controller is more effective than the UPFC with the conventional UPFC in damping the LFO. In this paper, the performance of UPFC on controlling of the real/reactive power flow in the line is examined with different control mechanisms based on P, PI, PID and fuzzy controllers. For the first case study, the results show that P controller does not sufficient on controlling the power flow while FLC shows the best performance on controlling the power flow. In the second case study, three phase fault is applied to the test system. The PI and fuzzy controllers show nearly same results but there is a low overshoot occurred during the fault in the fuzzy controllers results. To see the performances of UPFC on the faults conditions, the three-phase fault is applied to the transmission line, and results are compared in terms of compensation of the reactive power and controlling the bus voltage. The simulation results shows that the performance of

fuzzy logic based UPFC is increased in comparison with other control strategies.

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