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Stability Enhancement of SMIB System: A Performance Comparison between FACTS Devices and Fuzzy Logic Control

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ABSTRACT

The power system is a dynamic system subjected to various disturbances which leads to unstable conditions. Flexible AC Transmission Systems (FACTS) devices have been used in power systems for the improvement of its dynamic performance. In this paper performance comparison of different FACTS controllers (STATCOM, SSSC, UPFC) for SMIB system have been discussed. The investigation on the performance of the proposed Fuzzy Logic based UPFC Controller in damping the oscillations thereby enhancing the stability of single machine infinite bus system is done. The performance of Fuzzy Logic based UPFC controller is compared with conventional PI based UPFC and the superiority of proposed controller is established.

Keywords : FACTS, Fuzzy Logic Control, SSSC, STATCOM, UPFC

1 Introduction

FOR the successful operation of a power system, a reliable and uninterrupted supply of power to the loads is required. The first requirement of reliable service is to keep the synchronous generators running in parallel and with adequate capacity to meet the load demand. A second requirement of reliable electrical service is to maintain the integrity of the power network. The high-voltage transmission system connects the generating stations and the load centers [1]. Interconnections of power system have lead to the power transfer problem which must be dealt successfully by an electrical engineer [2]. Power transfer capacity along a transmission line is limited by various constraints such as thermal limit, steady state stability limit, transient stability limit and system damping. The Flexible AC Transmission system (FACTS) technology, introduced in 1988 by Hingorani, is an enabling technology that provides flexibility and have a capability to make transmission system stable[3][4]. The electrical damping of power systems needs to be reduced so that a stable and oscillation free power transfer can de done. Flexible AC Transmission Systems (FACTS) offer a viable solution to these problems, and are now finding wide usage in power systems worldwide [5]. A simulink model of single machine infinite bus system (SMIB) system installed with FACTS devices is used in the present work to investigate their performances with an objective to enhance the system stability. The present work proposes the use of UPFC based fuzzy controller to improve the performance of UPFC equipped SMIB system under consideration by damping power system oscillations more effectively.

2 Problem Statement

1. To examine the relative effectiveness of FACTS devices for damping power system oscillations under different conditions.
2. To design fuzzy logic based UPFC controller for damping control of the system under consideration.
3. To compare the performance of UPFC based damping controllers:
   (i)With conventional PI control, and
   (ii)With fuzzy logic control

3 Facts Devices

Instability in power system could be relieved or at least minimized with the help of most recent developed devices called Flexible AC Transmission System (FACTS) controllers [5]. The use of Flexible AC Transmission System (FACTS) controllers in power transmission system have led to many applications of these controllers not only to improve the stability of the existing power network resources but also provide operating flexibility to the power system[6].FACTS Controllers are broadly classified into four types with some major Controllers being listed below:

1) Series Controllers
- Static Synchronous Series Compensator (SSSC)
- Thyristor Controlled Series Compensator (TCSC)
- Thyristor Switched Series Compensator (TSSC)
- Thyristor Controlled Series Reactor (TCSR)

2) Shunt Controllers
- Static Synchronous Compensator (STATCOM)
- Static Var Compensator (SVC)
- Battery Energy Storage System (BESS)
- Thyristor Controlled Reactor (TCR)

3) Combined Series-Series Controllers
-Interline Power Flow Controller (IPFC)

4) Combined Series-Shunt Controllers
- Unified Power Flow Controller (UPFC)

FACTS controllers that are fast emerging in power systems applications include the STATCOM, SSSC, and UPFC.

3.1 Static Synchronous Compensator (STATCOM)

A STATCOM is a controlled reactive power source which uses VSC interfaced in shunt to a transmission line. It provides desired reactive power generation as well as absorption purely by means of electronic processing of voltage and current waveforms in a voltage source converter (VSC) as shown in fig.1 [7].

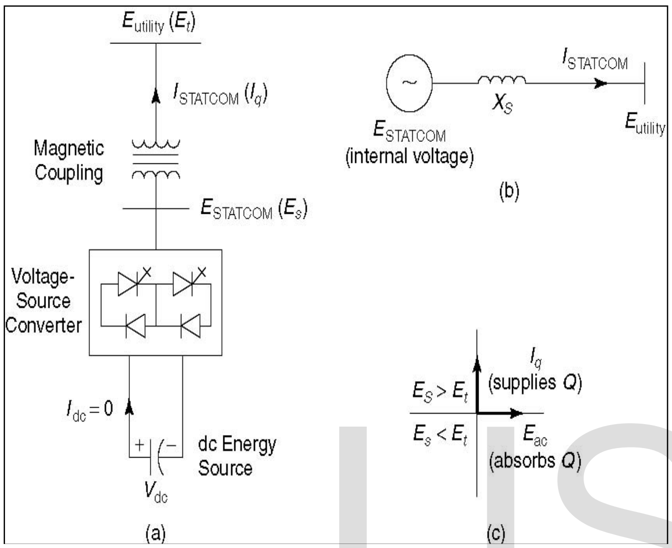

Fig. 1. The STATCOM principle diagram: (a) power circuit (b) an equivalent circuit (c) power exchange

3.2 Static Synchronous Series Compensator (SSSC)

SSSC is a series connected synchronous voltage source which can vary the effective impedance of a transmission line by injecting a voltage with an appropriate phase angle in relation to the line current. It is able to exchange both active and reactive power with the transmission line. The main aim of the device is to balance the reactive power as shown in block diagram illustrated as below in fig. 2[7].

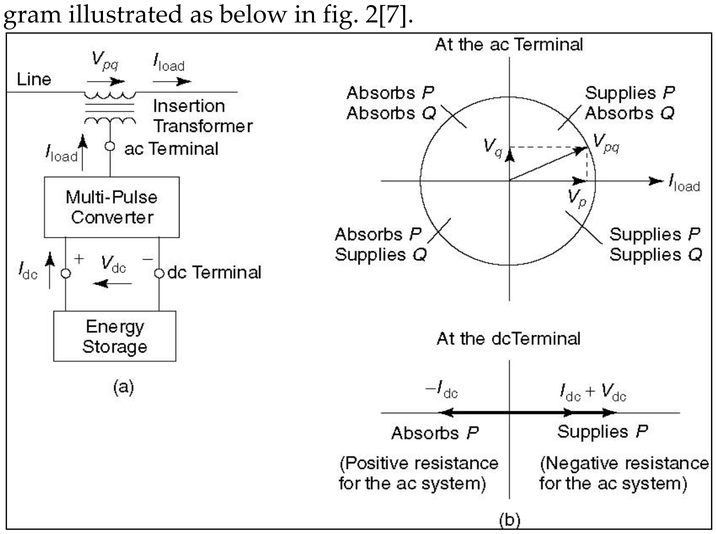

Fig. 2. Block diagram and operating principle of a SSSC

3.3 Unified Power Flow Controller (UPFC)

The Unified Power Flow Controller (UPFC) is the most versatile FACTS Controller which is a combination of STATCOM and SSSC which are coupled by DC link as shown in fig. 3. It is having powerful capabilities of voltage regulation, series compensation and phase shifting. It can control both real and reactive power flows in transmission line. The main objective of series converter (Convertor 2) is to produce an ac voltage Vpq of controllable magnitude and phase angle and inject this voltage at fundamental frequency in series with transmission line, which exchanges both real and reactive power with transmission line. The shunt convertor (Convertor1) behaves like STATCOM regulates the terminal voltage of the interconnected bus by generating/absorbing requisite amount of reactive power [7][8].

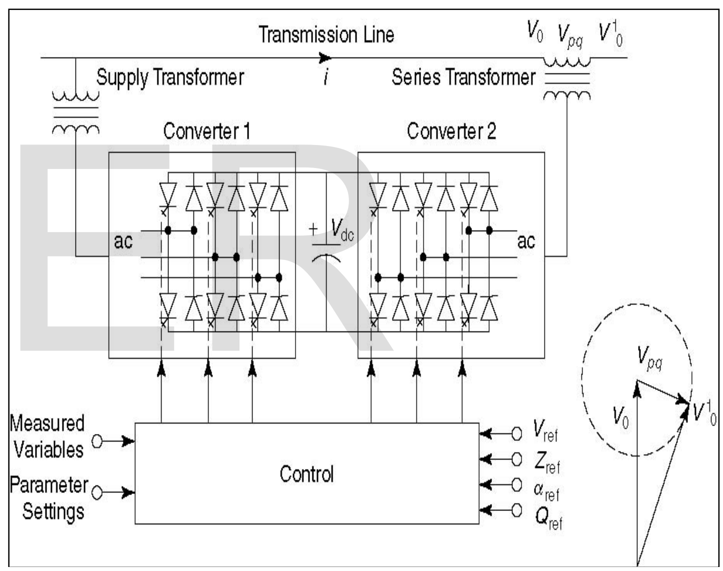

Fig.3. Basic Circuit Configuration of the Unified Power Flow Controller.

4 SYSTEM DESCRIPTION

The single machine infinite bus (SMIB) installed with UPFC as shown in given fig.4 has been considered in this work. The UPFC is installed at the end of transmission line. Similarly the STATCOM and SSSC are installed in transmission line by replacing UPFC. The proposed control strategy for UPFC series part is introduced [10]. The generator is a 1000-MVA, equivalent of four generators in parallel, each of a 250-MVA capacity. Each generator is directly connected to a transformer of 250MVA. The transmission system comprises 400-kV double lines 500 km long divided into two sections, 200 km and 300 km long. The considered contingency is a three-phase fault at the sending end of one transmission line while the generator is op-

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erating at its rated capacity. The three-phase short-circuit duration time in all simulations is considered between t = 0.2 and 0.4 s. The fault is cleared with operation of transmission-line reclosures. This fault period involves the maximum time of reaction of the protection system. The system parameters are given in Appendix.

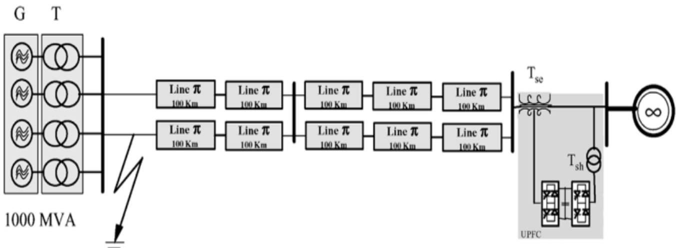


Fig. 4. Generator-infinite bus system with the UPFC

5 Fuzzy Logic Based UPFC Damping Control

As UPFC is the most versatile FACTS device, having the capability to improve the performance of the system, performance of UPFC needs to be enhanced for damping system oscillations. A Fuzzy Logic based UPFC controller is proposed to further enhance the performance of UPFC equipped system under consideration. The block diagram of Fuzzy Logic Controller (FLC) is given in fig.5. This supplementary fuzzy logic controller is having two inputs and one output. The electrical output power (P_{eo}) i.e. X_1 and rotor acceleration (α) or i.e. X_2 are considered as inputs to the damping controller. The output (y) damping signal is sent to series convertor (manual voltage injection mode) of main controller i.e. (UPFC) through the external control of reference series injected voltage [11].

When input signal is given to the fuzzy controller it fuzzifies the input signal before the rules are evaluated for given input and fired.

To accomplish this, a knowledge base consisting of data base and rule base is required.

In proposed work, data base consists of membership function for input variables (X_1) and (X_2) described by following linguistic variables.

For X1:

- Positive (P)
- Negative (N)

For X2:

- Negative (N)
- Near Zero (NZ)
- Positive (P)

For Y damping signal:

- Positive (P)
- Positive small (PS)
- Near zero (NZ)
- Negative small (NS)
- Negative (N) [7]

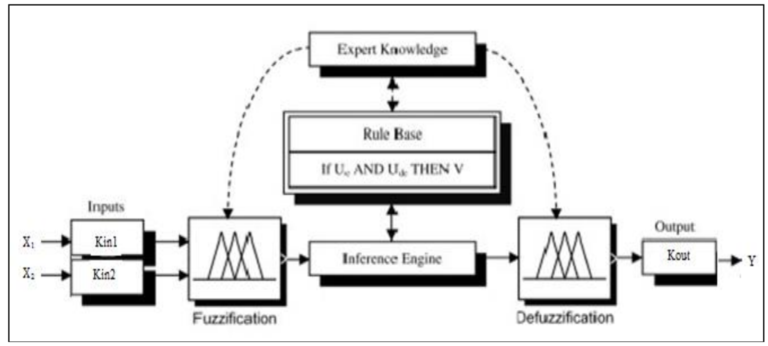


Fig. 5. Fuzzy logic based UPFC damping controller

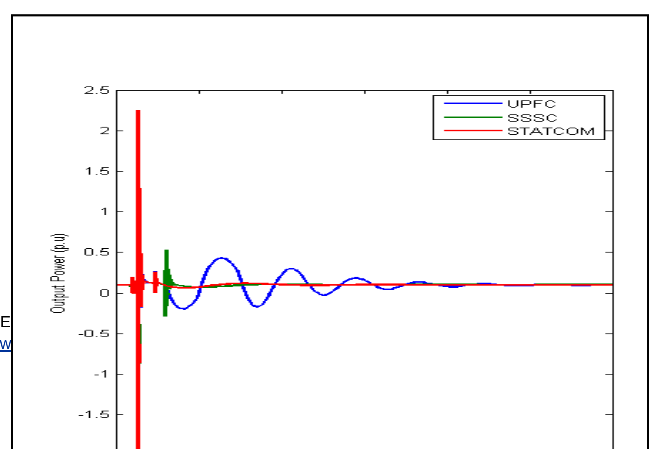
The variables are normalized by multiplying with respective gains Kin1, Kin2, Kout so that their value lies between -1 and 1.The Mamdani Fuzzy Inference Scheme (FIS) is used for designing the proposed controller. A set of rules which define the relation between the input and output of fuzzy controller is identified using the available knowledge in the area of designing UPFC controller. However, the aggregate of a fuzzy set gives a range of output values, which are defuzzified in order to receive a single output value from the set. The centriod method also called as centre of gravity or centre of area is considered for defuzzification in this work [12].

6 Simulation Results And Disscusion

The system under consideration equipped with STATCOM, SSSC and UPFC and proposed FLC are modeled and simulated in MATLAB/Simulink environment. The system subjected to said transient is simulated at various power levels. The performance of controllers has been examined for the following three conditions, i.e.

Case 1: P_{eo} = 0.1p.u
Case 2: P_{eo} = 0.5p.u
Case 3: P_{eo} = 0.7p.u

The considered electrical output power ($P_{eo)}$ for the system equipped with the FACTS devices for case1 is shown in fig.6, for case 2 in fig.7and for case 3 is shown in fig.8 respectively.



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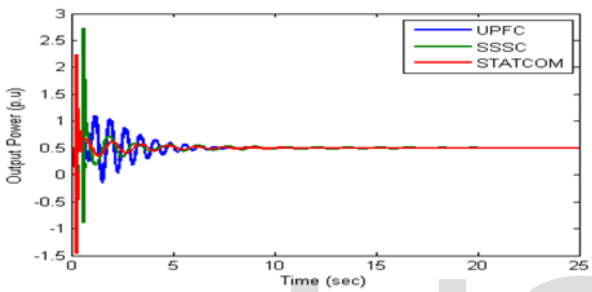
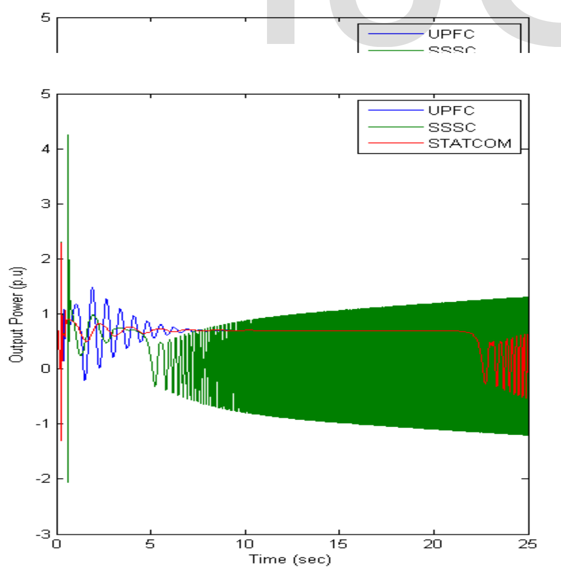


Fig. 7: Performance of FACTS devices for case 2



It is clear from the above results that STATCOM, SSSC, UPFC have a capability to stabilise the system at low power level. When the power level is increased, the performance of STATCOM and SSSC becomes poor for achieving system stability as compared with UPFC. When there is a further increase in power level, STATCOM and SSSC are not able to damp system oscillations and system becomes unstable. But UPFC still has the capability to damp system oscillations and makes the system stable.

The performance comaprison of conventional PI based UPFC with FLC based UPFC for electrical output power (P_{eo}) is shown in fig.9, fig.10, fig.11 for case1, case 2, case 3 respectively.

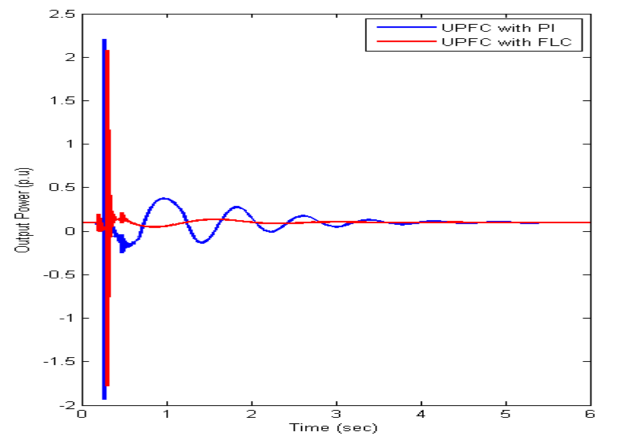


Fig. 9: Performance comparison of PI based UPFC and FLC based UPFC for case 1

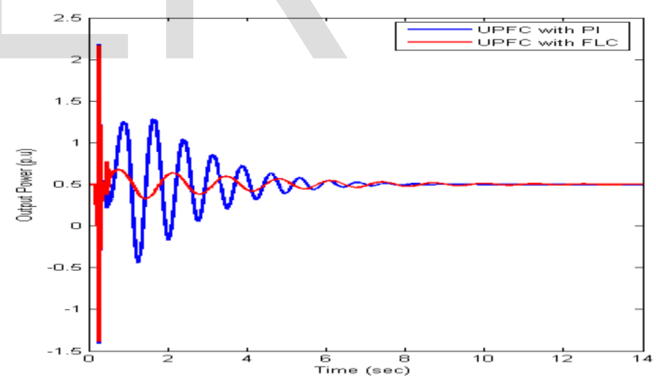
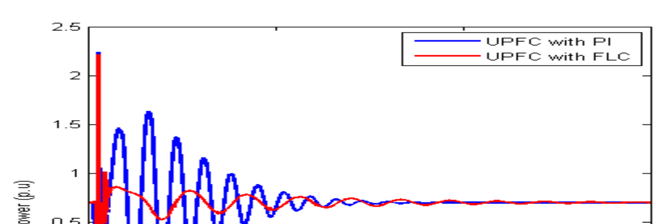


Fig.10: Performance comparison of PI based UPFC and FLC based UPFC for case 2



The above results reveals that the performance of FLC based UPFC is more effective in damping SMIB system oscillations in every case as compared with conventional PI based UPFC.

7 Conclusion

In this paper, the performance of STATCOM, SSSC and UPFC for stability of SMIB system is examined. The proposal for design of UPFC based Fuzzy logic controller for damping power system oscillations carried out for SMIB system and performance comparison with conventional UPFC is done. The main outcomes can be summarized as follows:

(a) Performance comparison of STATCOM, SSSC, UPFC devices establish the superiority of UPFC, which has the capability to damp out oscillations to greater extent and stabilize the system more effectively.
(b) Simulation results of FLC based UPFC and conventional PI based UPFC shows that the fuzzy logic UPFC controller has an excellent capability in damping power system oscillations and for the enhances the system stability.

8 Appendix

The electrical data of the considered system are as below :
Transformer (T):
• voltage ratio 15.7/400 kV;
• rated power 1000 MVA;
• resistance r: 0.0059p.u.;
• inductance l: 0.127p.u;
Transmission line:
• resistance r_{line} = 3.2Ω/ km;
• inductance l_{line} = 103mH/ km;
• capacitance c_{line} = 1.1μF/km;
Shunt transformer (T_{sh}):
• voltage ratio 20/400 kV;
• rated power 160 MVA;

TABLE 1
Units for Magentic Properties

S_n MVA	1000	x'_d p.u	0.32
V_n kV	15.7	x'_q p.u	0.32
x_d p.u	1.896	x''_d p.u	0.213
x_q p.u	1.896	x''_q p.u	0.213
x_2 p.u	0.26	t'_d s	1.083
x_0 p.u	0.0914	t'_q s	1.1
r_a p.u	.00242	t''_d s	0.135
J kg-m^2	10^5	t''_q s	0.135

• resistance r_{sh} = 0.004 p.u.;
• inductance l_{sh} = 0.1 p.u.
Series transformer(T_{se}):
• voltage ratio20/63 kV;
• rated power 160 MVA;
• resistance r_{se} = 0.005 p.u.;
• inductance l_{se} = 0.06p.u
For STATCOM
• voltage ratio 20/400 kV;
• rated power 160 MVA;
• resistance r_{sh} = 0.004 p.u.;
• inductance l_{sh} = 0.1 p.u
V_{ac} Regulator Gains: K_p = 0.5 K_i = 1000
V_{dc} Regulator Gains: K_p = 100 K_i = 200
Current Regulators Gains: K_p = 1 K_i = 1 K_f = 1
For SSSC
• voltage ratio20/63 kV;
• rated power 160 MVA;
• resistance r_{se} = 0.005 p.u.;
• inductance l_{se} = 0.06p.u
V_{dc} Regulator Gains: K_p = 1e-8 K_i = .1e-6
Injected Voltage Regulator Gains: K_p = 0.0005
K_i = 0.0001

The base of voltage and power for per-unit calculation is
• V_{base} = 15.7 kV (at the generator output bus);
• S_{base} = 1000 MVA

For Fuzzy Logic Controller:
K_{in1} = 0.33 K_{in2} = 1 K_{out} = 0.18

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