International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 10, Issue 8 (August 2014), PP.18-26

Application of Distributed Static Series Controller (DSSC) Modified with Fuzzy Logic and ANFIS Controllers as Auxiliary Controller in Extenuation of Sub-Synchronous Resonance

V.Narasimha Murthy[1], P. Bhaskar Prasad[2], K. Harinath Reddy[3]
[1]Corresponding Author, Department of Electrical and Electronics Engineering, Annamacharya Institute of technology and sciences, Rajampet, Kadapa. India.
[2]Assistant Professor, Department of Electrical and Electronics Engineering, Annamacharya Institute of technology and sciences, Rajampet, Kadapa, India.
[3] Assistant Professor, Department of Electrical and Electronics Engineering, Annamacharya Institute of technology and sciences, Rajampet, Kadapa. India

Abstract:-When a series compensated long transmission lines connects to a steam-turbine generator, it results in the unfavorable phenomenon called as sub-synchronous resonance (SSR). Subsynchronous Resonance (SSR) problems in series compensated steam-turbine power systems co-exist with the beneficial effects provided by the series capacitors. Damage of Turbine generator shaft might occur due to this phenomenon. To damp these SSR and Low-Frequency Oscillations (LFOs), Flexible AC Transmission Systems (FACTS) controllers are preferred. It is possible to damp Sub-Synchronous Resonance (SSR) caused by series capacitance with the help of an auxiliary SSR damping controller on DSSC. The intension of this paper is to assert the performance of the Distributed Static Series compensator (DSSC) as a member of D-FACTS family in mitigation of SSR. Two controllers i.e. Fuzzy Logic Based Damping Controller (FLBDC) and Adaptive Neuro Fuzzy Inference System (ANFIS) controllers are designed and implemented in the conventional controller of DSSC to provide effective damping. The ANFIS constructions were trained utilizing the generated database by the FLC of the DSSC.The Fast Fourier Transform (FFT) is carried out in order to evaluate the effect of DSSC based on ANFIS controller in damping SSR and LFO. The simulations were carried out with MATLAB/Simulink to IEEE second benchmark (SBM) model combined with DSSC module and the results were compared with the conventional controllers.

Keywords: SSR,DSSC,FLBDC,ANFIS

I. INTRODUCTION

The continuous growth in demand for electrical power requires the interconnection of large power systems where large amounts of power to be transmitted over a long distance. For this long ac transmission lines with series capacitive compensation must be the selective solution to enhance the power transfer capability [1]. Even so, usage of series capacitors may cause sub synchronous resonance [2], the condition in power system significant energy exchanges between electrical networks and mechanical units.

For the countermeasure of SSR we have devices such as, dynamic stabilizers [3-5], Flexible AC Transmission systems (FACTS) devices [6-12] have been proposed. Proposal in ref [4] is based on controlling sub-synchronous frequency of line current to zero and hence at the critical frequencies of the generator shaft, the network damping is increased. In ref [6] SVC and TCSC are proposed with two separate conventional controllers. SVC is a conventional lead-lag controller and the damping characteristics of the TCSC have been added through constant current control of TCSC. The hybrid compensation scheme with a combination of TCSC and fixed capacitor has been proposed in ref [13] to damp the SSR.

In the most of the above mentioned articles, the auxiliary damping controllers designed, based on linearized system model based and the controller parameters are tuned to some specified operation states. When the system is subjected to the large disturbances, the condition of the system will result in an extremely nonlinear behavior and the controllers would fail to dampen the oscillations, even destabilizing impact may be supplemented to the disturbance by the controller through for instance inserting negative damping [14–17].

To suppress such problems, the nonlinear dynamics of the power system should be considered by control scheme. Some of the power systems, stabilizing methods to control have been proposed [18]. With the development of fuzzy logic controller recently, functions based on human experiences, the controller provides a taxonomic way to control the nonlinear process. It is general formulation that can improve execution of closed loop control systems. A well-defined fuzzy controller can give better performance in the presence of fluctuations in parameters, load and external disturbances. In ref [17, 19], it shows that FLBDC with devices like PSS and FACTS, improved power system in a wide range of operating conditions. The mitigation of SSR is possible with FLBDC and it can reduce the low frequency oscillations respectively [20]. Once the Fuzzy logic based controller is developed it can be transformed into an adaptive network termed as Adaptive Neuro-Fuzzy inference system (ANFIS). This controller takes the all the advantages of neural network controller and enhances the Fuzzy Logic controller.

This paper utilizes the DSSC as a substitute in place of conventional FACTS devices. Normally, FACTS devices have some limitations that are haltered the widespread deployments of these devices such as, complexity, high initial cost, the entire system will be shut down when a failure takes place in one single point. Recently FACTS, distributed in nature, named Distributed-FACTS [25] devices have been bought in contrast to the above limitations. These devices are distributed all along the transmission line. D-FACTS are implemented in damp low frequency oscillations, enhancement of transient stability and alleviation of sub-synchronous resonance [26-28]. The Distributed Static series compensator (DSSC) is the deduced concept of static synchronous series compensation (SSSC). DSSC offers lower cost and more reliable compared to the SSSC. In [28] authors proposed that mitigation of SSR with auxiliary damping controller have been incurred with trial and error method.

II. POWER SYSTEM DESCRIPTION FOR SSR ANALYSIS

The power system network for this study is an IEEE second benchmark [29], shown in fig: 1, used to study sub-synchronous resonance and particularly torque amplification after a fault on a series-compensated power system. It consists in a single generator (600 MVA/22kV/60 Hz/3600 rpm) connected to an infinite bus via two transmission lines, one of which is 55% series-compensated. The compensation capacitor introduces sub-synchronous mode, after a three-phase fault has been applied and cleared, there can be observed a phenomenon that excites the oscillation torsional modes of the multi-mass shaft and the torque amplification. The mechanical system is modeled by 3-masses: mass 1 = generator; mass 2 = low pressure turbine (LP); mass 3 = high pressure turbine (HP).

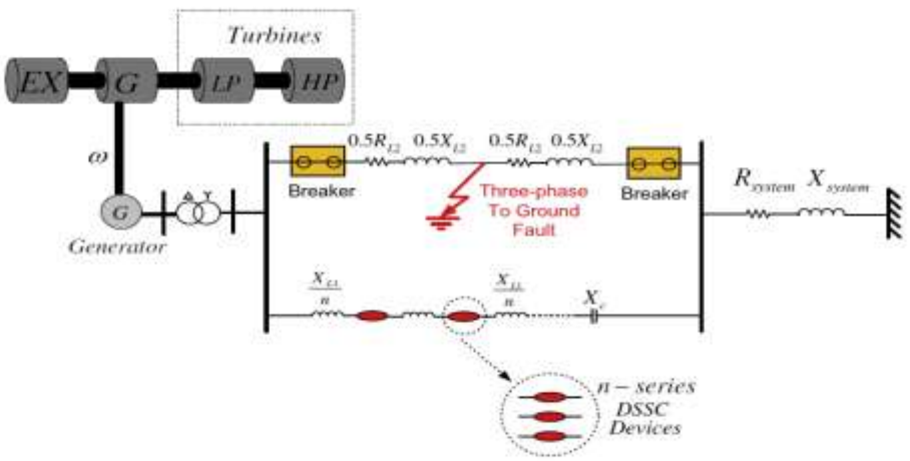


Figure: 1 The IEEE SBM model combined with DSSC

III. THE DSSC MODULES COMBINED SYSTEM MODEL

DSSC is a 1- Ø model of FACTS controller named Static Synchronous series compensator, with reduced size and distributed in nature for the control of power flow in transmission lines. Since DSSC is a 1-Ø device [30], individual DSSC modules are deployed in all the three phases of the transmission line to uphold symmetry in power flow. Each module is mounted on each of the transmission line conductors or as an alternative for conductor holding clamp on insulator discs. In doing so it takes an advantage of being no need of phase to ground insulation in counterpoint with the SSSC. With respect to its inherent nature of low-power, the distributed static series compensator calls for a number of DSSC modules along a single transmission line.

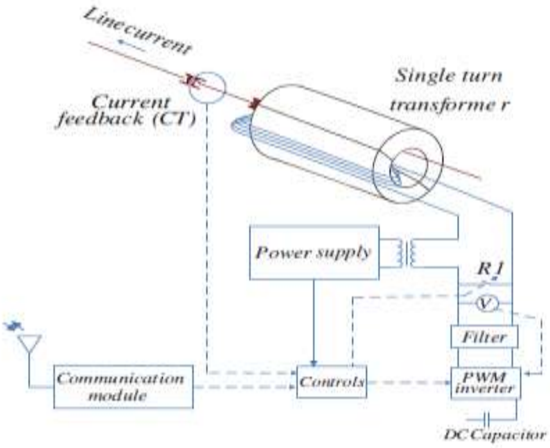


Figure: 2 Schematic circuit of DSSC module

The schematic representation of DSSC module is shown in fig: 2. The main components of this module are: a current transformer to provide a feedback current signal; a controller; single turn transformer (STT) to inject a control voltage into the line; a power supply and communication devices to send/receive signals to/from the other modules or centralized controllers [31]. LC filters to filter-out harmonics in the generated control voltage. By pass network, one of the advantages of this module is that, in an event of sleep or failure of any module, it can be bypassed. These events are controlled by the centralized remote controllers, communicating through wireless or PLC networks [32]. The Single turn transformer is in this module is constructed with a high turn ratio of (100 : 1) with transmission line as a secondary winding. Due to this the rating if the switching valves reduced and hence IGBTs can be used for economical implementation. The transmission line conductor is surrounded by the transformer is to provide a complete path to the magnetic circuit.

IV. CONVENTIONAL CONTROLLERS

The power flow in transmission line could be controlled either by direct or indirect control of schemes. For the direct control scheme, the control over the angular position ω and output voltage V_q are considered and for the indirect control scheme, the angular position only considered [34]. In this paper utilizes the indirect scheme of control, keeping the output voltage proportional to DC link. The scheme of control is as shown in fig: 3.

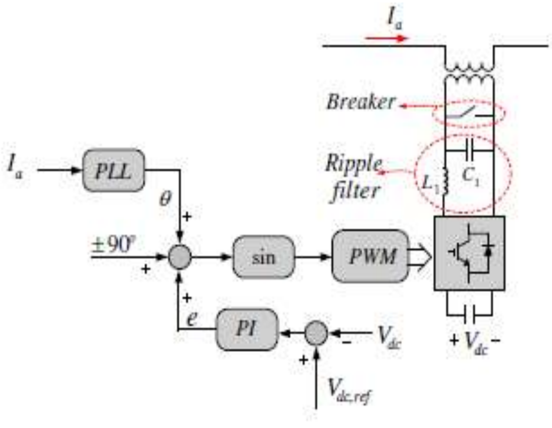


Figure: 3 control scheme of DSSC

The purpose of this controller is to inject a synchronous voltage in orthogonal to the line current I_a and to hold the changes in the DC bus capacitor. To control the DC capacitor voltage, a small error 'e' is required, which is result of the PI controller obtained by comparing the DC capacitor voltage V_{dc} with reference voltage $V_{dc\ ref}$.

V. CONTROLLER DESIGN

The main objective of the DSSC module is to damp Subsynchronous resonance. These modules are connected to a series compensated transmission lines. The purpose of DSSC module is to inject a compensating voltage in quadrature with the line current to control the power flow in the transmission lines. Auxiliary controllers are required to enhance its ability to mitigate low frequency oscillation and Subsynchronous resonance phenomenon [26-28]. His section proceeds with the designing of conventional controller, fuzzy logic based and ANFIS damping controllers.

a. Fuzzy Logic Controller:

Generally, the power system is considered to have nonlinear behavior. For this type of systems to yield better performance, the Fuzzy Logic controller is the selective solution. The conventional controllers are confined to a limited set of optimal values; fuzzy logic can be defined over infinite selective logics between 0 and 1. Instead of Boolean implements only two logics 0 and 1. Dynamic stability analysis, unit commitment, control of load frequencies were implemented with fuzzy logic controllers in which the control is based on human experiences/intelligence. Taking the changes in angular position $\Delta\omega$ of the rotor system and its derivative $d/dt\Delta\omega$ as inputs, shown in fig by using a set of rules defined provides an appropriate $V_{dc\ ref}$ to compare with the dc bus capacitor voltage.

The fuzzy controller is divided into four essential parts, they are Fuzzification, Fuzzy inference engine, Rule-base and Defuzzification. The Fuzzification involves conversion of input signals into fuzzy sets. Fuzzy inference engine and rule base are the heart of the fuzzy system, all the control strategy is defined through a set of possible rules and membership functions.

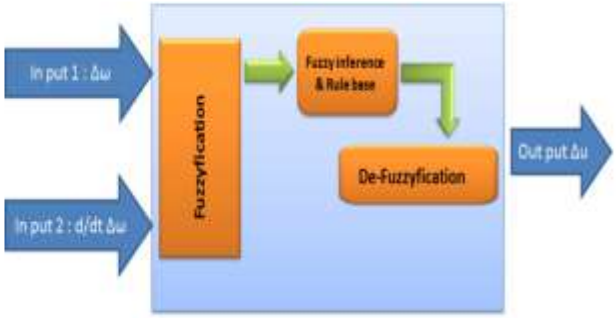


Figure: 4 scheme of fuzzy controller

The rules are chosen based on human experiences and system performance. On Defuzzification part the crisp values of the fuzzy rules are generated.

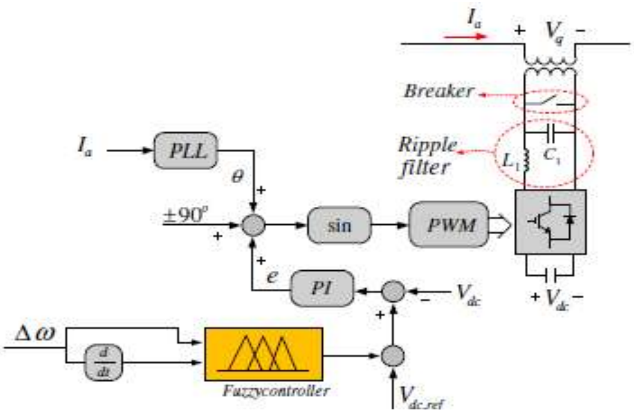


Figure:5 Fuzzy Logic Based Damping Controller added on to DSSC

b. ANFIS based controller:

In this paper, the Sugeno-type fuzzy inference system (FIS) controller is used in the proposed Adaptive Neuro-Fuzzy Inference system (ANFIS) . The parameters to FIS controller are decided by back propagation technique [36]. By taking $\Delta\omega$ and $d/dt\Delta\omega$ are taken as inputs, the ANFIS controller is determined. The output signal is calculated by using input variable membership functions.

The proposed ANFIS controller consists of five layers: input layer, input membership function layer, layer of rules, output membership function layer, and output layer. The fuzzy controller to generate output, it uses nine rules and two input membership functions in each variable as shown in fig:6.

The ANFIS controller is constructed using simple pattern using the rules are as follows [37].

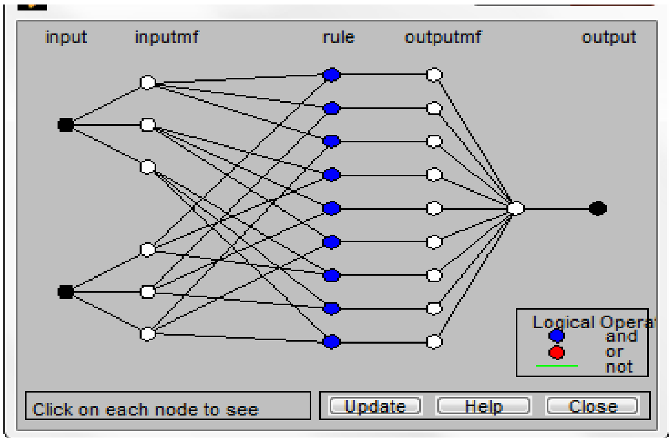


Figure:6 ANFIS architecture.

A. ANFIS Architecture :

Example: A two inputs (x and y) and one output (z) ANFIS

Rule 1 : IF x is A and y is B, then then $f_1 = p_1 x + q_1 y + r_1$

Rule 2 : IF x is A and y is B, then then $f_2 = p_2 x + q_2 y + r_2$

ANFIS architecture

Layer 1: adaptive nodes

$\mu_{A_i}(x)$ and $\mu_{B_i}(x)$: any appropriate parameterized membership functions

$$\mu_{A_i}(x) = \frac{1}{1 + [\frac{(x - c_i)^2}{a_i^{\,2}}]^{b_i}}$$

$\{a_i, b_i, c_i\}$ ➔ premise parameters

Layer 2: fixed nodes with function of multiplication

$O_{2,i} = w_i = \mu_{A_i}(x) \times \mu_{B_i}(x) \qquad i = 1,\ 2$ (firing strength of a rule)

Layer 3: fixed nodes with function of normalization

$$O_{3,i} = \overline{w}_i = \frac{w_i}{w_1 + w_2} \qquad i = 1,\ 2$$ (Normalized firing strength)

Layer 4: adaptive nodes

$O_{4,i} = \overline{w}_i f_i = \overline{w}_i (p_i x + q_i y + r_i)$

$\{p_i, q_i, t_i\}$: consequent parameters

Layer 5: a fixed node with function of summation

$$O_{5,1} = overall\ output = \sum_i \overline{w}_i f_i$$

B. Hybrid Learning Algorithm

When the premise parameters are fixed:

$$f = \frac{w_1}{w_1 + w_2} f_1 + \frac{w_2}{w_1 + w_2} f_2$$

$= \overline{w}_1 f_1 + \overline{w}_2 f_2$ ➔linear function of consequent parameters.

$$= (\overline{w}_1 x) p_1 + (\overline{w}_1 y) q_1 + (\overline{w}_1) r_1 + (\overline{w}_2 x) q_2 + (\overline{w}_2 y) q_2 + (\overline{w}_2) r_2$$

The basic steps to be followed to construct ANFIS controller for DSSC are as follows:

Step:1 Design Simulink model with Fuzzy Logic controller and simulate with the given rule base

Step:2 While simulating the model with fuzzy controller, the ANFIS controller gathers the training data

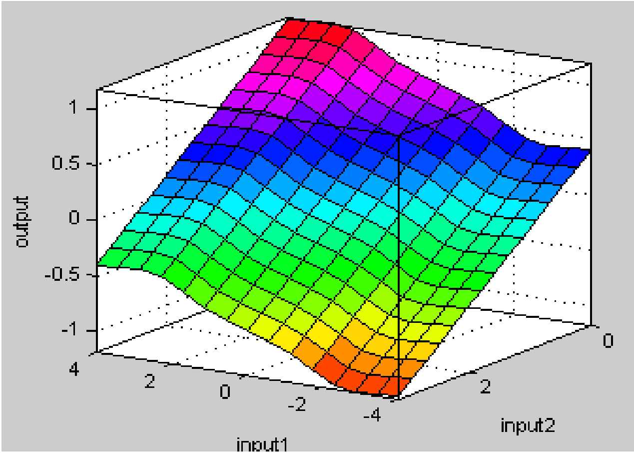
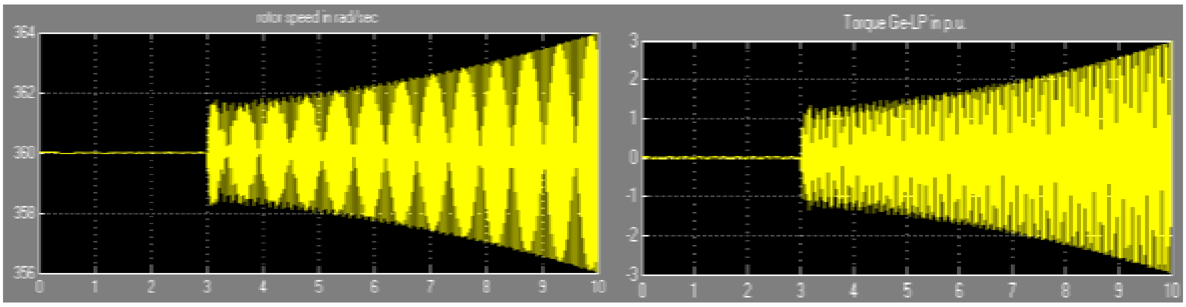


Figure:7 control surface of ANFIS based DSSC controller

Step:3 The training data is provided by the two inputs, speed deviation Δω and its derivative d/dtΔω. Step:4 Use anfisedit to generate ANFIS.fis file. Step:5 The data obtained in step:2 is loaded and generate the FIS with bell MFs. Step:6 the collected data is trained with the generated FIS around 20 Epochs. Step:7 save this ANFIS controller in Simulink with DSSC controller

VI. SIMULATION RESULTS AND DISCUSSION

In order to evaluate the performance of DSSC controller, the transmission line is adjusted for 55% of compensation and three-phase to ground fault is set in one of the lines at time 3 s and removed after 0.0168s. In the first case, the simulation results and FFT analysis of rotor speed and torque between generator and low-pressure turbine are shown in figure without any controllers. The FFT analysis for 55% of compensation, mode 1 oscillations are dominant at Subsynchronous frequency of 26 Hz.



(a) (b)

Figure:8 simulation results without any controller (a) rotor speed in Rad/s (b) the electrical torque between generator and low pressure turbine in p.u.

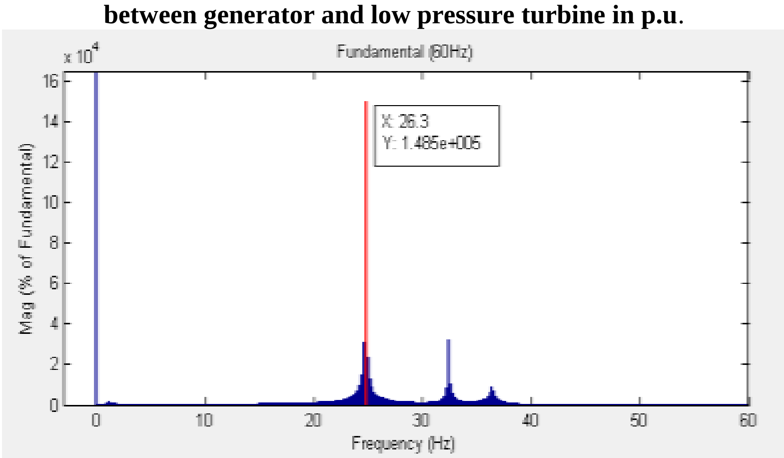
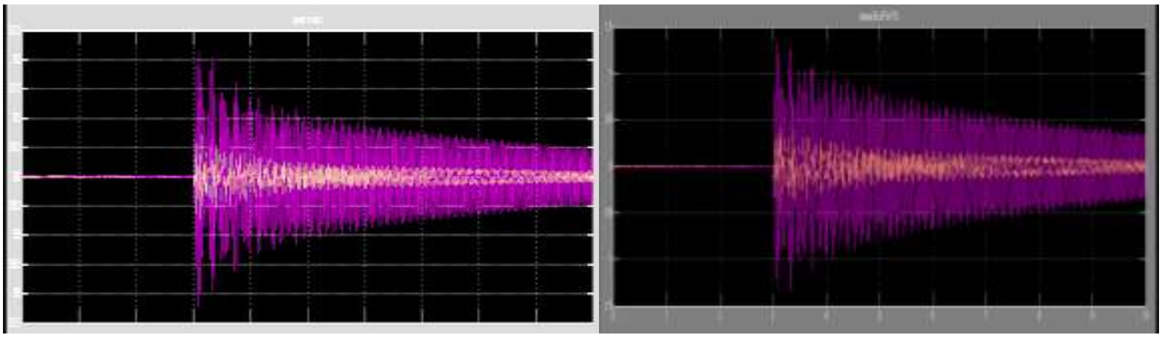


Figure:9 FFT analysis on generator rotor shaft in order to validate the dominate mode.

In second case DSSC controller is provided first with conventional controller, later with a fuzzy logic based damping controller. The Fuzzy logic based damping controller results are compared with conventional controllers. The conventional damping controller used here is PSO based damping controller provided with the optimal solution [35]. The FFT analysis shown in the figure below is for fuzzy logic controller based Damping controller.



(a) (b)

Figure:10 Simulation results comparison between FLBDC and CDC based DSSC controllers (a) speed in rad/s (b) the electrical torque between generator and low pressure turbine in p.u.

Observing the FFT analysis, it can be observed that the magnitude (% magnitude of the fundamental) is reduced at dominating mode 1 oscillations at 26 Hz.

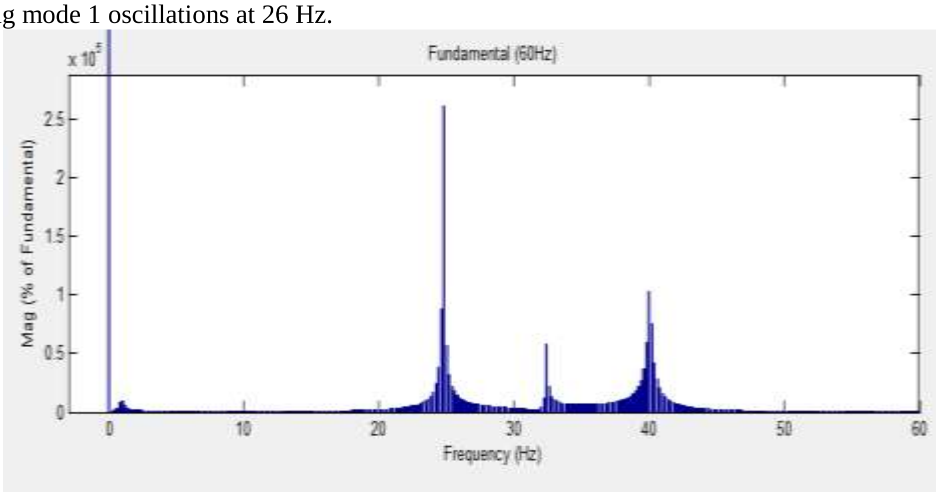
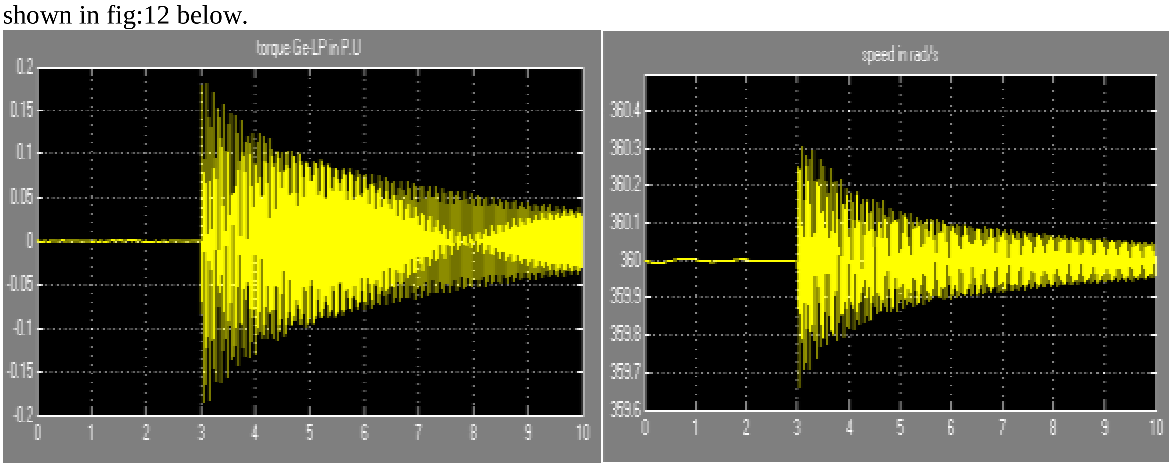


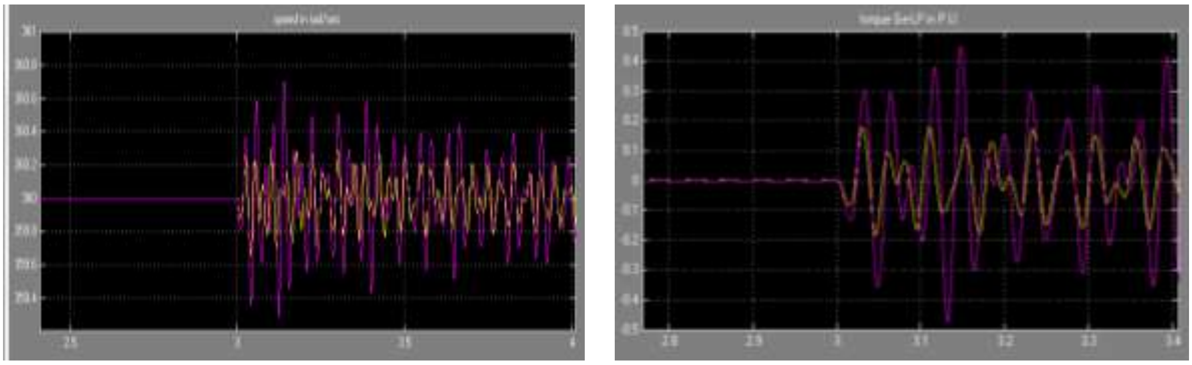
Figure:11 FFT analysis of generator rotor speed when DSSC is enhanced with FLBDC.

In the third case DSSC is provided with ANFIS controller, the performance of the controller is improved further with significant improvement. The results were compared with the FLBDC controller as shown in fig:12 below.



12(a) 12(b)

Figure:12 Simulation results of DSSC controller enhanced with ANFIS controller (a) speed in rad/s (b) the electrical torque between generator and low pressure turbine in p.u.



13(a) 13(b)

Figure:13 Simulation results comparison between ANFIS controller and FLBDC based DSSC controllers(a) speed in rad/s (b) the electrical torque between generator and low pressure turbine in p.u.

The FFT analysis provides support to the ANFIS proposal in this paper which enhances the performance of the DSSC in mitigating subsynchronous resonance.

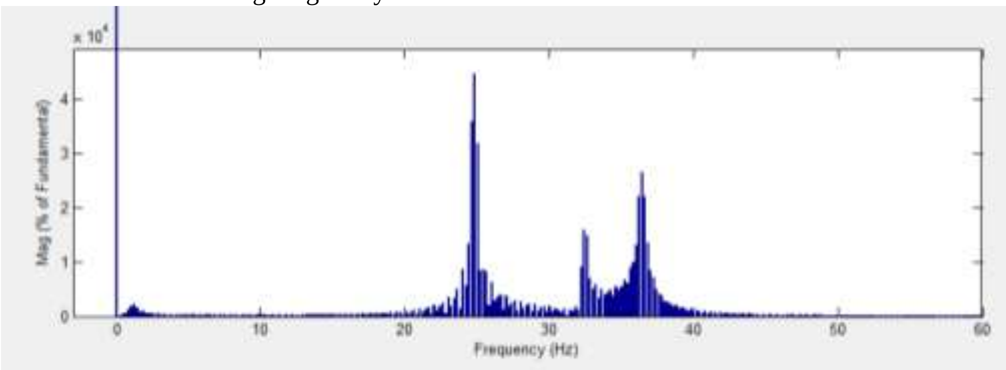


Figure: FFT analysis on generator rotor speed when DSSC is enhanced with ANFIS.

VII. CONCLUSION

This paper, from the simulation results and discussions show that the performance of the DSSC controller alone is not well. When the DSSC controller is provided with any of the auxiliary controllers like conventional damping controller (CDC), FLBDC and ANFIS then there is an improvement in the performance of the controller. CDC fails to provide alleviation of Low frequency oscillation besides SSR damping. Superior performance is provided by the ANFIS controller compared to FLBDC and CDC. ANFIS and FLBDC not only improve the performance in damp SSR but also LFO alleviation. Hence it can be said that DSSC enhanced with Fuzzy and ANFIS controller is the best choice in damp Subsynchronous resonance and LFO in the power system.

REFERENCES

[1]. Mathur RM, Varma RK. Thyristor-based FACTS controllers for electrical transmission systems. New York, USA: IEEE Press and Wiley Interscience; 2002.

[2]. IEEE Subsynchronous Resonance Working Group, ‘‘Terms, definitions and symbols for Subsynchronous oscillations’’. In: IEEE Trans power apparatus and systems, vol. PAS-104(6). 1985. p. 1326–1334.

[3]. Mohammad S. Widyan; ‘‘On the effect of AVR gain on bifurcations of Subsynchronous resonance in power systems’’. Electr Power Energy Syst 2010;32(6):60–76.

[4]. Bongiorno M, Svensson J, Angquist L. On control of static synchronous series compensator for SSR mitigation. IEEE Trans Power Electron 2008;23(2):735–43.

[5]. Ghorbani A, Pourmohammad S. A novel excitation controller to damp subsynchronousoscillations.Electr Power Energy Syst March 2011;33(3):411–9.

[6]. Varma RK, Auddy S, Semsedini Y. Mitigation of subsynchronous resonance in a series-compensated wind farm using FACTS controllers. IEEE Trans Power Del 2008;23(3):1645–54.

[7]. Domingues de Jesus F, Hirokazu Watanabe E, Felipe Willcox de Souza L, Alves JER. SSR and power oscillation damping using Gate-Controlled Series Capacitors (GCSC). IEEE Trans Power Del 2007;22(3):1806–12.

[8]. Khaparde SA, Krishna V. Simulation of unified static VAR compensator and power system stabilizer for arresting sub-synchronous resonance. IEEE Trans Power Syst 1999;14(3).

[9]. El-Moursi MS, Bak-Jensen B. Novel STATCOM controller for mitigating SSR and damping power system oscillations in a series compensated wind park. IEEE Trans Power Electron 2010;25(2).
[10]. Alomari MM, Nandakumar MP, Zhu JG. Bifurcation control of subsynchronous resonance using
[11]. SindhuThampatty KC, Nandakumar MP, Cheriyan Elizabeth P. Adaptive RTRL based neuro controller for damping subsynchronous oscillations using TCSC.EngApplArtifIntell 2011;24(1):60–76.
[12]. Padiyar KR, PrabhuNagesh. Design and performance evaluation of subsynchronous damping controller with STATCOM. IEEE Trans Power Del 2006;21(3):1398–405.
Rai D, Faried SO, Ramakrishna G, Edris A. Hybrid series compensation scheme capable of damping subsynchronous resonance. IET Gen TransmDistrib 2010;4(3):456–66.
[13]. Zimermann (Hans-Jurgen) H-J. Fuzzy set theory and it's applications. 3th ed. Kluwer Academic Publishers; 1996.
[14]. Lee CC. Fuzzy logic in control systems: fuzzy logic controller. IEEE Trans Syst Man Cybern 1990;20:404–18.
[15]. Reza Langari. Fuzzy control synthesis and analysis.Wiley Publications; 1995. [17] Zarghami M, Crow ML, Jagannathan S. Nonlinear control of FACTS controllers for damping inter-area oscillations in power systems. IEEE Trans Power Del 2010;25(4).
[16]. Leondes Cornelius T. Fuzzy theory systems: techniques and applications. London: San Diago, Calif. Academic Press; 1999.
[17]. Hiyama T. Rule-based stabilizers for multi-machine power system. IEEE Trans Power Syst 1990;5:403–11.
[18]. Pahlavani MRA, MohammadpourHA.Damping of sub-synchronous resonance and low-frequency power oscillation in a series-compensated transmission line using gate-controlled series capacitor.Electr Power Sys Res 2011;81(2):308–17.
[19]. doBomfim ALB, Taranto GN, Falcão DM. Simultaneous tuning of power system damping controllers using genetic algorithms. IEEE Trans Power Syst 2000;15(1):163–9.
[20]. Kennedy J, Eberhart R, Shi Y. Swarm intelligence. San Francisco: Morgan Kaufman Publishers; 2001.
[21]. Ho SL, Yang S, Ni G, Lo EWC, Wong HC. A particle swarm optimization based method for multi objective design optimizations. IEEE Trans Magnet 2005;41(5):1756–9.
[22]. Shayeghi H, Shayanfar HA, Jalilzadeh S, Safari A. Design of output feedback UPFC controllers for damping of electromechanical oscillations using PSO. Energy Convers Manage 2009;50:2559–61.
[23]. Divan D et al. A distributed static series compensator system for realizing active power flow control on existing power lines. IEEE Trans Power Del 2006;22:642–9.
[24]. Khalilian M, Mokhtari M, Nazarpour D, Tousi B. Transient stability enhancement by DSSC with a fuzzy supplementary controller. J ElectrEngTechnol 2010;5(3):415–22.
[25]. Mokhtari M, Khalilian M, Nazarpour D. Damping of low frequency oscillations in power system with Distributed Static Series Compensator (DSSC). J Int Rev Model Simul (I.RE.MO.S) 2009;2(5).
[26]. Khalilian M, Mokhtari M, Golshannavaz S, Nazarpour D. Distributed Static Series Compensator (DSSC) for subsynchronous resonance alleviation and power oscillation damping. J Euro Trans Electr Power 2011. http://dx.doi.org/10.1002/etep.59.
[27]. IEEE SSR Working Group. Second benchmark model for computer simulation of subsynchronous resonance. IEEE Trans Power Apparatus Syst1985;104(5):1057–64.
[28]. Fajri P, Afsharnia S, Nazarpour D, Tavallaei MA. Modeling simulation and group control of distributed static series compensators. Am J EngApplSci 2008:347–57 [ISSN 1941-7020].
[29]. Deepak Divan. Distributed intelligent power networks-a new concept for improving T&D system utilization and performance. In: IEEE transmission and distribution conference. New Orleans, Louisiana; 2005.
[30]. Marihart DJ. Communications technology guidelines for EMS/SCADA systems. IEEE Trans Power Del 2001;16(2):181–8.
[31]. Mark Rauls. Analysis and design of high frequency co-axial winding transformers MS thesis. US: University of Wisconsin Madison; 1992.
[32]. Hingorani NG, Gyugyi L. Understanding FACTS: concepts and technology of flexible ac transmission system. NY: IEEE Press; 2000.
[33]. JavadKhazaie ,MaghsoodMokhtari, Mansour Khalilyan, DaryoushNazarpour. "Sub-Synchronous Resonance damping using Distributed Static Series Compensator (DSSC) enhanced with fuzzy logic controller". J. Khazaie et al. / Electrical Power and Energy Systems 43 (2012) 80–89.
[34]. J.R. Jang, ANFIS: Adaptive-network-based fuzzy inference system, IEEE Trans. Syst. Man Cybern. 23 (3) (1993) 665–685.
[35]. Dr. YuMing Zhang, "ADAPTIVE NEUROFUZZY CONTROL", EE699 (06790).