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Transient Stability Improvement of Multi-machine Power System Using Fuzzy Controlled TCSC

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ABSTRACT

Power system is subjected to sudden changes in load levels. Stability is an important concept which determines the stable operation of power system. In general rotor angle stability is taken as index, but the concept of transient stability, which is the function of operating condition and disturbances deals with the ability of the system to remain intact after being subjected to abnormal deviations. A system is said to be synchronously stable (i.e., retain synchronism) for a given fault if the system variables settle down to some steady-state values with time, after the fault is removed.

For the improvement of transient stability the general methods adopted are fast acting exciters, circuit breakers and reduction in system transfer reactance. The modern trend is to employ FACTS devices in the existing system for effective utilization of existing transmission resources. These FACTS devices contribute to power flow improvement besides they extend their services in transient stability improvement as well.

In this paper, the studies had been carried out in order to improve the Transient Stability of WSCC 9 Bus System with Fixed Compensation on Various Lines and Optimal Location has been investigated using trajectory sensitivity analysis for better results.

In this paper, in order to improve the Transient Stability margin further series FACTS device has been implemented. A fuzzy controlled Thyristor Controlled Series Compensation (TCSC) device has been used here and the results highlight the effectiveness of the application of a TCSC in improving the transient stability of a power system.

In this paper, Trajectory sensitivity analysis (TSA) has been used to measure the transient stability condition of the system. The TCSC is modeled by a variable capacitor, the value of which changes with the firing angle. It is shown that TSA can be used in the design of the controller. The optimal locations of the TCSC-controller for different fault conditions can also be identified with the help of TSA.

The paper depicts the advantage of the use of TCSC with a fuzzy controller over fixed capacitor operation.

***Keywords**:* TCSC; Trajectory sensitivity analysis; Dynamic simulation; Transient stability margin; fuzzy controller

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1. Introduction

The demand of electrical power is ever increasing. However, the process of development of new infrastructure for power generation and dispatch is restricted due to mainly economic and partially environmental constraints. These result in the need for better utilization of the existing system. Flexible AC transmission system (FACTS) controllers are potent tools to achieve this goal. These devices help in pushing the system to their limits and thus to attain higher operational efficiency. The use of these controllers increases the flexibility of operation by providing more options to the power system operators. In the steady state, FACTS controllers like TCSC help in controlling and increasing the power flow through a line. However, the other important aspect of these controllers is their use during large disturbances like faults because of their capability to improve the transient stability condition of a power system. Evaluation of transient stability condition of the system is essential for understanding the effects of application of FACTS devices. Transient energy function (TEF) method is a standard tool used for this purpose. It is based on direct method of Lyapunov and depends on finding a suitable energy function and identifying the unstable equilibrium point of the post-fault system. This is a rather difficult task especially in the case of large power systems. The trajectory sensitivity (TS) has been proposed as an alternative to the TEF based methods. It helps to identify stressed systems for a set of contingencies and is independent of unstable equilibrium point calculations and model complexity. A bang–bang control of TCSC is used to improve stability of power systems. A power flow control loop and a stability control loop have been used in unison to provide the required control action for a TCSC.

In this paper, a dynamic simulation of the power system has been carried out. Dynamics of the network have been considered along with the dynamics of the generators and exciters. Trajectory sensitivity with respect to fault clearing time has been used to assess transient stability margin of power systems. At first, a controller has been designed for effective use of TCSC under various fault conditions. TS has been used for finding suitable values of the controller parameters. The effects of placement of TCSC controllers at various locations of a power system on the transient stability are studied. A comparison of the effects of TCSC controller with those of fixed capacitors is also carried out. The TCSC is represented by a fundamental frequency lumped reactance model that varies with the change in the firing angle. The system under consideration is the three-machine, nine bus WSCC system. System loads are taken as constant impedance.

2. Modeling of the TCSC and the power system

2.1. Modeling of TCSC

The TCSC model is given in following Figure. The overall reactance XC of the TCSC is given in terms of the firing angle

$XC = \beta 1\ (XFC + \beta 2) - \beta 4 \beta 5 - XFC$ (1)

Where

$\beta 1 = \frac{2(\pi - \alpha) + \sin 2(\pi - \alpha)}{\pi}$, $\beta 2 = \frac{XFC\,XP}{XFC - XP}$,

$\beta 4 = \beta 3 \tan[\beta 3 (\pi - \alpha)] - \tan(\pi - \alpha)$,

$\beta 5 = 4\beta_2^{\,2} \cos^2(\pi - \alpha)/\pi XP$

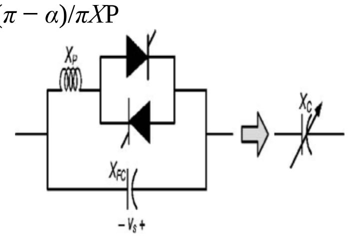

Fig. 1. TCSC circuit and its equivalent.

Let us denote the fundamental frequency capacitance of the TCSC, which is equal to $1/(\omega s XC)$, as Ctcsc. It is to be noted that in this work the TCSC is operated only in the capacitive mode. The capacitive reactance XFC of the TCSC is chosen as half of the reactance of the line in which the TCSC is placed and the TCR reactance XP is chosen to be 1/3 of XFC.

2.2 Modeling of system:

2.2.1 Representation of Generator

The synchronous machine is represented by a voltage source, in back of a transient reactance, that is constant in magnitude but changes in angular position. This representation neglects the effect of saliency and assumes constant flux linkages and a small change in speed. If the machine rotor speed is assumed constant at synchronous speed, a normal and accepted assumption for stability studies, then M is constant. If the rotational power losses of the machine due to such effects as wind age and friction are ignored, then the accelerating power equals the difference between the mechanical power and the electrical power [6]. The classical model can be described by the following set of differential and algebraic equations:

Differential:

$$\frac{d\delta}{dt} = \omega - 2\pi f$$

$$\frac{d^2\delta}{dt^2} = \frac{d\omega}{dt} = \frac{\pi f}{H}(P_m - P_e)$$

Algebraic:

$$E' = E_t + r_a I_t + j x_d' I_t$$

Where E'=voltage back of transient reactance

$E_{t=}$machine terminal voltage

I_t=machine terminal current

r_a=armature resistance

x_d' =Transient reactance

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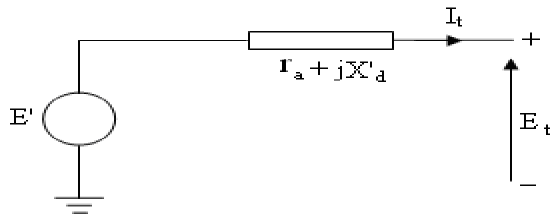

Fig.2. Generator Classical model

2.2.2 Representation of Loads

Power system loads, other than motors represented by equivalent circuits, can be treated in several ways during the transient period. The commonly used representations are either static impedance or admittance to ground, constant real and reactive power, or a combination of these representations. The parameters associated with static impedance and constant current representations are obtained from the scheduled busloads and the bus voltages calculated from a load flow solution for the power system prior to a disturbance [5]. The initial value of the current for a constant current representation is obtained from

$$I_{po} = \frac{P_{lp} - jQ_{lp}}{E_p^*}$$

The static admittance Y_{po} used to represent the load at bus P, can be obtained from

$$Y_{po} = \frac{I_{po}}{E_p}$$

Where E_p is the calculated bus voltage, P_{lp} and Q_{lp} are the scheduled busloads. Diagonal elements of Admittance matrix (Y – Bus) corresponding to the load bus are modified using the Y_{po}.

3. Transient stability analysis of Multi machine system:

The following steps easily follow for determining multimachine stability.

1. From the prefault load flow data determine E'k voltage behind transient reactance for all generators. This establishes generator emf magnitudes $|E_k|$ which remains constant during the study and initial rotor angle $\delta_k° = \angle E_k$. Also record prime mover inputs to generators, $P_{mk}=P°_{gk.}$
2. Augment the load flow network by the generator transient reactances. Shift network buses behind the transient reactances.
3. Find Ybus for various network conditions –during fault, post fault (faulted line cleared), after line reclosure.
4. For faulted mode, find generator outputs from power angle equations and solve swing equations step by step (point by point method) or any integration algorithms such as modified Euler's method, R.K fourth order method etc.
5. Keep repeating the above step for post fault mode and after line reclosure mode.
6. Examine δ (t) plots for all the generators and establish the answer to the stability question.

3.2.1 Classical stability study of a nine-bus system

The classical model of a synchronous machine may be used to study the stability of a power system for a period of time during which the system dynamic response is dependent largely on the stored kinetic energy in the rotating masses. For many power systems this time is on the order of one second or less. The classical model is the simplest model used in studies of power system dynamics and requires a minimum amount of data; hence, such studies can be conducted in a relatively short time and at minimum cost. Furthermore, these studies can provide useful information. For example, they may be used as preliminary studies to identify problem areas that require further study with more detailed modeling. Thus a large number of cases for which the system exhibits a definitely stable dynamic response to the disturbances under study are eliminated from further consideration.

A classical study will be presented here on a small nine-bus power system that has three generators and three loads. A one-line impedance diagram for the system is given in appendix.

3.2.2 Network Reduction Technique: (Algorithm)

Data preparation In the performance of a transient stability study, the following data are needed;

1).A load-flow study of the pretransient network to determine the mechanical power P_m of the generators and to calculate the values of $E_i \angle \delta_{i0}$ for all generators. The equivalent impedances of the loads are obtained from the load bus data.

2). System data follows:

(a) The inertia constant H and direct axis transient reactance X_d'for all generators.

(b) Transmission network impedances for the initial network conditions and the subsequent switching such as fault clearing and breaker reclosings.

3). The type and location of disturbance, time of switching and the maximum time for which a solution is to be considered.

Preliminary calculations

To prepare the system data for stability study, the following preliminary calculations are made:

1) All system data are converted to a common base; a system base of 100MVA is frequently used.

2) The loads are converted to equivalent impedances or admittances. The needed data for this step are obtained from the load flow study. Thus if a certain load bus has a voltage V_L, power P_L, reactive power Q_L, and current I_L flowing into a load admittance $Y_L=G_L+j\,B_L$, then

$$P_L+j\,Q_L=V_L\,I_L^* = V_L\,\{VL^*(G_L-jB_L)\} =V_L^2(G_L-j\,B_L)$$

The equivalent shunt admittance at that bus is given by

$$Y_L=P_L / V_L^2 - j\,(Q_L / V_L^2)$$

3) The internal voltages of the generators $E_i \angle \delta_{i0}$ are calculated from the load flow data. These internal angles may be computed from the pretransient terminal voltages $V\angle\alpha$ as

follows. Let the terminal voltage be used temporarily as a reference. If we define $I=I_1+j\ I_2$, then from the relation $P+j\ Q = VI^*$ we have $I_1+j\ I_2 = (P - j\ Q)/V$, But since $E\llcorner\delta' = V+jx_d'I$,

We compute $E\llcorner\delta' = (V + QX_d'/V) + j\,(PX_d'/V)$

The initial generator angle δ_0 is then obtained by adding the pretransient voltage angle α to δ', or $\delta_0 = \delta' + \alpha$

4) The Y matrix for each network condition is calculated. The following steps are usually needed:

a. The equivalent load impedances (or admittances) are connected between the load buses and the reference node; additional nodes are provided for the internal generator voltages (nodes 1,2,………, n) and the appropriate values of X_d' are connected between these nodes and the generator terminal nodes. Also, simulation of the fault impedance is added as required, and the admittance matrix is determined for each switching condition.

b. All impedance elements are converted to admittances.

c. Elements of the Y matrix are identified as follows: Y_{ii} is the sum of all the admittances connected to node I, and Y_{ij} is the negative of the admittance between node j and I.

5) Finally, we eliminate all the nodes except for the internal generator nodes and obtain the Y matrix for the reduced network. The reduction can be achieved by matrix operation if we recall that all the nodes have zero injection currents except for the internal generator nodes. This property is used to obtain the network reduction as shown below.

Let $I=YV$

Where $I = \begin{bmatrix} I_n \\ 0 \end{bmatrix}$

Now the matrices Y and V are partitioned accordingly to we get

$$\begin{bmatrix} I_n \\ 0 \end{bmatrix} = \begin{bmatrix} Y_{nn} & Y_{nr} \\ Y_{rn} & Y_{rr} \end{bmatrix} \begin{bmatrix} V_n \\ V_r \end{bmatrix}$$

Where the subscript n is used to denote generator nodes and the subscript r is used for the remaining nodes. Thus for the network in appendix figure. V_n has the dimension (n*1) and Vr, has the dimension (r*1)

Expanding the above matrix form we get

$$I_n=Y_{nn}V_n+Y_{nr}V_r \qquad 0=Y_{rn}V_n+Y_{rr}V_r$$

From which we eliminate V, to find

$$I_n= (Y_{nn}-Y_{nr}Y_{rr}^{-1}Y_{rn})V_n$$

The matrix $(Y_{nn}-Y_{nr}Y_{rr}^{-1}Y_{rn})$ is the desired reduced matrix Y. It has the dimensions (n*n) where n is the number of generators.

The network reduction illustrated by above equations is a convenient analytical technique that can be used only when the loads are treated as constant impedances. If the loads are not considered to be constant impedances, the identify of the load buses must be retained. Network reduction can be applied only to those nodes that have zero injection current.

3.2.3 Shortcomings of the Classical Model

System stability depends on the characteristics of all the components of the power system. This includes the response characteristics of the control equipment on the turbo generators, on the dynamic characteristics of the loads, on the supplementary control equipment installed, and on the type and settings of protective equipment used.

The machine dynamic response to any impact in the system is oscillatory. In the past the sizes of the power systems involved were such that the period of these oscillations was not much greater than one second. Furthermore, the equipment used for excitation controls was relatively slow and simple. Thus the classical model was adequate.

Today large system interconnections with the greater system inertias and relatively weaker ties result in longer periods of oscillations during transients. Generator control systems, particularly modern excitation systems, are extremely fast. It is therefore questionable whether the effect of the control equipment can be neglected during these longer periods. Indeed there have been recorded transients caused by large impacts, resulting in loss of synchronism after the system machines had undergone several oscillations. Another aspect is the dynamic instability problem, where growing oscillations have occurred on tie lines connecting different power pools or systems. As this situation has developed, it has also become increasingly important to ensure the security of the bulk power supply. This has made many engineers realize it is time to reexamine the assumptions made in stability studies.

3.2.4 Assumptions made in the classical model:

1).Transient stability is decided in the first swing. A large system having many machines will have numerous natural frequencies of oscillations. The capacities of most of the tie lines are comparatively small, with the result that some of these frequencies are quiet low (frequencies of periods in the order of 5-6 seconds are not uncommon). It is quite possible that the worst swing may occur at an instant in time when the peaks of some of these nodes coincide. It is therefore necessary in many cases to study the transient for a period longer than one second.

2).Constant generator main field-winding flux linkage. This assumption is suspect on two counts, the longer period that must now be considered and the speed of many modern voltage regulators. The longer period, which may be comparable to the field-winding time constant, means that the change in the main field winding flux may be appreciable and should be accounted for so that a correct representation of the system voltage is realized. Furthermore, the voltage regulator response could have a significant effect on the field winding flux. We conclude from this discussion that the constant voltage behind transient reactance could be very inaccurate.

3).Neglecting the damping powers. A large system will have relatively weak ties. In the spring-mass analogy used above, this is a rather poorly damped system. It is important to account for the various components of the system damping to obtain a correct model that will accurately predict its dynamic performance, especially in loss of generation studies.

4).Constant mechanical power. If periods on the order of a few seconds or greater are of interest, it is unrealistic to assume that the mechanical power will not change.

5).Representing loads by constant passive impedance. Consider a bus having a voltage V to which a load P_L+j Q_L is connected. Let the load be represented by the static admittances $G_L=P_L/V_L^2$ and $B_L=Q_L/V_L^2$.

During a transient the voltage magnitude V and the frequency will change. In this model, the change in voltage is reflected in the power and reactive power of the load, while the change in the bus frequency is not reflected at all in the load power. In other words, this model assumes $P_L \alpha\ V^2$, $Q_L\ \alpha\ V^2$, and that both are frequency independent. This assumption is often on the pessimistic side. (There are situations, however, where this assumption can lead to optimistic results. This discussion is intended to illustrate the errors implied.) To illustrate this, let us assume that the transient has been initiated by a fault in the transmission network. Initially, a fault causes a reduction of the output power of most of the synchronous generators. Some excess generation results, causing the machines to accelerate, and the area frequency tend to increase. At the same time, a transmission network fault usually causes a reduction of the bus voltages near the fault location. In the passive impedance model the load power decreases considerably (since $P_L \alpha\ V^2$), and the increase in frequency does not cause an increase in load power. In real systems the decrease in power is not likely to be proportional to V^2 but rather less than this. An increase in system frequency will result in an increase in the load power. Thus the model used gives a load power lower than expected during the fault and higher than normal after fault removal.From the foregoing discussion we conclude that the classical model is inadequate fro system representation beyond the first swing. Since the first swing is largely an inertial response to a given accelerating torque, the classical model does provide useful information as to system response during this brief period.

4. Application of trajectory sensitivity analysis in transient stability margin assessment

4.1 Computation of Trajectory Sensitivity

Multi machine power system is represented by a set of differential equations

$$\dot{x} = f(t, x, \lambda), \qquad x(t_0) = x_0 \tag{3.1}$$

Where x is a state vector and λ is a vector of system parameters. The sensitivities of state trajectories with respect to system parameters can be found by perturbing λ from its nominal value λ_0 .The equations of trajectory sensitivity can be found as

$$\dot{x}_\lambda = \left[\frac{\partial f}{\partial x}\right]x_\lambda + \left[\frac{\partial f}{\partial \lambda}\right], \qquad x_\lambda(t_o) = 0 \tag{3.2}$$

Where $x_\lambda = \partial x / \partial \lambda$. Solution of (3.1) and (3.2) gives the state trajectory and trajectory sensitivity, respectively. However sensitivities can also be found in a simpler way by using numerical method.

4.2 Numerical Evaluation: Alternative to Reduce Computation

To explain this method, let us choose only one parameter, i.e., λ becomes a scalar and the sensitivities with respect to it are studied. Two values of λ are chosen (say λ_1 and λ_2). The corresponding state vectors x1 and x2 respectively are then computed. Now the sensitivity at λ_1 is defined as

$$Sens = \frac{x_2 - x_1}{\lambda_2 - \lambda_1} = \frac{\Delta x}{\Delta \lambda} \tag{3.3}$$

If $\Delta\lambda$ is small, the numerical sensitivity is expected to be very close to the analytically calculated trajectory sensitivity.

In the case of power system, sensitivity of state variables, e.g., the generator rotor angle (δ) and per unit speed deviation ($\Delta\omega_r$) can be computed as in (3.3) with respect to some parameter λ . Now one of the generators, say the jth one, is taken as the reference. Then, the relative rotor angle of the i^{th} machine (i.e. the excursion of δ_{ij} with respect to the rotor angle of reference machine) is given by $\delta_{ij} = \delta_i - \delta_j$. The sensitivity of δ_{ij} with respect to λ is computed as

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$$\frac{\partial \delta_{ij}}{\partial \lambda} = \frac{\partial \delta_i}{\partial \lambda} - \frac{\partial \delta_j}{\partial \lambda} \quad (3.4)$$

The sensitivity of relative rotor angle is considered here instead of the sensitivity of δ of an individual machine because the relative rotor angle is the relevant factor when angular stability is concerned.

4.3 Quantification of TS and Its Implication

Trajectory sensitivities ($\partial\delta_{ij} / \partial\lambda$ and $\partial\Delta\omega_{ri} / \partial\lambda$) give us information about the effect of change of parameter on individual state variables and hence on the generators (to which the particular state variable correspond) of the system. However to know the overall system condition, we need to sum up all these information . The norm of the sensitivities of δ_{ij} and $\Delta\omega_{ri}$ are calculated for this . The sensitivity norm for an *m* machine system is given as

$$S_N = \sqrt{\sum_{i=1}^{m} \left[\left(\frac{\partial \delta_{ij}}{\partial \lambda} \right)^2 + \left(\frac{\partial \Delta\omega_{ri}}{\partial \lambda} \right)^2 \right]} \quad (3.5)$$

A new tem η (ETA) is introduced. η is defined as the inverse of the maximum of S_N , i.e ., $\eta = 1/\max(S_N)$. As the system moves towards instability, the oscillation in TS will be more resulting in larger values of SN. This will result in the smaller values of η. ideally η should be zero at the point of instability. Therefore the value of η gives us an indication of distance from instability. In this paper η is used for assessing the relative stability conditions of the system with different values of fault clearing time, system load and firing angle of TCSC.

Consider a fault in one of the lines of the system. The post-fault conditions are studied by continuously increasing the fault clearing time (tcl). The system states will oscillate more and take longer time to settle as tcl is increased. The sensitivities of the state variables will also exhibit large oscillations for increasing tcl. These oscillations will become unbounded as tcl exceeds the critical clearing time. Thus large peaks in trajectory sensitivity (TS) clearly indicate the proximity of the parameter to the critical value beyond which the system becomes unstable.

1. **The control scheme:**

In the next step, a controller is employed along with the TCSC. The block diagram of the control scheme used is shown in Fig. below.

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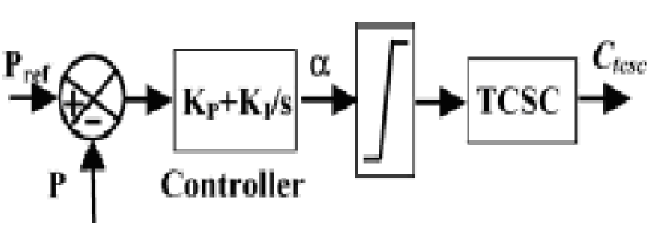


The active power flow (*P*) through the line containing TCSC is taken as the control variable. It is compared with the reference value of active power flow (*P*ref) and the error is fed to a PI controller. The output of the PI is the firing angle of the TCSC, *α*. This *α* is passed through a limiter to keep it within the capacitive operation zone of the TCSC (between 145◦ and 180◦). The output of the limiter is supplied to the firing circuit of TCSC. The capacitance value of the TCSC (*C*tcsc) is computed as described in Modeling Section. This capacitance is then included in the line dynamics. This scheme is sufficient if the fault is only of self-clearing type, because there is no change in system configuration and hence the steady state power flow should remain the same before and after the fault. But when isolating the faulty line clears the fault, the system configuration changes resulting in a change of the steady state power flow through the lines. Therefore, a corresponding change in *P*ref is needed.

The effect of the TCSC on the transient stability of the system depends largely on the proper functioning of the controller. Therefore, choice of suitable values of controller constants *K*P and *K*I is very important.

TCSC causes improvement of system stability condition the most when it is placed in line 6–9 or line 5–7. So, henceforth we shall study the effect of TCSC (along with controller) in these two locations.

Another issue of interest is the comparison between the effects of TCSC-controller and the TCSC used in open loop, i.e., without a controller. In open loop, the TCSC acts as a fixed capacitor throughout the period of disturbance. Let us term this as the fixed capacitor mode of operation. The effects of this fixed capacitor and the effects of a TCSC-controller combination (with suitably chosen controller constants) on the transient stability condition are investigated and compared here.

Therefore, it can be concluded that the improvement in the transient stability condition of the system is much more with the TCSC-controller combination. These results highlight the effectiveness of the application of a TCSC along with a controller in improving the transient stability of a power system.

5.1. Fuzzy Controller Model

Fuzzy modeling is the method of describing the characteristics of a system using fuzzy inference rules. The method has a distinguishing feature in that it can express linguistically complex non-linear system. It is however, very hand to identify the rules and tune the membership functions of the reasoning. Fuzzy Controllers are normally built with fuzzy rules. These fuzzy rules are obtained either from domain experts or by observing the people who are currently doing the control. The membership functions for the fuzzy sets will be derive from the information available from the domain experts and/or observed control actions. The building of such rules and membership functions require tuning. That is, performance of the controller must be measured and the membership functions and rules adjusted based upon the performance. This process will be time consuming.

The basic configuration of Fuzzy logic control based as shown in Fig. 3.1 consists of four main parts i.e. (i) Fuzzification, (ii) knowledge base, (iii) Inference Engine and (iv) Defuzzification.

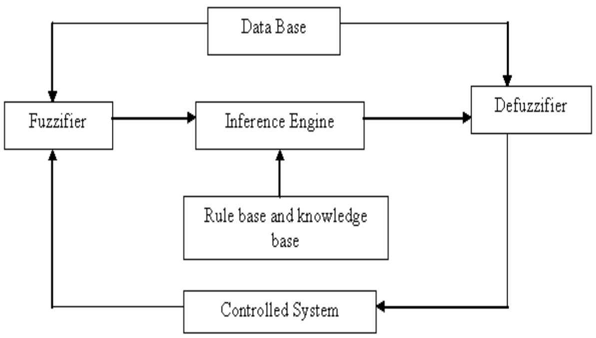


Fig.3. Structure of Fuzzy Logic controller

Fuzzy inputs:

Input 1 : ERR(t)=(Pref(i)-Pflow(i))

Inpur 2 : CHERR(t)=ERR(t)-ERR(t-dt)

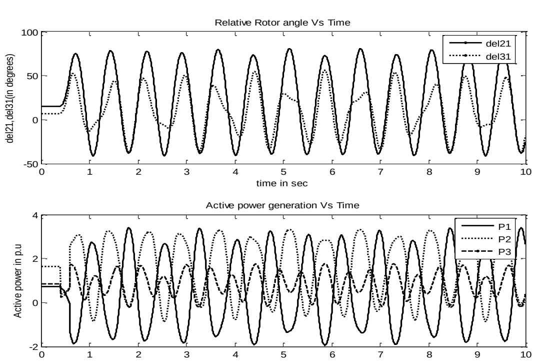
Fuzzy outputs:

Output: Xtcsc(t) (compensation to be provided 30-70%)

Rule base for fuzzy controller

ERR \ CHERR	NB	NM	NS	ZE	PS	PM	PB
NB	PM	PS	NB	NM	NS	ZE	PM
NM	PS	NM	NM	NB	ZE	ZE	PS
NS	PM	NS	NS	ZE	NM	PS	NS
ZE	PB	ZE	ZE	ZE	NM	PS	NM
PS	ZE	ZE	PM	NS	NS	PM	NS
PM	ZE	PM	PM	PS	PB	PM	NS
PB	PM	PS	PM	PS	PM	PB	NS

6. RESULTS

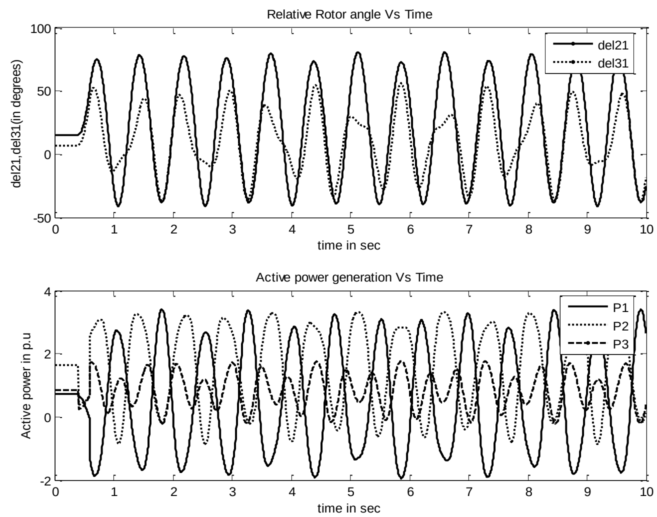


Static transient stability results for WSCC 9 bus system:
Case (1) No Damping in the system (Self clearing type), Fault at Bus 5

Here Fault is at Bus 5 and Fault is self cleared and fault clearance time is 0.2 sec and here no damping in the system, such that oscillations continues.

Case (2) With Damping in the system (Self Clearing type) Fault at Bus 5

By observing the above two cases, we can say that by providing damping to the system the oscillations will die out

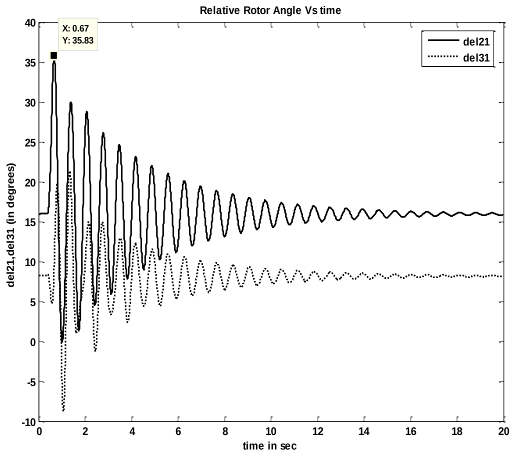


and they will settle to a final steady state value with in a very short time duration.

Normalized (ETA) values of a Nine Bus System for different fault locations

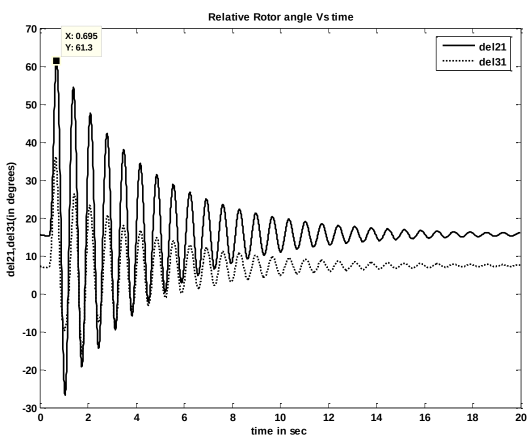
Faulted bus no, base Eta	Tcsc placed in line					
	4-5	4-6	5-7	6-9	7-8	8-9
5, 0.10801	.86288	1.0138	1.0137	**1.0924**	.99898	1.0045
6, 0.11304	.99650	.86633	**1.08011**	.85105	1.012057	1.001114
8, 0.09162	1.1022	1.10290	**1.15568**	1.15323	.87650	.91739

With Compensation Fault is at Bus 5



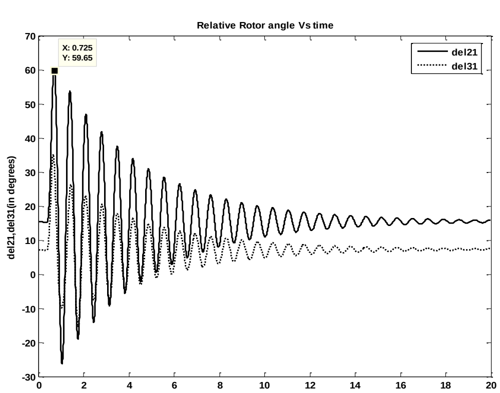
a) fault is of self clearing type and it is at bus 5 and fault cleared time is 0.2sec and with *fixed compensation* 50.% compensation and peak value of first swing is 61.3**.**

b) Fault is of self clearing type and it is at bus 5 and fault cleared time is 0.2sec *With PI Controller* (initial compensation 50% with KP=0.5 and Ki = 6.5) and the first swing is 59.65



c) With *Fuzzy Controller*, the System, with fault clearing time 0.2sec the first swing is 36.88 deg..

C



By comparing the above results we can conclude that, with TCSC Controller incorporated in the line 6-9 for a fault at bus 5. This shows the improvement of Transient Stability with FUZZY controller over PI Controller and there is a significant improvement in the Transient Stability with variable series Compensation.

7. CONCLUSION

Transient stability is the ability of the power system to maintain synchronism after subjected to severe disturbance. The synchronism is assessed with relative rotor angle violations among the different machines. Accurate analysis of the transient stability requires the detailed modeling of generating units and other equipment. At present, the most practical available method of transient stability analysis is time-domain simulation in which the nonlinear differential equations are solved by R.K. fourth order method or network reduction techniques.

In the present work, the transient stability assessment of WSCC-9 bus system is carried out for three phase fault of self clearing type at different fault locations. When effect of damping of the system is incorporated the analysis shows better results.

Further, a TCSC controller has been modeled and implemented on the WSCC-9 bus system at the optimal location. The effective location of TCSC for different faults locations is obtained by performing trajectory sensitivity analysis with respect to clearing time. The case studies depicts the optimal location of fixed compensation in the WSCC- 9 bus system as line 5-7, based on the stability index(ETA).

In the steady state, FACTS controllers like TCSC help in controlling the power flow through a line. Since power systems are non-linear, conventional controllers PI cannot perform well in maintaining power system stability. When firing angle of TCSC is controlled using conventional PI controller reduction in first swing peak value is observed when compared to fixed compensation.

Further, a fuzzy controlled TCSC has been implemented on WSCC-9 bus system to improve stability of system. The fuzzy controlled TCSC is observed to perform better compared to conventional PI controller

APPENDIX

Test system: *WSCC 9-bus system (Western System Coordinating Council), Anderson Text)*

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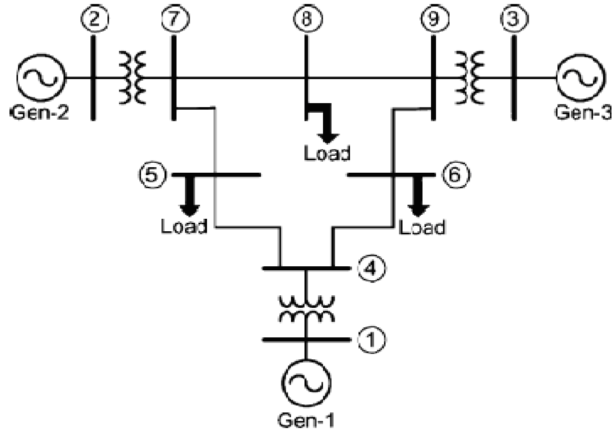

(i) **Generators data**

Generator	X_d'	H
1	0.0608	23.64
2	0.1198	6.4
3	0.1813	3.01

(ii) **Transformers data**

Transformer	X
1	0.0576
2	0.0625
3	0.0586

(iii)**Transmission network data**

Bus No.		R	X	$y_{pq}/2$
p	Q			
1	4	0.0	0.0576	0.0
2	7	0.0	0.0625	0.0
3	9	0.0	0.0586	0.0
4	6	0.017	0.092	0.079
5	7	0.032	0.161	0.153
6	9	0.039	0.17	0.179
7	8	0.0085	0.072	0.0745
8	9	0.0119	0.1008	0.1045

(iv) Bus Data

Bus No.	P_{GEN}	P_D	Q_D	V_{sp}
1	0.0	0.0	0.0	1.04
2	1.63	0.0	0.0	1.025
3	0.85	0.0	0.0	1.025
4	0.0	0.0	0.0	--
5	0.0	1.25	0.5	--
6	0.0	0.9	0.3	--
7	0.0	0.0	0.0	--
8	0.0	1.0	0.35	--
9	0.0	0.0	0.0	--

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