Simulation of Nine Bus System Using PI, PID, FOPID and Fuzzy Controller with TCSC to Improve Voltage Stability with Reduced Congestion

[1]P. Kalaimani and [2]K. Mohana Sundaram

[1]Research Scholar, Department of Electrical and Electronics, Anna University, Chennai, India
[2]Professor, Department of Electrical and Electronics,
Vel Tech Multi Tech Dr. Rangarajan Dr. Sakunthala Engineering College, Chennai, India

Abstract: In the present power system environment, enhancing the voltage stability of power system and improving the transmission capability of multi machine power system with reduced congestion of transmission line is a predominant concern of electrical engineers. Various intelligent techniques have been introduced to enhance the voltage stability of the system. One such technique gaining more importance in enhancing the stability and power transfer capability of the power system is flexible alternating current transmission system (FACTS).Thyristor controlled series compensator (TCSC) is a series connected FACTS device used for real power flow control. In the system considered, TCSC uses PI, PID, FOPID and Fuzzy controller thereby achieving the combined advantages of each controller. The designed combination of controller is tested using IEEE 9 bus test system using MATLAB/SIMULINK software. The Simulation results obtained using different combination of controller with TCSC shows the new design delivers an excellent and fast realization compared to other types.

Key words: Voltage Stability · Congestion management · FACTS · TCSC · PI · PID · FOPID · FUZZY

INTRODUCTION

Maintaining power system stability and reliability in the existing scenario is a crucial challenge for power engineers as the demand is increasing at a faster rate day by day. The introduction of flexible alternating current transmission system made less difficult for the power engineers as the FACTS devices are more demanding in improving the transient stability and power transfer capability of the transmission line with reduced congestion.

Improving the transient stability of the power system is an important issue for electrical engineers as the disturbances are more. The power system is restructured and thus the private parties are now participating in the power production. Due to participation of private parties, the transmission line loading limit becomes more crucial as the participants tries to sell their power through the transmission line. The transient stability of the system is solved by using local fuzzy based damping controller using mat lab simu link program [1]. The fractional order PID controller based TCSC is introduced to improve the transient stability by combining with the integral AGC to improve the reliability [2].Transient stability analysis is performed under several cases like optimal placement of TCSC to solve transient problem using particle swarm optimization technique [3]. An active power sensitivity approach is introduced to place the TCSC optimally with a coordinated design of PSS [4].The flexible alternating current transmission system device TCSC is used to maintain the transient stability of the system using bacterial foraging algorithm [5].The FACTS device TCSC is designed , modelled and tuned using differential algorithm to solve the transient stability problems using MAT LAB simulink software [6].

Thyristor Controlled Series Capacitor (TCSC): The simplified representation of elementary Thyristor-Controlled-Series-Capacitor is presented in Figure 1. A ripple less adjustable series-capacitive reactance is obtained by paralleling series compensating capacitor with Thyristor-controlled Reactor which forms the basic

Corresponding Author: P. Kalaimani, Department of Electrical and Electronics, Anna University, Chennai, India.

construction of TCSC. Thyristor Controlled Reactor (TCR) is bridged opposite to a series capacitor. In a practical TCSC circuit, primitive compensators may be connected in series to fetch the required voltage rating and operating characteristics. The inductive-reactance of the transmission line is compensated by optimally locating TCSC, thus reducing the exchange- reactance between the overloaded buses of the transmission system. to improve the power transfer capability of the power transmission system.
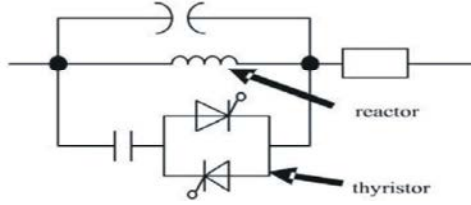
Fig. 1: Equivalent circuit of TCSC

In this paper FACTS device is utilized to reduce congestion and improve the power flow capacity of the system

Modelling of TCSC: Various types of FACTS devices are employed to solve congested condition in transmission line and to enhance the voltage stableness of power system. In this paper Thyristor-Controlled-Series-Compensator is introduced for enhancing the voltage stability of the system. An elementary representation of transmission line is shown in Figure 1. It consist of two buses represented by the notation, bus-a and bus-b. The voltages-of two-buses are represented as $V_a \angle \delta_a$ and $V_b \angle \delta_b$. The real power flow between the two buses are mathematically represented as:
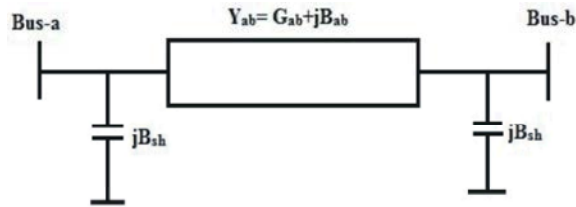

Fig. 2: Elementary model of transmission line

$$P_{ab} = V_a^2 G_{ab} - V_a V_b [G_{ab} \cos(\delta_{ab}) + B_{ab} Sin(\delta_{ab})] \quad (1)$$

where $\delta_{ab} = \delta_a - \delta_b$.

Similarly the true power flow from bus-a to bus-b (P_{ba}) is

$$P_{ba} = V_b^2 G_{ab} - V_a V_b [G_{ab} \cos(\delta_{ab}) + B_{ab} Sin(\delta_{ab})] \quad (2)$$

The elementary representation of transmission line with incorporating TCSC between two buses bus-a and bus-b is shown in Figure 2.
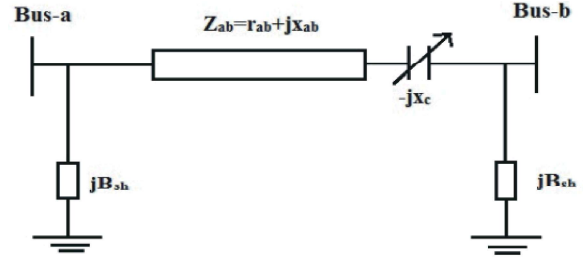

Fig. 3: Model of TCSC

At stable condition of the power system network, the TCSC is considered as fixed reactance $-jx_c$. The real power flow from bus-a to bus-b (P^k_{ab}) and from bus-b to bus-a (P^k_{ba}) of the transmission line with series impedance $Z_{ab} = r_{ab} + jx_{ab}$ and series reactance $-jx_c$ are represented as:

$$P_{ab}^K = V_a^2 G'_{ab} - V_a V_b [G'_{ab} \cos(\delta_{ab}) + B'_{ab} Sin(\delta_{ab})] \quad (3)$$

$$P_{ba}^K = V_b^2 G'_{ab} - V_a V_b [G'_{ab} \cos(\delta_{ab}) + B'_{ab} Sin(\delta_{ab})] \quad (4)$$

where, $$\frac{r_{ab}}{r_{ab}^2 + (x_{ab} - x_c)^2} \quad (5)$$

and

$$B'_{ab} = \frac{-(x_{ab} - x_c)}{r_{ab}^2 + (x_{ab} - x_c)^2} \quad (6)$$

The abnormal power flow conditions in the transmission line due the presence of series capacitance effect can be compensated by infusing more (complex) power to the transmission line at sending end (S_{ac}) and receiving end (S_{bc}) without series capacitance. It is designed as power injection model of TCSC as shown in Figure 3. The power flows mathematical notations are represented as:

$$P_{ac} = P_{ab} - P_{ab}^c = V_a^2 \Delta G_{ab} - V_a V_b [\Delta G_{ab} Cos\delta_{ab} + \Delta B_{ab} Sin\delta_{ab}]$$
$$(7)$$

$$P_{bc} = P_{ba} - P_{ba}^c = V_b^2 \Delta G_{ab} - V_a V_b [\Delta G_{ab} Cos\delta_{ab} + \Delta B_{ab} Sin\delta_{ab}]$$
$$(8)$$

where,

$$\Delta G_{ab} = \frac{x_c r_{ab}(x_c - 2x_{ab})}{\left(r_{ab}^2 + x_{ab}^2\right)\left(r_{ab}^2 + (x_{ab} - x_c)^2\right)} \tag{9}$$

and

$$\Delta B_{ab} = \frac{-x_c\left(r_{ab}^2 - x_{ab}^2 + x_c x_{ab}\right)}{\left(r_{ab}^2 + x_{ab}^2\right)\left(r_{ab}^2 + (x_{ab} - x_c)^2\right)} \tag{10}$$

Simulation Results: The case study of IEEE nine bus test system without TCSC is modelled and simulated using mat lab. The IEEE 9 bus system consist of 3 generators connected at bus 1, bus 2 and bus 3 respectively. Similarly the loads are connected at bus 5, bus 6 and bus 7 respectively. An additional load is being added to bus-6 using a switch. The additional load is a sudden disturbance to the circuit which affects the voltage, real power and reactive power at bus-6 The waveforms for output voltage, real power and reactive power at bus 6 is obtained by Simulation.
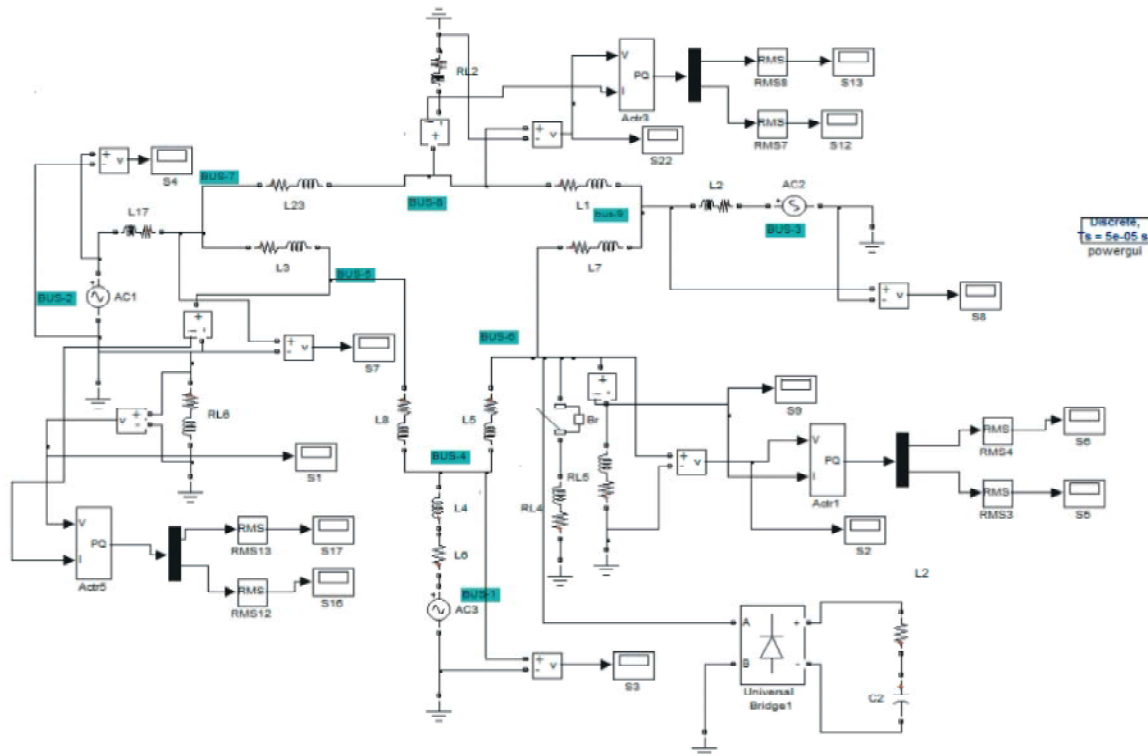
Fig. 4: Nine bus system without TCSC
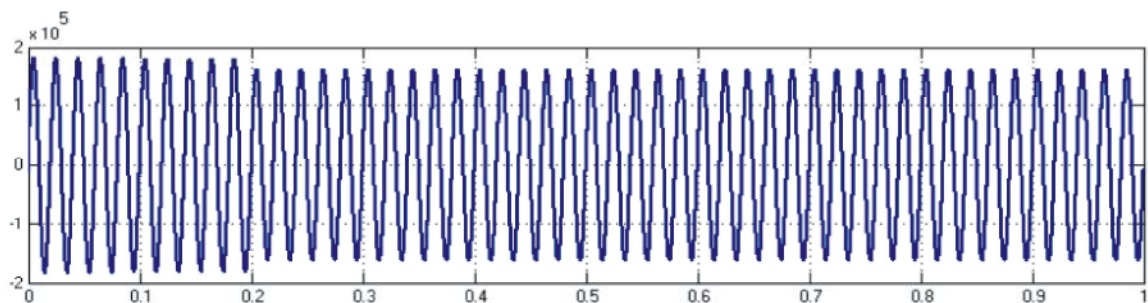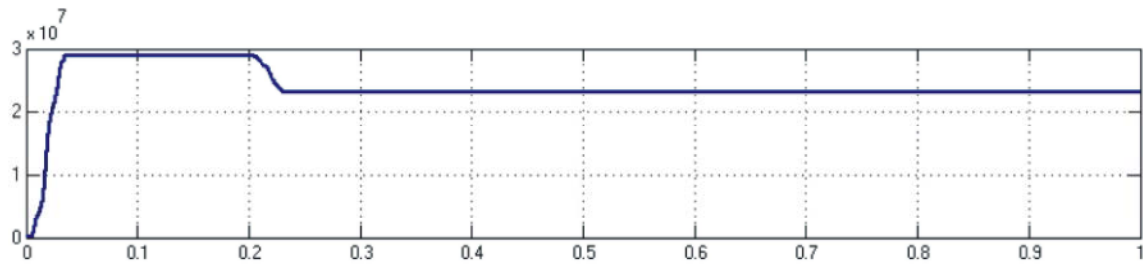

Fig. 5: Output voltage at bus 6 without TCSC

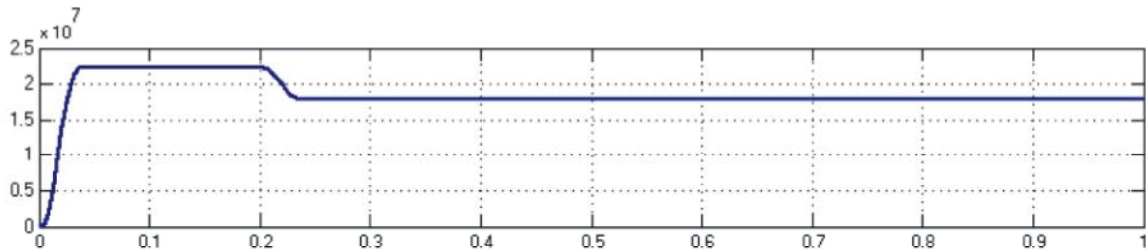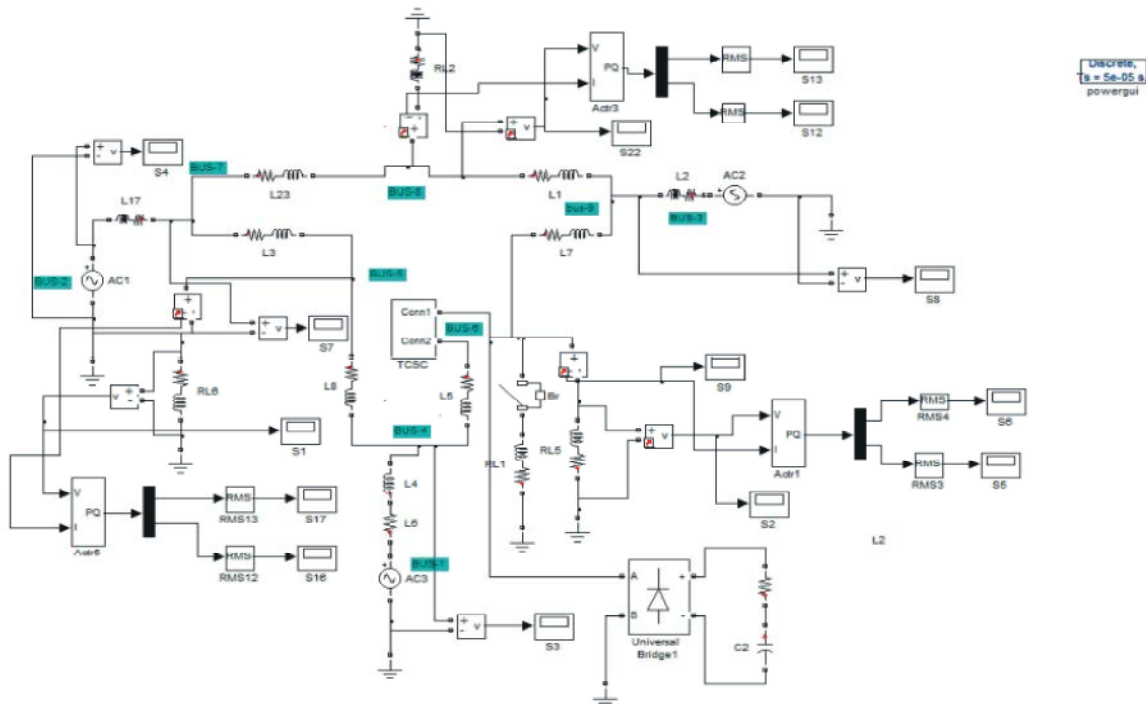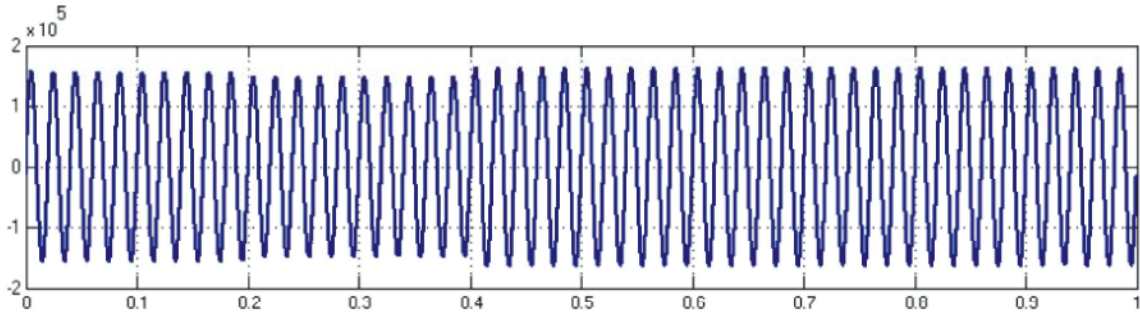Fig. 6: Real power at bus 6 without TCSC

Fig. 7: Reactive power at bus 6 without TCSC

The output voltage at bus 6 is 162 kilovolts. The real and reactive power at bus 6 is found to be 25.45 megawatts and 17.25 megawatts respectively.

Nine Bus System with TCSC: The case study of IEEE nine bus test system with TCSC controller is presented in this section. The FACTS device TCSC is connected between bus 4 and bus 6 were an additional load is given. The waveforms of voltage, real and reactive power at load bus 6 is obtained by simulation.

Fig. 8: Ninebus system with TCSC

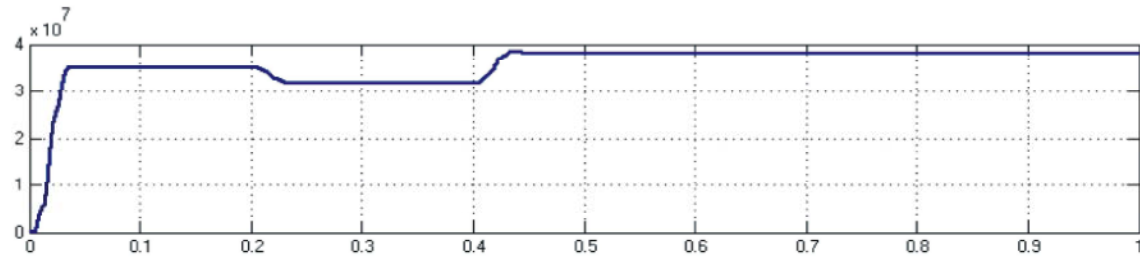Fig. 9: Output voltage at bus 6 with TCSC
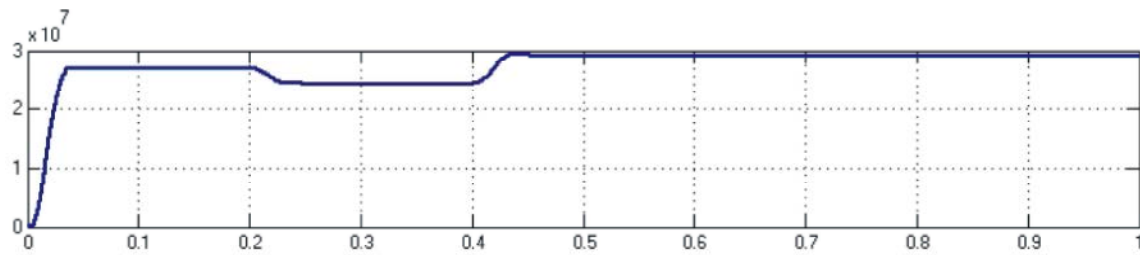

Fig. 10: Real power at bus 6 with TCSC

Fig. 11: Reactive power at bus 6 with TCSC

Table 1: Real power & Reactive power at bus 6

Bus No	Real power (MW) Without TCSC	Real power (MW) With TCSC	Reactive power (MVAR) Without TCSC	Reactive power (MVAR) With TCSC
Bus6	25.45	38.05	17.25	28.60

Table 2: Load voltage at bus 6

Bus No	Voltage (KV) without TCSC	Voltage (KV) with TCSC
Bus-6	162	175

The output voltage at bus 6 is 175 kilovolts. The real and reactive power at bus 6 is 38.05 megawatts and 28.60 megawatts respectively. The cumulative results of the real power, reactive power and load bus voltage observed from the waveforms are summarized in Table 1 and Table 2 respectively.

Nine Bus System with Closed Loop TCSC and PI Controller: The performance of the system is further improved by connecting PI controller with TCSC. The wave forms of Voltage at bus 6, the real power and reactive power of the system at bus 6 are shown below.

In Figure 12, the PI controller with closed loop is connected with TCSC to improve the voltage stability of the system and also to improve real power and reactive power flow of the considered test system. The output voltage at bus 6 is 180 KV. The real power flow at bus 6 is 40 MW. The Reactive power flow at bus 6 is 31 MVAR.
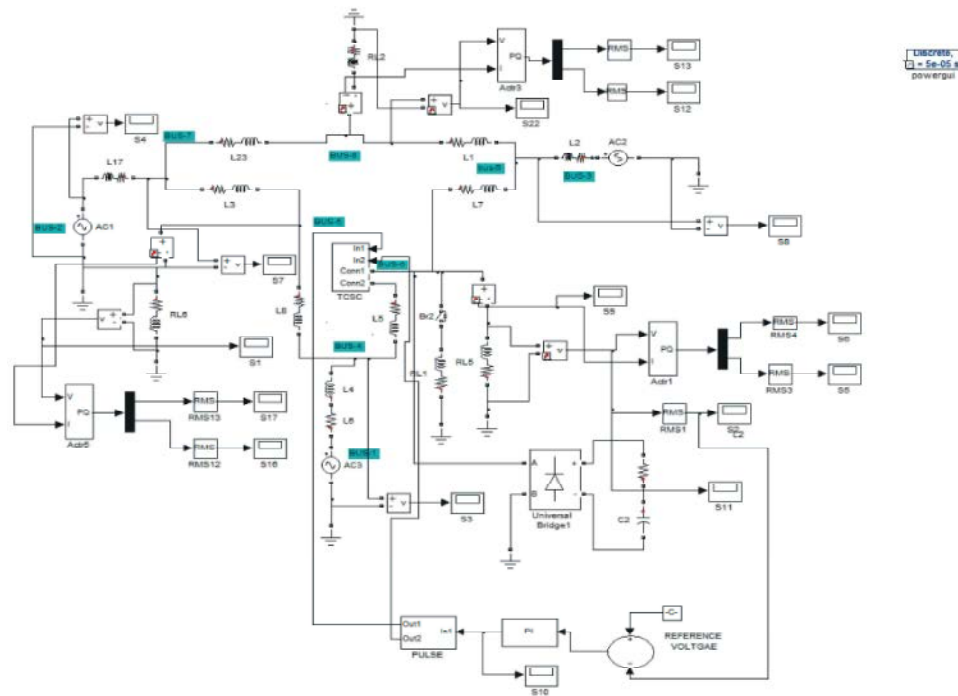
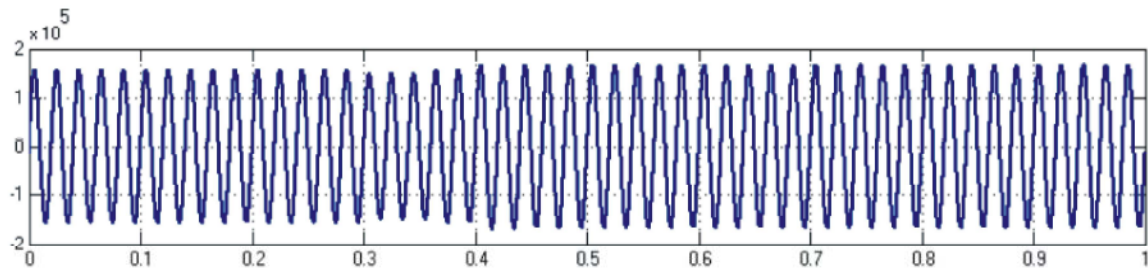Fig. 12: Closed loop system with PI controller
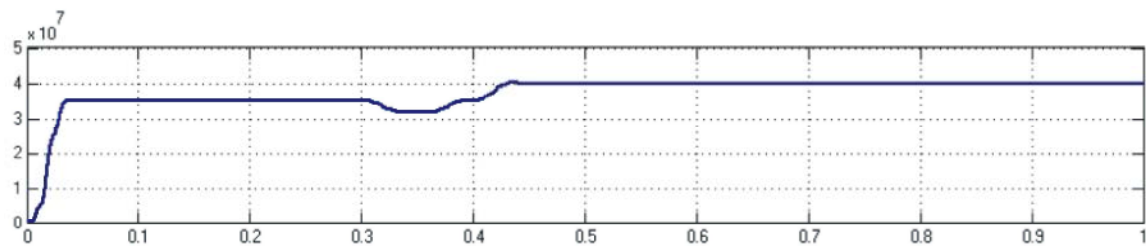

Fig. 13: Output voltage at bus 6
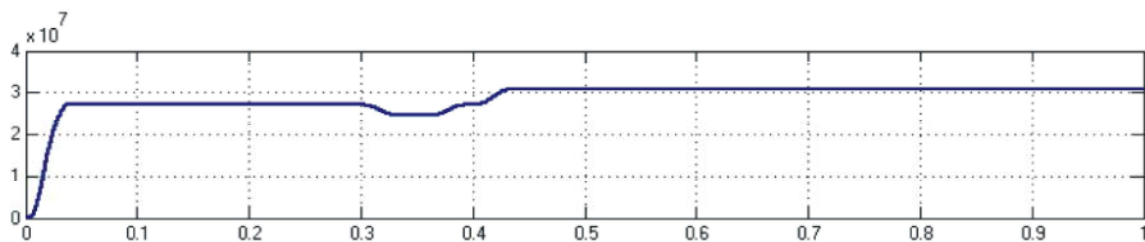

Fig. 14: Real power at bus 6

Fig. 15: Reactive power at bus 6

Nine Bus System with Closed Loop TCSC and PID Controller: The IEEE 9 bus system is simulated using PID controller with the FACTS device TCSC and the performance of the system were analysed. The output voltage at bus 6 is shown in Figure 17. The real power flow at bus 6 using PID controller with the FACTS device TCSC is shown in Figure 18. Similarly the reactive power flow at bus 6 using PID controller with TCSC is shown in Figure 19.

In Figure 16, the PID controller with closed loop is connected with TCSC to enhance the voltage stability of the system and also to improve real power and reactive power flow of the considered IEEE 9 bus test system. The output voltage at bus 6 is 170 KV. The real power flow at bus 6 is 40 MW. The Reactive power flow at bus 6 is 31 MVAR .The performance of the system with PI controlled TCSC and PID controlled TCSC shows no variations in terms of voltage boost and real power and reactive power flow.

Nine Bus System with Closed Loop TCSC and FOPID Controller: The IEEE 9 bus system simulated using FOPID controller with FACTS device TCSC is shown in Figure 20. The fractional order PID controller is introduced in this system to validate the parameters of the considered IEEE 9 bus test system. The output voltage at bus 6 obtained using FOPID controlled TCSC is shown in Figure 21. Similarly the real power flow and reactive power flow at bus 6 using FOPID controller with the FACTS device TCSC is shown in Figure 22 and Figure 23 respectively.

The output voltage at bus 6 is 180 KV. The real power flow at bus 6 is 39 MW. The Reactive power flow at bus 6 is 24 MVAR .The performance of the system with PID controlled TCSC and FOPID controlled TCSC shows no variations in terms of voltage boost and real power and reactive power flow. The Summary of the various parameters obtained without any controllers, with FACTS device TCSC and with the combination of FACTS device TCSC with PI, PID and FOPID controllers are summarized below. The Summary of real power at bus 6 due to sudden disturbance given to the bus through a breaker with different combinations of controllers are explained in Table 3. Similarly the reactive power profiles of the system at different combination of TCSC are explained in Table 4. The time domain analysis of different controllers with TCSC is summarised in Table 5.
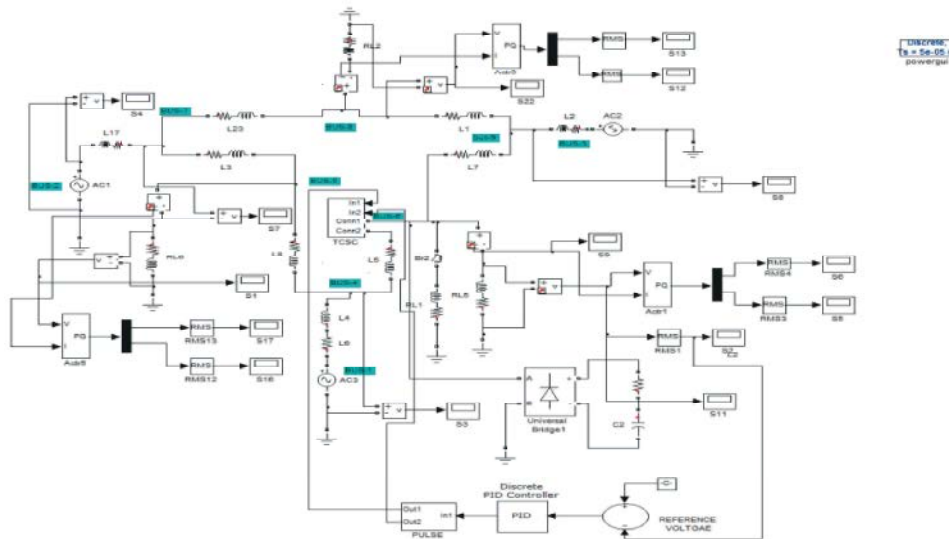

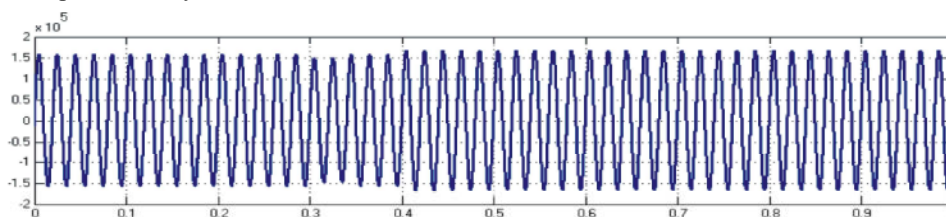Fig. 16: Closed loop nine bus system with PID controller

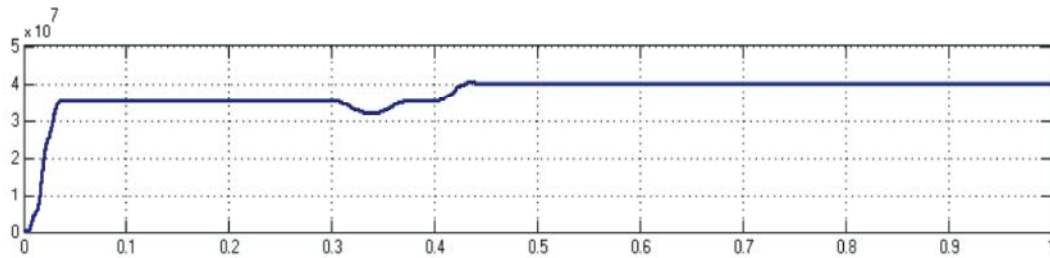Fig. 17: Output voltage at bus 6

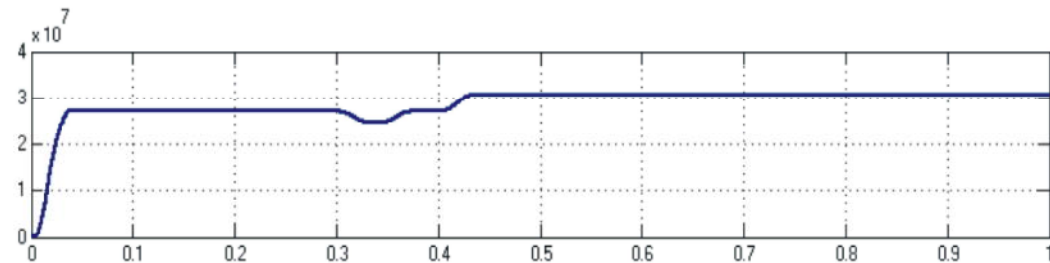Fig. 18: Real power at bus 6
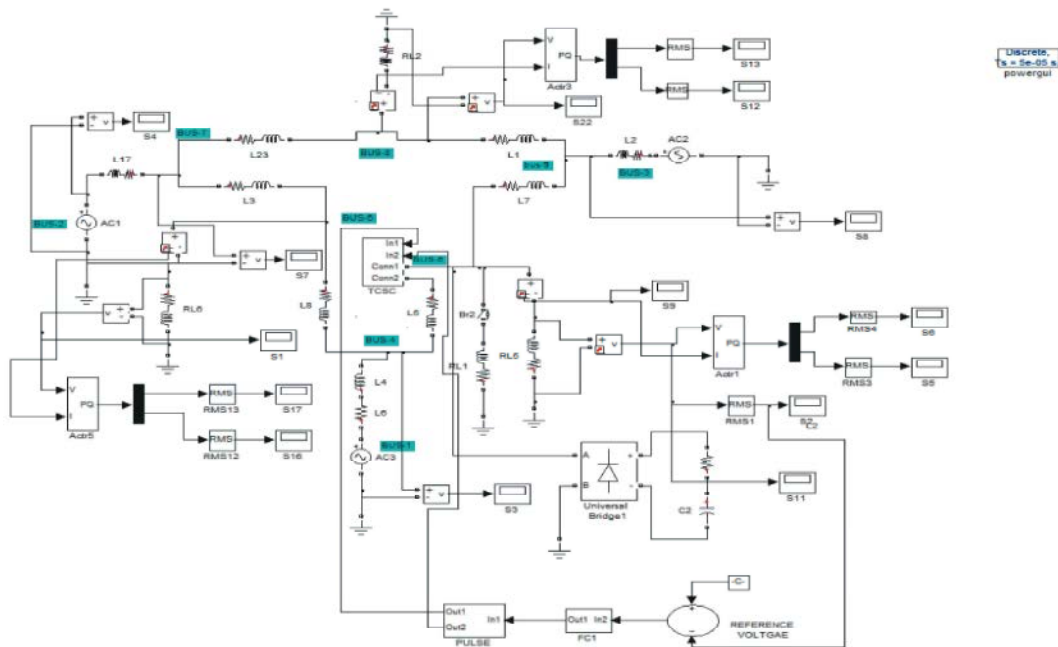

Fig. 19: Reactive power at bus 6

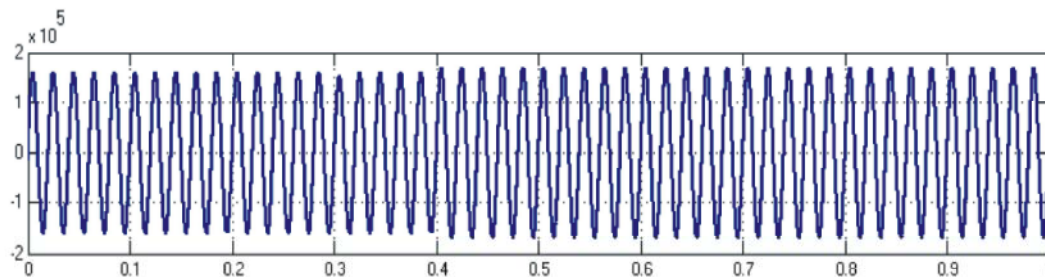Fig. 20: Closed loop nine bus system with FOPID controller
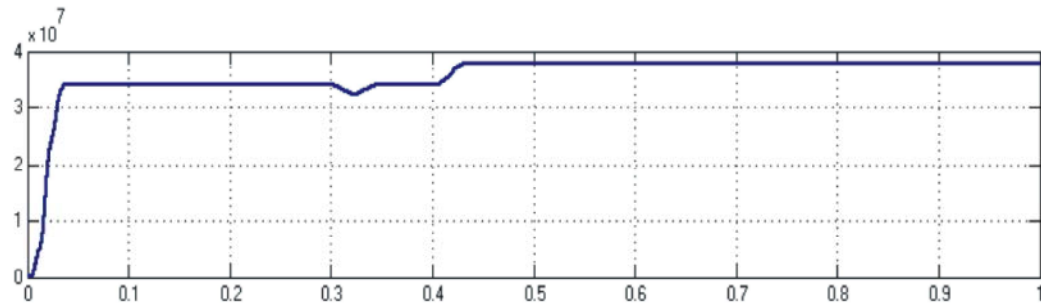

Fig. 21: Output voltage at bus 6
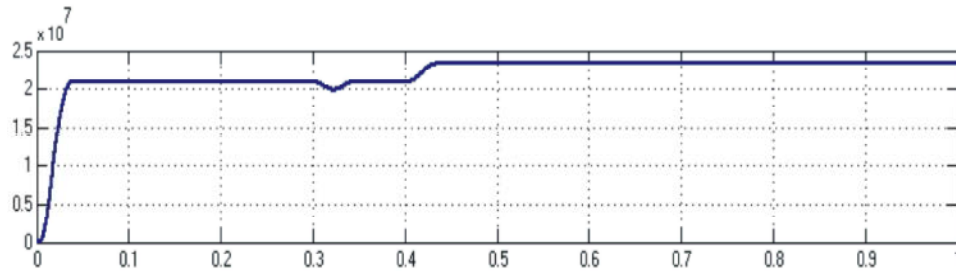
Fig. 22: Real power at bus 6

Fig. 23: Reactive power at bus 6

Table 3: Summary of Real power at bus 6 with different combinations

TCSC at Different Conditions	Real power (MW)
Without TCSC	25.45
With TCSC	38.05
PI Controller with TCSC	40
PID Controller with TCSC	40
FOPID Controller with TCSC	39

Table 4: Summary of Reactive power at bus 6 with different combinations

TCSC at Different Conditions	Reactive power (MVAR)
Without TCSC	17.25
With TCSC	28.60
PI Controller with TCSC	31
PID Controller with TCSC	31
FOPID Controller with TCSC	24

Table 5: Comparison of time domain parameters of Different Controllers

Controllers With TCSC	Rise time (Sec)	Peak time (Sec)	Settling time (Sec)	Steady state error (V)
PI	0.33	0.35	0.42	2.21
PID	0.32	0.33	0.36	1.53
FOPID	0.30	0.31	0.32	0.09

Nine Bus System with Closed Loop TCSC and Fuzzy Controller: Fuzzy logic controller is considered to be one of the most dominant controllers in translating the existing and the conventional designs of the power system with the modern requirements of the power system to adhere with the modern technology. The fuzzy modelling is most difficult as it depends on the fuzzy rules. The system characteristics are generally defined using such set of fuzzy rules. The Exact formations of fuzzy rules are derived from the system information's.

The Fuzzy membership functions are generally determined from the control action requirements. The efficient performance of the power system depends on the dynamic formation of the membership function and the fuzzy rules. The four basic parts of fuzzy logic controller are Fuzzification, Knowledge Base and inference engine and finally defuzzification. The fuzzy rules and the input and the output membership functions are shown in Figure 24, Figure 25 and Figure 26 respectively.

Table 6: Fuzzy Rule

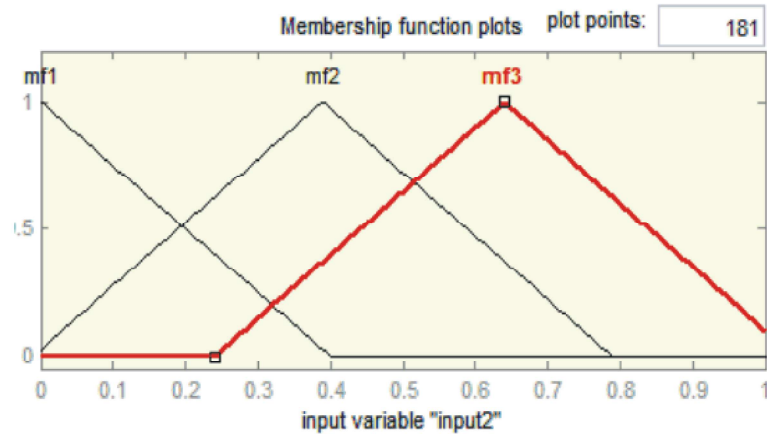| e/Δe	NL	Z	PS
NL	PB	NL	NB
Z	NL	Z	NS
PS	NB	PB	PS

Fig. 24: Membership Function of 1st input variable
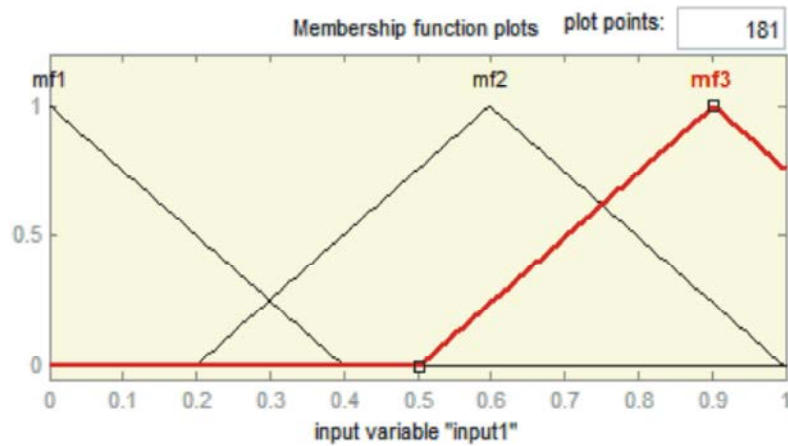

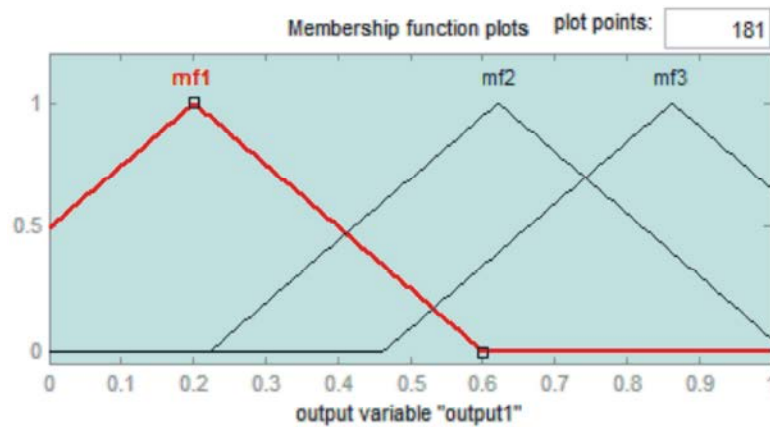Fig. 25: Membership Function of 2nd input variable

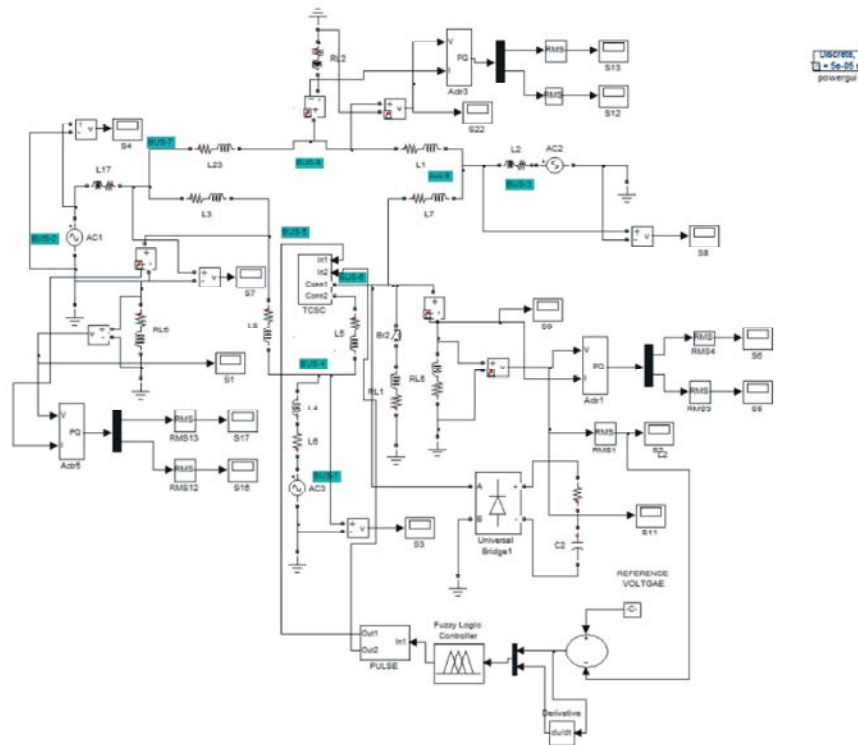Fig. 26: Membership Function of output variable

Fig. 27: Closed loop nine bus system with fuzzy logic controller
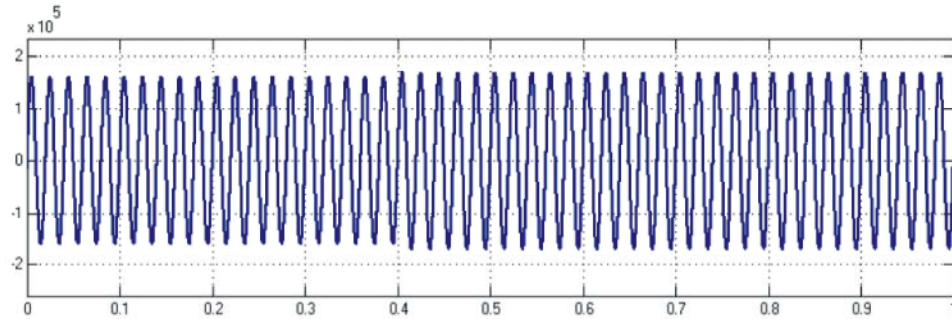

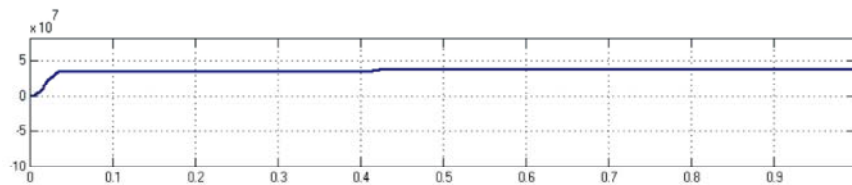Fig. 28: Output voltage at bus 6
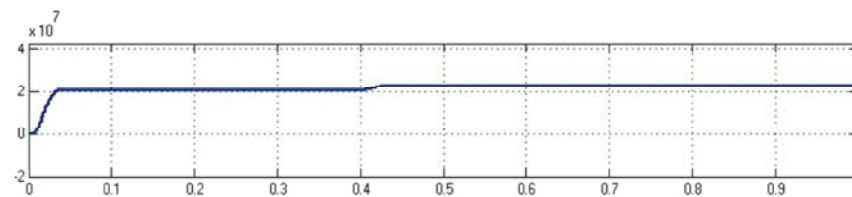

Fig. 29: Real power at bus 6

Fig. 30: Reactive power at bus 6

Table 7: Comparison of time domain parameters of Different Controllers

Controllers With TCSC	Rise time (Sec)	Peak time (Sec)	Settling time (Sec)	Steady state error (V)
PI	0.33	0.35	0.42	2.21
PID	0.32	0.33	0.36	1.53
FOPID	0.30	0.31	0.32	0.09
FUZZY	0.02	0.03	0.05	0.07

The IEEE 9 bus system simulated using Fuzzy logic controller with FACTS device TCSC is shown in Figure 27. The fuzzy logic controller is introduced in the IEEE 9 bus system to validate the parameters of the considered IEEE 9 bus test system. The output voltage at bus 6 obtained using Fuzzy controlled TCSC is shown in Figure 28. Similarly the real power flow and reactive power flow at bus 6 using Fuzzy controller with the FACTS device TCSC is shown in Figure 29 and Figure 30 respectively.

The output voltage at bus 6 is 185 KV. The real power flow at bus 6 is 47 MW. The Reactive power flow at bus 6 is 25 MVAR .The performance of the system with Fuzzy controller shows that the voltage at bus 6 has been boosted up when compared to the other conventional methods. Similarly the real power flow has been improved upto 47 MW when compared to the other conventional methods.

From Table 7 it is clear that when compared to the conventional methods like PI, PID and FOPID, Fuzzy controller proves to be more efficient in bring the power system to stable state as soon as possible when the disturbance is occurred in the system.

CONCLUSION

Nine bus system has been simulated with and without TCSC to observe its performance. It is clear that the real power transmitted with TCSC is higher than without TCSC. The FACTS device TCSC is implemented as it is cheaper than other FACTS devices such as UPFC and IPFC. It is observed that TCSC is more suitable to reduce transmission congestion and to control the power through the transmission line . The disadvantage of TCSC is that it introduces current harmonics into the transmission line. The nine bus system has also been simulated with TCSC for PI , PID, FOPID and FUZZY controller to observe its time domain specifications. The scope of the present work is to improve voltage stability and power flow in transmission line. The present work will be extended to PI controller and fuzzy controller for IEEE 14 bus system results for investigation of improving voltage stability and improved power flow for IEEE 14 bus system.

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