Effectiveness of Fuzzy Logic-based FACTS Controller and Classical Controller in Enhancement of Power System Dynamic Stability – A Comparative Study

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Abstract
Performances of Fuzzy Logic based impedance types FACTS controllers and classical controllers in damping power system oscillations have been studied and their effectiveness have been compared. Different FACTS devices are considered, namely (i) Thyristor Controlled Series Compensator (TCSC), (ii) Thyristor Controlled Phase Shifter (TCPS) (iii) Static VAR Compensators (SVC), and their combinations. Mamdani type fuzzy inference system is used. PSS, Lead-Lag and proportional type classical controllers have been considered. Performances of the controller have been demonstrated through time domain simulation studies. Simulation results have been compared and conclusions have been drawn. Results show that the Fuzzy Logic controllers have excellent and comparatively better potential in damping power system oscillations.

Keywords: FACTS devices such as SVC, Power System Stabilizer (PSS), TCSC, TCPS and Fuzzy logic (FL) Controller

1. Introduction
Now-a-days, power system is a large, interconnected electrical network. Due to large mechanical time constant of machine's rotating members, any change appearing in line power flow, either due to occurrence of fault in the transmission line or due to sudden changes in load or in input mechanical power, the input-output power balance gets upset. This generates low frequency mechanical oscillation of the rotating part of the generator, in range of 0.2 to 3.0 Hz with consequent occurrence of oscillations in power flow through the lines. The oscillation, once started, continues to exist a short time, at that time either disappears or continues to grow causing system separation. Such oscillation deteriorates power transmission capability, hampers efficient operation and threatens power system security. This is referred to as the power system dynamic stability. In order to damping these oscillations and enhance system dynamic stability, employ of PSS is both inexpensive and efficient. Series compensator, parallel compensator and phase shifter are used in order to boost the power transmission capacity of lines. It was observed that by operating these compensators using solid state power electronic devices; system security might be extensively enhanced, allowing complete utilization of system capability. This concept is called Flexible AC Transmission Systems (FACTS), and gave birth to thyristor controlled SVC, TCSC and TCPS. Their capabilities in damping system oscillations have been explored. In the present paper, Phillips-Heffron (PH) model of the power system, formed by incorporating the FACTS devices, has been considered. A new fuzzy logic controller has been designed to control FACTS devices in a Single-Machine Infinite-Bus (SMIB) power system, as shown by figure 1. The simulation results show that the designed controller has the best capability to enhance the power system dynamic stability.
2. SMIB System with facts Devices

The linearised Phillips-Heffron model\(^9,12\) for SMIB with FACTS and/or PSS and/or Fuzzy-logic controller is shown in Fig.-2.

3. Damping Controller

The speed and angle deviations (i.e., \(\Delta w\) and \(\Delta \delta\)) are used as the input to the damping controllers. Classical and fuzzy Logic based damping controllers are used in this paper.

4. Classical Controller

Lead-lag controllers are used in order to obtain quick and accurate steady-state response. It also increases the system bandwidth and low frequency gain, making the system response speedy. In general, the lead segment of this controller provides large bandwidth and consequently shorter rise and settling times, whereas the lag part of this controller provides the most important system damping. Lead-lag damping controller based system stabilization and different types of FACTS devices has been presented in\(^{13,14}\).

5. Fuzzy Logic (Fl) Controller\(^{15}\)

A simple Mamdani type fuzzy inference system based dual inputs and single output FL controller\(^{16}\), as shown in Fig. 3(a, b), has been considered in this paper. Fig.-4(a, b) show the membership functions for both the signals i.e. for input (\(\Delta \omega\)) and output (\(\Delta \delta\)) signals.

The rules used in this controller are chosen as follows:
- If \(\Delta w\) is P and \(\Delta \delta\) is P then output is P.
- If \(\Delta w\) is P and \(\Delta \delta\) is N then output is Z.
- If \(\Delta w\) is N and \(\Delta \delta\) is P then output is Z.
- If \(\Delta w\) is N and \(\Delta \delta\) is N then output is N.

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**Figure 1.** SMIB with TCSC, TCPS and SVC.

**Figure 2.** Phillips Heffron (PH) model of a SMIB with TCSC, TCPS, SVC and controller.

**Figure 3(a).** Fuzzy logic controller for SVC/TCSC/TCPS.

**Figure 3(b).** Mamdani type FIS.
6. Simulation Results and Analysis

To evaluate and compare the capabilities of the controllers in damping power system oscillation, time-domain digital simulation of the PH model of a SMIB system with TCPS, TCSC and SVC, is obtained by changing the reference mechanical power suddenly. Digital simulation of the same PH-model is obtained again with PSS, Lead-Lag (LL) (Fig-5) and proportional controllers. Responses of the speed and angular deviations with all the designed controllers are presented in Table-1.

Details of the simulation results, presented in Table-1, are: Figs: 1- without any controller; 2(a)-with proportional controller, 2(b)- with PSS; 3(a) & 3(b)- with LL & FL controllers operated on SVC; 4(a) & 4(b)- with LL & FL controllers operated on TCSC; 5(a) & 5(b)- with LL & FL controllers operated on TCPS; 6(a) & 6(b)- with LL & FL controllers operated on SVC+TCSC+TCPS & PSS. Out of these the results in 2(a), 2(b), 3(a), 4(a), 5(a) and 6(a) constitute classical controllers whereas those in 3(b), 4(b), 5(b) & 6(b) constitute FL-based controllers. A comparative chart, showing the dynamic responses of the classical controllers and those of FL-based controllers, is presented in Table-2. The system and controller parameters has been given in the Appendix.
### Table 1

| Figs. | Response with Controller | Deviations in $\Delta \omega$ and $\Delta \delta$ based on Impulse input $\Delta P_m$ |
|-------|--------------------------|-----------------------------------------------------------------------------------|
| 1.    | Without controller       | ![Graph](image1.png) ![Graph](image2.png)                                       |
| 2a.   | Power System Stabilizer (PSS) | ![Graph](image3.png) ![Graph](image4.png)                                       |
| 2b.   | FACTS-based Proportional Feedback Controller | ![Graph](image5.png) ![Graph](image6.png)                                       |
| 3a.   | SVC-based Lead-Lag Controller | ![Graph](image7.png) ![Graph](image8.png)                                       |
| 3b.   | Fuzzy Logic based SVC controller | ![Graph](image9.png) ![Graph](image10.png)                                       |
### 4a. Lead-Lag-based TCSC Controller

| ΔW | Δδ |
| --- | --- |
| ![Graph 1](image1.png) | ![Graph 2](image2.png) |

| t | t |
| --- | --- |

### 4b. TCSC-based FL Controller

| ΔW | Δδ |
| --- | --- |
| ![Graph 1](image3.png) | ![Graph 2](image4.png) |

| t | t |
| --- | --- |

### 5a. TCPS-based Lead-Lag Controller

| ΔW | Δδ |
| --- | --- |
| ![Graph 1](image5.png) | ![Graph 2](image6.png) |

| t | t |
| --- | --- |

### 5b. FL-based TCPS

| ΔW | Δδ |
| --- | --- |
| ![Graph 1](image7.png) | ![Graph 2](image8.png) |

| t | t |
| --- | --- |

### Coordinated Control

| ΔW | Δδ |
| --- | --- |
| ![Graph 1](image9.png) | ![Graph 2](image10.png) |

| t | t |
| --- | --- |

### 6a. SVC, TCSC, TCPS, PSS-based Lead-Lag Controller

| ΔW | Δδ |
| --- | --- |
| ![Graph 1](image11.png) | ![Graph 2](image12.png) |

| t | t |
| --- | --- |
7. Simulation Results Analysis and Comparison

The following notes might be drawn from the responses obtained in Table-1:

1. Comparison of figures from Fig-2a to Fig-6 with Fig-1 it is seen that damping can be introduced with PSS & all other controllers, used here.
2. Comparison between Fig-2(b) & Fig-3(a) indicates that damping offered by PSS & LLC-operated SVC is almost same.
3. Comparison between Fig-3(b) & Fig-6(b) indicates that the response from FL-operated SVC and that from FL-based coordinate controller are almost similar.
4. Comparison between Fig-3(a) & Fig-3(b) indicates that damping offered by FLC-operated SVC is superior to that offered by LLC-operated SVC.
5. Figs-3 to 5 indicates that the responses offered by FLC-operated SVC controller [Fig-3(a)] is the best amongst them.
6. While considering all the responses, from Figs-1 to 6, it is seen that the response presented by Fuzzy Logic based controller [Fig-6(b)] is the best of all the responses obtained.

NB: **OS** - Overshoot, **ST** - Settling time, **SSE** - Steady state error. From the comparative chart, shown in Table-2, it is seen that out of all the responses offered by different controllers, the responses offered at (x), by FL-based coordinated SVC, TCSC, TCPS, PSS is the best results and those offered at (vii), By FL-based SVC is the second best.

8. Conclusion

Fuzzy logic based FACTS Controller have been designed for enhancement of a power system (SMIB) dynamic stability. Digital Simulation has been obtained in MATLAB simulink environment. Responses of the design controllers have been compared. From the responses it is concluded that FL based FACTS controller has better damping system oscillations capabilities than those of all other controllers. But, FL based coordinated controller has the best power system damping capability in comparison to either FL-based FACTS or classical controller.

### Table 2. (Chart showing comparative responses)

| Controller Type | OS $10^3$ | ST ms | SSE | OS | ST | SSE |
|-----------------|-----------|-------|-----|----|----|-----|
| Classical       | i) Proportional | 7.0   | 9.0 | 0.0 | 0.8 | 8.0 | 0.2 |
|                 | ii) PSS    | 7.0   | 8.0 | 0.0 | 0.8 | 8.0 | 0.2 |
|                 | iii) LL + SVC | 6.5   | 7.0 | 0.0 | 0.4 | 6.0 | 0.2 |
|                 | iv) LL+TCSC | 7.5   | 10.0 | 0.0 | 2.0 | 12.0 | 0.2 |
|                 | v) LL+TCPS | 7.5   | 12.0 | 0.0 | 0.9 | 14.0 | 0.2 |
|                 | vi) LL+SVC+TCSC + TCPS+PSS | 6.0   | 4.0 | 0.0 | 0.2 | 5.0 | 0.1 |
| Fuzzy-Logic     | vii) SVC   | 3.5   | 2.0 | 0.0 | 0.1 | 2.0 | 0.2 |
|                 | viii) TCSC  | 7.0   | 8.0 | 0.0 | 0.8 | 8.0 | 0.2 |
|                 | ix) TCPS   | 6.0   | 9.0 | 0.0 | 0.2 | 9.0 | -0.2 |
|                 | x) SVC+TCSC+TCPS+PSS | 2.5   | 2.2 | 0.0 | 0.0 | 2.0 | 0.2 |
9. Appendix

9.1 Parameters of SMIB system

H = 9.26; D=4.0; T_{do} = 7.76; x = 0.973; X' =0.3;x = 0.6, R= 0.034; x = 0.997; g=0.249; b=0.262; K_{A} = 50.0; T_{A} =0.05s; K_{S} = 1.0; T_{S} = 0.05; v = 0.95pu; P_{e} = 0.8; |u_{ps}|≤0.2pu; |B_{SVC}|≤0.4pu; |X_{TCSC}|≤0.5pu; |Ф_{TCPS}|≤150; |E_{fd}|≤7.3pu.

9.2 Parameters of the Lead- Lag controller

| Parameters | PSS | SVC | TCSC | TCPS |
|------------|-----|-----|------|------|
| T1         | 0.1 | 0.9596 | 0.0402 | 0.0846 |
| T2         | 0.9 | 0.3 | 0.1 | 0.1 |
| T3         | 0.2 | 0.01 | 0.0787 | 0.0844 |
| T4         | 0.7 | 0.3 | 0.1 | 0.1 |
| K          | 10 | 98.377 | 87.359 | 100 |

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