ANN Based Hybrid TCSC for Damping Inter-Area Oscillations

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ABSTRACT

In this paper the effectiveness of a hybrid series capacitive compensation scheme in damping power system oscillations is evaluated using Artificial Neural Network (ANN). Compared to conventional PI controller the ANN gives the better damping response. The proposed hybrid scheme is a series capacitive compensated by fixes series capacitor and the third phase compensated by a TCSC in series with a fixed capacitor. The effectiveness of this proposed scheme in damping power system oscillations for various network conditions namely with different system faults and tie-line power flows is evaluated using MATLAB/SIMULINK environment.

Key words: FACTS controllers, ANN, TCSC.

I. INTRODUCTION

Flexible AC Transmission Systems (FACTS) technology provides unprecedented way for controlling transmission grids and increasing transmission capacity [1]. FACTS Controllers provide the flexibility of controlling both real and reactive power which could result in an excellent capability for improving power system dynamics . A problem of interest in the power industry at which FACTS Controllers could play a significant role in it is increasing damping of low frequency power oscillations that often arise between areas in large interconnected power networks. These oscillations are termed inter-area oscillations, which are normally characterized by poor damping [2]. Inter-area oscillations can severely restrict system operations by requiring the curtailment of electric power transfers level as an operational measure. These oscillations can also lead to widespread system disturbances, e.g. cascading outages of transmission lines and, therefore, system wide voltage collapse. Several studies have investigated the potential of using FACTS Controllers' capability in damping inter-area oscillations. The use of Thyristor Controlled Series Capacitor (TCSC) and Static Synchronous Series Compensator (SSSC) has been the subjects of several studies evaluating their respective effectiveness in enhancing power system dynamics [3]. Series capacitive compensation is the potential risk of sub synchronous resonance (SSR), where electrical energy is exchanged with a generator shaft system in a growing manner which may result in damage of the turbine-generator shaft system .Therefore, mitigating SSR has been and continues to be a subject of research and development aiming to develop effective SSR counter measures. The recently proposed phase imbalanced series capacitive compensation concept has been shown to be effective in enhancing power system dynamics as it has the potential of damping power swing as well as sub synchronous resonance oscillations [4]. Fig. 1 shows a scheme for a phase imbalanced capacitive compensation. It is a *"hybrid"* series compensation scheme, where the series capacitive compensation in one phase is created using a single-phase TCSC in series with a fixed capacitor (Cc), and the other two phases are compensated by fixed series capacitors (C). The TCSC control is initially set such that its equivalent compensations at the power frequency combined with the fixed capacitor yield a resultant compensation equal to the other two phases. Thus, the phase balance is maintained at the power frequency while at any other frequency, a phase imbalance is created. To further enhance power oscillations damping, the TCSC is equipped with a supplementary controller.

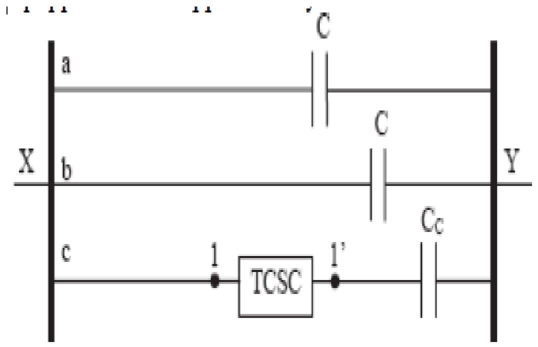


Fig.1 A schematic diagram of the hybrid series compensation scheme.

The phase imbalance of the proposed scheme can be explained mathematically as follows: 1) At the power frequency, the series reactances between buses X and Y, in Fig.1, in phases a, b, and c are given by:

This scheme would, definitely, be economically attractive when compared with a full three-phase TCSC which has been used/proposed for power oscillations damping. Furthermore, reducing the number of thyristor valves to one third will also have a positive impact on system reliability The effectiveness of the scheme in damping power system oscillations for various network conditions, namely different system faults and tie-line power flows is evaluated using the MATLAB simulation program and compare these results with fixed capacitive compensation scheme.

II. PROPOSED SYSTEM

The single-phase TCSC is modeled in the MATLAB as a single module using an ideal thyristor pair and an RC snubber circuit as shown in Fig. 3. A Phase Locked Loop (PLL) is used to extract phase information of the fundamental frequency line current, which will be used to synchronize TCSC operation. The thyristor gating control is based on the Synchronous Voltage Reversal (SVR) technique[4]-[6]. The TCSC impedance is measured in terms of a boost factor *kB*, which is the ratio of the apparent reactance of the TCSC seen from the line to the physical reactance of the TCSC capacitor bank. A positive value of *kB* is considered for capacitive operation. A low-pass filter based estimation algorithm is used to estimate the voltage and the current phasors. A boost measurement block performs complex impedance calculations for the boost factor of the TCSC as $Kb = \mathrm{Imag}\{\hat{V}C / \hat{I}C\}/ XCTCSC$, where, $\hat{V}C$ and $\hat{I}C$ are the estimated phase voltage and current and $XCTCSC$ is the capacitive reactance of the TCSC capacitor branch at the fundamental frequency. A proportional-integral (PI) control based boost level controller is implemented to control the TCSC boost level to the desired value by adjusting the instant of the expected capacitor voltage zero crossing. The integral part of the controller helps in removing the steady state errors. The controller parameters were determined by performing repeated time domain simulations for the different operating conditions. This algorithm uses the difference between the actual boost level and the reference boost level (*err*) shown in Fig. 3 as an objective function. The algorithm starts with arbitrary initial values for the control parameters and calculates the values of the objective function each time. The control parameters are incremented for the next iteration and the procedure is repeated until the objective function approaches a minimum value (below a threshold value). The procedure described above is widely used by industry for tuning of controller parameters.

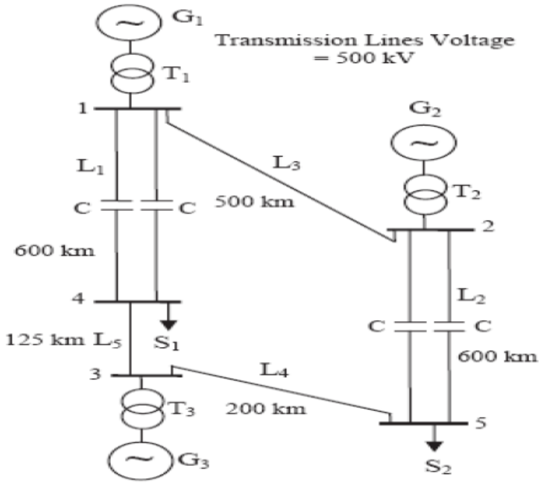


Fig. 2 Test benchmark

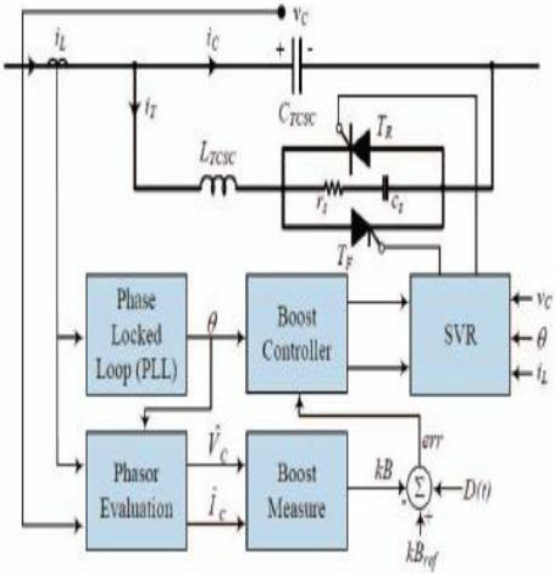


Fig. 3 Block diagram of a TCSC controller In Fig. 3, D(t) is a supplemental signal generated from an *m*-stage lead-lag compensation based controller. As the real power flow in the transmission line is proportional to the inverse of the total line reactance, the power swing damping can be achieved by properly modulating the apparent TCSC reactance through this controller. The supplemental controller input (stabilizing) signals could be local (e.g. real power flows) or remote (e.g. load angles or speed deviations of remote generators). If a wide-area network of Synchronized Phasor Measurement (SPM) units is available, then the remote signals can be downloaded at the controller in real time without delay. Local signals are generally preferred over

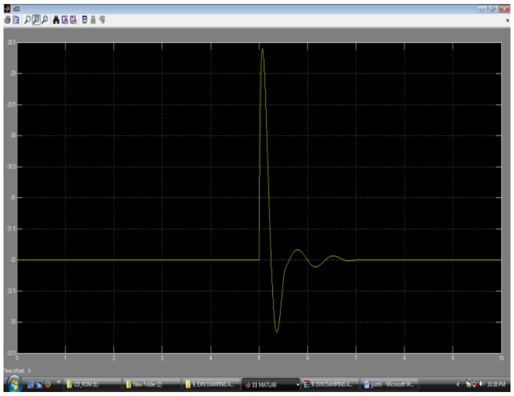
remote signals as they are more reliable since they do not depend on communications. In Fig. 3, *kBref* is the TCSC boost level set point. The Synchronous Voltage Reversal block solves for angle γ from the non-linear relation, $uCZ = XoiLM[\lambda\gamma - \tan(\lambda\gamma)]$, where *uCZ* is the estimated capacitor voltage at the desired instant when the capacitor voltage zero crossing occurs, *iLM* is the measured value of the line current *iL*, *X0* is the TCSC capacitor reactance at the TCSC resonance frequency, λ is the ratio between the TCSC resonance frequency and the system fundamental frequency and γ is the angle difference between the firing time and the voltage zero-crossing. The value of γ is used to calculate the exact firing instants of the individual thyristors.

III. SIMULATION RESULTS

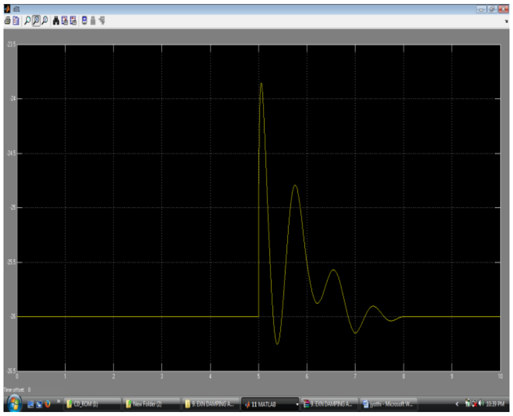
Comparing the responses of the fixed series capacitor compensation to the hybrid TCSC compensation scheme in Fig. 8, the positive contribution of the proposed hybrid scheme to the damping of the system oscillations is very clear. As it can be seen from Fig.8, the power swing damping controller effectively damps the system oscillations. It can also be seen from Fig. 9 that the best damping of the relative load angle responses are achieved with the □ 31-□ 21 combination. The second best damped responses are obtained with the □ 31-□ 21 combination. These results should be expected due to the direct relationship between the relative load angles and the generators that yield the problem. It can also be seen from Fig. 9 that the worst damped responses are obtained with PL1- □21 combination which results also in the increase of the first swings.

Hsc-d21d21-a-ann

D21

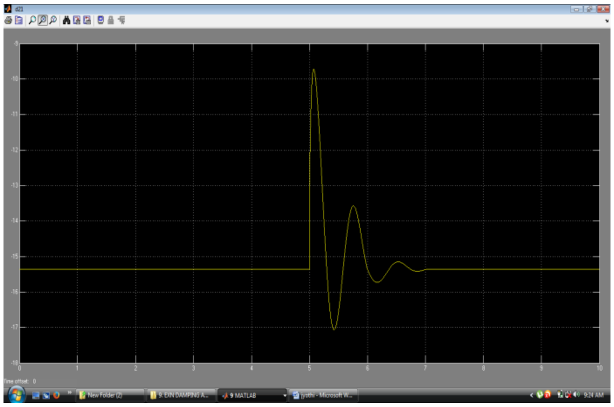


D31

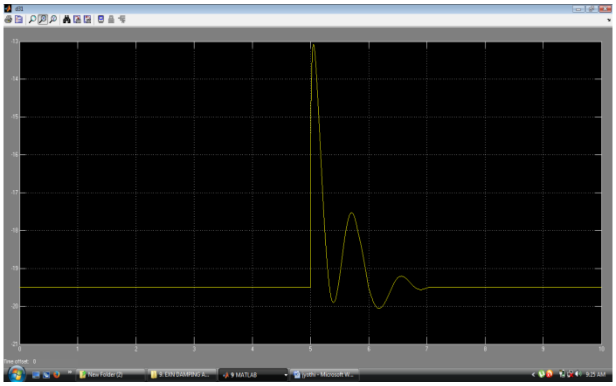


Hsc-d21d21-b-ann

D21

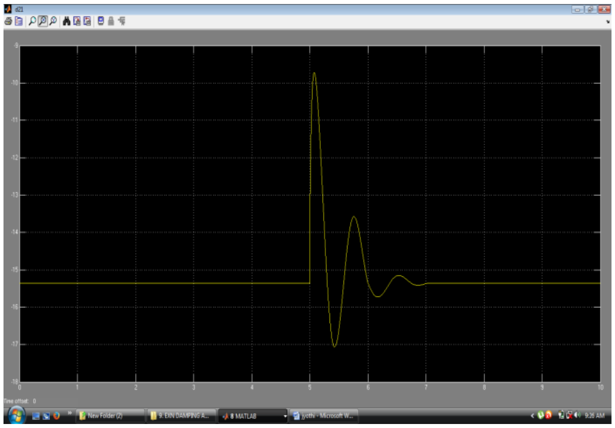


D31

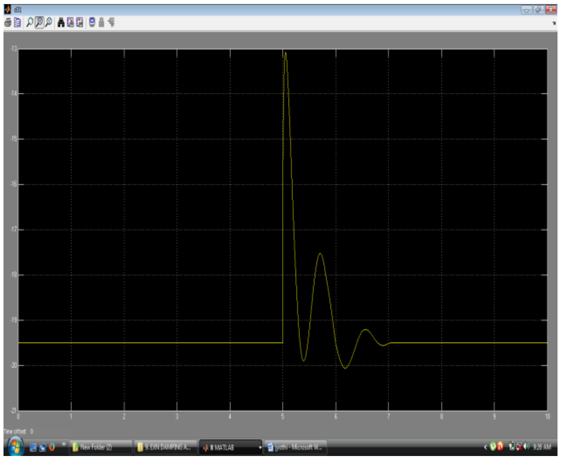


Hsc-d21d21-c-ann

D21

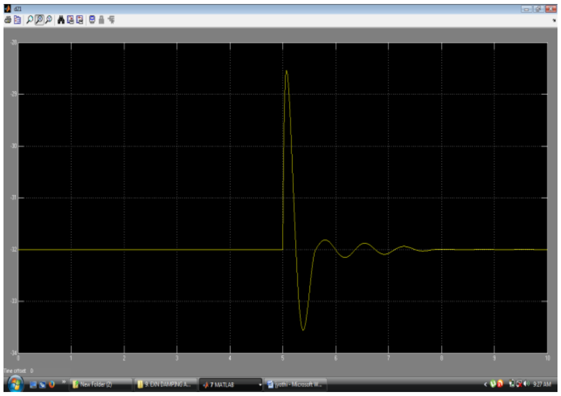


D31



Hsc-d31d21-a-ann

D21



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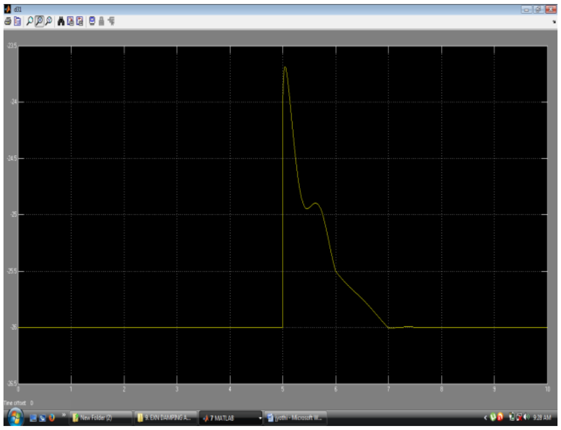
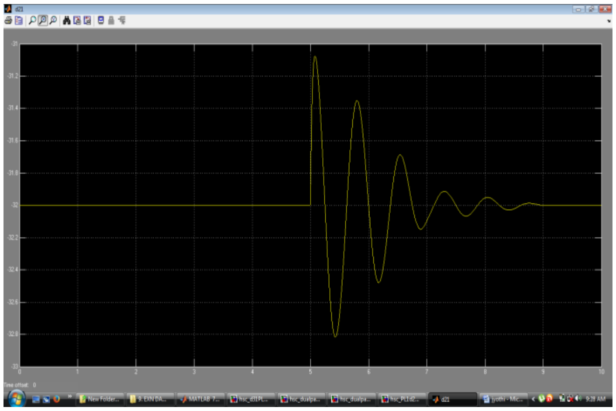


Hsc-d31pl2-a-ann

D21



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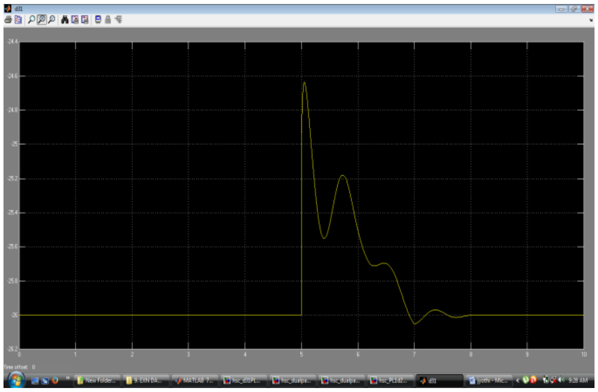
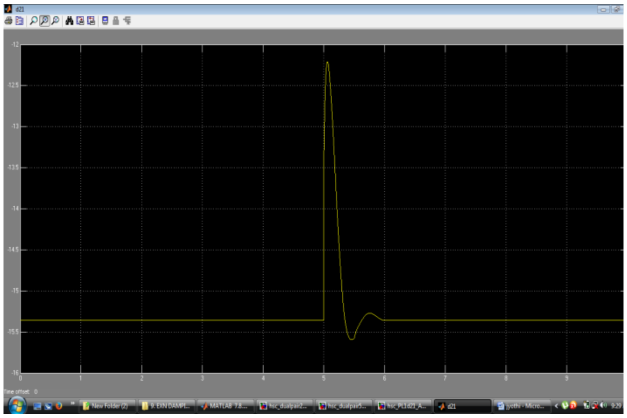


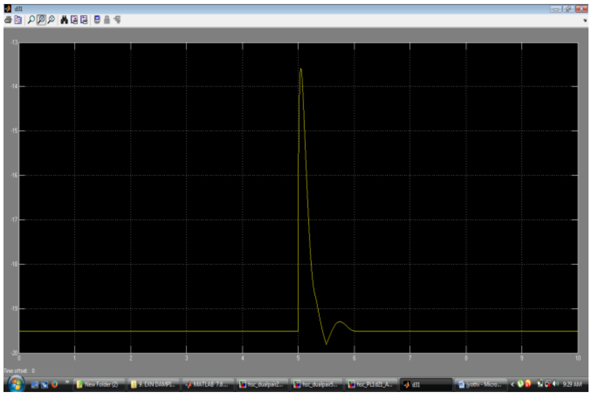
Hsc-dualpair2-c-ann/three phase fault

Hsc-dualpair2-c-ann

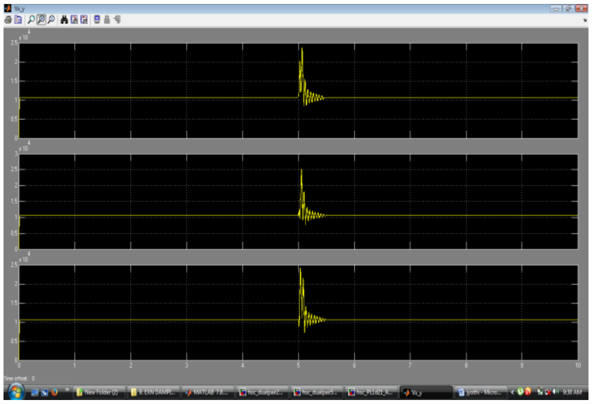
D21



D31

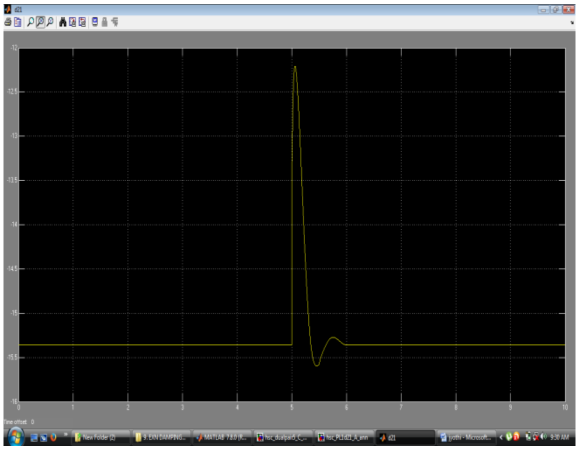


Vx-y

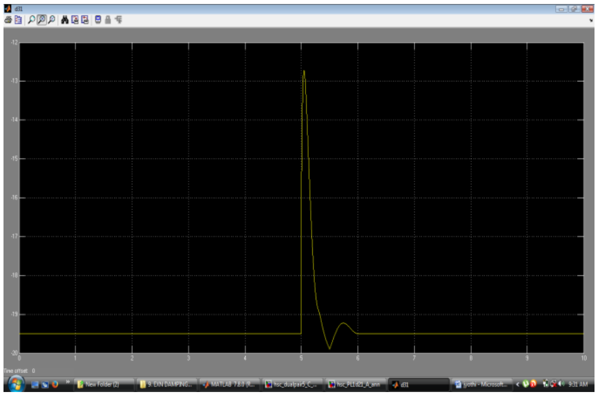


Hsc –dualpair5-c-ann

D21

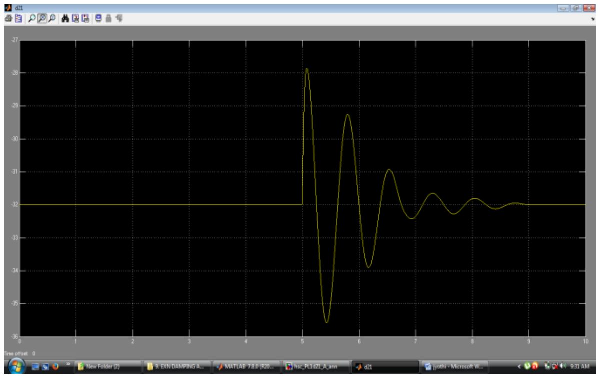


D31

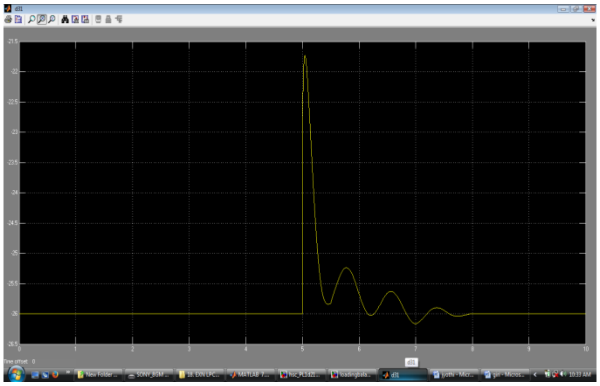


Hsc-PL1d21-a-ann

D21



D31



IV. CONCLUSION

This paper presents an application of a new hybrid series capacitive compensation scheme in damping power system oscillations. In this presented scheme is of damping oscillations are demonstrated in several digital computer simulations. This scheme is a series capacitive compensation scheme is technically sound and has an industrial application. Flexible AC Transmission Systems (FACTS) technology provides unprecedented way for controlling transmission grids and increasing transmission capacity FACTS Controllers provide the flexibility of controlling both real and reactive power which could damping oscillations. This presented hybrid series capacitive compensations scheme can be improved by choosing proper compensation scheme for TCSC that can reduce time to minimize the fault and control the real and reactive power.

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