TRANSIENT STABILITY IMPROVEMENT BY D-FACTS DEVICES WITH AUXILARY NEURO- CONTROLLER

Seyedreza Aali

Sama Technical and Vocational Training Colleague, Sarab Branch, Islamic Azad University, Sarab, Iran
Email: seyedaali@yahoo.com

Abstract--*The distributed flexible AC- transmission system (D-FACTS) is a recently developed FACTS technology. Distributed static series compensator (DSSC) operates using the D-FACTS concept, which is to use multiple small-size single-phase converters instead of the one large-size three-phase series converter in the static synchronous series compensator (SSSC). Also, the DSSC has fewer prices with more capabilities. It places in transmission lines in a distributed method. This paper presents the application of artificial neural network (ANN) controller in DSSC auxiliary controller to improve transient stability in a two-machine, two-area power system. The simulations have been carried out using Matlab/Simulink and it verified DSSC based auxiliary ANN controller offers improved transient performances over the auxiliary classic controller used by the DSSC over a wide range of system operating conditions.*

Key words*: Distributed static series compensator (DSSC), Artificial Neural Network (ANN) Controller, Transient Stability, Distributed Flexible AC Transmission System (D-FACTS) Devices, and Auxiliary Nero- Controller.*

1. Introduction

The flexible AC transmission systems (FACTS) are technology operates with realizing a smart grid and achieving power flow control. FACTS devices, such as STATCOM, SVC, SSSC and UPFC can be inserted in series, parallel, or a combination of the two with the transmission line. These devices achieve more control functions, including voltage regulation, system damping and power flow control [1].

The static synchronous series compensator (SSSC) is one of the recently FACTS controllers. The SSSC with a transformer is connected in series with a transmission line [2].

Distributed FACTS (D-FACTS) devices are similar approach to the implementation of high power FACTS devices. The D-FACTS devices can provide a higher performance and lower cost method for enhancing reliability of transmission and distribution system and controllability, improving asset utilization and end-user power quality, while minimizing system cost and environmental impact. The concept of a Distributed Static Series Compensator (DSSC) is used to illustrate the feasibility of a D-FACTS approach. The DSSC using several voltage source converters distributed in transmission line injects a controllable voltage in

quadrature with the line current of a power system. It is capable of rapidly providing both capacitive and inductive impedance compensation independent of the line current [3], [4].

Power systems containing generators and power electronic based FACTS devices are large-scale nonlinear system, multivariable systems with dynamic characteristics over a wide range of operating conditions. The conventional linear control techniques (classic or PI controller) have been used to design the internal controllers of FACTS devices [1].

Nonlinear controllers such as fuzzy logic controller, neural network and etc can provide good performance over a wide operating range. These controllers also need no mathematical model of power system [5].

This paper designs auxiliary controller based neural network for the DSSC, followed by its transient-state analysis. An algorithm for training the ANN controller is back propagation (BP) algorithm and trained offline. Simulation shows DSSC based ANN auxiliary controller mitigates low frequency oscillations (LFO) better than classic controller. The performance of the ANN controller based DSSC compared with classic controller results in transient analysis. The proposed auxiliary controller improves transient stability and the power system is stable with this controller.

2. D-FACTS Devices

The DSSC can be considered as a SSSC that employs the D-FACTS concept and the concept of exchanging power through harmonic. DSSC inherits all the advantages of the SSSC and the D-FACTS, which are as follows: Comparing with the SSSC, the DSSC have three major advantages: 1) low cost because of the low-voltage isolation and the low component rating of the series converter and 2) high reliability because of the redundancy of the series converters 3) high control capability because of the DSSC can also be used to improve the power quality and system stability, such as low frequency oscillation damping [6], [7].

Fig. 1 shows a conceptual schematic of the DSSC deployed in a power line so as to alter the power flow by controlling the line impedance.
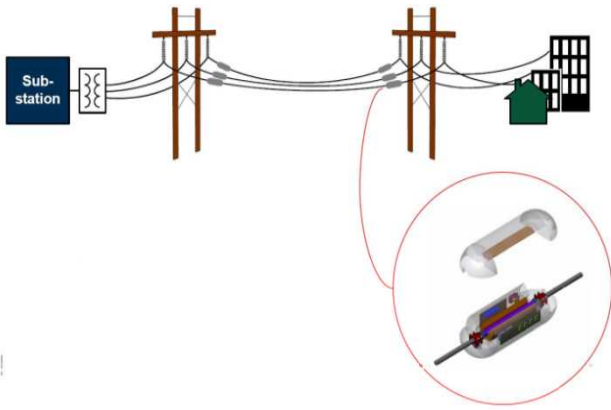
Fig. 1. D-FACTS placed on the power line

It consists of mass-produced power electronics and communications components. The DSSC modules apply conductor clip-on power electronics converters that float electrically and mechanically on a power line and increase or decrease the line impedance, and can inject positive or negative impedance to push current from line or pull current into line [8].
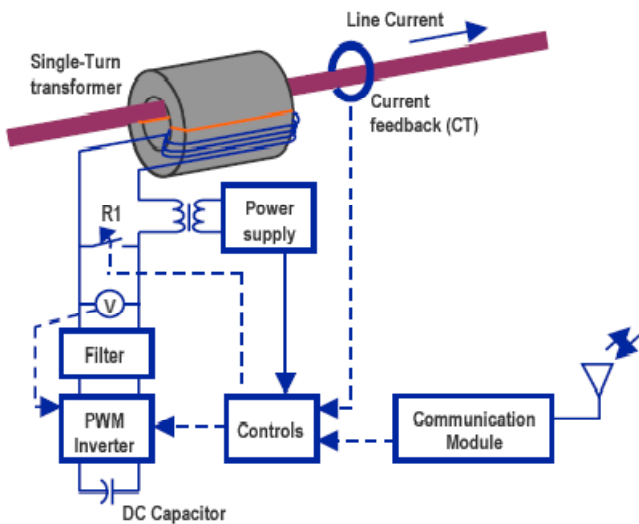

Fig. 2. the DSSC unit configuration

3. Impact of DSSC on Power System

The DSSC is placed in series to the transmission line and has the ability of injecting a synchronous voltage, which is orthogonal to the line current directly into the transmission conductor. Hence, the transmitted power obtains a parametric function of the injected voltage (V_q) and can be expressed as [9]:

$$P_{12} = \frac{V_1.V_2}{X_L}\sin\delta - \frac{V_1.V_q}{X_L}\cos(\delta/2).\left[\frac{\sin(\delta/2)}{\sqrt{(\frac{V_1+V_2}{2V_2})^2 - \frac{V_1}{V_2}\cos^2(\delta/2)}}\right] \quad (1)$$

Where
V_1: and V_2 The bus voltage magnitudes
δ The voltage phase difference; and
X_L The impedance of the line, assumed to be purely inductive

The DSSC can change the power of transmission line, simply by reversing the polarity of the injected ac voltage. Fig.3 shows the variation of the transmitted power verses phase angle with different quadrate voltage injections for equal bus voltage magnitudes [10].
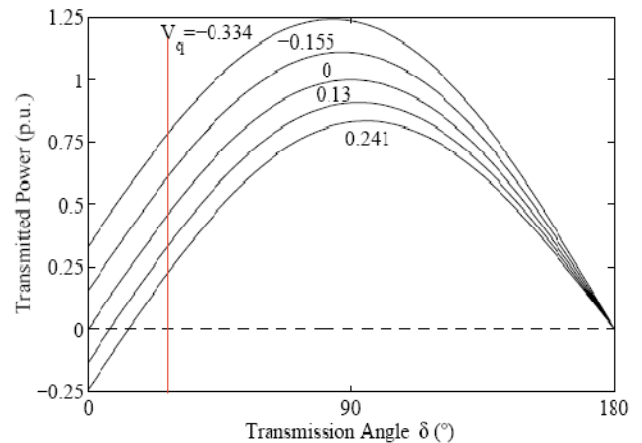

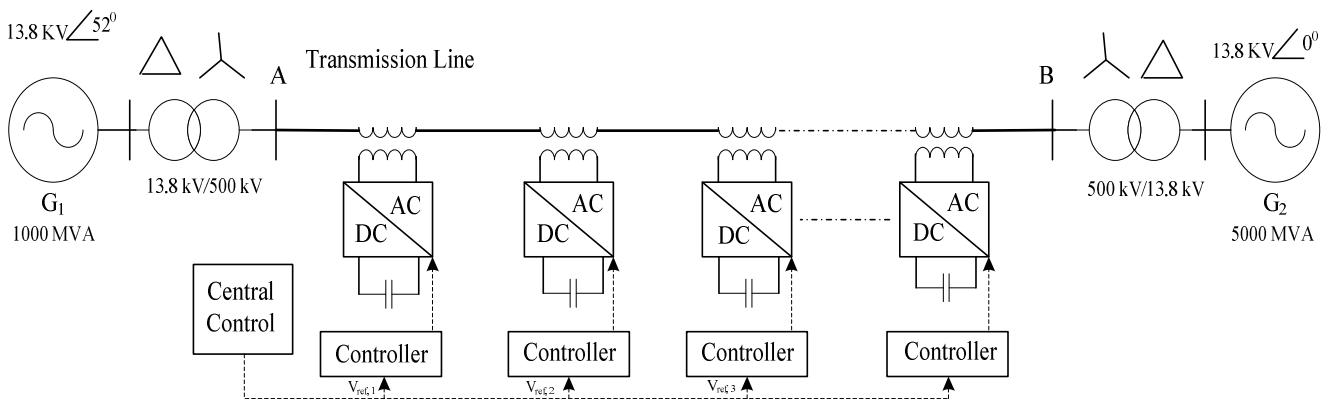Fig. 3. Variations of transmitted power by quadrate voltage injection

Fig. 4. DSSC model in two-machine system for transient stability test

4. The Control Strategy of DSSC

The central control generates the reference signals for the series converters of the DSSC [7].

A. The DSSC Controller

To control the multiple converters, DSSC consists of three types of controllers; they are central controller, series control, as shown in Fig. 5. The phase-locked loop (PLL) in the series converter extracts phase (θ) from the line current. The phase shifter changes the phase θ to $\theta - 90^0$ to increase power flow in transmission line. The voltage regulator regulates DC voltage and it approaches to reference DC-voltage. Hence, The DSSC inject voltage is in quadrature with the line current, and control active, reactive power in the transmission line.
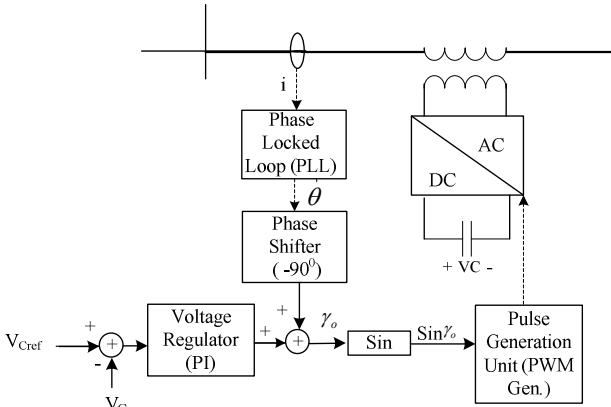

Fig. 5 the controller strategy of the DSSC

The influence of FACTS controllers and these controllers with additional- damping controller on the synchronizing power and damping power of a single machine infinite bus system has been examined in [1], [11], [12].

To damping the oscillations and enhancement of stabilization, the auxiliary controller should be added to DSSC controller, Gain K_1, K_2 was chosen by trial and error method [13], [14]. To make the DSSC able to mitigate low frequency power oscillation and stabilize the system, a control loop was added in DSSC controller shown in Fig. 6.

The classic controller fails to perform satisfactorily under parameter variations nonlinearity disturbance, etc. recently, neural network based controllers provide fast dynamic response while maintaining stability of the converter system over wide range (transient stability).
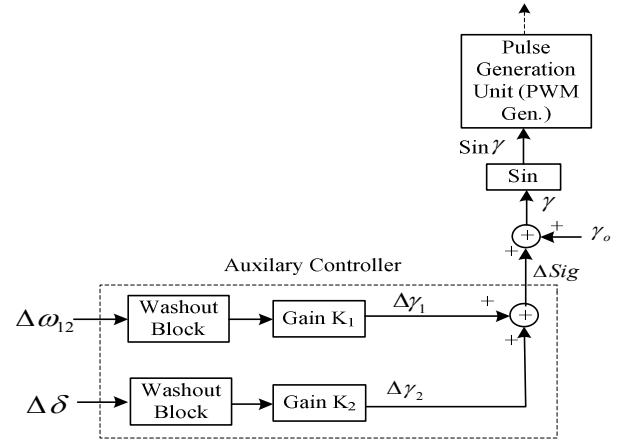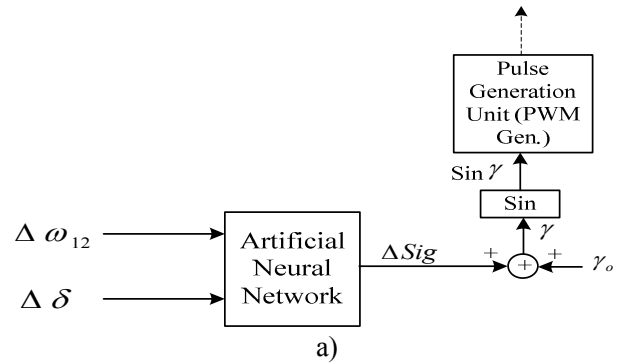

Fig. 6   The suplementary controller based conventional controller

B. The Auxillary Controller baseed Artifical Neural Network

The multilayer perceptron (MLP) neural network (NN) can be used as a general function approximator. It can approximate (or estimate) any function with a finite number of discontinuities arbitrarily well, given sufficient neurons in the hidden layer [15].

For improving the performance of a UPQC, a MLP - type NN-based controller is designed. This network is designed with three layers, the input layer with 7, the hidden layer with 5, and the output layer with 3 neuron, respectively. The large data of the derivations of load angle ($\Delta\delta$), derivations of rotor speed ($\Delta\omega$) and $\Delta\gamma_1 + \Delta\gamma_2$ (ΔSig) for and intervals from the classic method are collected and are stored in the Matlab workspace. These data are used for training the NN. The NN is trained for outputting fundamental maxillary signal (ΔSig).
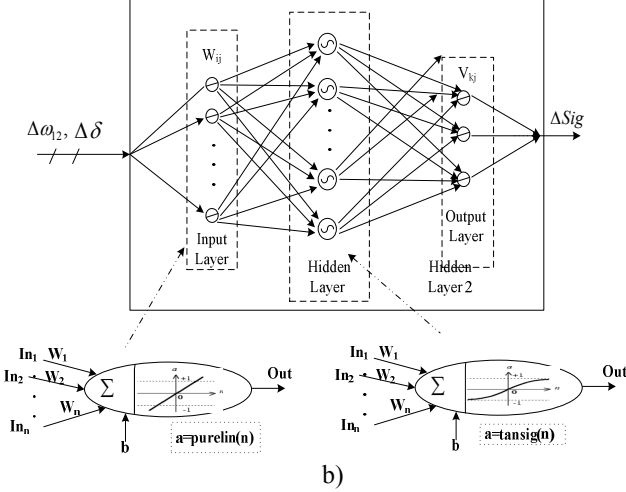

a)

Fig. 7. a) The suplementary controller based MLP neural network, b) the architect of neural network

Fig. 8. Training validation and test curves of neural network

5. The Procedure of Training ANN

The ANN is trained by varying the weights W_{ij} and the biases B_j. The training criterion is taken as the mean square error of the ANN output with a value of 0.0001 and the error function is defined to following equation.

$$J = \sum_{i=1}^{N} E(i)^2 \qquad (2)$$

Where N is the number of output neurons and $E(i)$ is the instantaneous error between the actual and estimated values of the output. The training is completed when the value of J is less than 0.0001 [16]. Before starting training, weights are started with small random values to decrease the chance of prematurely saturating the logistical neurons and thus reducing the training speed. The common principle of second order algorithms is to compute a descent direction obtained by a linear transformation of the cost function gradient. For the gradient algorithm, the weights are updated at each step according to:

$$W(t+1) = W(t) + \Delta W \qquad (3)$$

$$\Delta W_{ij} = -\eta \frac{\partial J}{\partial W_{ij}} \qquad (4)$$

Where η is the learning coefficient. If η is large, learning occurs quickly but if it is too large it may lead to instability and errors may even increase. A large learning coefficient might lead to oscillations in the convergence trajectory, while a small learning coefficient produces a smooth trajectory at the cost of slow convergence speed [17].

The performance of the proposed detection method using artificial neural network (ANN) based DSSC has been simulated in Matlab/Simulink environment. The applied learning samples are input-output samples selected from several simulations with the machine being controlled by the auxiliary classic controllers. These samples cover different conditions, normal and faulty ones. Fig.8 shows the training, validation and test errors to check the progress of training. These results are reasonable, since the test set error and the validation set error have similar characteristics, and they don't appear that any significant over fitting has occurred.
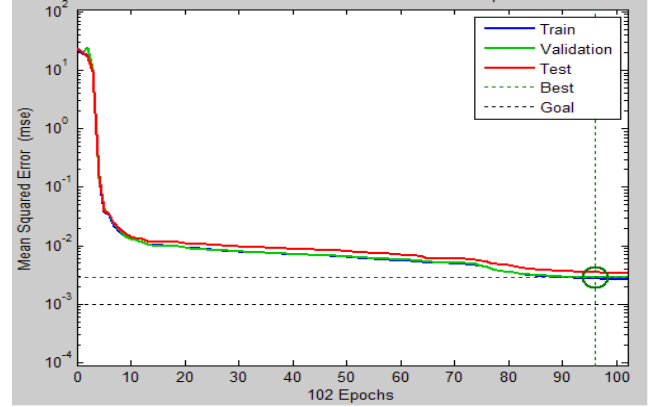
6. The Results of Simulation

A. Low Frequency Oscillation (LFO) Damping

In an attempt to verify the response of the transient-state, damping controller based ANN shown in Fig. 7. For a large disturbance, a relatively strong transient was created by connecting a small resistor at bus A in Fig. 6 at t= 5 sec and disconnecting it at t=5.085 sec. Fig. 9 shows that the DSSCs with classic or ANN auxiliary controller damps the oscillations after fault; however, the DSSCs with ANN controller showed a higher influence in oscillation damping in comparison with the classic auxiliary controller.
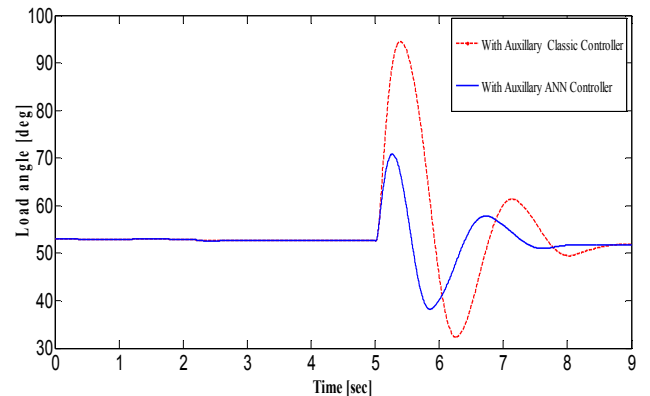

Fig. 9.. Comparing between LFO damping based DSSC with auxillary classic controller and DSSC with auxillary ANN controller

B. Transient Stability Analysis

A three-phase fault with duration of 0.085 s was applied in bus A near machine G1. Fig .10, 11 show that improvement of the transient stability by the ANN auxiliary controller is better than classic controller. When DSSCs are equipped with a supplementary ANN controller, however, the system became stable after a severe disturbance.
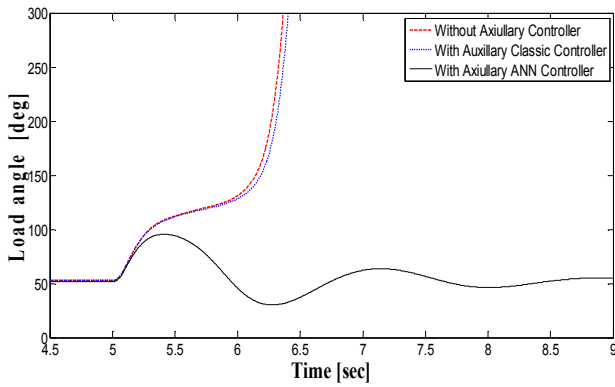
Fig. 10. Rotor angle deviation after the fault with ANN and classic controller
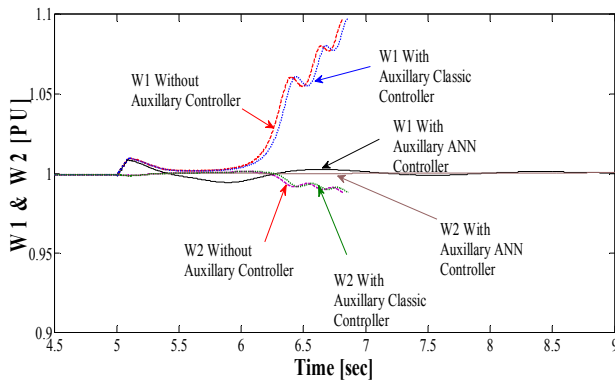

Fig. 11. Angular speed of the machines variation after the fault with ANN and classic controller

Fig. 12 indicates the machine voltage variations after the fault with ANN and classic controller. It is seen DSSC based ANN auxiliary controller regulate the bus voltage of the generators.
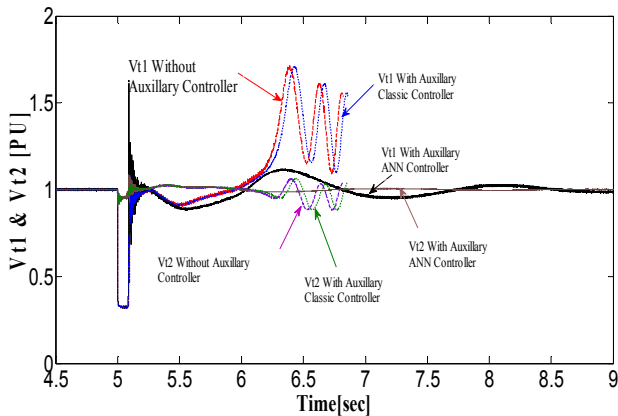

Fig. 12. Machine voltage variation after the fault with auxiliary ANN and classic controller

Fig. 13 shows the voltage of capacitors (DC- link) in different auxxillery controllers. The DC deriviation of capacitors in each phase with ANN auxxillery controller is less than oher controllers. As illustrated in Fig. 12 the capacitors voltages are balancing with using the

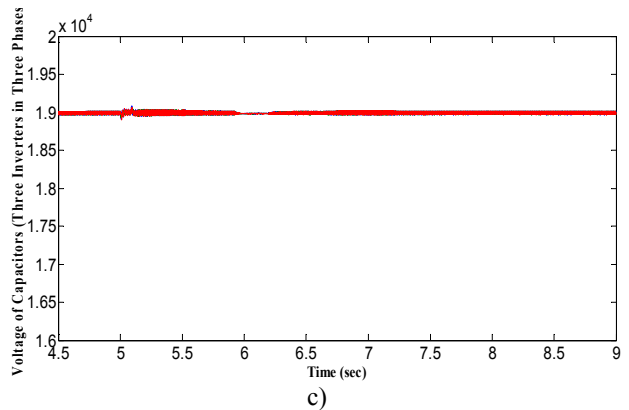purposed controller and the each of them track the reference value (V_{dcref}).
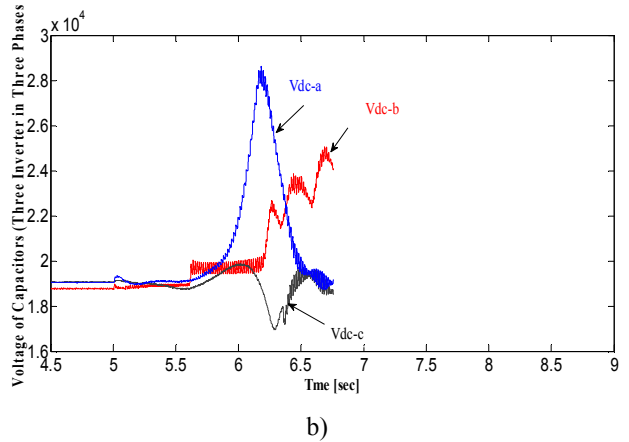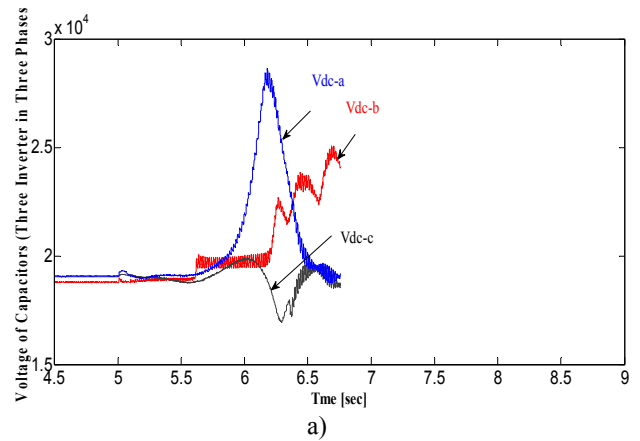

a)

b)

c)

Fig. 13. the voltage of capacitors a) without auxillery controller, b) with auxxillery classic controller and c) with ANN auxxillery controller

Fig. 14 shows the variation of ANN output signal (ΔSig) after the fault in terms of transient stability enhancement of the system.
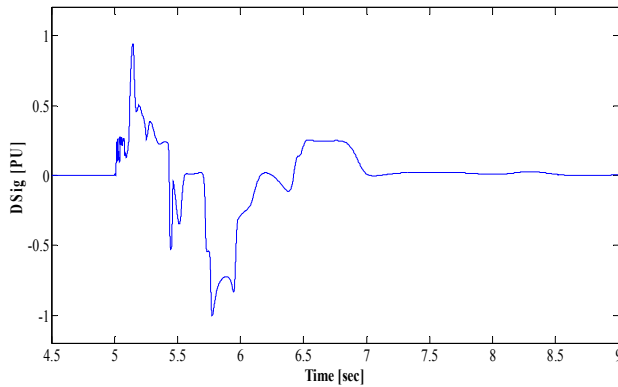
Fig. 14. Variation of ANN output signal after the fault (ΔSig)

7. Conclusion

In this paper, the transient-state behavior of the DSSC is analyzed, and the control capability of the DSSC is expressed in the parameters of the network and the DSSC.

The results show the DSSC without specific controller can't mitigate oscillations in a power system. The DSSC with auxiliary controller was able to improve transient stability. But, in a large disturbance, DSSC based auxiliary classic controller is unstable. Therefore, the auxiliary controller has been designed based neural network. The DSSC based auxiliary neural network can effectively damp electromechanical oscillations and improve transient stability.

Appendix
Table 1) The Parameters of Power System

Generator 1 (G_1)	S_1= 1000MVA, V_1= 13.8 kV$<52^0$ $[X_d , X'_d , X''_d , X'_q , X''_q , X_l]$= [1.305, 0.296, 0.252, 0.474, 0.243, 0.18] $[T'_{d0} , T''_{d0} , T'''_{q0}]$= [1.01, 0.053, 0.1] Stator Resistance R_s= 2.8544e-3
Generator 2 (G_2)	S_2= 500MVA, V_2= 13.8 KV$<0^0$ $[X_d , X'_d , X''_d , X'_q , X''_q , X_l]$= [1.305, 0.296, 0.252, 0.474, 0.243, 0.18] $[T'_{d0} , T''_{d0} , T'''_{q0}]$= [1.01, 0.053, 0.1] Stator Resistance R_S= 2.8544e-3
Transformer A	1000 MVA 13.8 kV/500 kV
Transformer B	5000MVA 500 kV/13.8 kV
Transmission line Length	700 Km
DC Voltage of Capacitors	19000V
Gain	Gain K_1= 0.5, Gain k_2= 3.25

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Biographies

Seyedreza Aali received his B.Sc. Degree in electronic engineering in 2007 from Islamic Azad University of Tabriz, Tabriz, Iran, where he received his M.Sc. degree in power engineering from Urmia University, Urmia, Iran. He is member of Young Researchers Club (YRC). He has published more than 10 papers in journals and international conferences. His special fields of interest included advance controller design based fuzzy and artificial neural network for power electronics devices and flexible AC transmission systems (FACTS) devices, and interconnection system design for renewable energy source.