Effect of Changing Membership Functions in the Operation of Fuzzy Controllers for FACTS Devices in a Power System Network

Manju P[1], Narendiran S[2], Ajith B Singh[3] , Shanthi K[4]

[1]*Professor, Dept. of Instrumentation & Control Engineering, Sri Krishna College of Technology, Tamilnadu, India*
[2]*Associate Professor, Dept. of Instrumentation & Control Engineering, Sri Krishna College of Technology, Tamilnadu, India*
[3]*Assistant Professor, Dept. of Instrumentation & Control Engineering, Sri Krishna College of Technology, Tamilnadu, India*
[4]*Assistant Professor, Dept. of Instrumentation & Control Engineering, Sri Krishna College of Technology, Tamilnadu, India*

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Abstract - *Various FACTS controllers serves the function of power flow control, voltage and angle stability enhancement. This paper investigates the operation of three FACTS controllers namely Static Synchronous Series Compensator, Static Var Compensator & Unified Power Flow Controller in the operation of a generation system. It compares the response of the generating station to a conventional FACTS controller design along with fuzzy based controllers for these FACTS controllers. The paper investigates the effect of fuzzy based controllers in the power system operation and also the effect of changing membership function in the operation of fuzzy controller. MATLAB/Simulink based simulation is utilized to demonstrate the application of fuzzy controller based FACTS Controllers. The results confirmed that the fuzzy based FACTS controllers can add considerable damping to system oscillations. The results also depicted the changing effects of triangular, trapezoidal, gaussian and gbell shaped membership functions in the operation of fuzzy controller.*

Key Words: Fuzzy logic Controller, FACTS Controller, Static Synchronous Series Compensator, Static Var Compensator, Unified Power Flow Controller, Membership Functions

I. INTRODUCTION : FUZZY BASED FACTS CONTROLLERS

In the modern day power system stability, operation & control (PSOC), FACTS plays a very important role. Usage of FACTS in the power systems not only enhances the dynamic performance, but also increases the stability of the power systems, enhances the controllability & increases its power transfer capability. Some of the devices used in the control of FACTS are the SVC, SSSC, STATCOM, UPFC and the IPFC. The FACTS controllers utilize power electronics based technology and can provide dynamic control on line power flows, bus voltages, line impedance & phase angles. The FACTS initiative was originally launched in 1980's to solve the emerging problems faced due to restrictions on transmission line construction, and to facilitate growing power export / import and wheeling transactions among utilities. The two basic objectives behind the development of FACTS technology; is to increase power transfer capability of transmission systems, and to keep power flow over designated routes, significantly increase the utilization of existing (and new) transmission assets, and play a major role in facilitating contractual power flow in electricity markets with minimal requirements for new transmission lines.

According to IEEE, FACTS [2,4] is defined as "alternating current transmission systems incorporating power electronics based and other static controllers to enhance controllability and power transfer capability". Dynamic reactive power compensation and damping power system oscillations can also be achieved using FACTS controllers. Injecting the series voltage phasor, with desirable voltage magnitude and phase angle in a line can provide a powerful means of precisely controlling the active and reactive power flows, by which system stability can be improved, system reliability can be enhanced while operating and transmission investment cost can be reduced. It is possible to vary the impedance of specific transmission line to force power flow along a desired "contract path" in the emerging power systems, and to regulate the unwanted loop power flows and parallel power flows in the interconnected system.

The FACTS controllers have been broadly developed on two different principles, one that alters the line series reactance or bus shunt reactance or voltage phase difference across a line and utilizes conventional thyristor switches for control. In general, FACTS controllers can be divided into four categories based on their connection in the network, viz., series, shunt, combined series-series, and combined series-shunt. FACTS devices have shown very promising results when used to improve the power system steady state performance. In addition, because of the extremely fast control action associated with FACTS-device operations, they have been very promising candidates for utilization in power system damping enhancement. The control mechanism and the controller have an important effect on the performance of FACTS device.

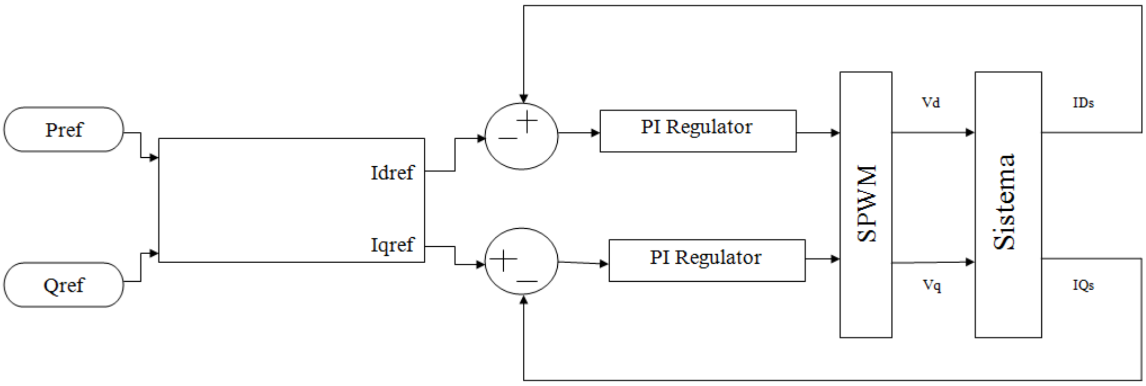
In the literature, several control mechanisms are used in FACTS devices and among which, fuzzy inference system are of at most importance. The fuzzy logic control technique has been an active research topic in automation and control theory since the work of Mamdani proposed in 1974 based on the fuzzy sets theory of Zadeh proposed in 1965 to deal with the system control problems which are not easy to be modelled. The concept of FLC is to utilize the qualitative knowledge of a system to design a practical controller. For a process control system, a fuzzy control algorithm embeds the intuition and experience of an operator designer and researcher. The control doesn't need accurate mathematical model of a plant, and therefore, it suits well to a process where the systems with uncertain or complex dynamics. Of course, fuzzy control algorithm can be developed by adaptation based on learning and fuzzy model of the plant. The fuzzy control is basically non-linear and adaptive in nature, giving robust performance under parameter variation and load disturbance effect. In general, a fuzzy control algorithm consists of a set of heuristic decision rules and can be regarded as an adaptive and non-mathematical control algorithm based on a linguistic process, in contrast to a conventional feedback control algorithm Fuzzy control using linguistic information possesses several advantages such as robustness, model-free, universal approximation theorem and rules-based algorithm. Recent literature has explored the potentials of fuzzy control for machine drive application. It has been shown that a properly designed direct fuzzy controller can outperform conventional proportional integral derivative (PID) controllers. Note that fuzzy logic controllers are nothing but rule-based controllers in which a set of rules representing a control decision mechanism to adjust the effect of certain cases coming from power system is considered. Further, these FLCs do not require a mathematical model of the system & can cover a wide range of operating conditions with much robustness inherency. Fuzzy control using linguistic information possesses several advantages such as robustness, model-free, universal approximation theorem and rules-based algorithm. Recent literature has explored the potentials of fuzzy control for machine drive application. It has been shown that a properly designed direct fuzzy controller can outperform conventional proportional integral derivative (PID) controllers. Note that fuzzy logic controllers are nothing but rule-based controllers in which a set of rules representing a control decision mechanism to adjust the effect of certain cases coming from power system is considered. Further, these FLCs do not require a mathematical model of the system & can cover a wide range of operating conditions with much robustness inherency.

In this work, the effect of fuzzy based FACTS controllers in a power system network is analysed and the results are compared with their conventional counterparts. The effect of changing membership functions in the operation of fuzzy controller for FACTS devices are analysed and the best shape of the membership function is found for various FACTS controllers. Three major FACTS controllers are considered for the study of the effect of changing membership functions and they include the SVC, SSSC & UPFC.

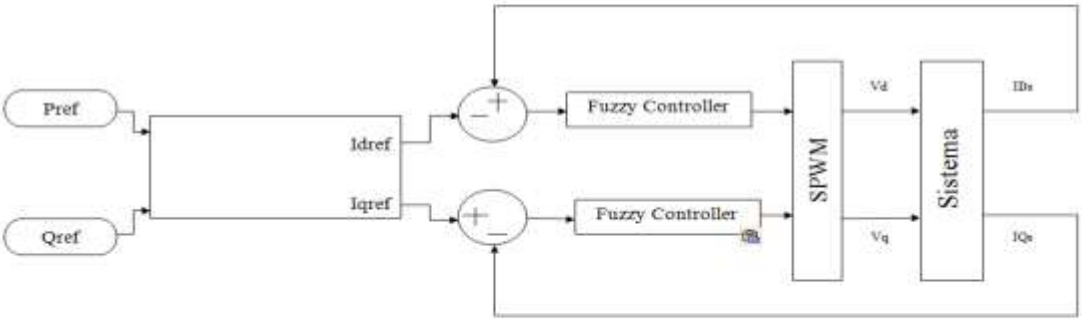
2. EFFECT OF CHANGING MEMBERSHIP FUNCTIONS IN A FUZZY BASED SSSC

Synchronous generators in any power system exhibit rotor oscillations around their nominal steady state and power system stabilizers are used to damp out these oscillations. The SSSC [5] serves the function of power flow control, voltage and angle stability enhancement. SSSC can induce both capacitive and inductive series voltage on a line and gives a better possibility for damping electromechanical oscillations. This work investigates the operation of an SSSC model in the operation of a generation system. It compares the response of the generating station with a conventional SSSC along with a fuzzy based SSSC. The work investigates the effect of fuzzy based SSSC in the power system operation and also the effect of membership function in the operation of fuzzy controller[8,9], designed for SSSC.

The basic structure of a conventional SSSC configuration is as shown in Figure 1(a). The PI regulators in the configuration are replaced with Fuzzy Controllers in this work as shown in Figure 1(b).



(a)



(b)

Fig 1(a) Basic structure of a conventional SSSC (b) Basic configuration of Fuzzy based SSSC

The Fuzzy Logic Toolbox in MATLAB is used to design the fuzzy based controllers. A Mamdani Inference System is used in the design and a set of 14 rules, defines the control action for the designed fuzzy regulator. The input variable to the fuzzy controller is the difference between the actual and reference currents and the output variable is the firing angle to the converter module. Four different types of membership functions as shown in Figure 2 are used in the analysis of fuzzy controllers [10]. They include:

- Trapezoidal Membership Function
- Triangular Membership Function
- Gaussian Membership Function
- Generalised Bell (GBell) Shaped Membership Function

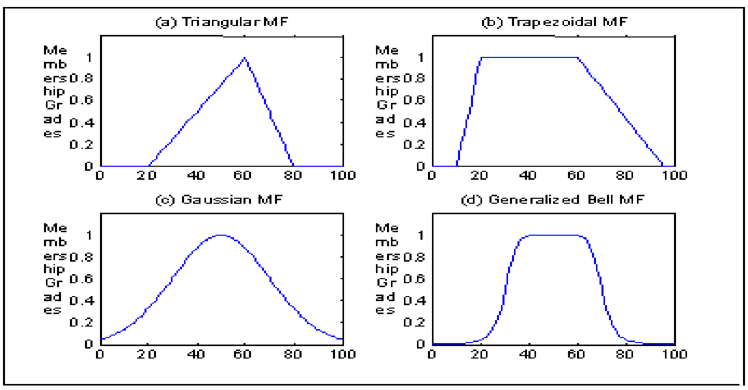


Fig 2 Membership Functions

2.1 System under study

MATLAB/Simulink based simulation is utilized to demonstrate the application of fuzzy controller based SSSC for voltage regulation during fault scenarios and their contribution in enhancing the performance of power systems. The results confirmed that the fuzzy based SSSC can add considerable damping to system oscillations. The results also depicted the changing effects of triangular, trapezoidal, Gaussian and GBell shaped membership functions in the operation of fuzzy controller. Two power generation stations of 2000MVA and 1000 MVA each and one major three phase load are taken as the system of study as shown in Figure 3. A three-phase fault (using a fault breaker) is simulated at the midpoint of the transmission line in the model. A typical three-level PWM SSSC model (with Power oscillation Damping Controller) is implemented in this system of study. The generating stations are equipped with PSS, which also aids in power oscillation damping. The operation of the generating stations with Conventional PSS and Conventional SSSC are studied, and compared with the performance of Fuzzy Based PSS & Fuzzy Based SSSC in the generating station performances.

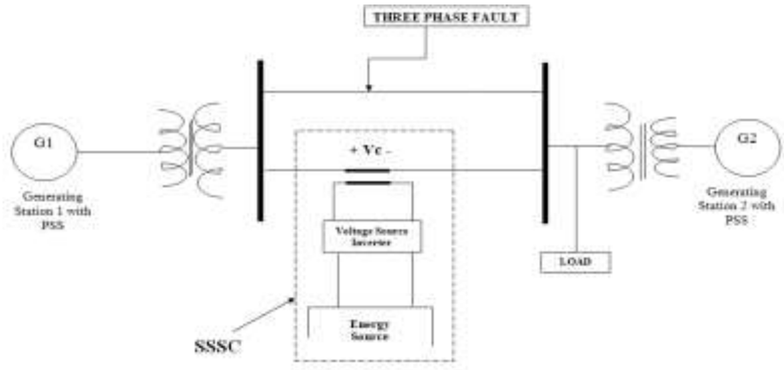


Fig 3 System under study with SSSC

The Fuzzy based SSSC is studied for trapezoidal, triangular, gaussian and gbell shaped membership functions.

2.2 Simulation Results & Conclusions

The system under study is simulated using conventional SSSC in MATLAB/Simulink. A three-phase fault (using a fault breaker) is simulated at the midpoint of the transmission line in the system. The system performance is as shown in Figure 4. The conventional SSSC is then replaced with fuzzy based SSSC. The effect of fuzzy logic controllers are compared in the simulation results. The effect of changing the Membership Function (MF) is also studied using trapezoidal, triangular, gaussian and gbell shaped membership functions and is as depicted in Figures 4 to 8. The effect of fuzzy controller and its changing membership functions in the operation of SSSC on the voltage and line power of the system is shown in the simulation results.

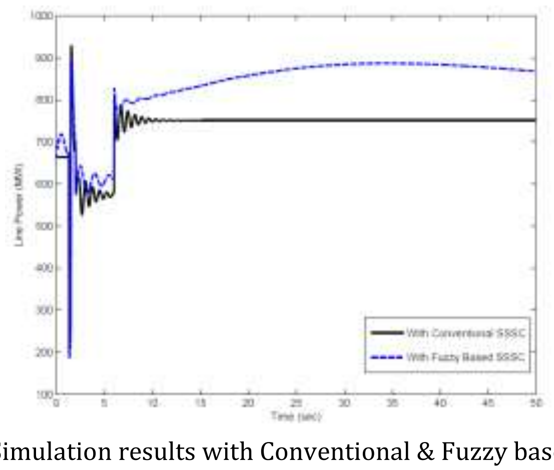


Fig 4 Simulation results with Conventional & Fuzzy based SSSC

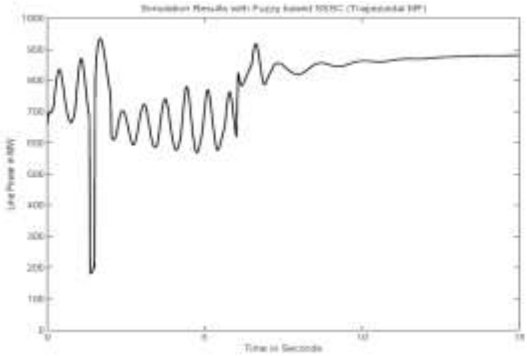


Fig 5 Simulation results with Fuzzy based SSSC (Trapezoidal MF)

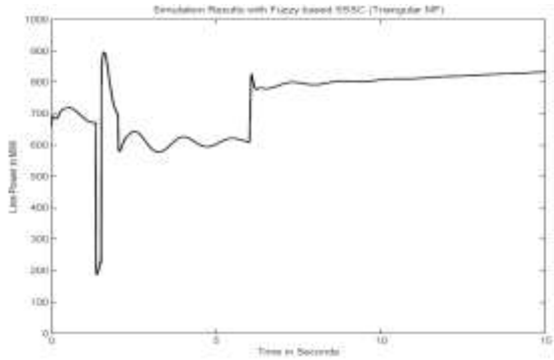


Fig 6 Simulation results with Fuzzy based SSSC (Triangular MF)

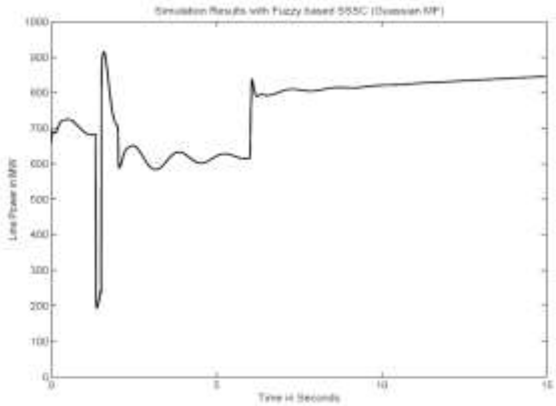


Fig 7 Simulation results with Fuzzy based SSSC (Gaussian MF)

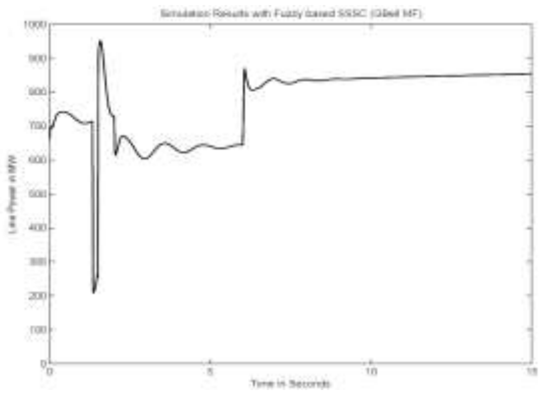


Fig 8 Simulation results with Fuzzy based SSSC (Gbell Shaped MF)

To overcome the limitations of conventional PI regulators in SSSC, they are replaced with fuzzy controllers in this work. The comparison of the simulations results infers that the triangular membership functions for the input and output variables in the fuzzy controller of SSSC, further enhances its ability to damp out power oscillations, when compared to trapezoidal, gaussian and gbell shaped membership function. The results are as summarised in Table 1.

Table 1 Summary of Results of Line Power with changing MFs in a Fuzzy based SSSC

Parameter	Trapezoidal MF	Triangular MF	Guassian MF	Gbell Shaped MF
Peak Overshoot (%)	26.6	18.66	21.33	26.6
Settling Time (seconds)	9.67	5.67	6.67	6.67

3. EFFECT OF CHANGING MEMBERSHIP FUNCTIONS IN A FUZZY BASED SVC

SVC is a member of FACTS devices category, which helps in improving the transient stability of power grids. SVC is a shunt device that helps in regulating the voltage at its terminals by controlling the reactive power either injected to or absorbed from the power system network. SVC becomes capacitive for low system voltages and inductive for high system voltages. The reactive power is varied by switching operations of capacitor or inductor banks. The basic configuration of SVC control is as shown in Figure 9. The voltage regulator unit uses the voltage error to determine the SVC susceptance that is required to keep the system voltage constant. In this work, the conventional PI regulator in the voltage regulator unit of SVC control is replaced with fuzzy based controller and the effect of this intelligent controller in the performance of SVC connected to a power system network is analysed.

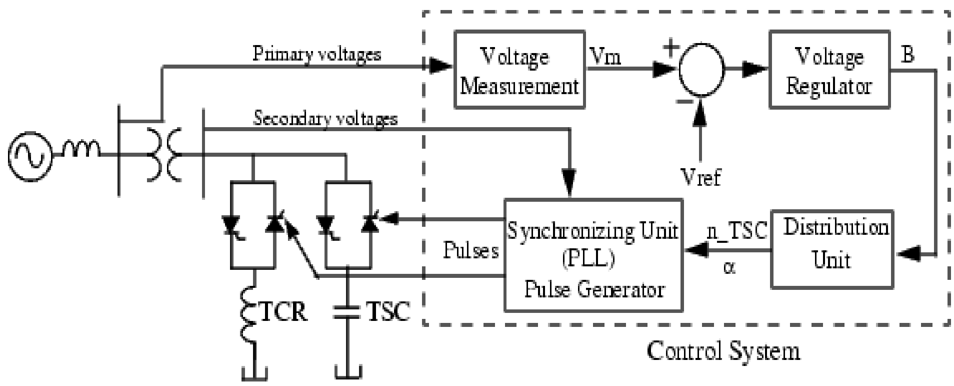


Fig 9 Basic configuration of SVC Control Scheme

3.1 System under study

A power generation station along with an SVC connected to infinite bus and one load are taken as the system of study. A three-phase variable voltage source is taken and the response of SVC to the variations in voltage is studied. The operation of the generating station with SVC with conventional voltage regulator unit is studied, and compared with the performance of SVC with Fuzzy Based voltage regulator. The fuzzy controller designed for the voltage regulator unit of SVC is also further modified with four different membership functions of Trapezoidal, Triangular, Gaussian and GBell shaped. The effect of changing membership functions on the operation of fuzzy controller is also analyzed. The Fuzzy Logic Toolbox in MATLAB is used to design the fuzzy based controllers. A Mamdani Inference System is used in the design and a set of 14 rules, defines the control action for the designed fuzzy regulator.

3.2 Simulation Results & Conclusions

The system under study is simulated using SVC with conventional voltage regulator and fuzzy based regulator in MATLAB/Simulink. The simulation results of the system under study with conventional voltage regulator for SVC [3] are as shown in Figure 10. The SVC with fuzzy based voltage regulator is simulated and the responses for various membership functions of fuzzy controller are depicted in Figures 10 to 14. The response of the line voltage with conventional SVC and fuzzy based SVC is analysed and the impact of changing membership functions on the fuzzy based SVC operation is also determined.

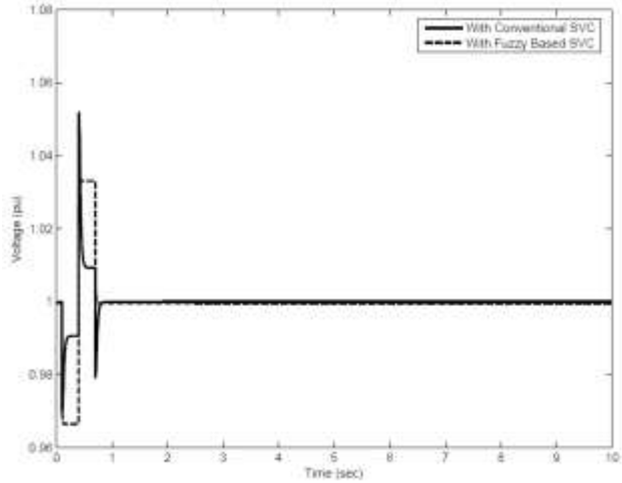


Fig 10 Simulation results of Voltage in pu with Conventional Voltage Regulator & Fuzzy controller for SVC

The SVC with fuzzy based controller for the voltage regulator is simulated and the responses for various membership functions of fuzzy controller are depicted in Figures 11 to 14. The response of the line voltage is analysed and the impact of changing membership functions on the fuzzy based SVC operation is determined.

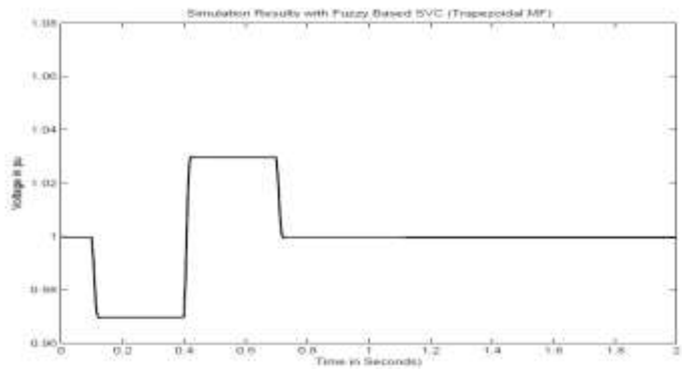


Fig 11 Simulation results of Fuzzy based SVC (Trapezoidal MF)

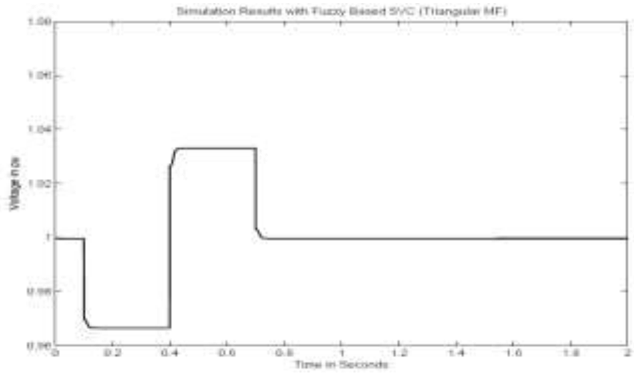


Fig 12 Simulation results of Fuzzy based SVC (Triangular MF)

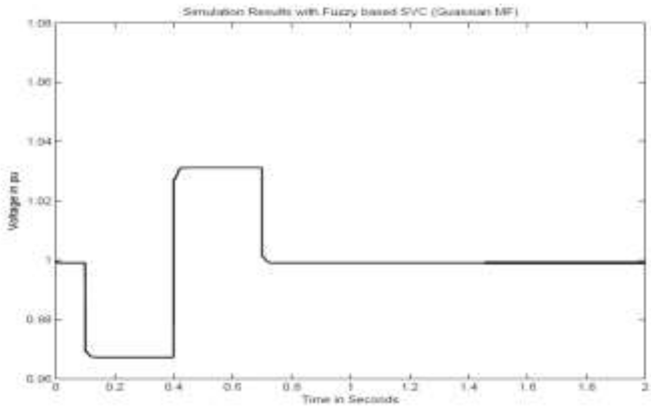


Fig 13 Simulation results Fuzzy based SVC (Gaussian MF)

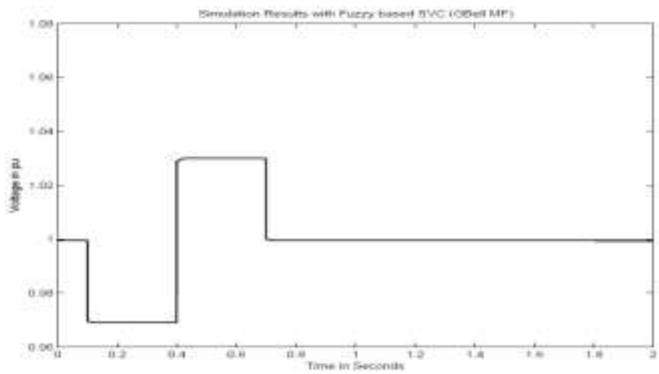


Fig 14 Simulation results Fuzzy based SVC (GBell Shaped MF)

The comparison of the simulations results infers that the GBell membership functions for the input and output variables in the fuzzy controller of SVC, enhances its ability to damp out power oscillations to a greater extent, when compared to trapezoidal, triangular and gaussian membership function. The result of the comparative study is as given in Table 2. In Table 2, the settling time for the fuzzy logic controller is Nil describes the absence of oscillations in the output voltage.

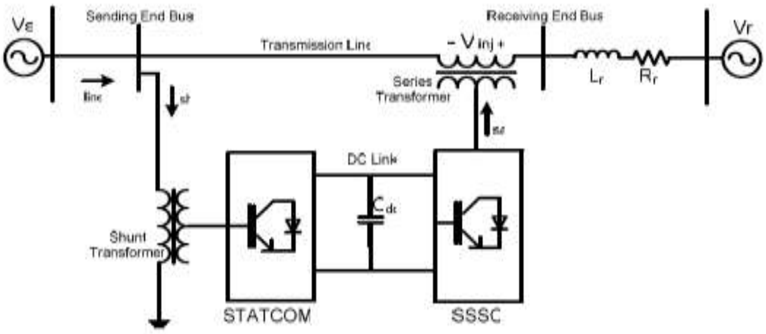
Table 2 Summary of Results of Line Voltage with changing MFs in a Fuzzy based SVC

Parameter	Trapezoidal MF	Triangular MF	Guassian MF	Gbell Shaped MF
Peak Overshoot	3	3.5	2.7	2.9

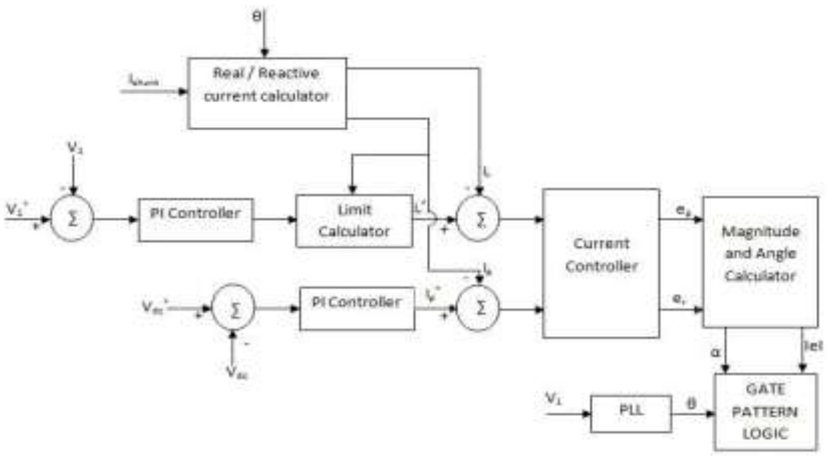
(%)				
Settling Time (seconds)	0.03	0.09	0.04	0.03

4. EFFECT OF CHANGING MEMBERSHIP FUNCTIONS IN A FUZZY BASED UPFC

The UPFC is the most versatile member of the FACTS family using power electronics to increase controllability of power flow in the power grids. The UPFC uses a combination of a shunt controller [1] (STATCOM) and a series controller (SSSC) interconnected through a common DC bus as shown on the Figure 15(a). All the parameters of the power transmission line (impedance, voltage and phase angle) can be controlled simultaneously by UPFC [6,7]. In addition, it can perform the control function of the transmission line real/reactive power flow, UPFC bus voltage and the shunt-reactive-power flow control. Both the series and shunt converters use a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSCs use forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage from a DC voltage source. The PI and conventional voltage regulators in the shunt and series converter control as shown in Figure 15(b & c) of the UPFC are replaced with fuzzy controllers in this work. The Fuzzy Logic Toolbox in MATLAB is used to design the fuzzy based controllers. The fuzzy controller operation for various membership functions in the UPFC model is analyzed in a detailed way. In the modelling of fuzzy controller for the converters, Mamdani type inference system is used in the decision making process Centroid method is used in the defuzzification process. Fourteen rules are framed for the fuzzy controllers of series and shunt converters of UPFC. The UPFC is simulated with conventional PI regulators controlling the shunt and series converters. The PI regulators are then replaced with Fuzzy controllers and its effect on the system performance are analysed.



(a)



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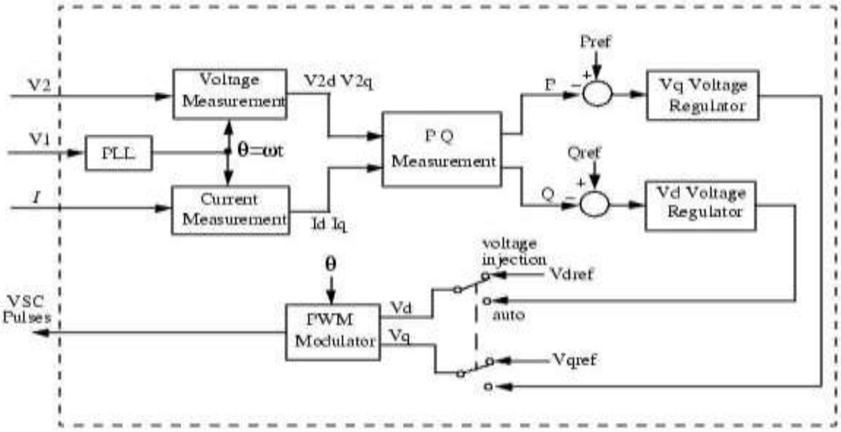

(c)

Fig 15 (a) Detailed structure of the UPFC (b) Block diagram of shunt VSC controller

(c) Block diagram of series VSC controller

4.1 System under study

Two power plants interconnected is taken as the system of study. UPFC model consists of two IGBT-based, converters (one connected in shunt and one connected in series and both interconnected through a DC bus on the DC side and to the AC power system, through coupling reactors and transformers). A three-phase fault (using a fault breaker) is simulated in the transmission line in the system under study. A typical simulink UPFC model is implemented in this system of study. The operation of the generating stations with Conventional UPFC are studied, and compared with the performance of Fuzzy Based UPFC in the generating station performances. The work investigates the effect of fuzzy based UPFC in the power system operation and also the effect of membership function in the operation of fuzzy controller, designed for UPFC.

4.2 Simulation Results & Conclusions

The system under study is simulated using conventional UPFC in MATLAB/Simulink. A three-phase fault (using a fault breaker) is simulated in the transmission line in the system. The system performance with conventional UPFC is as shown in Figure 16. The conventional UPFC is replaced with fuzzy based UPFC. The effect of fuzzy logic controllers and changing membership functions are then compared in the results. The fuzzy controllers are designed with triangular, trapezoidal, Gaussian and GBell shaped membership functions and the responses are analysed. The simulation results of voltage and active power flow in the study system are depicted in Figures 17 to 20.

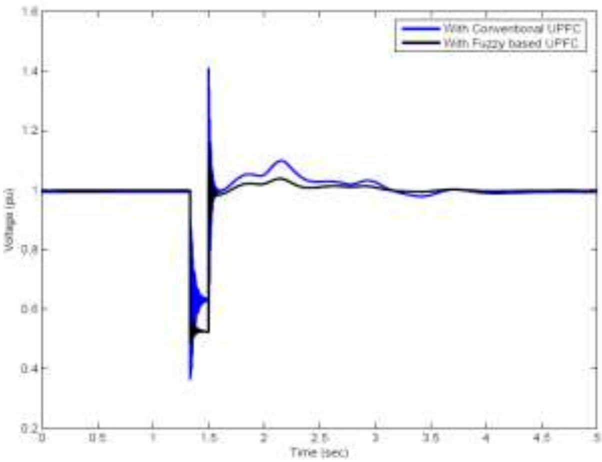

Fig 16 Simulation Response with Conventional & Fuzzy based UPFC

The system under study is simulated using fuzzy based UPFC in MATLAB/Simulink. The simulation diagram is given in Appendix 3 for ready reference. The effect of fuzzy logic controllers and their changing membership functions in the operation of UPFC are compared in the results. The fuzzy controllers are designed with triangular, trapezoidal, Gaussian and GBell shaped membership functions and the responses are analysed. The simulation results of voltage and active power flow in the study system are depicted in Figures 3.10 to 3.13.

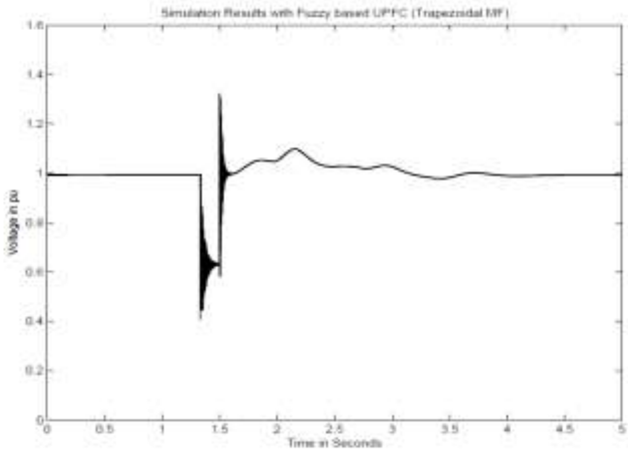

Fig 17 Simulation Response with Fuzzy based UPFC (Trapezoidal MF)

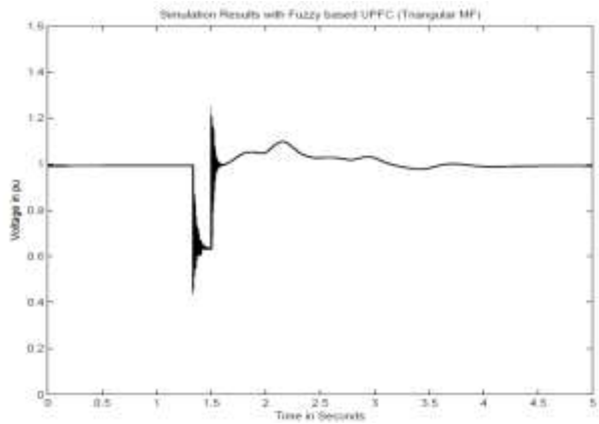

Fig 18 Simulation Response with Fuzzy based UPFC (Triangular MF)

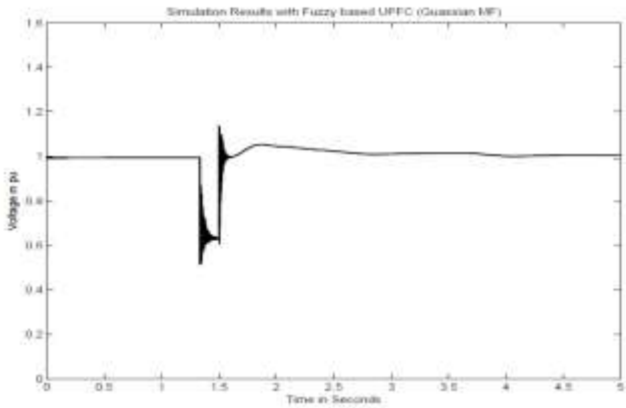

Fig 19 Simulation Response with Fuzzy based UPFC (Gaussian MF)

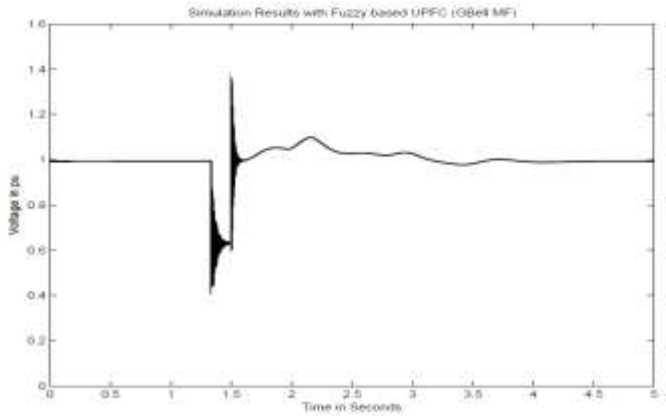

Fig 20 Simulation Response with Fuzzy based UPFC (GBell MF)

The effect of various membership functions for the input and output variables of the fuzzy controller, helps to conclude the dominance of triangular membership function in improving system stability, when compared to the other functions in the UPFC device. The summaries of results are as tabulated in Table 3.

Table 3 Summary of Results of Voltage with changing MFs in a Fuzzy based UPFC

Parameter	Trapezoidal MF	Triangular MF	Guassian MF	Gbell Shaped MF
Peak Overshoot (%)	25	21	10	39
Settling Time (seconds)	2.77	2.67	0.92	2.77

5. CONCLUSIONS

In this work, the conventional regulators in three major FACTS devices namely SSSC, SVC and UPFC are replaced with fuzzy controllers. The system under study with each of these FACTS devices are simulated using Simulink and the Fuzzy Logic Toolbox in MATLAB. The simulation results depicts that the fuzzy controller for FACTS devices helped in enhancing the power system performance by reducing the overshoots, undershoots and settling time.

Further, these fuzzy controllers in each of the FACTS devices are simulated with four different membership functions namely the triangular, trapezoidal, gaussian and gbell functions.

The simulations results infer that selection of membership functions do play a vital role in the operation of fuzzy controller. For different FACTS devices and operating conditions, the best fit membership function varies. Thus, the selection of membership function done from human expertise should be taken care of to improve the performance of fuzzy controllers.

REFERENCES

[1] Haque, M. H.“Improvement of First Swing Stability Limit by Utilizing Full Benefit of Shunt FACTS Devices,” IEEE Trans. Power Syst., Vol. 19, No. 4, pp. 1894–1902, 2004.

[2] Hingorani N. G. and Gyugyi L., Understanding FACTS, Concepts, and Technology of Flexible AC Transmission Systems, Piscataway, NJ:IEEE Press, 2000.

[3] Karpagam, N and Devaraj, D “Fuzzy logic control of Static Var Compensator for Power System Damping,” International Journal of Electrical Power and Energy Systems, Vol.2, no.2, pp. 105-111, 2009.

[4] Majumder, R . , Pal, B. C., Dufour, C. and Korba, P. “Design and realtime implementation of robust FACTS controller for damping inter area oscillation,” IEEE Trans. Power Syst., Vol. 21, no. 2, pp.809–816, 2006.

[5] Panda, S., Padhy, N. P. and Patel, R. N. “Power system stability improvement by PSO optimized SSSC-based damping controller”, Electr. Power Comp. Syst., Vol. 36, no.5, pp. 468-490, 2008.

[6] Ruan, S. , Li, G., Ooi, B. and Sun, Y. “Power system damping from energy function analysis implemented by voltage-source-converter stations,” Electric Power Systems Research, Vol. 78, , pp. 1353-1360, 2008

[7] Sharma, N K, and P P Jagtap. "Modelling and Application of Unified Power Flow Controller (UPFC)", 3rd International Conference on Emerging Trends in Engineering and Technology, 2010

[8] Takagi, T., Sugeno, M. “Fuzzy Identification of Systems and Its Applications to Modeling and Control”. IEEE Transaction on Systems, Man and Sybern, Vol 1, pp. 116-132, 1985

[9] Timothy J. Ross, “Fuzzy Logic with engineering application”, McGraw- Hill, Inc.1995.

[10] Zadeh, L. A. “Fuzzy Sets”, Information and Control, Vol. 8, pp .338-353, 1965.