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Transient Stability Improvement in Three-Machine Power System by Using SSSC with Fuzzy Controller

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Abstract

The proposed paper is a precise and straight forward master framework, i.e., fuzzy system is connected to outline a static synchronous series compensator (SSSC)-based controller for development of transient strength in a three-machine power framework. The fuzzy structures were prepared utilizing the produced database of fuzzy controller for SSSC. The results demonstrate that the proposed fuzzy controller is based with SSSC discovered to be hearty to blame area and change in working conditions. An exhaustive examination with the ordinary lead-lag controller is completed, considering the consequences of past distributions. The SSSC-based fuzzy controller yield gives guaranteeing brings about terms of exactness and calculation time. At last, conclusions are appropriately drawn.

Keywords- multi-machine power system; fuzzy controller; static synchronous series compensator (SSSC); transient stability

1. Introduction:

Arrangement capacitive recompense was acquainted decades back with drop a part of the receptive line impedance and there-by expansion the transmittable force [1]. Late advancement of force hardware presents the utilization of adaptable air conditioning transmission framework (FACTS) controllers in force frameworks [2]. Thusly, inside the FACTS activity, it has been showed that variable arrangement remuneration is profoundly viable in both controlling force stream in the lines and in enhancing dependability [3, 4]. The voltage sourced converter based arrangement compensator, called static synchronous series compensator (SSSC) gives the virtual recompense of transmission line impedance by infusing the controllable voltage in arrangement with the transmission line. The capacity of SSSC to work in capacitive and also inductive mode makes it exceptionally compelling in controlling the force stream of the framework [5, 6]. Static Synchronous Series Compensator (SSSC) is one of the imperative parts of FACTS family which can be introduced in arrangement in the transmission lines. With the capacity to transform its reactance trademark from capacitive to inductive, the SSSC is exceptionally compelling in controlling force stream in force frameworks [5]. An assistant settling sign can likewise be superimposed on the force stream control capacity of the SSSC in order to enhance power framework wavering steadiness [7]. The applications of SSSC for force wavering damping, steadiness upgrade and recurrence adjustment can be found in a few references [8-11].

As of late, new computerized reasoning based methodologies have been proposed to outline a FACTS-based supplementary damping controller. These methodologies incorporate molecule swarm improvement [12, 13], hereditary calculation [14], differential advancement [15], and multi-objective evolutionary calculation [16]. The applications incorporate sparing burden dispatching, force framework stabilizers (PSS), and so forth. The results have demonstrated that fuzzy have extraordinary potential in enhancing force framework online and logged off applications [17-20]. The proposed controller has been connected and tried under diverse aggravations for a multi-machine power framework. The framework comprises of three generators partitioned into two subsystems and are joined through an intertie. The counterfeit fuzzy system controller focused around fuzzy control, i.e., (fuzzy controller) is petitioned arrangement FACTS gadget, i.e., static synchronous arrangement compensator (SSSC). For the outline reason, MATLAB/Simulink model of the force framework with SSSC controller is created. Reproduction results are exhibited at diverse working conditions and under different unsettling influences to demonstrate the viability of the proposed controller. The results demonstrate that the proposed SSSC-based controller can enhance the voltage profile and transient solidness of the test framework more productive than the ordinary lead-slack controller of above gadgets [13].

2. Power System Under Study:

The multi-machine power system with SSSC shown in Fig. 1 is considered in this study. It is similar to the power system used in references [21, 22]. The system consists of three generators divided into two subsystems and are connected through an inter-tie. The generators are equipped with hydraulic turbine and governor (HTG) and excitation system. The HTG represents a nonlinear hydraulic

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turbine model, a PID governor system, and a servomotor. The excitation system consists of a voltage regulator and DC exciter, without the exciter's saturation function. Following a disturbance, the two subsystems swing against each other resulting in instability. To improve the stability the line is sectionalized and a SSSC is assumed on the mid-point of the tie-line. In Fig. 1, G_1, G_2 and G_3 represent the generators; T/F_1, T/F_2 and T/F_3 represent the transformers and L_1, L_2 and L_3 represent the line sections respectively. The relevant data for the system is given in Appendix.

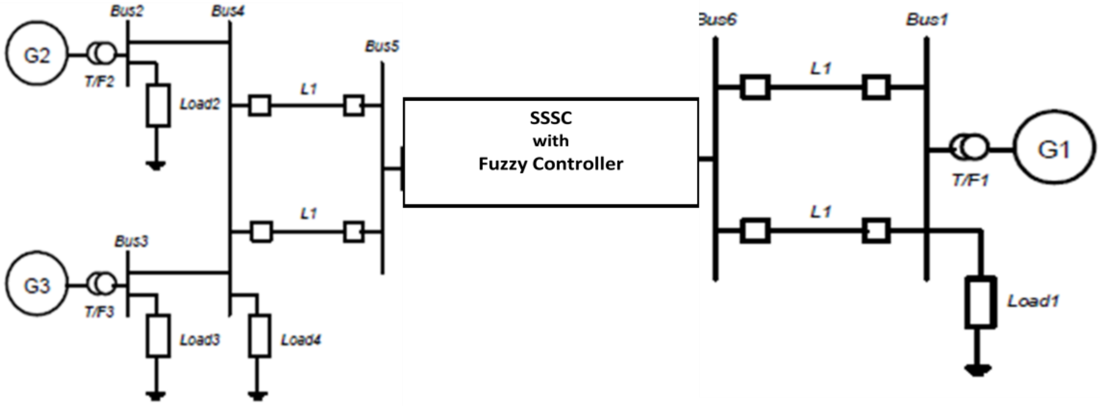

Fig.1: Line diagram of a three machine power system with Fuzzy Controller based SSSC.

3. Fuzzy Approach:

A **fuzzy control system** is a control system based on fuzzy logic a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false, respectively).Fuzzy or Adaptive Fuzzy Inference System (AFIS) approach is considered to be an adaptive network. Adaptive network has no synaptic weights, but so called adaptive and non- adaptive nodes. It must be said that adaptive network can be easily transformed to fuzzy networks' architecture with classical feed forward topology. AFIS is an adaptive network which works like adaptive network simulator of Takagi-Sugeno's fuzzy controllers. This adaptive network is functionally equivalent to a fuzzy inference system (FIS). Using a given input/output data set, AFIS adjusts all the parameters using back propagation gradient descent and least squares type of method for non-linear and linear parameters, respectively. It is assumed for simplicity that the fuzzy inference system under consideration has two inputs x and y and one output z. suppose that the rule base contains two fuzzy if-then rules of Takagi and Sugeno's type [23-26]. The given concept of AFIS structure can be explained using a simple example whose rule base is given below.

- Rule 1: If x *is* A_1 *and* y *is* B_1, then $f_1 = p_1x + q_1y + r_1$,
- Rule 2: If x *is* A_2 *and* y *is* B_2, then $f_2 = p_2x + q_2y + r_2$.

The AFIS is applied for designing the SSSC-based fuzzy controller. This structure of AFIS has an input layer, an output layer, and one hidden layer. Research has proved that AFIS have a wide number of applications in the power engineering due to many advantages [17, 18]

- Capability of synthesizing complex and transparent mappings.
- Rapidity due to parallel mechanism.
- Robustness and fault tolerance.
- Adaptability due to its inherent property to adopt new conditions.
- Easy software simulation and hardware implementation.
- Less memory required.

In this paper, application of fuzzy approach is done in MATLAB/Simulink because the fuzzy controller provides faster control and enhanced stability than the compared result of lead-lag controller [13]. The proposed AFIS controller uses membership functions through-time algorithm [27]. The back-propagation is an iterative method employing the gradient decent algorithm for minimizing the min. square error between the actual output and the target for each pattern in the training is applied, the generalized delta rule in the back-propagation algorithm. In this paper, we present a data pattern from training set with fuzzy inputs and fuzzy desired output vectors. Then update the network weights in a recursive algorithm starting from the output layer and working backward to the first hidden layer. The learning procedure of AFIS system takes the semantically properties of the underlying fuzzy system into account. This results in constraints on the possible modifications applicable to the system

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parameters.

4. Modeling of Fuzzy Controller based SSSC:

The proposed fuzzy controller utilizes Sugeno-type Fuzzy Inference System (FIS) controller, with the parameters inside the FIS decided by the fuzzy network back propagation method. The fuzzy controller is designed by taking speed deviation & acceleration as the inputs, and the injected voltage by SSSC as the output. The output stabilizing signal, i.e., injected voltage is computed using the fuzzy membership functions depending on the input variables. The effectiveness of the proposed approach to modeling and simulation of SSSC controller is implemented in Simulink environment of MATLAB. AFIS-Editor in MATLAB is used for realizing the system and implementation of the proposed fuzzy or AFIS approach. In a conventional fuzzy approach the membership functions and the consequent models are fixed by the model designer according to a prior knowledge. If this set is not available but a set of input-output data is observed from the process, the components of a fuzzy system (membership and consequent models) can be represented in a parametric form.

The fuzzy controller uses 49 rules and 7 membership functions in each variable to compute output and exhibits good performance. Now main aim is to extract a smaller set of rules using AFIS learning and to do the same the following steps are followed:

- ***Data generation:*** To design the SSSC-based fuzzy controller, some data is needed, i.e., a set of two-dimensional input vectors and the associated set of one-dimensional output vectors are required. Here, the training data has been generated by sampling input variables, i.e., speed deviation & acceleration uniformly, and computing the value of stabilized signal for each sampled point.
- ***Rule extraction and membership functions:*** After generating the data, the next step is to estimate the initial rules. Then after applying Subtractive Clustering algorithm [28], rules are extracted. These rules are not so close to the identified system. Hence, there is a need of optimization of these rules. Hybrid learning algorithm is used for training to modify the above parameters after obtaining the Fuzzy inference system from subtracting clustering. This algorithm iteratively learns the parameter of the premise membership functions via back propagation and optimizes the parameters of the consequent equations via linear least-squares estimation. The training is continued until the error measure becomes constant.
- ***Results:*** The AFIS learning has been tested on a variety of linear and nonlinear processes. The objective here is to justify whether the fuzzy controller with less number of rules and membership functions can provide the same level of performance as that of the original one (system with 49 rules). To demonstrate the effectiveness of the proposed combination, the results are reported for system with 25 rules and system with optimized rule base. After reducing the rules the computation become fast and it also consumes less memory. In below figure illustrate five fuzzy sets namely “cold”,”cool”,”normal”,”warm”,”hot”. Each of the fuzzy set is defined by the corresponding membership function as shown in figure 2, 3.The following are set of temperatures are T0-T2, T1-T3, T2-T4, T3-T5, T4-T6.

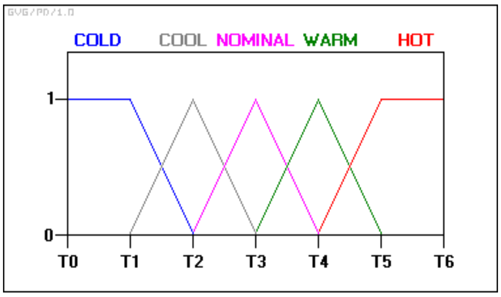

Fig. 2: Variations of temperature

For any set X, a membership function on X is any function from X to the real unit interval [0,1] membership functions on X represent fuzzy subsets of X. The membership function which represents a fuzzy set $\tilde{A}$ is usually denoted by μ_A. For an element x of X, the value $\mu_A(x)$ is called the *membership degree* of x in the fuzzy set $\tilde{A}$. The membership degree $\mu_A(x)$ quantifies the grade of membership of the element x to the fuzzy set $\tilde{A}$. The value 0 means that x is not a member of the fuzzy set; the value 1 means that x is fully a member of the fuzzy set. The values between 0 and 1 characterize fuzzy members, which belong to the fuzzy set only partially.

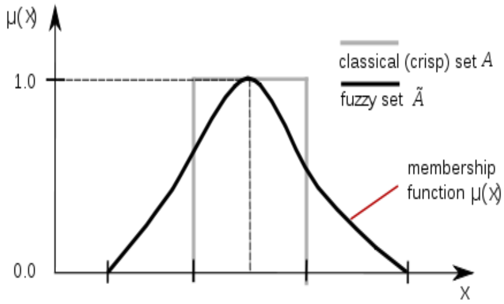

Fig.3: Membership degree in the fuzzy set

5. Simulation Diagram of a Proposed System:

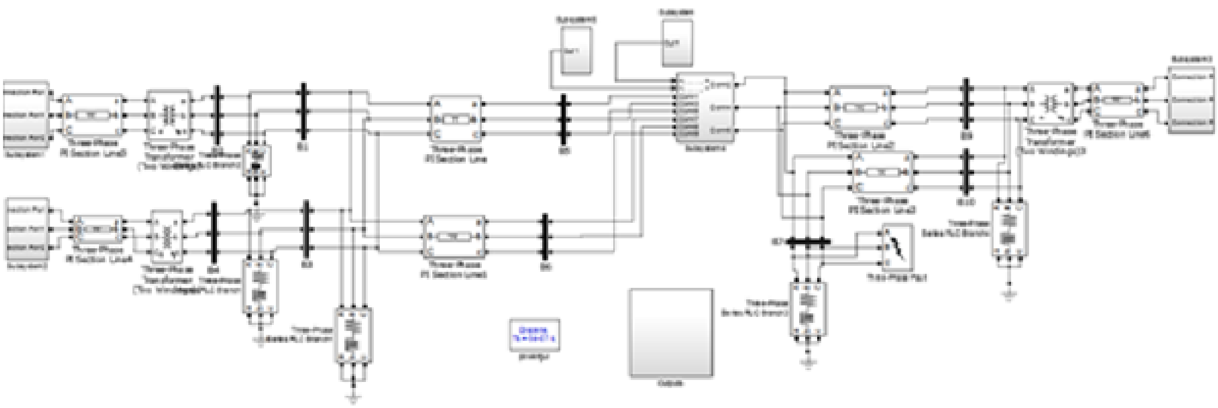

Fig.4: Simulated diagram of a three machine power system with Fuzzy Controller based SSSC.

6. Simulation Results:

The Sim Power Systems (SPS) toolbox is used for all simulations and fuzzy controller-based with SSSC design. In order to optimally tune the parameters of the SSSC-based fuzzy controller, as well as to assess its performance, the model of example power system shown in Fig. 1 is developed using SPS block-set. The ratings of the generators are taken as 2100MVA each (G2 and G3) in one subsystem and 4200MVA (G1) in the other subsystem. The generators with output voltages of 13.8KV are connected to an inter-tie through 3 -phase step up transformers. All of the relevant parameters are given in the Appendix.

Local control signals, although easy to get, may not contain the inter-area oscillation modes. So, compared to wide-area signals, they are not as highly controllable and observable for the inter-area oscillation modes. Owing to the recent advances in optical fiber communication and global positioning systems, the wide-area measurement system can realize phasor measurement synchronously and deliver it to the control center even in real time, which makes the wide-area signal a good alternative for control input. In view of the above, the speed deviation and acceleration of generators G1 and G2 are chosen as the control input of the SSSC-based fuzzy controller in this article.

To assess the effectiveness and robustness of the proposed fuzzy controller, load flow is performed with Machine 1 as a swing bus and Machines 2 and 3 as PV generation buses. The initial operating conditions used are:

Machine1 generation: Pe_1 = 3480.6 MW (0.8287 p.u.),

Qe_1 = 2577.2 MVAR (0.6136 p.u.)

Machine 2 generation: Pe_2 = 1280 MW (0.6095 p.u.),

Qe_2 = 444.27 MVAR (0.2116 p.u.)

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Machine 3 generation: Pe_3 = 880 MW (0.419 p.u.),

Qe_3 = 256.33 MVAR (0.1221 p.u.)

Simulation studies are carried out for the example power system subjected to various severe disturbances as well as small disturbances. The simulation results are also compared with the result of lead-lag controller as given by ref. [13]. The original system is restored upon the clearance of the fault.

A three-cycle, three -phase fault is applied at one of the line sections between Bus 1 and Bus 6, near Bus 6, at t = 1 sec. The fault is cleared by opening the faulty line, and the line is reclosed after three cycles. The original system is restored after the fault clearance. Fig.5 (a)–5(d): show the variations of the inter-area and local mode of oscillation and the SSSC-injected voltage against time.

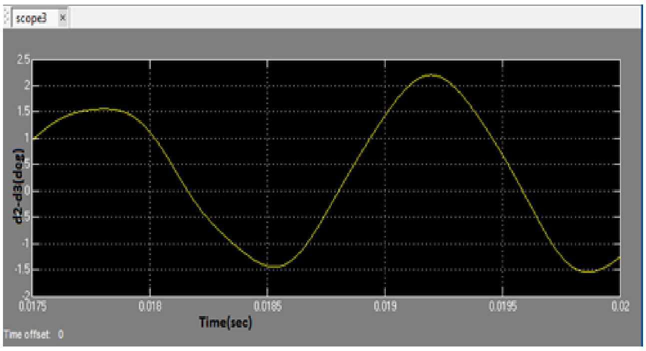

Fig .5(a): inter-area mode

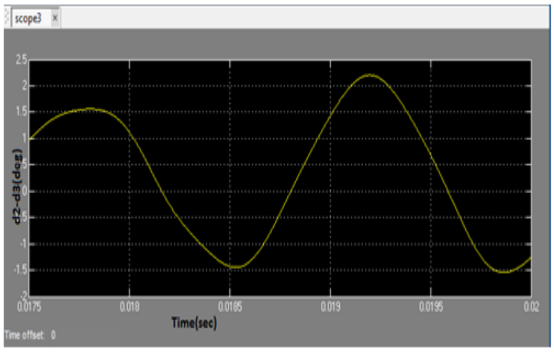

Fig .5(c): Local mode

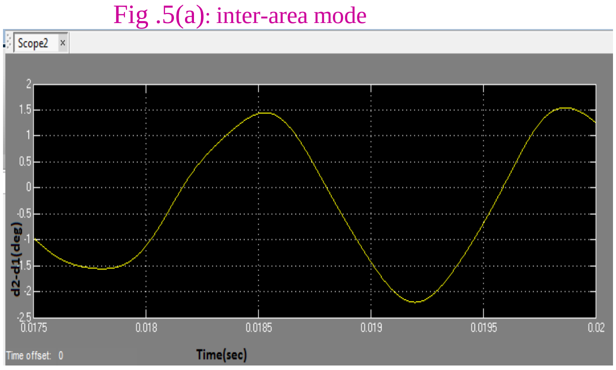

Fig .5(b): inter-area mode

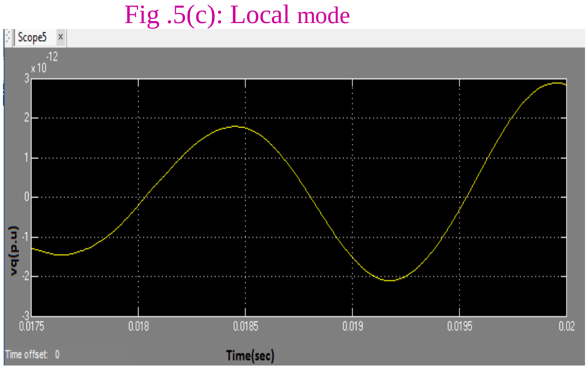

Fig.5 (d): SSSC-injected voltage, Vq

Figure .5: Variation of inter-area and local modes of oscillations against time for a three-cycle, three-phase fault near Bus 6: (a) And (b) inter-area mode; (c) local mode; (d) SSSC-injected voltage, Vq

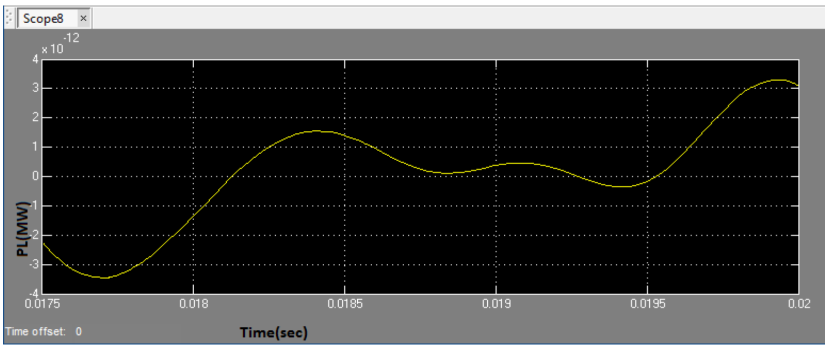

Figure. 6: Variation of tie-line power flow for a three-cycle, three-phase fault near Bus 6 cleared by a three-cycle line tripping

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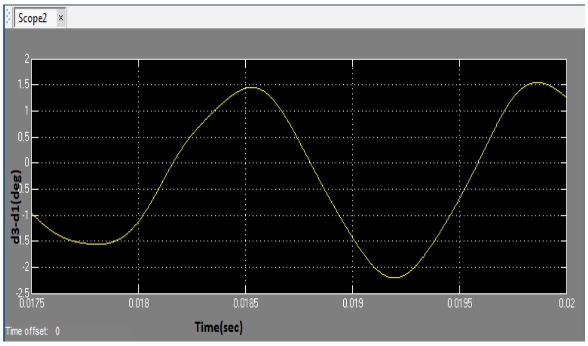

Fig .7 (a): L-G Fault

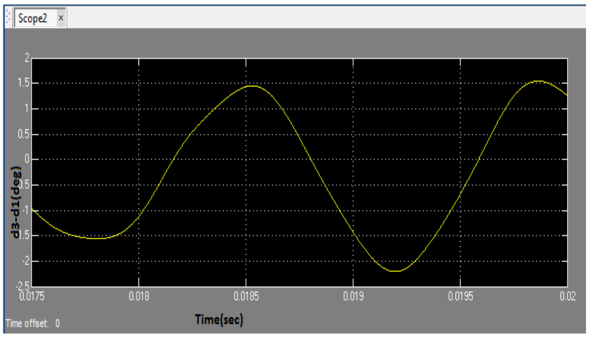

Fig.7 (b): L-L-G Fault

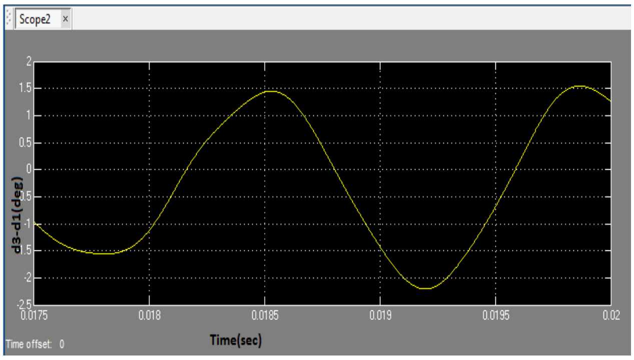

Fig.7(c): L-L Fault

Figure.7: Variation of inter-area mode of oscillations against time for three cycle unbalanced faults at Bus 1: (a) L-G fault; (b) L-L-G fault; (c) L-L fault

From these figures, it can be seen that the inter-area modes of oscillations are highly oscillatory in the absence of both SSSC-based damping controller as well as fuzzy controller, and the proposed fuzzy controller significantly improves the power-system stability by damping these oscillations. Furthermore, the proposed controller is also effective in suppressing the local mode of oscillations. The power flow through the tie-line (at Bus 1) for the above contingency is shown in Fig. 5, which clearly shows the effectiveness of the proposed controller to suppress power-system oscillations. The effectiveness of the proposed controller on unbalanced faults is also examined by applying self-clearing type unsymmetrical faults, namely L-G, L-L-G, and L-L, each of three -cycle duration at Bus 1 at t = 1 sec. The inter-area and local modes of oscillations against time are shown in Figs. 6-7. It is clear from the figures that the power-system oscillations are poorly damped in the uncontrolled case, even for the least-severe L-G fault, and the proposed SSSC-based fuzzy controller effectively stabilizes the power angle under various unbalanced fault conditions.

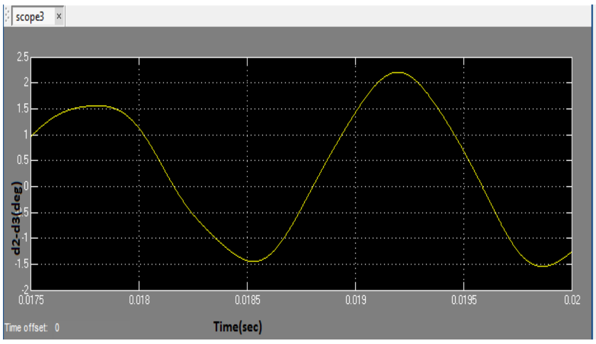

Fig.8 (a): L-G Fault

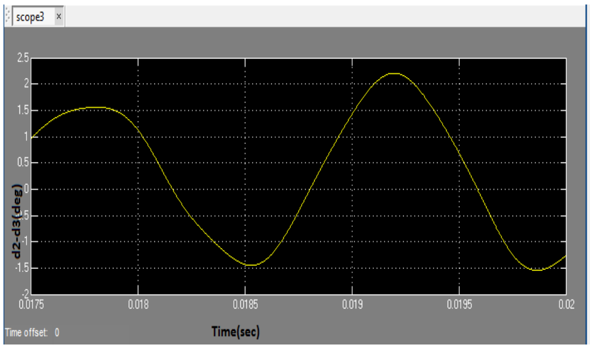

Fig.8 (b): L-L-G Fault

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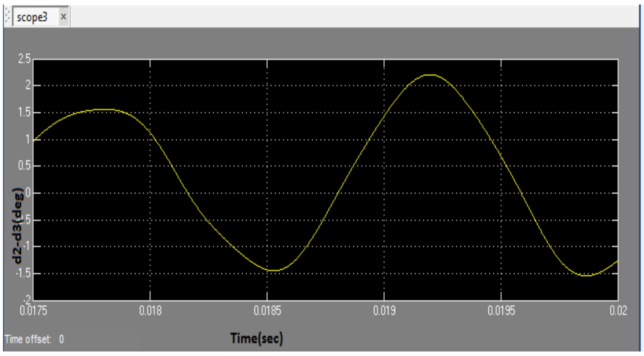

Fig .8(c): L-L Fault

Figure .8: Variation of local mode of oscillations against time for three-cycle unbalanced faults at Bus 1: (a) L-G fault; (b) L-L-G fault; (c) L-L fault

Simulation results show that the performance of the fuzzy controller is better than that of conventional lead-lag controller. In all cases, the damping following the disturbance has improved significantly. It is clear from these figures that the fuzzy controller improves the stability performance of the example SSSC-based power system and, also, power system oscillations are well damped out.

7. Conclusion:

The research paper concludes, Fuzzy controller in enhancing power system security is additionally exhibited. The element execution of proposed SSSC-based controller under different stacking and aggravation conditions are investigated and analyzed. It is watched that the proposed SSSC-based fuzzy controller gives proficient damping to power framework motions and significantly enhances the framework voltage profile. The between territory and nearby modes of force framework motions are successfully damped by utilizing the proposed SSSC controller. The research work is planned to discover the most suitable designs of the fuzzy controller for the FACTS gadget. The prevalence of fuzzy controller is obvious from the simulation results for different types of aggravations.

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