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Comparitive study of controllers performance in TCSC for transient stability improvement using multi-machine power system

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***Abstract*—Stability is a fundamental concept which is responsible for the stable operation of power system. 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. To improve transient stability there exists some general methods like fast acting exciters, circuit breakers and reduction in system transfer reactance. But the recent trend is to employ FACTS devices for effective utilization of existing transmission resources. The experiments conducted in this paper are by using WSCC 9 Bus System. Fixed Compensation is adopted on Various Lines and Optimal Location is investigated using trajectory sensitivity analysis for better results. There exist of many controllers such as P, PI, PID and fuzzy logic to control firing angle of TCSC and improve Transient stability margin. In this work, we summarized the state of the art and made comparative study among above said controllers. A fuzzy controlled TCSC device proved to perform better than the conventional controllers.**

Keywords- TCSC; Trajectory sensitivity analysis; Transient stability margin; fuzzy controller

I. INTRODUCTION

In recent years, the transmission of the power becomes critical by the invention of electronics loads such as circuit breakers, industrial loads. There by the nominal condition of the system changes invariably like the faults in the bus system. In order to minimize the faults and able to maintain the system in stability limits we apply the inventory methods. In past, the methods by the use of high speed excitation systems, reduction in system transfer reactance, use of high speed re-closing breakers and Increase of system voltages, use of AVR leads to increase in line power losses. The modern trend in this era is by employing the FACTS devices for effective utilization of existing resources.

In this paper, we present the criteria of FACTS technology, through the series compensators by the TCSC device to achieve the transient stability of fault occurring conditions. For approaching the fault analysis, stability criteria of the system is calculated by several controllers to controlling the TCSC [4].

Controller is a technique to command the firing angle of the Thyristor Controlled Series Capacitor (TCSC) to maintain the terminal voltage of the device at faulty conditions. Thus the Controllers technique plays a vital role in the FACTS device. Several controllers like P, PI, fuzzy controllers are exists in the literature. The present work deals with a comparative study on the performance of above said controllers with Multi Machine Nine Bus System as case. Objectives of this paper are summarized below

- To improve the power flow in the line with compensation
- To improve the transient stability of a multi machine power system with Facts devices (TCSC) using fuzzy controller and study the effect of fuzzy controller
- Finding the optimal location using trajectory sensitivity analysis
- Comparative study among performance of the controllers like P, PI and Fuzzy

The rest of the paper is organized as follows: Information regarding transient stability improvement is explained in Section II. The detailed description of FACTS controllers is described in Section III. Experimental results are summarized in Section IV. Finally conclusion is presented in Section-V.

II. TRANSIENT STABILITY IMPROVEMENT

Power system stability enables the system to remain in a state of operating equilibrium under normal conditions and to regain an acceptable state of equilibrium after being subjected to the disturbance. one of the most important strategies for the improvement of the transient stability of the power system against disturbances is using FACTS devices various linear and non-linear control systems have been suggested for controlling FACTS devices [9].

Factors influencing transient stability:

- How heavily the generator is loaded.
- The generator output during the fault, this depends on the fault location and type.
- The post fault transmission system reactance.
- The generator reactance. a lower reactance increases peak power and reduces initial rotor angle.
- The generator inertia is higher, then slower rate of change in angle. This reduces the kinetic energy gained during fault; i.e., area A1 is reduced.
- The generator internal voltage magnitude (E') depends on the field excitation.
- The infinite bus voltage magnitude E_B.
- Switching time of the firing angle of the Power Electronics devices [5].

A. With out compensation:

As per the without compensation transmit the power 'P_m'. Assume the both uncompensated and series compensated systems are subjected to the same fault of same time period. As prior to the fault both of them transmit power pm at an angle δ1. During the fault is transmitted, the electrical power become zero. While the mechanical input power to the generators remains constant, the sending end generator accelerates to the steady state angle δ_1 to δ_2.When the fault is clear, the accelerating energies represented by area $A_1$is equal to area A_2. After fault clearing power transmitted, the electrical power exceeds the mechanical input power the sending end machine decelarates. Then the angle δ decelarates means negative.

B. With compensation:

Assume the both uncompensated and series compensated systems are subjected to the same fault of same time period. As prior to the fault both of them transmit power pm at an angles δ1and δs1. During the fault is transmitted then the electrical power become zero. While the mechanical input power to the generators remains constant. The sending end generator accelerates to the steady state angle δ1 to δs1. When the fault is clear, the accelerating energies represented by area A1and area As1. After fault clearing transmitted then the electrical power exceeds the mechanical input power the sending end machine decelerates. However the accumulated kinetic energy increases until a balance between the accelerating and decelerating energies, represented by areas A1, As1 and A2, As2 respectively, is reached at the maximum angular swings δ3 and δs3 respectively.

C. TCSC modeling:

Thyristor controlled series compensator (TCSC) device is a series compensator to govern the power flow by compensating the reactance of transmission line. Both capacitive and inductive reactance compensation are possible by proper selection of capacitor and inductor values of the TCSC device which can be realized through reactance equation. A TCSC which consist of a series compensating capacitor(C) shunted by a Thyristor controlled reactor (TCR). TCR is a variable inductive reactor tuned at firing angle α. These can be shown in following equations [10].

$$Xc = \beta_1(Xfc + \beta 2) - \beta_4\ \beta_5 - Xfc \quad (1)$$

Where

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

$$\beta 2 = \frac{(X_{FC} - X_P)}{X_{FC} X_P} \quad (3)$$

$$\beta_3 = \sqrt{\frac{X_{FC}}{X_P}} \quad (4)$$

$$\beta_4 = \beta_3 \tan[\beta_3(\pi - \alpha)] - \tan(\pi - \alpha) \quad (5)$$

$$\beta_5 = \frac{4\beta_2^2 \cos^2(\pi - \alpha)}{\pi X_p} \quad (6)$$

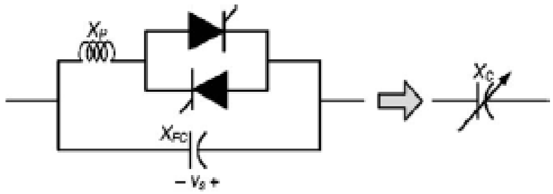

Figure-1: Equivalent circuit of TCSC

The above loop equations are the solved by the runge-kutta method for the dynamic analysis of the modeling of the TCSC. 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 [6].

The block diagram of the control scheme used is shown in figure 2.

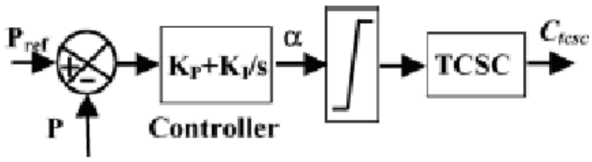

Figure-2: Control scheme of TCSC

The description of the block is below:

- Power is compared to the reference signal and error signal is passing through the controller.
- The controlling signal is increased to the efficient value by integrating the signal.
- The integrated value given as a signal to the TCSC and device controlling is done.
- The output of the TCSC is then compare with reference signal and loop continues.

III. FACTS CONTROLLERS

A transient stability analysis is performed by combining a solution of the algebraic equations describing the network with a numerical solution of the differential equations. The solution of the network equations retains the identity of the system and thereby provides access to system voltages and currents during the transient period.

A. P controller

In general it can be said that P controller cannot stabilize higher order processes. For the 1st order processes, meaning the processes with one energy storage, a large increase in gain can be tolerated. Proportional controller can stabilize only 1st order unstable process. Changing controller gain K can change closed loop dynamics A large controller gain will result in control system with:

a) Smaller steady state error, i.e. better reference following

b) Faster dynamics, i.e. broader signal frequency band of the closed loop system and larger sensitivity with respect to measuring noise.

c) Smaller amplitude and phase margin .When P controller is used; large gain is needed to improve steady state error. Stable systems do not have problems when large gain is used. Such systems are systems with one energy storage (1st order capacitive systems).If constant steady state error can be accepted with such processes, than P controller can be used. Small steady state errors can be accepted: if sensor will give measured value with error or if importance of measured value is not too great anyway [7].

B. PI controller

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller. PI controllers are very often used in industry, especially when speed of the response is not an issue. A control without D mode is used when:
a) Fast response of the system is not required
b) Large disturbances and noise are present during operation of the process
c) There is only one energy storage in process (capacitive or inductive)
d) There are large transport delays in the system

C. Fuzzy controller :

Fuzzy modeling is the method of describing the complex non-linear system. It is however, very characteristics of a system using fuzzy inference rules method has a distinguishing feature in that it can express linguistically hand to identify the rules and tune the membership functions of the reasoning.FuzzyControllers are normally built with fuzzy rules [1]. 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 Figure consists of four main parts [3].
(i) Fuzzification (ii) knowledge base, (iii) Inference Engine and (iv) Defuzzification

(i) Fuzzification: The Fuzzification involves the following functions to measures the value of input variables.
1. Performs a scale mapping that transfers the range of values of input variables into corresponding universe of discourse.
2. Performs the function of fuzzification that converts input data into suitable linguistic variables, which may be viewed as labels of fuzzy sets.

(ii) Knowledge Base (KB): Knowledge it able linguistic variables, which may be viewed as labels of fuzzy sets. The number of linguistic variables specifies the quality of control which can be achieved using the fuzzy controller.
As the number of linguistic variables increases, the computational time and required memory increases. Therefore a compromise between the quality of control and computational time is needed to choose the number is seven. Each linguistic variables NB, NM, NS, ZE, PS, PM, PB.Page base comprises of the definitions of fuzzy MFs for the input and output variables and the necessary control rules, which specify the control action by using linguistic terms. It consists of a database and linguistic control rule base.
1. The database provides necessary definitions, which are used to define linguistic control rules and fuzzy data, manipulation in a FLC.
2. The rule base characterizes the control goals and control policy of the domain experts by means set of linguistic control rules.

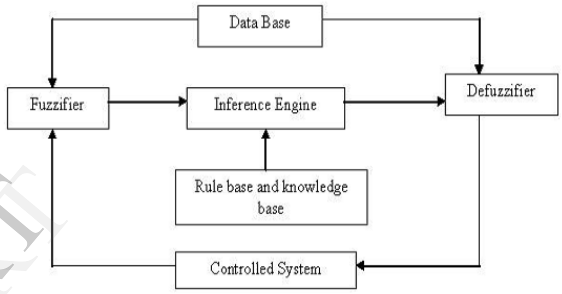

Figure-3: Structure of Fuzzy logic control

(iii) Inference Mechanism: The Decision Making Logic Which plays an essential role and contains a set of fuzzy if-then rules such as If x is A and y is B then z is C Where x, y and z are linguistic variables representing two input variables and one control output: A, B and C are linguistic values. It is kernel of an FLC; it has the capability of simulating human decision making based on fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic.

(iv) Defuzzification

Defuzzification on coverts the linguistic variables to determine numerical values. Centroid method of defuzzification is used in this study. A scale mapping, this converts the range of values of input variables into corresponding universe of discourse. Defuzzification, which yields a non-fuzzy control action from an inferred fuzzy control action.

IV. RESULTS AND DISCUSSIONS

The system studied in this paper is the 3 machine nine-bus system shown in figure-4. 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 [2].

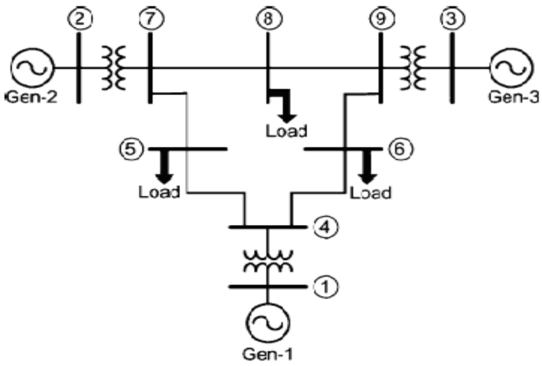

Figure-4: Multi machine nine bus system

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.

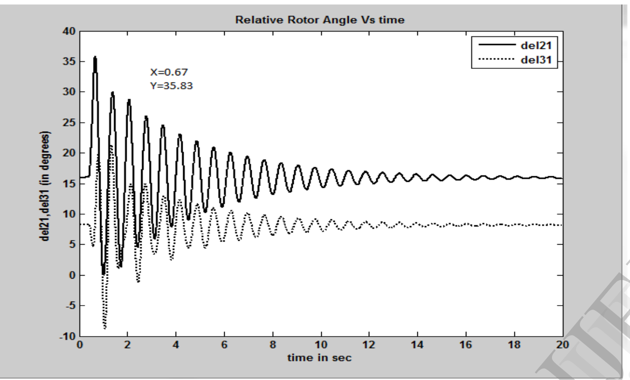

Figure-5: Fuzzy controller in line 6-9, fault at bus 5 tcl 0.2s

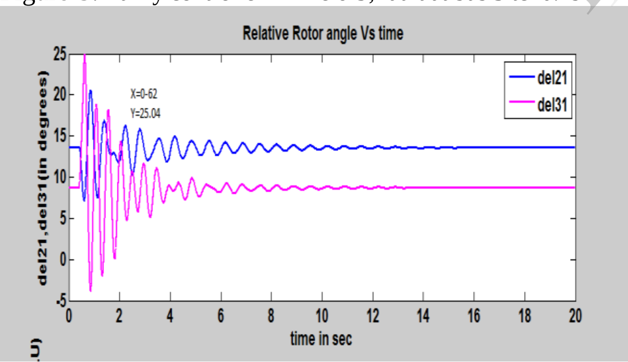

Figure-6: Fuzzy controller in line 5-7, fault at bus 6 tcl 0.2s

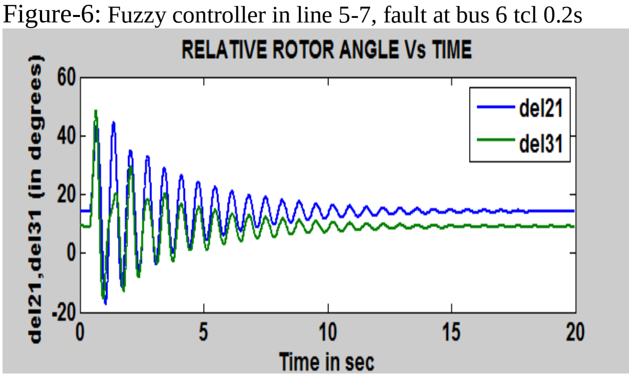

Figure-7: Fuzzy controller in line 5-7, fault at bus 8 tcl 0.2s

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 [8].

Simulation results of the fuzzy, PI,P controllers are shown in table1 and output waveforms with fuzzy controller placed at different buses like 5,6,7 are shown in figures 5,6,7 respectively.

Table-1: Simulation results of Fuzzy, PI and P controllers

	Fuzzy controller		PI controller		P controller	
	X	Y	X	Y	X	Y
Fault at 5th bus	0.67	35.83	0.725	59.65	0.786	61.43
Fault at 6th bus	0.615	24.52	0.655	45.47	0.698	46.68
Fault at 8th bus	0.69	45.32	0.678	61.23	0.796	63.45

V. 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. In the present work, the transient stability assessment of multi machine-9 bus system is carried out for three phase fault of self clearing type at different fault locations by applying the various controllers.. Further, a TCSC controller has been modeled and implemented in the multi machine-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 depict the optimal location of fixed compensation in the MM- 9 bus system as line 5-7, based on the fuzzy logic controllers). 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.. The fuzzy controlled TCSC is observed to perform better compared to conventional P and PI controllers.

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