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Transient Stability Enhancement 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. 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 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.

1. Introduction

Power system stability has been recognized as an important problem for secure system operation since the 1920s. Many major blackouts caused by power system instability have illustrated the importance of this phenomenon. As power systems have evolved through continuing growth in interconnections, use of new technologies and controls, and the increased operation in highly stressed conditions, different forms of system instability have emerged. For example, voltage stability, frequency stability and inter area oscillations have become greater concerns than in the past. This has created a need to review the definition and classification of power system stability. A clear understanding of different types of instability and how they are interrelated is essential for the satisfactory design and operation of power systems. Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact [2]. The power system is a highly nonlinear system that operates in a constantly changing environment; loads, generator outputs and key operating parameters change continually. When subjected to a disturbance, the stability of the system depends on the initial operating condition as well as the nature of the disturbance. Stability of an electric power system is thus a property of the system motion around an equilibrium set, i.e., the initial operating condition. In an equilibrium set, the various opposing forces that exist in the system are equal instantaneously or over a cycle.

Power systems are subjected to a wide range of disturbances, small and large. Small disturbances in the form of load changes occur continually; the system must be able to adjust to the changing conditions and operate satisfactorily. It must also be able to survive numerous disturbances of a severe nature, such as a short circuit on a transmission line or loss of a large generator. A large disturbance may lead to structural changes due to the isolation of the faulted elements. At an equilibrium set, a power system may be stable for a given (large) physical disturbance, and unstable for

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another. It is impractical and uneconomical to design power systems to be stable for every possible disturbance [2]. The design contingencies are selected on the basis that they have a reasonably high probability of occurrence. Hence, large-disturbance stability always refers to a specified disturbance scenario. The response of the power system to a disturbance may involve much of the equipment. For instance, a fault on a critical element followed by its isolation by protective relays will cause variations in power flows, network bus voltages, and machine rotor speeds; the voltage variations will actuate both generator and transmission network voltage regulators; the generator speed variations will actuate prime mover governors; and the voltage and frequency variations will affect the system loads to varying degrees depending on their individual characteristics. Further, devices used to protect individual equipment may respond to variations in system variables and cause tripping of the equipment, thereby weakening the system and possibly leading to system instability. If following a disturbance the power system is stable, it will reach a new equilibrium state with the system integrity preserved i.e., with practically all generators and loads connected through a single contiguous transmission system. Some generators and loads may be disconnected by the isolation of faulted elements or intentional tripping to preserve the continuity of operation of bulk of the system. Interconnected systems, for certain severe disturbances, may also be intentionally split into two or more "islands" to preserve as much of the generation and load as possible. The actions of automatic controls and possibly human operators will eventually restore the system to normal state. On the other hand, if the system is unstable, it will result in a run-away or run-down situation; for example, a progressive increase in angular separation of generator rotors, or a progressive decrease in bus voltages. An unstable system condition could lead to cascading outages and a shutdown of a major portion of the power system.

Power systems are continually experiencing fluctuations of small magnitudes. However, for assessing stability when subjected to a specified disturbance, it is usually valid to assume that the system is initially in a true steady-state operating condition.

2. System Configuration with TCSC

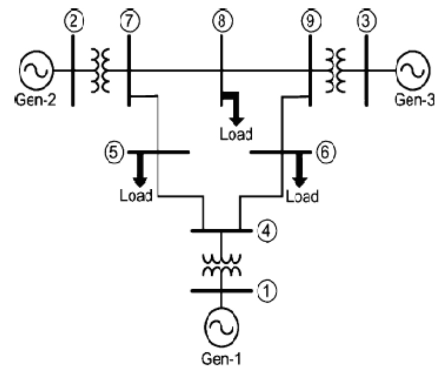


Fig.1. Test system: WSCC 9-bus system (Western System Coordinating Council)

Fig.1. shows a test system of WSCC 9-bus system with TCSC controller to performing transient stability improvement. It consists of the series compensating capacitor shunted by a Thyristor-Controlled Reactor. In a practical TCSC implementation, several such basic compensators may be connected in series to obtain the desired voltage rating and operating characteristics.

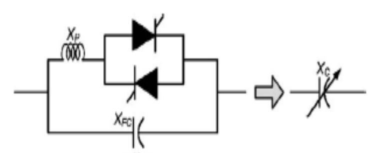


Fig.2. Equivalent circuit of TCSC

The TCSC model is given in Fig.2. The overall reactance X_C of the TCSC is given in terms of the firing angle α as

$$X_C = \beta_1(X_{FC} + \beta_2) - \beta_4\beta_5 - X_{FC}$$

where

$$\beta_1 = \frac{2(\pi - \alpha) + \sin 2(\pi - \alpha)}{\pi}, \quad \beta_2 = \frac{X_{FC}X_P}{X_{FC} - X_P},$$

$$\beta_3 = \sqrt{\frac{X_{FC}}{X_P}}, \quad \beta_4 = \beta_3 \tan[\beta_3(\pi - \alpha)] - \tan(\pi - \alpha),$$

$$\beta_5 = \frac{4\beta_2^2 \cos^2(\pi - \alpha)}{\pi X_P}$$

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 paper 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.

A three-phase fault is simulated in one of the lines of the nine-bus system. The simulation is done in three steps. To start with, the pre-fault system is run for a small time. Then, a symmetrical fault is applied at one end of a line. Simulation of the faulted condition continues till the fault is cleared after a time *t*cl. Then, the post-fault system is simulated for a longer time (say 5 s) to observe the nature of the transients. The fault may be of self-clearing type (i.e. isolation of line is not required for fault clearance) or may be cleared by isolating the faulted line.

3. Trajectory Sensitivity Analysis

3.1 Computation of Trajectory Sensitivity

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

$$\dot{x} = f(t, x, \lambda), \qquad x(t_0) = x_0 \tag{1}$$

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,

$$\dot{x}_\lambda = \left[\frac{\partial f}{\partial x}\right] x_\lambda + \left[\frac{\partial f}{\partial \lambda}\right], \qquad x_\lambda(t_o) = 0 \tag{2}$$

Where $x_\lambda = \partial x / \partial \lambda$. Solution of (1) and (2) gives the state trajectory and trajectory sensitivity, respectively. However sensitivities can also be found in a simpler way by using numerical method.

3.2 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

$$Sens = \frac{x_2 - x_1}{\lambda_2 - \lambda_1} = \frac{\Delta x}{\Delta \lambda} \tag{3}$$

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 ith 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

$$\frac{\partial \delta_{ij}}{\partial \lambda} = \frac{\partial \delta_i}{\partial \lambda} - \frac{\partial \delta_j}{\partial \lambda} \tag{4}$$

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.

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

4. 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.

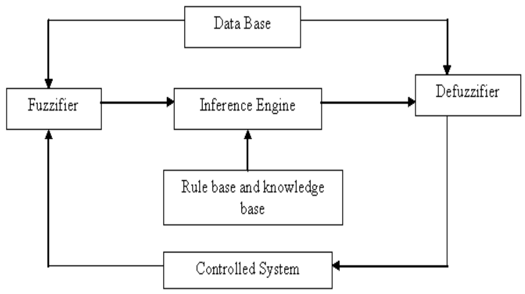


Fig.2. Structure of Fuzzy Logic controller

The basic configuration of Fuzzy logic control based as shown in Fig.2. consists of four main parts i.e. (i) Fuzzification, (ii) Knowledge base, (iii) Inference Engine and (iv) Defuzzification.

5. Fuzzy 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

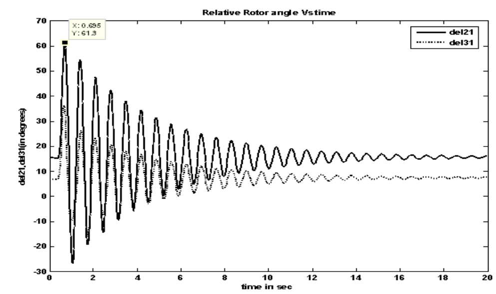
CHERR

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

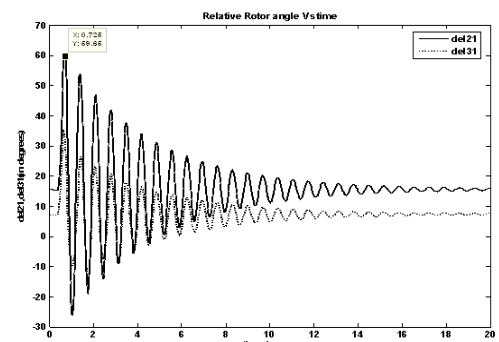
6. Results and Discussion

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.

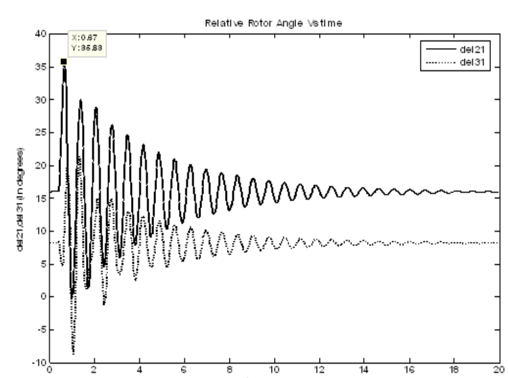
Case (1) Fault is at Bus 5



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

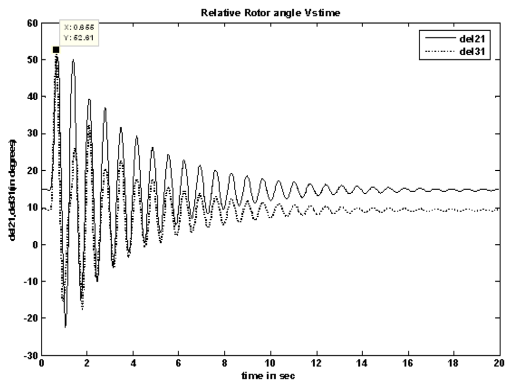


b) Fault is of self clearing type and it is at bus 5 and fault cleared time is 0.2sec With PI Controller (initial compensation 50% with (K_P=0.5 and K_i = 6.5) and the first swing is 59.65.

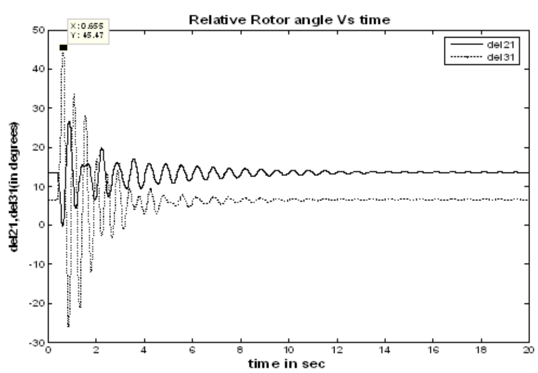


c) With **Fuzzy** Controller, the System, with fault clearing time 0.2sec the first swing is 36.88 deg.

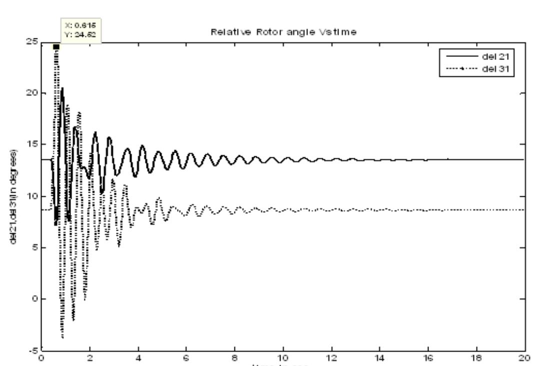
Case (1I) Fault is at Bus 6



a) fault is of self clearing type and it is at bus 6 and fault cleared time is 0.2sec and with fixed compensation 50% compensation and peak value of first swing is 52.61

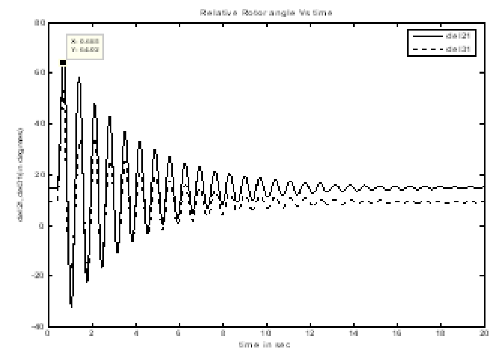


b) Fault is of self clearing type and it is at bus 6 and tcl= 0.2sec with PI Controller (initial compensation 50% with KP=0.5 and Ki = 6.5) and the first swing 45.47.

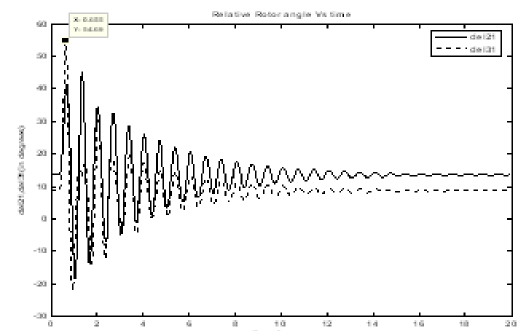


c) With Fuzzy Controller, the System, with fault clearing time 0.2sec the first swing is 24.52 deg.

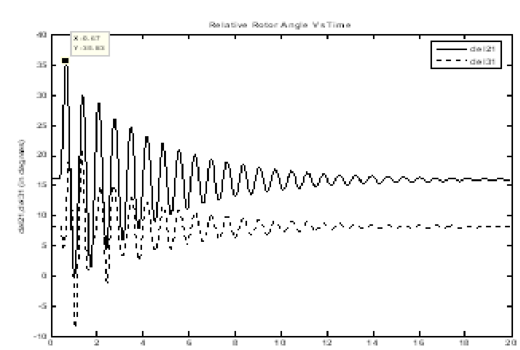
Case (II1) Fault is at Bus 8



a)Here fault is of self clearing type and it is at bus 8 and fault cleared time is 0.2sec and with fixed compensation 50% compensation and peak value of first swing is 64.02



b) Fault is of self clearing type and it is at bus 8 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 54.69



c) With Fuzzy Controller, the System, with fault clearing time 0.2sec the first swing is 35.83 deg

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 modelling 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 modelled 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 can not 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.

8. Reference

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