Scienceline Publication www.science-line.com
Journal of World's Electrical Engineering and Technology
J. World. Elect. Eng. Tech. 1(1): 27-34, 2012
JWEET

Novel Methods with Fuzzy Logic and ANFIS Controller Based SVC for Damping Sub-Synchronous Resonance and Low-Frequency Power Oscillation

Akbar Lak*, Daryoosh Nazarpour, Hasan Ghahramani

Engineering Department of Urmia University, Urmia, Iran

*Corresponding author's email: akbar.lack@gmail.com

Abstract *– A long transmission line needs controllable series as well as shunt compensation for power flow control and voltage regulation. In this paper, series fixed capacitive compensation and shunt compensation provided by a Static VAR Compensator (SVC) installed at the transmission line are considered. It is possible to damp Sub-Synchronous Resonance (SSR) caused by series capacitors with the help of an auxiliary SSR damping controller on SVC. In this work, two novel control methods for damping SSR is added to the SVC main control in order to demonstrate the SSR damping capability of SVC. The control methods are presented, namely: Fuzzy Logic Damping Controller (FLDC) and Adaptive Neuro-Fuzzy Inference System (ANFIS) controller. The ANFIS constructions were trained utilizing the generated database by the FLC of the SVC. The simulation results prove that ANFIS controller is found to be robust to fault type and change in operating situations. The Fast Fourier Transform (FFT) is carried out in order to evaluate the effect of TCSC based ANFIS controller in damping SSR and LFO. The study system was adopted from the IEEE Second Benchmark Model (ISBM) by installing the SVC. The MATLAB/Simulink software program was used to verify the effectiveness of each control method.*

Keywords*: Sub-Synchronous Resonance (SSR), Static VAR Compensator (SVC), Fuzzy Logic Controller (FLC), Adaptive Neuro-Fuzzy Inference System (ANFIS), Fast Fourier Transform (FFT).*

ORIGINAL ARTICLE

INTRODUCTION

The increase of power transfer capability of long transmission lines can be achieved by decreasing the effective line reactance, providing dynamic voltage support by the SVCs and by static phase shifters [1-3]. Series compensation of long lines is an economic solution to the problem of improvement power transfer and improving system stability. However, series-compensated transmission lines connected to turbo-generators can result in the SSR, SSR may occur when an electrical resonance frequency is close to the complement of one of the torsional mode frequencies of the turbine-generator shaft system. This phenomenon if not properly controlled, torsional oscillation will be increased and failure of the turbine-generator shaft will be resulted [3], [4].

Flexible AC transmission systems (FACTS) controllers for instance Static Var Compensator (SVC), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC), and GTO-Controlled Series Capacitor (GCSC) have been implemented to mitigate the SSR in power networks [5-8]. In addition, due to some merits of SVC toward other FACTS devices such as: quick voltage regulation of power systems, reactive power compensation, power oscillation damping and steady state stability, it may be installed in the power systems broadly [9-10]. Many papers have investigated the implementation of SVC for additional purposes such as: SSR damping, or dynamic stability with designing supplementary controllers. For example, in [11], R.K.Varma and S.Auddy have demonstrated the performance of SVC for damping the SSR at the wind farm terminal beside of its main function.

Many techniques have been utilized in the scheme of auxiliary damping controllers for SVC in the recent papers, for example: self-tuning adaptive control algorithm or conventional Proportional Integral (PI) controllers [11], [12]. The major obstacle with these methods which are mentioned above is that, the control rule is based on a linearized model and control variables are adjusted to some nominal performance positions.

Recently, fuzzy logic controllers have generated a great deal of interest in various applications and have introduced in power-electronic field [13], [14]. The

To cite this paper: Lak A, Nazarpour D, Ghahramani H. 2012. Novel Methods with Fuzzy Logic and ANFIS Controller Based SVC for Damping Sub-Synchronous Resonance and Low-Frequency Power Oscillation. *J. World Elect. Eng. Tech.* 1(1): 27-34.
Journal homepages: http://www.jweet.science-line.com/

advantage of fuzzy logic control emerges to be the most promising, because of to its lower computational burden and robustness. In addition, in the scheme of fuzzy logic controllers, a mathematical model is not needed to explain the system under study. Though, in case of fuzzy control, the main problem is that the parameters related with the membership functions and the rules depend extensively on the intuition of the engineer. On the other side, fuzzy systems are fundamentally approximate systems, which a general solution to the adjusting problem. It must be noted that, when a control problem includes dynamic nonlinear systems, the two methodologies (FLC and ANN) walking together as neuro-fuzzy systems, can help to manage the complexity and to decrease the design time. Both of them are powerful design methods with their own weaknesses and strengths [15], [16]. To overcome this limitation ANFIS controller is utilized. Recently, the use of ANFIS based SSR and LFO damping controller has been emerged as an effective method to control the power networks.

This paper presents a FLDC strategy for SVC to alleviate the SSR and improve the power system stability. The FLDC is varied widely by a suitable choice of membership functions and parameters in the rule base. $\Delta\omega$ [p.u] (generator speed deviation) and $d\Delta\omega/(dt) = \Delta\alpha$ [p.u] (the derivative of speed deviation) are two supplemental signals that exhibit the sub-synchronous information, will be inserted as the FLDC input signals, then output signal of supplementary FLDC is used to modulate the reference voltage regulator of SVC controller for effective SSR damping. The ANFIS constructions were trained utilizing the generated database by the FLC is used to modulate the reference voltage regulator of SVC controller for effective SSR damping. The results reveal the superior performance of suggested ANFIS controller toward FLC.

The paper is organized as follows: In section 2, sub-synchronous resonance phenomenon is explained briefly. Power system structure for SSR study is clarified in section 3 . In Section 4, the Fast Fourier Transform (FFT) analysis on the generator rotor speed is demonstrated. The structure of the SVC is briefly presented in section 5. In Sections 6 and 7 novel methods the FLC and ANFIS controller are proposed, respectively. Simulation results with detailed comparison between two proposed controllers (FLD and ANFIS controller) in two cases are included in section 8. Finally, in section 9, the results obtained from previous sections are concluded.

SUB-SYNCHRONOUS RESONANCE

Generally, SSR happens in series compensated transmission lines. Series compensation of transmission line can be lead to the excitation of oscillatory modes of the rotor shaft in sub-synchronous resonance [4]. A series capacitor-compensated power system has an electrical resonant with natural frequency (f_e) which is following by:

$$f_e = f_o\sqrt{X_c/X_l} \tag{1}$$

Where, X_l is the reactance of compensated line, X_c is the reactance of series capacitor and f_o is the synchronous frequency of the power network in Hz. At this sub-synchronous natural frequency, these oscillatory modes cause rotor torques and currents at the complementary frequency, f_r as: $f_r = f_o$-f_e. Therefore, if f_r is nearby one of the torsional frequencies of the rotor shaft, the torsional oscillations will be excited and this situation will be caused undesirable occurrences namely SSR [4]. Generally, SSR has two major parts: transient torque or transient SSR and the second part are self-excitation which is named by steady-state SSR. Self-excitation is divided into two major parts: the first one is Induction Generator Effect (IGE), and the second one is torsional interaction (TI). The IGE is impracticable in series compensated power networks. However, the TI and transient SSR are mostly happen in series compensated power networks [17]. Because the main purpose of this study is to mitigate the SSR in series compensated transmission line, the suggested controller is planned to eliminate major SSR problems, transient torque and TI.

STUDY MODEL

For the analysis presented in this paper, the ISBM is employed, which is installed the SVC is shown in Fig. 1 [18]. The system composed of a synchronous generator supplying power to an infinite bus via two parallel transmission lines, it is a Single Machine Infinite Bus (SMIB) power network that has two transmission lines, and one of them is compensated by a series capacitor. A 600 MVA turbine-generator is connected to an infinite bus, and the rated line voltage is 500KV, while the rated frequency is 60Hz. The SVC that is a combination of one Thyristor Controlled Reactor (TCR) and one fixed capacitor is connected to bus 1 by step-down transformer. The shaft system consists of four masses: the generator (G) and rotating Exciter (EX), low pressure turbine (LP), and a high pressure turbine (HP). All masses are mechanically connected to each other by elastic shaft. The complete mechanical and electrical information for the study system are demonstrated in [24]. It should be noted that, Z_{L1}, Z_{L2} are defined as:

$$Z_{L1} = R_{L1} + jX_{L1}, \quad Z_{L2} = R_{L2} + jX_{L2} \tag{2}$$

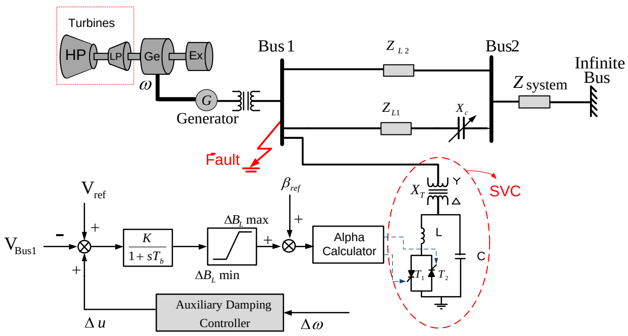

Fig. 1. The IEEE Second Benchmark Model combined with SVC for SSR analysis

Fast Fourier Transform analysis

For an evaluation of the dynamic features of the power system, the FFT analysis is achieved by M-file in the MATLAB program. Fig.2 describes the FFT plot of generator rotor speed in time interval of 1 to 2.5 sec. percentage of compensation which means the proportion of series capacitive reactance to line reactance $(X_C/X_{L1} \times 100)$, is set to 55% to excite the oscillatory mode of the generator rotor shaft that, three modes exist in the rotor speed in this study. As shown Fig.2, it can be deduced that, due to the chosen level of series compensation, the electrical resonance happens at 23.33 Hz. From FFT analysis of the mechanical system, the oscillatory modes of the generator shaft are 23.33, 30 Hz and 1.333 Hz is the low frequency oscillation. Furthermore, maximum destabilization is for 23.33 Hz mode, or in other way, the dominant mode which has sub-synchronous frequency is 23.33 Hz.

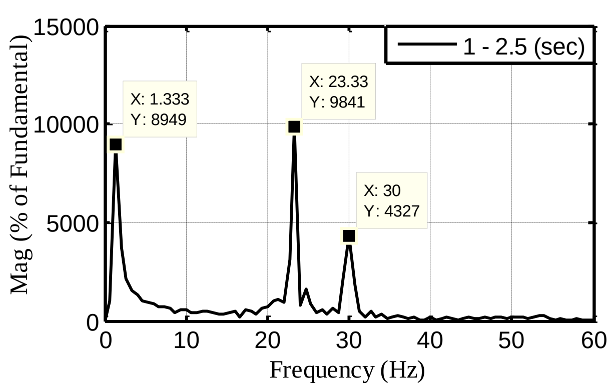

Fig. 2 FFT analysis on generator rotor shaft in order to confirm the dominant mode

SVC STRUCTURE

It is essential to balance the supply and demand of active and reactive power in an electrical power system. The power system collapse occurs when the system frequency and voltage begin to oscillate increasingly, which may happen if the balance between supply and demand of active and reactive power lost. With proper voltage and reactive power control, the power system will operate in stable condition. SVC is one of the advanced power electronics equipment which provides fast and continuous capacitive and inductive reactive power supply to the power system. The main merits of SVC can be cited as: quick voltage regulation of power systems, reactive power compensation, power oscillation damping, steady state stability [9-11].

A typical structure of SVC with Thyristor Controlled Reactor (TCR) and fixed capacitor which is connected to a Bus 1 through a step-down transformer is shown in Fig. 1. Where, X_T is the transformer reactance, C and L are the capacitance and inductance of SVC respectively. The main scope of SVC controller is to create pulses for Thyristor valves in order to fix the AC bus voltage of SVC.

The TCR is composed of a fixed reactor with inductance L, and a bidirectional Thyristor switch. A Thyristor switch can be brought in to conduction by concurrent application of gate pulse to Thyristors. The switch automatically is turned off when the current passes zero, unless the gate signal is applied again. The current in the reactor can be adjusted from maximum (switch closed) to zero (switch open) by the method of firing delay angle control: the magnitude of the current in the reactor differs continuously by adjusting of delay angle from maximum $(\alpha = 0)$ to zero ($\alpha=\pi/2$). The amplitude $I_{LF}(\alpha)$ of the fundamental reactor current $i_{LF}(\alpha)$ can be explained as a function of angle α:

$$I_{LF}(\alpha) = V/\omega L(1 - 2\alpha/\pi - ((1/\pi)\sin(2\alpha))) \qquad (3)$$

Where, V is the magnitude of the AC voltage, L is the inductance of the TCR, ω is the angular frequency of the AC voltage in rad/s. The fundamental current can be controlled continuously from zero (switch open) to maximum (switch close) by TCR, as if it was a changeable reactive admittance. Efficient reactive admittance, $\beta_L(\alpha)$, for the TCR as function of angle α, can be obtained from equation (3). Obviously, the admittance $\beta_L(\alpha)$ changes with α in the same as the fundamental current $I_{LF}(\alpha)$ [19], [20]:

$$\beta_L(\alpha) = 1/\omega L(1 - (2\alpha/\pi) - ((1/\pi)\sin(2\alpha))) \qquad (4)$$

Among the existing FACTS devices, the SVCs have been used extensively to provide voltage support at strategic locations of the system [19], [20].

FLDC design for SVC

Recently, Fuzzy Logic Controllers (FLCs) have emerged as an effective tool to stabilize the power network with different devices such as FACTS devices or other power electronic apparatuses [13], [14].

Fuzzy Logic Controller (FLC) presents methodical approach to control a nonlinear strategy based on human experience that can be regarded as a heuristic technique to enhance the operation of closed loop system. The FLC performance is based on its capability to simulate many functions at its same time process and output results of FLC is considerably thorough. Fig.5 shows schematic of the auxiliary FLDC which is used for enhancing the SVC with damping controller. In this part, rotor speed deviation and its derivative ($\Delta\omega$ and $d\Delta\omega/(dt) = \Delta\alpha$), are used as inputs for suggested FLDC that is schemed based on Mamadani inference engine [22].

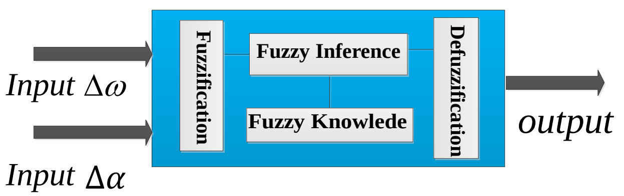

Fig.5. Generalized SVC auxiliary fuzzy controller and Structure of SVC sub-synchronous resonance damping controller

The basic structure of FLDC is classified in four sections: Fuzzification Block, Fuzzy Knowledge-based Block, a Fuzzy Inference Engine and a Defuzzification Block.
In this paper, the inputs and the single output are normalized for the base values defined for the system. The frame and number of the membership functions explaining the fuzzy value of controller (for the inputs and output) are described off-line. Zmf and Smf (Z and S shape Membership Function) membership's functions are employed for the inputs and output fuzzy sets of the FLDC. The designed membership functions for: $\Delta\omega$, $\Delta\alpha$ as inputs and Δu as output are shown in Fig. 6. The control rules of the fuzzy controllers are showed by set of heuristically selected fuzzy rules.
The fuzzy sets have been determined as: N: negative, Z: zero, P: Positive, respectively. The rule base with two proposed input is shown as:

1. If ($\Delta\omega$ is P) and ($\Delta\alpha$ is P) then (Δu is P)

2. If ($\Delta\omega$ is P) and ($\Delta\alpha$ is N) then (Δu is Z)

3. If ($\Delta\omega$ is N) and ($\Delta\alpha$ is P) then (Δu is Z)

4. If ($\Delta\omega$ is N) and ($\Delta\alpha$ is N) then (Δu is N)

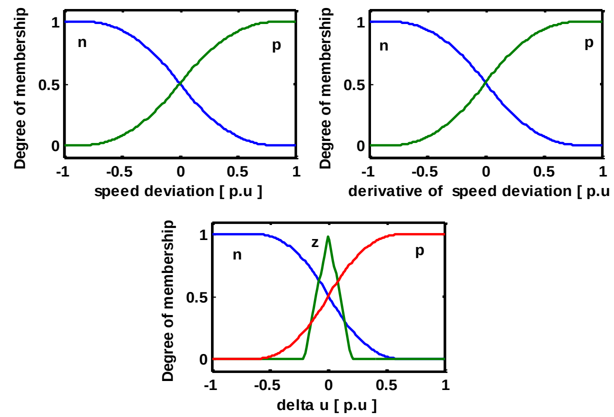

Fig.6. membership functions for inputs and output fuzzy sets of the FLDC

SVC-based ANF1S Controller

In this paper, the suggested ANFIS controller uses Sugeno-type Fuzzy Inference System (FIS) controller, with the parameters inside the FIS determined by the neural-network back propagation technique. The ANFIS controller is determined by taking speed deviation & acceleration as the inputs, and the α by the SVC as the output. The output stabilizing signal, i.e., α is calculated utilizing the fuzzy membership functions depending on the input variables. The effectiveness of the proposed approach to the modeling and simulation of the SVC controller is applied in the Simulink environment of MATLAB.

The fuzzy controller utilizes 4 rules and 2 membership functions in each variable to compute output and demonstrations good performance. The given concept of ANFIS construction can be described using a simple pattern whose rule base is given below.

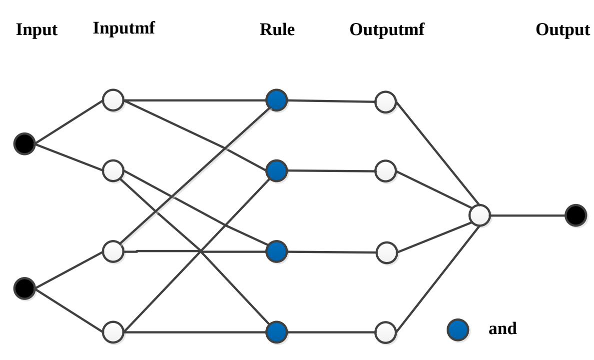

Fig. 8 The corresponding equivalent ANFIS architecture

Rule 1 : (4)
If x is A_1 and y is B_1, then $f_1 = p_1x + q_1y + r_1$.
Rule 2 : (5)
If x is A_2 and y is B_2, then $f_2 = p_2x + q_2y + r_2$.

The node functions in the same layer are of the same function family as described below:

Layer 1: Every node i in this layer is an adaptive node with a node function

$$O_{1,i} = \mu_{A_i}(x), \quad \text{for } i = 1,2, \text{ or} \tag{5}$$

$$O_{1,i} = \mu_{B_{i-2}}(y), \quad \text{for } i = 3,4.$$

Where x (or y) is the input to node i and Ai (or B_{i-2}) is a linguistic label ("small" or "large") associated with the node. Here the membership function for A (or B) can be any continuous and piecewise differentiable functions, such as commonly used trapezoidal or triangular-shaped membership functions, are also qualified candidates for node functions in this layer [22], [23].

$$\mu_A(x) = \exp\left[-\left(\frac{x - c_i}{a_i}\right)^2\right] \tag{6}$$

Where $\{c_i, a_i\}$ is the parameter set. These are named premise parameters.

Layer 2: Every node in this layer is a fixed node labelled $\sum$, whose output is the produce of all the incoming signals [22], [23].

$$O_{2,i} = w_i = \mu_{A_i}(x)\mu_{B_i}(y), \quad i = 1,2. \tag{7}$$

Layer 3: Here, the ith node computes the ratio of its rule's firing strength to the sum of all rule's firing strengths [22], [23].

$$O_{3,i} = \bar{w}_i = w_i/(w_1 + w_2), \quad i = 1,2. \tag{8}$$

Layer 4: Every node i in this layer is an adaptive node with a node function

$$O_{4,i} = \bar{w}_i f_i = \bar{w}_i(P_i x + q_i y + r_i), \tag{9}$$

Where w_i is a normalized firing strength from layer 3 and $\{p_i, q_i, r_i\}$ is the parameter set of the node. These parameters are referred to as consequent parameters [22], [23].

Layer 5: The single node in this layer is a fixed node labelled $\sum$, which calculates the overall output as the total of all incoming signals [22], [23]:

$$O_{5,1} = \sum_i \bar{w}_i f_i = \sum_i w_i f_i \Big/ \sum_i w_i \tag{10}$$

The ANFIS construction for the SVC is displayed in Fig.10. The basic steps followed for designing the ANFIS controller in MATLAB/Simulink are outlined [24]:
(1) Draw the Simulink model with the fuzzy controller and simulate it with the presented rule base.

(2) The first step for designing the ANFIS controller is collecting the training data while simulating the model with the fuzzy controller.

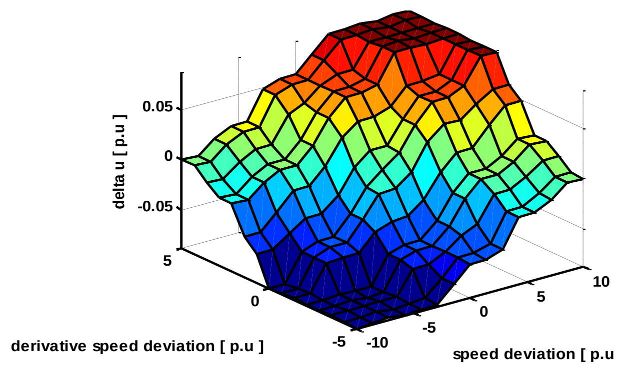

Fig.10. Control surface of ANFIS-based SVC controller

(3) The two inputs speed deviation & derivative speed deviation and the output signal Δu give the training data.
(4) Usage anfisedit to generate the ANFIS .fis file.
(5) Load the training data collected in Step 2 and generates the FIS with gbell MFs.
(6) Train the collected data with the generated FIS up to a special number of Epochs.
(7) Save the FIS where there is the Simulink model with the ANFIS based controller.

SIMULATION RESULTS AND DISCUSSION

Simulation results with novel methodologies with FLDC and ANFIS controller were implemented using MATLAB/SIMULINK for damping SSR and LFO. To examine the efficiency of this controller in different types of disturbance, two cases of faults were considered.
Initially, the power system without any damping controllers is simulated when faults occurred at t=0.7s.Simulation results for the current line, rotor speed deviation, torque between Generator and LP turbines, and Line Current are provided in Fig.11 (a, b). Due to unstable mode, when the fault is cleared, large oscillations will be experienced between sections of the turbine generator shaft. For this state, the system is completely

unstable and as depicted in Fig.11.a, the rotor speed is oscillating with sub-synchronous frequency of 23.33 Hz.

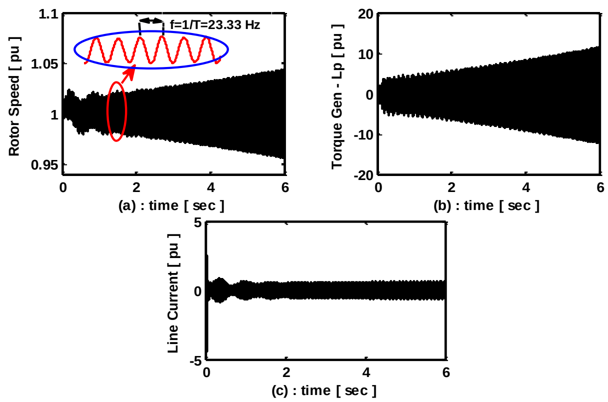

Fig.11 Simulation results for un-damped condition: (a): ω of generator, (b): torque between generator and Low pressure turbine

AS results, for damping oscillations the power system with FLDC and ANFIS controller in two cases are simulated. Firstly, an inductive fault occurs. Secondly, a fault resistive occurs.

Case I: Simulation results with the inductive fault

Simulation results with occurrence an inductive fault by connecting a reactor in t=0.7s with 16.9 ms time duration are conducted with SVC in order to prove the effectiveness of the proposed FLDC and ANFIS controller in SSR attenuation. Fig.12 shown that despite FLDC and ANFIS controller the inductive fault increased the line current from 1 to about 5 p.u. Simulation results for rotor speed deviation, the torque between Generator and LP turbines, and Line Current are provided in Fig.12 (a, d). From this figure, it is observed that, ANFIS operates better than the FLDC since the system with ANFIS-based controller has less overshoot and less settling time compared with the FLDC.
The FFT analysis on the generator rotor speed for SVC enhanced with ANFIS controller is depicted in Fig.13. It is observed that the dominant torsional mode with frequency of 23.33 Hz is diminishing as the time is going on. Also, this figure shows that, for 2-4 second, a low frequency power oscillation with frequency of 1.5 Hz can be found that is completely eliminated with this ANFIS controller.

Case II: Simulation results with the resistive fault

In this case, a resistive fault by connecting a resistive in t=0.7s with 20ms time duration happens. Again, like Case I simulation results proposed FLDC and ANFIS controller. Fig.14 shown that despite FLDC and ANFIS controller the inductive fault increased the line current from 1 to about 1.1 p.u. From this figure, it is observed that, the ANFIS controller is found to be robust to fault type and also excellent ability in damping SSR and LFO in the power system than the FLDC.

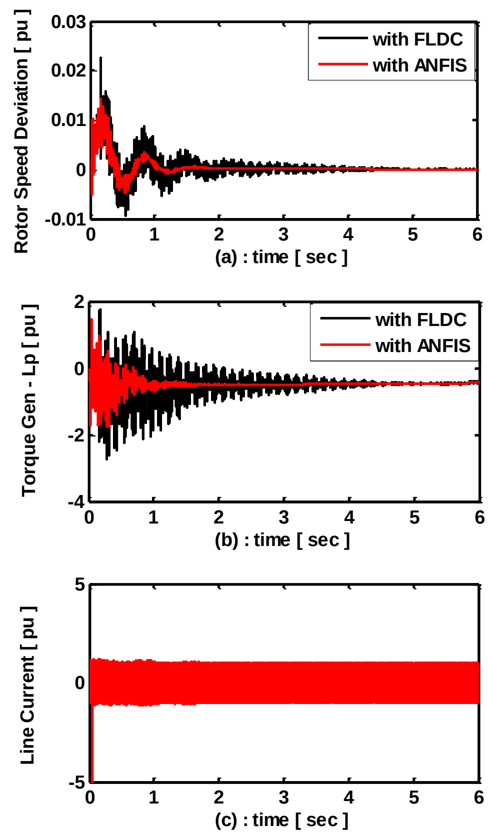

Fig.12 simulated results for comparison between FLDC and ANFIS Controller with fault inductive: (a): rotor speed deviation (b): Torque between generator and low pressure turbines (c) line current

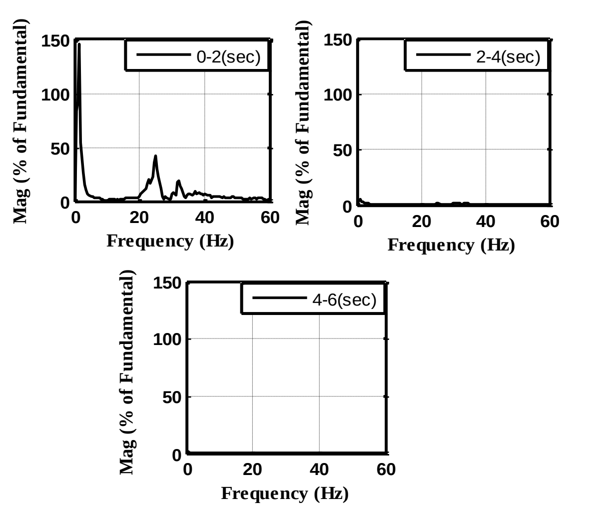

Fig.13 FFT analysis on generator rotor speed with ANFIS controller on SVC for resistive fault

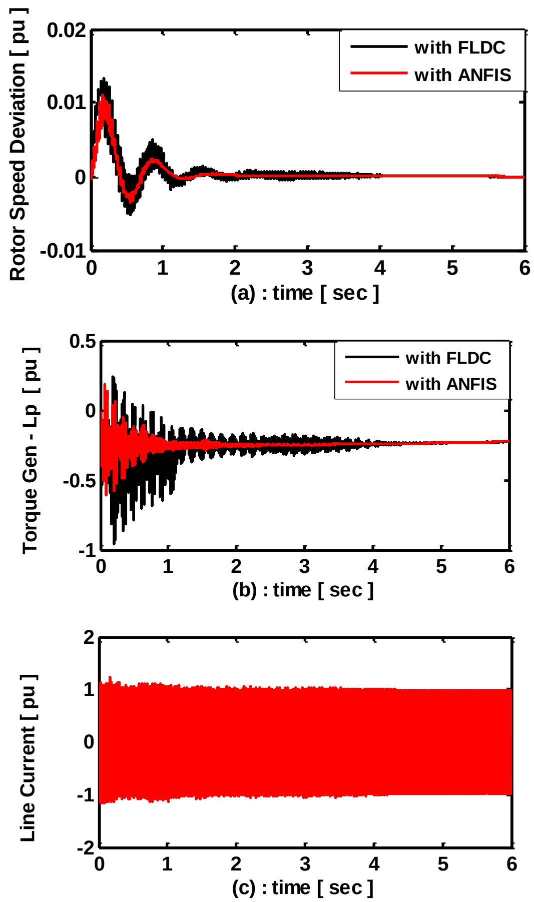

Fig.14 simulated results for comparison between FLDC and ANFIS Controller with fault resistive: (a): rotor speed deviation (b): Torque between generator and low pressure turbines (c) line current

The results of the FFT analysis of Case2 are very similar to Case I , thus they have not been shown here.

CONCLUSION

In this paper, the FLC and ANFIS controller SVC have been developed to damp SSR in a highly unstable power system through simulation with MATLAB software. Simulations are carried out on IEEE Second Benchmark Model accumulated with SVC in two separate cases: the Case I included FLDC and ANFIS controller based SVC with occurrence the inductive fault and the Case II included FLDC and ANFIS controller based SVC with occurrence the resistive fault based SVC . It was shown that although with the developed FLC in the two cases the SSR is damped, but there, FLDC is fundamentally approximate system and a general solution to the adjusting problem. In order to improve the dynamic response of the SVC based FLC, the ANFIS controller was presented. The performance of ANFIS controller was compared with the performance FLC presented in this paper and the conclusions clearly indicate the effectiveness and validity of the presented ANFIS controller. Also, Simulation results showed that the inductive fault is stronger than the resistive fault and the ANFIS controller is found to be robust to fault type. Hence, can be said ANFIS controller is a good candidate in damping SSR and LFO in the power system toward the FLDC.

REFERENCES

[1] C. W. Taylor, Power System Voltage Stability. New York: McGraw-Hill, 1994.
[2] Voltage Stability Assessment: Concepts, Practices, and Tools. Piscataway,NJ: IEEE/PES Power System Stability Subcommittee, IEEE Special Publication, 2003.
[3] P. Kundur, "Power Systems Stability and Control,". New York: Mc-Graw-Hill, 1994.
[4] IEEE Committee Report, "Reader's Guide to Sub-synchronous Resonance," IEEE Trans. on Power Systems, vol. 7, no. 1, pp. 150-157, February 1992.
[5] R. K. Varma and S. Auddy, "Mitigation of subsynchronous oscillations in a series compensated wind farm using static var compensator," in Proc. IEEE Power Eng. Soc. General Meeting Conf., 2006, pp. 1–7, Paper 06 GM1272
[6] Massimo Bongiorno, Jan Svensson, Lennart Angquist, "On Control of Static Synchronous Series Compensator for SSR Mitigation", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 23, NO. 2, MARCH 2008.
[7] J.Guo, M.L.Crow, J.Sarangapani "An improved UPFC Control for Oscillation Damping" IEEE Transactions on Power Systems, Vol. 24, No. 1, Feb. 2009 ,pp.288 – 296.
[8] de Jesus, F.D.; Watanabe, E.H.; de Souza, L.F.W.; Alves, J.E.R.;" SSR and Power Oscillation Damping Using Gate-Controlled Series Capacitors (GCSC) ", IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 22, NO. 3, JULY 2007.
[9] S. Kincic, X. T. Wan, D. T. McGillis, A. Chandra, "Voltage Support by Distributed Static VAR Systems (SVS)," IEEE Transactions On Power Delivery, Vol. 20, No. 2, April 2005
[10] Cheng CH, Hsu YY, " Damping of generator oscillations using an adaptive static var compensator," IEEE Trans Power Systems, 1992;7(7):718–25.
[11] R. R. Padiyar, R. K. Varma, "Damping Torque Analysis of Static Var System Controllers," IEEE Trans on Power Systems, VoI.6, No. 2, may1991.
[12] A.H.M.A. Rahim, E.P. Nowicki, O.P. Malik, "Enhancement of power system dynamic performance through a non-line self-tuning adaptive SVC controller," Electric Power Systems Research 76 (2006) 801-807.
[13] Mohammadpour, H.A.; Mirhoseini, S.M.H.; Shoulaie, A, "Comparative study of proportional and TS fuzzy controlled GCSC for SSR mitigation,", Power Engineering, Energy and Electrical Drives, 2009. Page(s): 564 – 569.
[14] Ajami, A.; Taheri, N.; Younesi, M, "A Novel Hybrid Fuzzy/LQR Damping Oscillations Controller Using STATCOM ,", Computer and Electrical Engineering, 2009. Page(s): 348 – 352.
[15] M. Ansarian, S.M. Sadeghzadeh, A.M. Nasrabadi, G.H. Shakouri, Optimized power system stabilizer based artificial neural network structure, in: 20thInternational Power System Conf., 2005.
[16] I. Rojas, J.L. Bernier, R. Rodriguez-Alvarez, Z. Prieto, What are the main functional blocks involved in the design of adaptive neuro-fuzzy inferencesystems? in: IEEE-INNS-ENNS Conf. Neural Netw., 6, 2000, pp. 551–556.
[17] K. R. Padiyar, Power System Dynamics: Stability and Control.Bangalore, India: Interline, 1996.
[18] IEEE SSR Working Group, Second Benchmark Model for Computer Simulation of Subsynchronous Resonance, IEEE Trans. on Power Apparatus and Systems. 104, N0.5 PP:1057-1064, 1985.

[19] N.G. Hingorani, L. Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission System, IEEE Press, 2000.
[20] R. M. Mathur and R. K. Varma, “Thyristor-Based FACTS Controllers for Electrical Transmission Systems,” Piscataway, NJ: IEEE Press, Feb. 2002.
[21] H.-J. Zimermann (Hans-Jurgen), “Fuzzy Set Theory and it's Applications,” Kluwer Academic Publishers, 3th Edition, 1996.
[22] J.R. Jang, ANFIS: Adaptive-network-based fuzzy inference system, IEEE Trans. Syst. Man Cybern. 23 (3) (1993) 665–685.
[23] T. Takagi, M. Sugeno, Derivation of fuzzy control rules from human operator’s control actions, in: IFAC Symp. Fuzzy Inf. Knowledge Repres. Dec.Analysis, 1983, pp. 55–60.
[24] SimPowerSystems 4.3 user’s guide, Available at: http://www.mathworks.com/products/simpower/.