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Analysis of Classical and Intelligent Controller by using Facts Devices for Power System Damping

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Abstract: A Typical TCSC module consists of a fixed series capacitor (FC) in parallel with a thyristor controlled reactor (TCR). It offers smooth and flexible control of the line impedance with much faster response compared to the traditional control devices. Static Var Compensator (SVC) is a shunt type FACTS device which is used in power system primarily for the purpose of voltage and reactive power control. Generator speed and the electrical power are chosen as input signals for the Fuzzy Logic Controller (FLC). The effectiveness and feasibility of the proposed control is demonstrated with nine Bus systems. In this paper FACTS devices are implement to achieve transient stability enhancement and a comparative analysis is done among FACTS devices for power system oscillation damping.

Keywords: Thyristor Control Series Capacitor (TCSC), Static Var Compensator (SVC), Proportional Integral Derivative (PID) Controller, Fuzzy Logic Control (FLC), Transient Stability.

I. INTRODUCTION

Power system load growth is increasing at a faster rate as compared to the increase in transmission capability. In the last decade the increase in transmission capacity is approximately 50% of the increased generation capacity. This has forced the system to move large amount of power over transmission system and created challenges associated with it.This has increased the need of improvements in the transfer capability of the system while maintaining the system security and reliability. Power System Stability is the ability of the system to regain its original operating conditions after a disturbance to the system. Power system transient stability analysis is considered with large disturbances like sudden change in load, generation or transmission system configuration due to fault or switching. Dynamic voltage support and reactive power compensation have been identified as a very significant measure to improve the transient stability of the system. Flexible AC Transmission Systems (FACTS) devices with a suitable control strategy have the potential to increase the system stability margin. According to the type of connections the FACTS devices are categories four types but here we mainly concentrate on series and shunt type connections. Series FACT devices are most commonly used for power flow control, power oscillation damping and transient stability improvement where as shunt FACTS devices play an important role in reactive power flow in the power network.

In large power systems, low frequency electro-mechanical oscillations often follow the electrical disturbances. In a proportional – integral – derivative (PID) was found that significant improvements in system damping can be achieved by the PID. Although PID controllers are simple and easy to design, their performances deteriorate when the system operating conditions vary widely and large disturbances occur. Fuzzy logic control approach is an emerging tool for solving complex problems whose system behavior is complex in nature. An attractive feature of fuzzy logic control is its robustness in system parameters and operating conditions changes. Fuzzy logic controllers are capable of tolerating uncertainty and imprecision to greater extent. This project presents power system oscillation damping by using TCSC and svc FACTS devices with PID and fuzzy controller.

Power System Damping: As the damping of electro-mechanical power system dynamics inherently is low, sources of supplementary damping are sought for. The individual generator is equipped with a PSS (power system stabilizer) and damper windings. Systems based on high power electronic equipment is known as FACTS (Flexible AC Transmission System [Hingorani 1988]). Such devices have received much attention during the last five years. They are mostly located on tie-lines and influence the electro-mechanical oscillations through the power flow on the line.

II. MODELING AND CONTROL OF TCSC

TCSC is a series FACTS device which allows rapid and continuous changes of the transmission line impedance. It has great application potential in accurately regulating the power flow on a transmission line, damping inter-area power oscillations, mitigating sub synchronous resonance (SSR) and improving transient stability. TCSC controllers use thyristor-controlled reactor (TCR) in parallel with capacitor segments of series capacitor bank (Fig.1). The combination of TCR and capacitor allow the capacitive reactance to be smoothly controlled over a wide range and switched upon command to a condition where the bi-directional thyristor pairs conduct continuously and insert an inductive reactance into the line. According to IEEE definition, “A TCSC is a capacitive reactance compensator which consists of a series capacitor bank shunted by a Thyristor Controlled Reactor (TCR) in order to provide a smooth variation in series capacitive reactance.” TCSC controllers use TCR in parallel with segments of series capacitor bank. The combination of TCR and capacitor allow the capacitive reactance to be smoothly controlled over a wide range and switched upon command to a condition where the bi-directional thyristor pairs conduct continuously and insert appropriate reactance into the line. This thyristor controlled series capacitor is type of series compensator. This TCSC controller is design only for reduction of voltage sags in transmission system and the TCSC controller is controlled with the help of pulse width generator its work when gate pulse are given in this system then capacitor and inductor through control the voltage sags in the system.

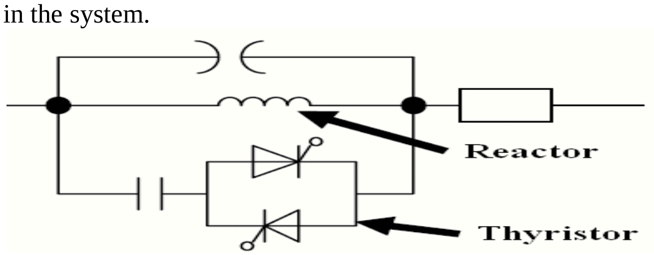

Fig.1. Schematic diagram of TCSC.

Fig.1 shows the simple diagram of TCSC comprised of a series capacitor bank, shunted by a Thyristor Controlled Reactor (TCR), to provide a smoothly variable series capacitive reactance. It is a one-port circuit in series with transmission line; it uses natural commutation; its switching frequency is low; it contains in significant energy storage and has no DC port. Insertion of a capacitive reactance in series with the lines inherent inductive reactance lowers the total, effective impedance of the line and thus virtually reduces its length. As a result, both angular and voltage stability gets improved. TCSC - Thyristor Controlled Series Capacitor compensator consisting of the series compensating capacitor, whereto is parallel connected thyristors controlled reactor (TCR), and it is one of FACTS devices which are mainly used to control active power flow in power system and increase the transmission power lines capacity. TCSC is involved in a series to line (in terminal) and allows changing impedance of the transmission path and thus affecting the power flows. Control is fast, efficient and increased between the transmitted powers. Basic scheme of TCSC device is shown in the follows fig.2.

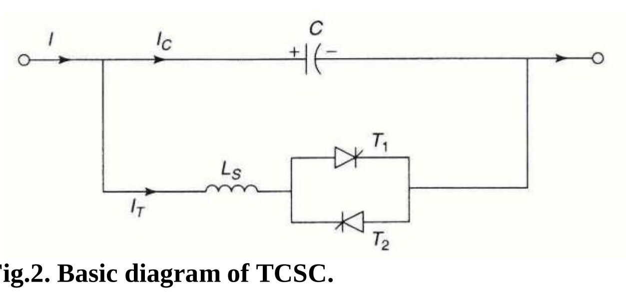

Fig.2. Basic diagram of TCSC.

Change of impedance of TCSC is achieved by changing the thyristor controlled inductive reactance of inductors connected in parallel to the capacitor. The magnitude of inductive reactance is determined by angle switching thyristors, which can also be controlled continuously flowing amplitude of current reactor from the maximum value to zero. Magnitude of inductance this compensator is given by Where $X_C = 1/2\pi FC$ is capacitive reactance of capacitor and C its capacity. For sufficiently small inductive reactance of reactor towards capacitive reactance of capacitor ($X_L<X_C$), the operating diagram of TCSC contains inductive and capacitive mode operation of TCSC and the transition between areas is the resonance region. Under normal operating conditions TCSC can operate in four modes of operation, namely: blocked mode, bypassed mode, capacitive and inductive mode.

Thyristor-Controlled Series Compensation (TCSC) is used in power systems to dynamically control the reactance of a transmission line in order to provide sufficient load compensation. The benefits of TCSC are seen in its ability to control the amount of compensation of a transmission line, and in its ability to operate in different modes. These traits are very desirable since loads are constantly changing and cannot always be predicted. TCSC designs operate in the same way as Fixed Series Compensation, but provide variable control of the reactance absorbed by the capacitor device. A thyristor-controlled series compensator is composed of a series capacitance which has a parallel branch including a thyristor controlled reactor. TCSC operates in different modes depending on when the thyristors for the inductive branch are triggered. The modes of operation are as listed:

Blocking Mode: Thyristorvalveis always off, opening inductive branch, and effectively causing theTCSC to operate as FSC.

Bypass Mode: Thyristor valve is always on, causing TCSC to operate as capacitor and inductor in parallel, reducing current through TCSC.

Capacitive Boost Mode: Forward voltage thyristor valve is triggered slightly before capacitor voltage crosses zero to allow current to flow through inductive branch, adding to capacitive current. This effectively increases the observed capacitance of the TCSC without requiring a larger capacitor within the TCSC.

Because of TCSC allowing different operating modes depending on system requirements, TCSC is desired for several reasons. In addition to all of the benefits of FSC, TCSC allows for increased compensation simply by using a different mode of operation, as well as limitation of line current in the event of a fault. A benefit of using TCSC is the damping of sub synchronous resonance caused by torsional oscillations and inter-area oscillations. The ability to dampen these oscillations is due to the control system controlling the compensator. This results in the ability to transfer more power, and the possibility of connecting the power systems of several areas over long distances.

III. MODELING AND CONTROL OF SVC

The Static Var Compensator is basically a shunt connected variable Var generator whose output is adjusted to exchange capacitive or inductive current to the system. One of the most widely used configurations of the SVC is the FC- TCR type in which a Fixed Capacitor (FC) is connected in parallel with Thyristor Controlled Reactor (TCR). The magnitude of the SVC is inductive admittance BL (α) is a function of the firing angle α and is given by

$$B_L(\alpha) = (2\pi - 2\alpha + \sin 2\alpha)/\pi X_s \quad (1)$$

For $\frac{\pi}{2} \leq \alpha \leq \pi$

Where $X_s = V_s^2 / Q_L$

V_s=SVC bus bar voltage and QL = MVA rating of reactor. As the SVC uses a fixed capacitor and variable reactor combination (TCR- FC), the effective shunt admittance is

$$B_s = \frac{1}{X_c} - B_L(\alpha) \quad (2)$$

Where X_c = Capacitive reactance.

An SVC with firing control system can be represented, for the sake of simplicity by a first order model characterized by a gain KSVC and time constants T_1 and T_2 as shown in Fig.3. The controller send firing control signals to the thyristor switching unit to modify the equivalent capacitance of the SVC. The fuzzy controller provides an auxiliary control, which is in addition to the voltage feedback loop.

The auxiliary control loop of the SVC uses stabilizing signals, such as speed, frequency, phase angle difference etc., to improve the dynamic performance of the system. This figure shows that the speed of mechanical switches (primarily circuit breakers) for conventional equipment solutions can be as fast as a couple of cycles of 60(or 50) Hz. This speed of switching in and of it self may be fast enough to solve many power system constraints. Although there is a vast improvement in switching time from mechanical to power electronic based solutions (Fig.3) illustrates that the speed of power electronics switches is a fraction of a cycle), the main benefit that FACTS controller solutions provide is the "cycling/repeatability" and "smooth control" that accompanies the power electronic based switching. In other words, a mechanically switched based (conventional) solution is usually a "one and done" or "on or off" impact to the power system in the time frame needed for power system stability, whereas the power electronic based solution can provide a smooth, continuous, and/or repeatable option for power system control. Thus by applying power electronic based solutions to alleviate power system constraints, it is not just "speed" but "cycling" and "smooth control" that is gained.

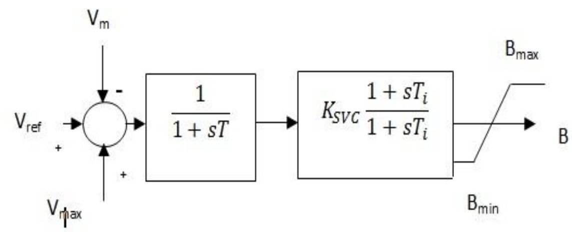

Fig.3. Block Representation of SVC Control.

IV. REVIEW OF FUZZY LOGIC

Fuzzy logic arose from a desire to incorporate logical reasoning and the intuitive decision making of an expert operator into an automated system. The aim is to make decisions based on a number of learned or predefined rules, rather than numerical calculations. Fuzzy logic incorporates a rule-base structure in attempting to make decisions. However, before the rule-base can be used, the input data should be represented in such a way as to retain meaning, while still allowing for manipulation. Fuzzy logic is an aggregation of rules, based on the input state variables condition with a corresponding desired output. A mechanism must exist to decide on which output, or combination of different outputs, will be used since each rule could conceivably result in a different output action. Fuzzy logic can be viewed as an alternative form of input=output mapping. Consider the input premise, x, and a particular qualification of the input x represented by A_i. Additionally, the corresponding output, y, can be qualified by expression C_i. Thus, a fuzzy logic representation of the relationship between the input x and the output y could be described by the following:

R_1: if x is A_1 then y is C_1
R_2: if x is A_2 then y is C_2
. . . .
. . . .
R_n: if x is an then y is C_n

Where x is the input (state variable), y is the output of the system, A_i are the different fuzzy variables used to classify the input x and C_i are the different fuzzy variables used to classify the output y. The fuzzy rule representation is linguistically based.

Thus, the input x is a linguistic variable that corresponds to the state variable under consideration. Furthermore, the elements Ai are fuzzy variables that describe the input x. correspondingly, the elements C_i are the fuzzy variables used to describe the output y. In fuzzy logic control, the term ''linguistic variable'' refers to whatever state variables the system designer is interested in. Linguistic variables that are often used in control applications include Speed, Speed Error, Position, and Derivative of Position Error. The fuzzy variable is perhaps better described as a fuzzy linguistic qualifier. Thus the fuzzy qualifier performs classification. (Qualification) of the linguistic variables. The fuzzy variables frequently employed include Negative Large, Positive Small and Zero. Several papers in the literature use the term ‘‘fuzzy set’’ instead of ‘‘fuzzy variable’’, however; the concept remains the same. Table 30.1 illustrates the difference between fuzzy variables and linguistic variables. Once the linguistic and fuzzy variables have been specified, the complete inference system can be defined.

The fuzzy linguistic universe, U, is defined as the collection of all the fuzzy variables used to describe the linguistic variables. I.e. the set U for a particular system could be comprised of Negative Small (NS), Zero (ZE) and Positive Small (PS). Thus, in this case the set U is equal to the set of [NS, ZE, PS]. For the system described by Eq. (30.1), the linguistic universe for the input x would be the set U_x . .A_1A_2 . . . A_n... Similarly,

TABLE I: Fuzzy and Linguistic Variables

Linguistic Variables		Fuzzy Variables (Linguistic Qualifiers)	
Speed error	(SE)	Negative Large	(NL)
Positive error	(PE)	Zero	(ZE)
Acceleration	(AC)	Positive medium	(PM)
Derivative of positive error	(DPE)	Positive very small	(PVS)
Speed	(SP)	Negative medium small	(NSM)

The linguistic universe for the output y would be the set U_y. .C_aC_2 . . . C_n.

The Fuzzy Inference System (FIS) The basic fuzzy inference system (FIS) can be classified as:

- Type 1 Fuzzy Input Fuzzy Output (FIFO)
- Type 2 Fuzzy Input Crisp Output (FICO)

Type 2 differs from the first in that the crisp output values are predefined and, thus, built into the inference engine of the FIS. In contrast, type 1 produces linguistic outputs. Type 1 is more general than type 2 as it allows redefinition of the response without having to redesign the entire inference engine. One drawback is the additional step required, converting the fuzzy output of the FIS to a crisp output. Developing a FIS and applying it to a control problem involves several steps:

- Fuzzification
- Fuzzy rule evaluation (fuzzy inference engine)
- Defuzzification.

The total fuzzy inference system is a mechanism that relates the inputs to a specific output or set of outputs. First, the inputs are categorized linguistically (fuzzification), then the linguistic inputs are related to outputs (fuzzy inference) and, finally, all the different outputs are combined to produce a single output (defuzzification). Fig.4 shows a block diagram of the fuzzy inference system.

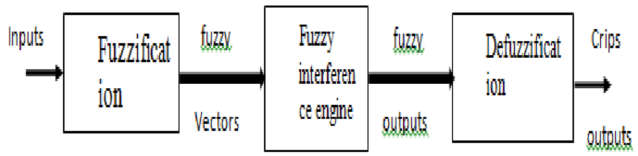

Fig.4. Fuzzy inference system.

Fuzzification: Fuzzy logic uses linguistic variables instead of numerical variables. In a control system, error between reference signal and output signal can be assigned as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive small (PS), Positive Medium (PM), Positive Big (PB). The triangular membership function is used for fuzzifications. The process of fuzzification convert numerical variable (real number) to a linguistic variable (fuzzy number).

Defuzzification: The rules of fuzzy logic controller generate required output in a linguistic variable (Fuzzy Number), according to real world requirements; linguistic variables have to be transformed to crisp output (Real number). This selection of strategy is a compromise between accuracy and computational intensity.

V. FLC BASED DAMPING CONTROLLER DESIGN

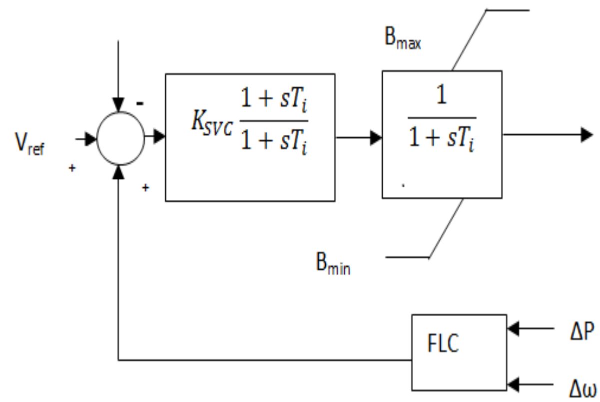

Fig.5. Block diagram of proposed Fuzzy logic controller.

Fig.5 shows the schematic diagram of a SVC along with Fuzzy logic based damping controller. Generator speed deviation ($\Delta\omega$) and (ΔP) are taken as the input signals of the fuzzy controller. The number of membership functions for each variable determines the quality of control which can be achieved using fuzzy logic controllers. In the present investigation, five membership functions are defined for the input and output variables. Fig.6 shows the membership functions defined. The mentioned membership functions are used to specify a set of rules called a rule base. The rules developed are based on the knowledge and experience. With two inputs and five linguistic terms, 25 rules were developed which is given in Table 1. In inference mechanism all the rules are compared to the inputs to determine which rules apply to the current situation. After the matching process the required rules are fired. The controlled output B svc is determined for the different input conditions. The defuzzification produces the final crisp output of FLC with the fuzzified input. Centroid method is employed where the output will be calculated as

$$O/P=\frac{\sum_{i=1}^{5} b_i \int \mu_{(i)}}{\sum_{i=1}^{5} \int \mu_{(i)}} \quad (3)$$

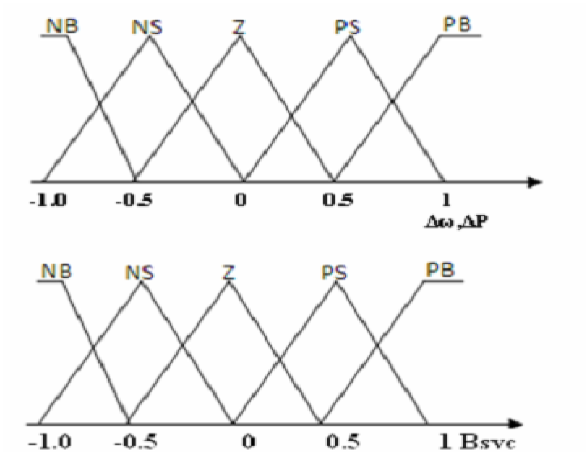

Fig.6. Membership functions of ($\Delta\omega$), (ΔP) and Bsvc.

TABLE II: Fuzzy Inference Rules

Output (B_{svc})				ΔP		
		NB	NS	Z	PS	PB
	NB	NB	NS	NB	NS	Z
	NS	NS	NB	Z	Z	PS
Δω	Z	NS	Z	Z	PS	PS
	PS	Z	Z	PS	PS	PS
	PB	Z	PS	PS	PS	PB

VI. NINE BUS SYSTEM

A Multi machine system equipped with Generator, Transmission line is shown in fig.7

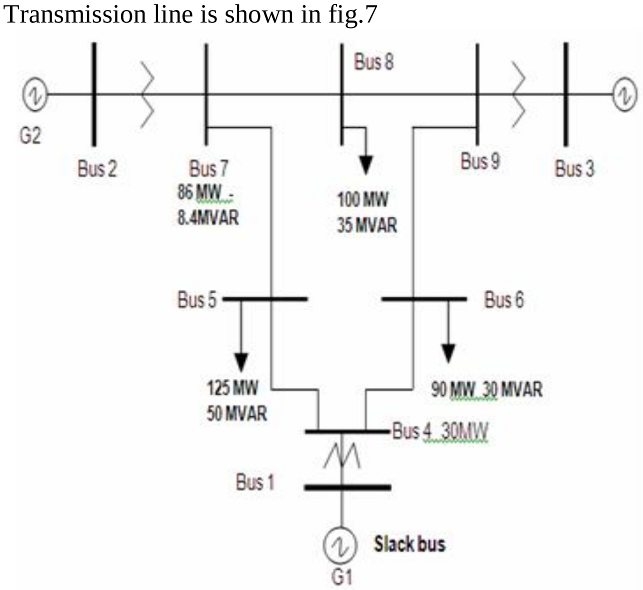

Fig.7. Single line diagram of nine bus system.

The FLC based TCSC is installed at bus 8 near the generator 2. With the initial power flow conditions, a three phase to ground short circuit was simulated near bus 7. In Figs.8 and 9 the variation of rotor angle δ, TCSC voltage and speed deviation Δω TCSC with PID controller and with FLC based TCSC controller are plotted. In this study case, fault condition at 0.3 seconds, existing for the period of 0.1 second and cleared at 0.4 seconds is shown in Fig.8. It is clear that the rotor angle damping using fuzzy controller is more effective than PID controller. The settling time of both controllers is found to be same, but the amplitude of rotor angle is reduced in FLC controller. The FLC based SVC is installed at bus 8 near the generator 2. With the initial power flow conditions, a three phase to ground short circuit was simulated near bus 7. In Figs 9 and 10 the variation of rotor angle δ, SVC voltage and speed deviation Δω SVC with PID controller and with FLC based SVC controller are plotted. In this study case, fault condition at 0.3 seconds, existing for the period of 0.1 second and cleared at 0.4 seconds is shown in Fig.10. It is clear that the rotor angle damping using fuzzy controller is more effective than PID controller. The settling time of both controllers is found to be same, but the amplitude of rotor angle is reduced in FLC controller.

VII. SIMULATION RESULTS

To assess the effectiveness of the proposed controller, simulation studies are carried out for the most severe fault conditions and overload conditions in Multi machine system. The details of the simulation are presented here. When the TCSC with conventional PID controller is placed at bus 1 and the same fault condition is simulated, it is observed that the damping is improved but still oscillations are present. With the FLC based TCSC the oscillations are fully damped out and the system comes back to original steady state. Figs 8 and 9 show the dynamic response of the power angle δ and the speed deviation Δ_ω, under fault conditions with different controllers.

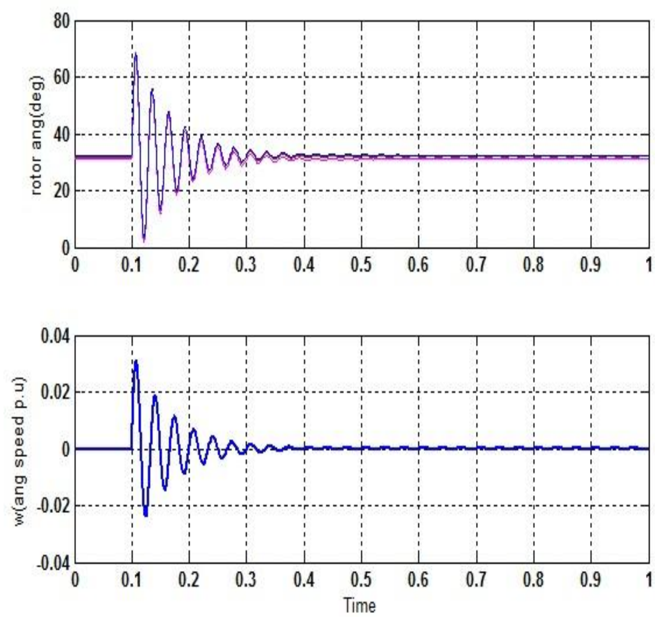

Fig.8. Rotor angle and speed deviation of TCSC with PID.

When the SVC with conventional PID controller is placed at bus 1 and the same fault condition is simulated, it is observed that the damping is improved but still oscillations are present. With the FLC based SVC the oscillations are fully damped out and the system comes back to original steady state. Figs.10 and 11 show the dynamic response of the power angle δ and the speed deviation Δω, under fault conditions with different controllers.

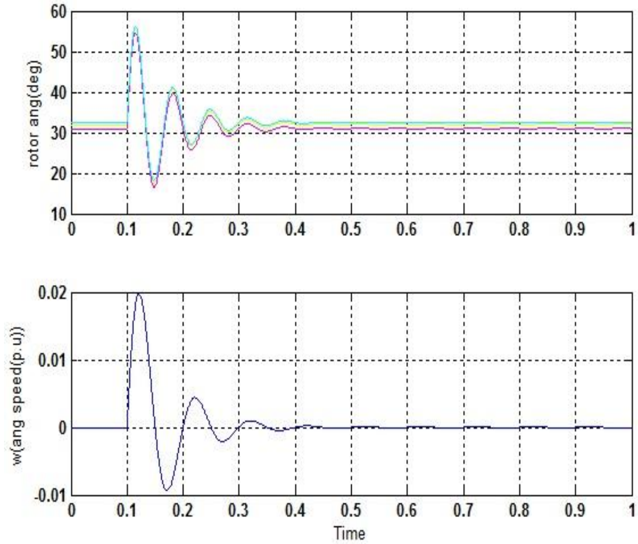

Fig.9. Rotor angle and speed deviation of TCSC with FUZZY.

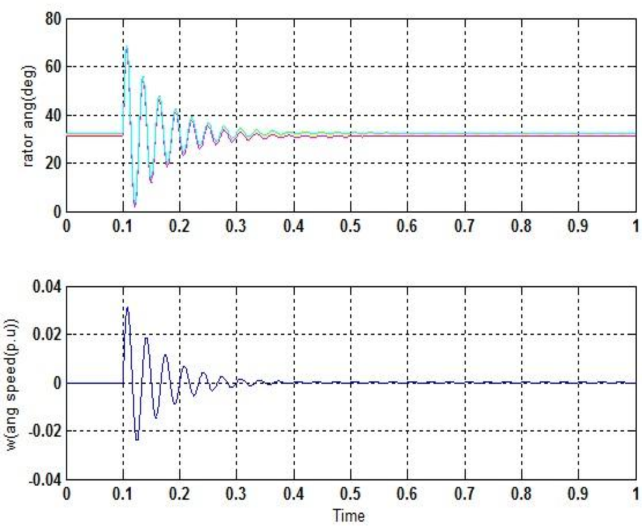

Fig.10 Rotor angle and speed deviation of SVC with PID.

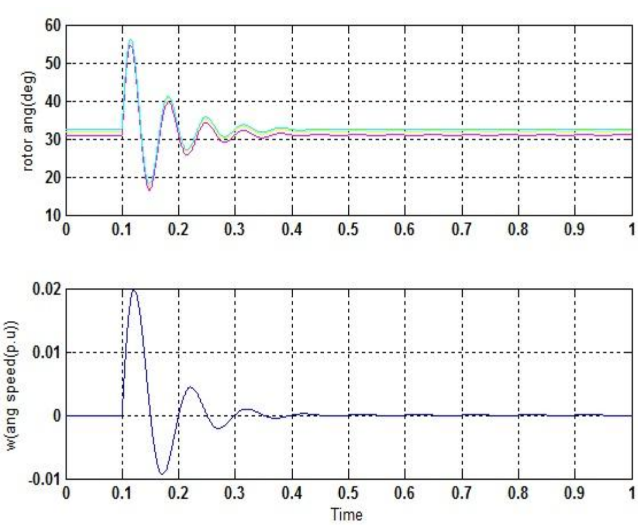

Fig.11. Rotor angle and speed deviation of SVC with FUZZY.

VIII. CONCLUSION

This project presents the application of a fuzzy logic based auxiliary control for TCSC and SVC to achieve transient stability enhancement. The proposed Fuzzy Logic Control for TCSC and SVC is simulated for a simple nine bus system. And is proved to be effective and robust in damping power system oscillations and thereby enhancing system transient stability. Fuzzy rules are easily derived from the measurable global signals like line active power flow, and remote generator speed deviation. The performance of various controllers using TCSC and SVC is then compared based on non-linear simulation results which are shown in Fig.8 to 11. Among these the performance of the SVC with FUZZY controller is found to be better and damp out the system oscillations at faster rate. It was also observed that for multimachine system, SVC controller works accurately. Digital computer simulations were performed using MATLAB/ SIMULINK software.

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