RTDS Implementation of STATCOM for Power System Stability Improvement

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Abstract**-- In this paper, analysis and implementation of STATCOM based stabilizers to enhance damping of low frequency oscillations is studied and demonstrated. The effectiveness of STATCOM gain and phase modulation channels to enhance the damping characteristics is investigated. The coordination among the internal AC and DC voltage controllers and the proposed damping controllers on each channel is designed. Differential Evolution as an intelligent optimization technique is considered to design the STATCOM supplementary damping controllers. The implementation of STATCOM based stabilizers on Real Time Digital Simulator (RTDS) is carried out. The RTDS experimental setup of a power system with STATCOM is verified. The power system considered is tested through nonlinear time domain simulations to examine the validity of the proposed approach to damp low frequency oscillations. Comparisons with similar results reported in literature are demonstrated.**

Index Terms**—FACTS, Power System Stability, PSS, STATCOM, RTDS.**

I. INTRODUCTION

In recent years, power transmission systems have grown-up in size and complexity with a huge number of interconnections. Adaptable voltage regulation and system stabilization measures are applied to utilize the capacity in existing transmission networks more effectively, in preference to allocating larger resources to new lines and stations. Moreover, the role of long distance and large power transmission lines become more important. Though, the constructions of new transmission lines are becoming difficult due to economic, social and environmental problems. Recent developments in power electronics play a major role in the accomplishment of more efficient power systems. The main reason is the ability of power electronic devices to deal with power system dynamics and control power flow in transmission lines. On the basis of the above background, many flexible ac transmission system (FACTS) technologies have been developed. Furthermore, as a typical FACTS device, static synchronous compensators (STATCOMs) have been developed and put into operation to maintain voltage, to improve the power swing damping by reactive power control, to enhance the power quality provided to consumers, and to handle unbalanced voltages in distribution power systems. Several distinct models have been proposed to represent STATCOM in static and dynamic analysis. In [1], STATCOM is modeled as parallel connected current source; where in the controllable parameter is assumed to be current magnitude. In [2], a per unit STATCOM model is proposed. This model is suitable for study the performance of STATCOM under unbalanced distorted system voltage. Different models for transient stability and steady state stability analysis of the power system with STATCOM are presented in [3]. However, the models were based on the assumptions that voltages and currents are sinusoidal, balanced and operate near fundamental frequency, hence could not be applied to systems under the impact of large disturbance that have voltage and/or current with high harmonic content. A comparative study is carried out for dynamic operation of different models of STATCOM and their performance [4].

New developments in the RTDS Simulator with particular focus on the simulation of multilevel VSCs using PWM control are presented [5]. The work conducted clearly shows that the RTDS Simulator can be relied upon to accurately test VSC firing pulse controls using PWM frequencies in the range of 1500 Hz. The RTDS main network is solved with a typical time-step size of about 50 µs. Recently, RTDS added the capability of simulating power electronic switches used in Voltage Source Converters (VSC) on GPC (Gigabyte Processing Card) with significantly smaller time steps from 1.4 to 2.5 µs. In [6], the author proposes a third order dynamic model of the power system to incorporate STATCOM in the system to study its damping properties. Conclusions from the previous study and extends the previous investigation, validating a five-level STATCOM model implemented in the RTDS small time-step environment is presented in [7]. A simulation performed on the RTDS hardware is controlled from RSCAD/RunTime [8]. A technique explored by Hui and Christopoulos, whereby the Dommel network conductance does not need to be decomposed or inverted during the simulation, was implemented [9, 10]. K. Lian [11] presented a method based on Time Averaging is presented the RTDS.

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In this paper, the single-infinite model, STATCOM based stabilizer model with its control scheme is presented. STATCOM is implemented on RTDS®. The modeling of STATCOM is done in small time-step, which could be used any power hardware-in-loop test. Simulation studies are carried out with the RTDS simulation. The dynamic behavior of the system was obtained for fault disturbance.

II. POWER SYSTEM MODEL [12]

In this study, a single machine infinite bus system as shown in Fig. 1 is considered. The generator is equipped with a PSS and the system has a STATCOM installed somewhere at point m in transmission line as shown in Fig. 1. The generator has a local load of admittance $Y_L = g + jb$ and the transmission line has impedances of $Z_1 = R_1 + jX_1$ and $Z_2 = R_2 + jX_2$ for the first and the second sections respectively. The generator is represented by the third-order model comprising of the electromechanical swing equation and the generator internal voltage equation. The swing equation is divided into the following equations

$$\dot{\delta} = \omega_b(\omega - 1) \tag{1}$$

$$\dot{\omega} = (P_m - P_e - D(\omega - 1))/M \tag{2}$$

where, P_m and P_e are the input and output powers of the generator respectively; M and D are the inertia constant and damping coefficient respectively; δ and ω are the rotor angle and speed respectively. The output power of the generator can be expressed in terms of the d-axis and q-axis components of the armature current, *i*, and terminal voltage, *v*, as

$$P_e = v_d i_d + v_q i_q \tag{3}$$

The internal voltage, E'_q, equation is

$$\dot{E}'_q = (E_{fd} - (x_d - x'_d)i_d - E'_q)/T'_{do} \tag{4}$$

Here, E_{fd} is the field voltage; T'_{do} is the open circuit field time constant; x_d and x'_d are the d-axis reactance and the d-axis transient reactance of the generator respectively.

A. EXCITER AND PSS

The IEEE Type-ST1 excitation system shown in Fig. 2 is considered in this work. It can be described as

$$\dot{E}_{fd} = (K_A(V^{ref} - v + u_{PSS}) - E_{fd})/T_A \tag{5}$$

where, K_A and T_A are the gain and time constant of the excitation system respectively; V_{ref} is the reference voltage. As shown in Fig. 2, a conventional lead-lag PSS is installed in the feedback loop to generate a stabilizing signal uPSS. The terminal voltage v can be expressed as

$$v = (v_d^2 + v_q^2)^{1/2} \tag{6}$$

$$v_d = x_q i_q \tag{7}$$

$$v_q = E'_q - x'_d i_d \tag{8}$$

where x_q is the q-axis reactance of the generator.

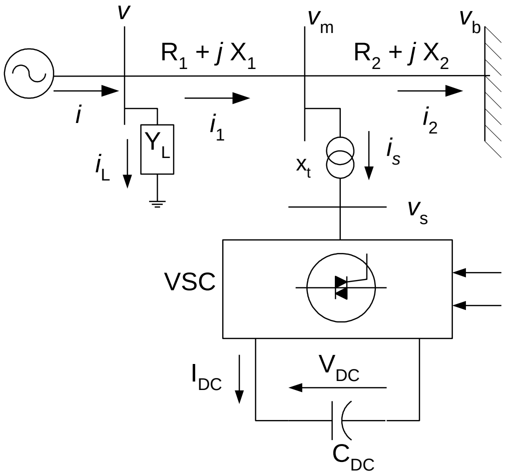

Fig. 1 Single machine infinite bus system with a STATCOM

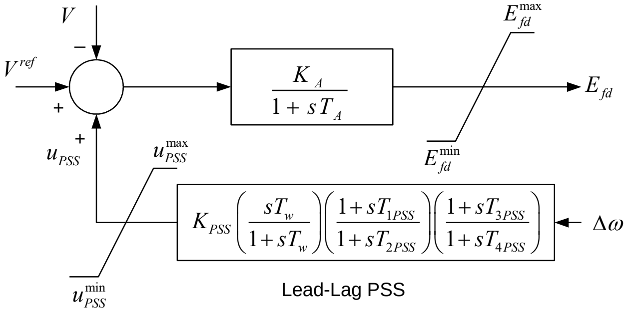

Fig. 2 IEEE Type-ST1 excitation system with a Lead-Lag PSS

As shown in Fig. 1, the STATCOM is connected to the transmission line through a step-down transformer with a leakage reactance of x_t. The STATCOM consists of a three-phase gate turn-off (GTO) – based voltage source converter (VSC) and a DC capacitor. The VSC generates a controllable AC voltage V_s given by

$$V_s = CV_{DC}\angle\phi \tag{9}$$

where $C = mk$, m is the modulation ratio defined by pulse width modulation (PWM), k is the ratio between the AC and DC voltage depending on the converter structure, V_{DC} is the DC voltage, and ϕ is the phase defined by PWM. The magnitude and the phase of V_s can be controlled through m and ϕ respectively. By adjusting the STATCOM AC voltage V_s, the active and reactive power exchange between the STATCOM and the power system can be controlled through the difference between V_s and the STATCOM-bus voltage V_m. The DC voltage V_{DC} is governed by

$$\dot{V}_{DC} = \frac{I_{DC}}{C_{DC}} = \frac{C}{C_{DC}}\left(i_{sd}\cos\phi + i_{sq}\sin\phi\right) \tag{10}$$

where C_{DC} is the DC capacitor value and I_{DC} is the capacitor current while i_{sd} and i_{sq} are the d and q components of the

STATCOM current is respectively. Fig. 3 illustrates the block diagram of STATCOM AC voltage PI controller with a lead-lag compensator while Fig. 4 illustrates the block diagram of STATCOM DC voltage PI controller with a lead-lag compensator. The proportional and integral gains are K_{PAC}, K_{IAC} and K_{PDC}, K_{IDC} for AC and DC voltages respectively. The STATCOM damping controllers are lead-lag structure where K_C and K_φ are the AC and DC voltage controller gains respectively, T_w is the washout time constant, and T_{1C}, T_{2C}, T_{3C}, T_{4C}, $T_{1\varphi}$, $T_{2\varphi}$, $T_{3\varphi}$, and $T_{4\varphi}$ are the controller time constants.

III. PROBLEM FORMULATION

For the PSS and the STATCOM-based damping stabilizers, the commonly used lead-lag structure shown in Figs 2-4 is chosen in this study. The transfer function of the stabilizer is

$$u = K\left(\frac{sT_w}{1+sT_w}\right)\left(\frac{1+sT_1}{1+sT_2}\right)\left(\frac{1+sT_3}{1+sT_4}\right) y \tag{11}$$

where u and y are the stabilizer output and input signals respectively, K is the stabilizer gain, T_w is the washout time constant, and T_1, T_2, T_3, and T_4 are the stabilizer time constants. In this structure, T_w, T_2, and T_4 are usually prespecified. The controller gain K and time constants T_1 and T_3 are to be determined. For the internal AC and DC voltage controllers of the STATCOM, the PI structure is used as shown in Figs. 3 and 4.

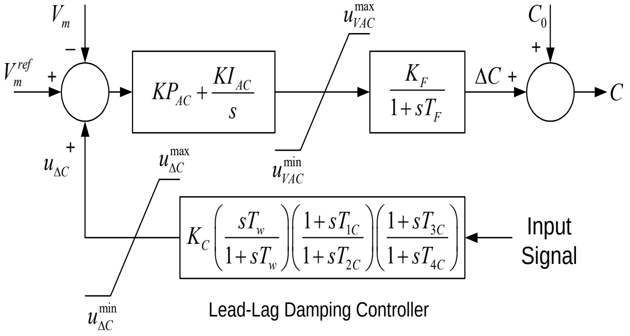

Fig. 3 STATCOM PI controller for AC voltage with a lead-lag damping controller

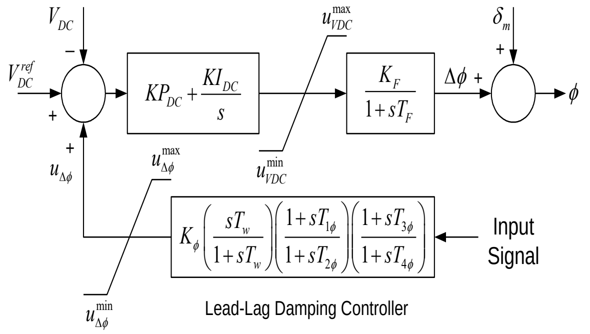

Fig. 4 STATCOM PI controller for DC voltage with a lead-lag damping controller

IV. REAL-TIME DIGITAL SIMULATOR

RTDS is a fully digital, real time power system simulator developed at the Manitoba HVDC research center in the late 1980's. It operates in real time. This is achieved by having many digital signal processors sharing the computational burden. The processors are working in parallel, which means that the size of the system can be increased without limiting the real time capability as long as the number of processor units is increased accordingly. RTDS is a combination of computer hardware and software. The hardware is made up of individual racks of coupled digital signal processors. The processors are connected to one another through a common backplane [13]. One rack is made up of different types of processor cards. There are cards taking care of the communication between the hardware and the software, cards that are used for communication, synchronization and coordination between different racks and cards used to solve the equations representing the power system and control components modeled in the software. There are also various cards for outputting analogue or digital signals to other equipment and for receiving input signals to the RTDS [14]. The RTDS software is organized in a three-level hierarchy; a graphical user interface, midlevel compiler and communication and the low-level operating system. The user works only with the highest level, the graphical user interface called RSCAD. In RSCAD/Draft a circuit can be built, using predefined electrical and control components.

V. REAL-TIME IMPLEMENTATION RESULTS

This section presents the real-time implementation results of the system shown in Fig. 1 at the following cases:

A. PSS only.
B. C-based stabilizer only.
C. Φ-based stabilizer only.
D. PSS and C-based stabilizer.
E. PSS and Φ-based stabilizer.

The system is implemented on a RTDS®. The single-infinite model, STATCOM model with its control scheme is presented. The modeling of STATCOM is done in small time-step, which could be used any power hardware-in-loop test. Simulation studies are carried out with the RTDS simulation for the system described previously. The dynamic behavior of the system was obtained for fault disturbance.

A. *PSS only*

The system response (ω and V_{ac}) for a three–phase fault has been introduced in Fig. 5 when the generator is controlled by PSS only. The modulating and carrier signals in this case are given in Fig. 6.

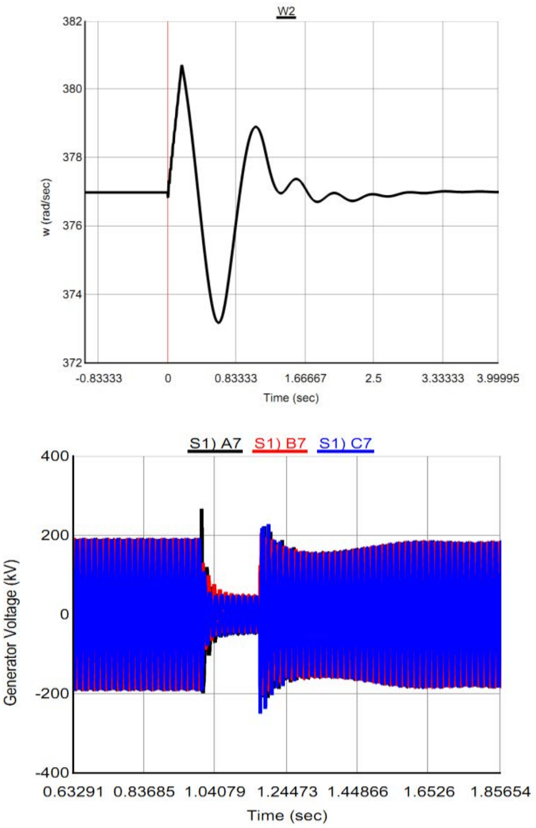

Fig. 5 Response of the system equipped with PSS only

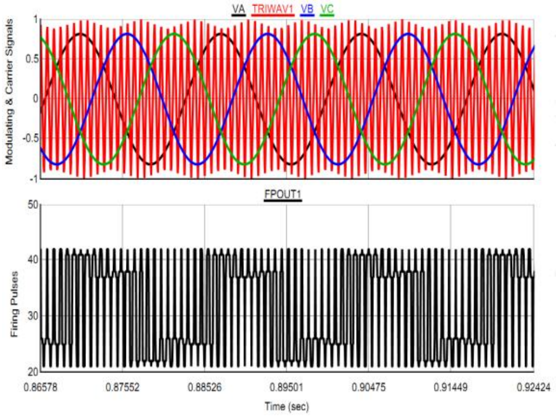

Fig. 6 The modulating and carrier signals of the system equipped with PSS only

B. C-based stabilizer only

The system response (ω, V_{ac} and V_{dc}) for a three–phase fault has been introduced in Fig. 7 when the system equipped with C-based stabilizer. The modulating and carrier signals in this case are given in Fig. 8.

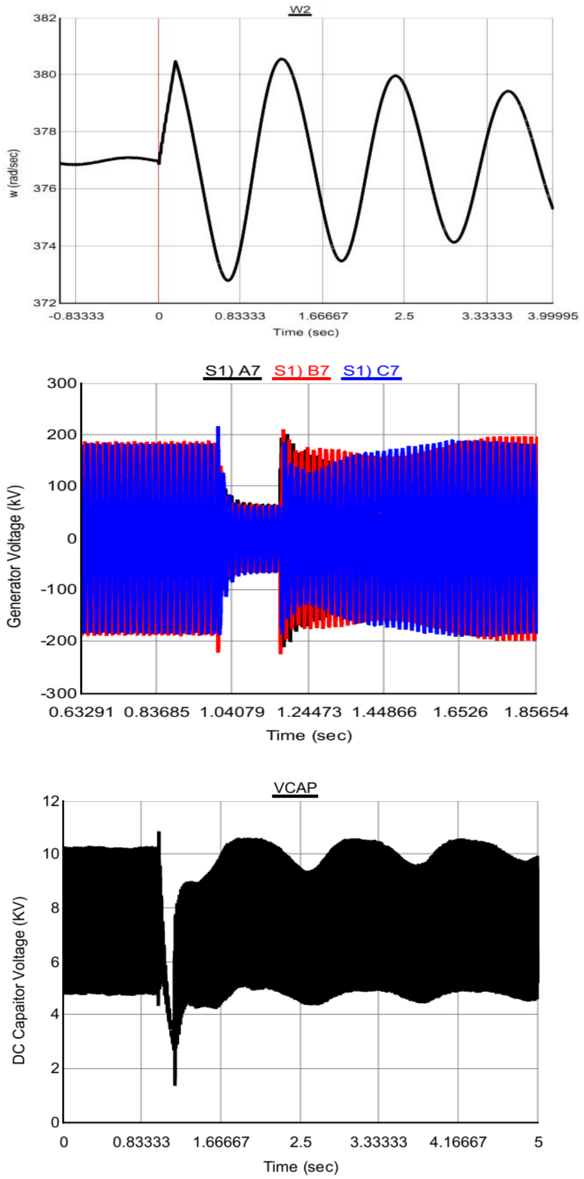

Fig. 7 Response of the system equipped with C-based stabilizer only

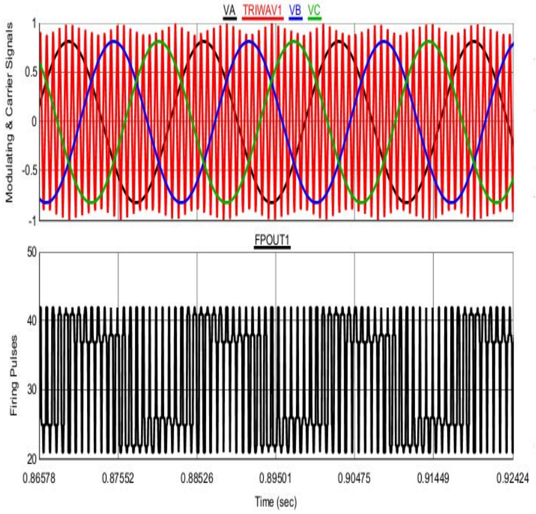

Fig. 8 The modulating and carrier signals of the system equipped with C-based stabilizer only

C. Φ-based stabilizer only

The system response (ω, V_{ac} and V_{dc}) for a three–phase fault has been introduced in Fig. 9 when the system equipped with Φ-based stabilizer. The modulating and carrier signals in this case are given in Fig. 10.

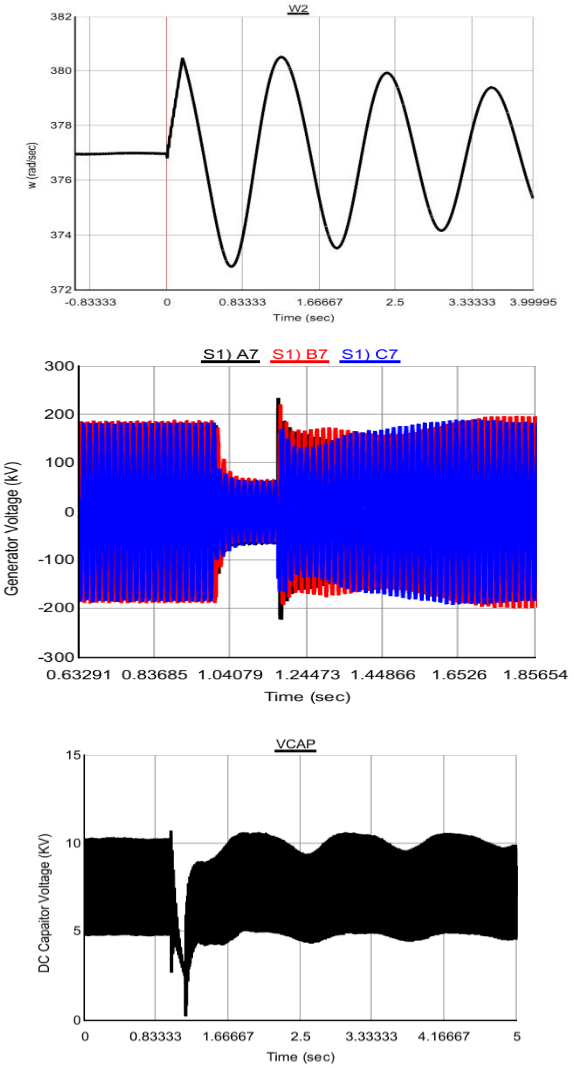

Fig. 9 Response of the system equipped with Φ-based stabilizer only.

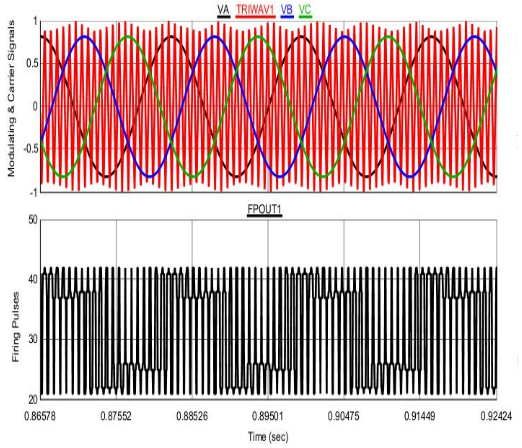

Fig. 10 The modulating and carrier signals of the system equipped with Φ -based stabilizer only.

D. PSS and C-based stabilizer

The system response (ω, V_{ac} and V_{dc}) for a three–phase fault has been introduced in Fig. 11 when the system equipped with PSS and C-based stabilizer. The modulating and carrier signals in this case are given in Fig. 12.

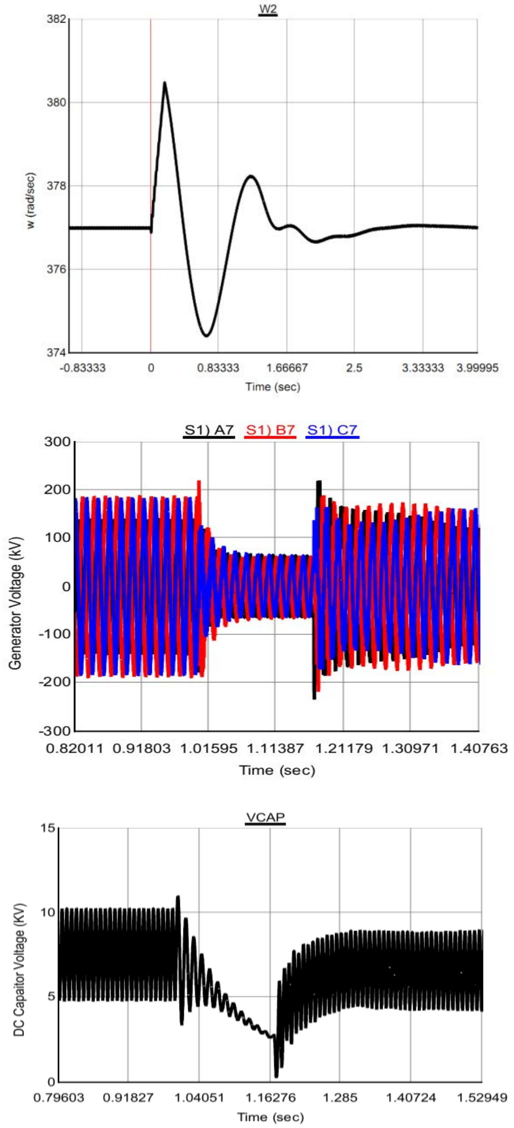

Fig. 11 Response of the system equipped with PSS and C-based stabilizer only.

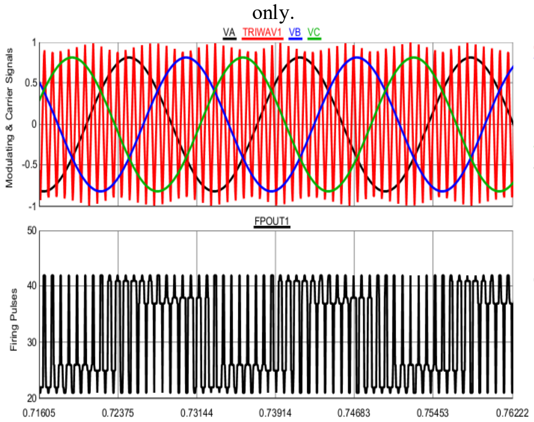

Fig. 12 The modulating and carrier signals of the system equipped with PSS and C-based stabilizer only.

E. PSS and Φ-based stabilizer

The system response (ω, V_{ac} and V_{dc}) for a three–phase fault has been introduced in Fig. 13 when the system equipped with PSS and Φ-based stabilizer. The modulating and carrier signals in this case are given in Fig. 14.

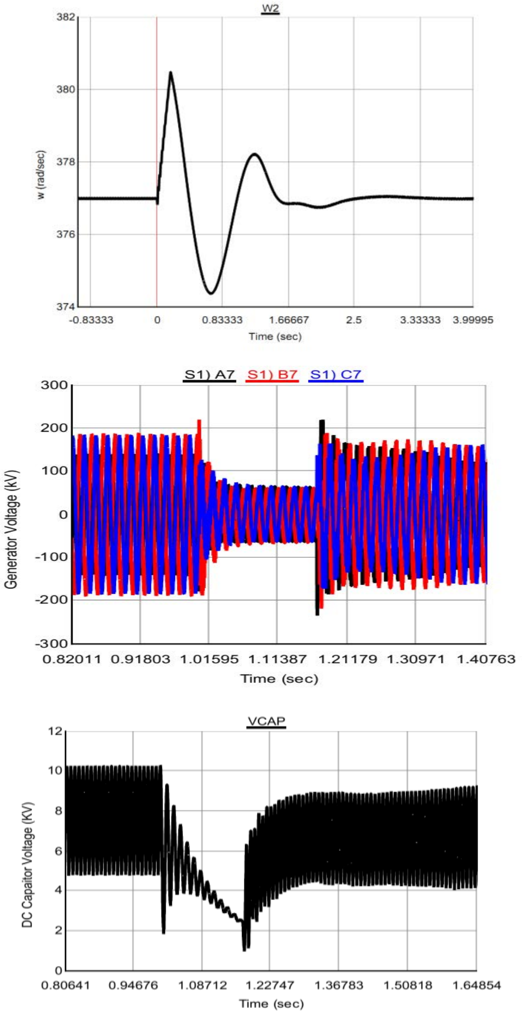

Fig. 13 Response of the system equipped with PSS and Φ-based stabilizer only

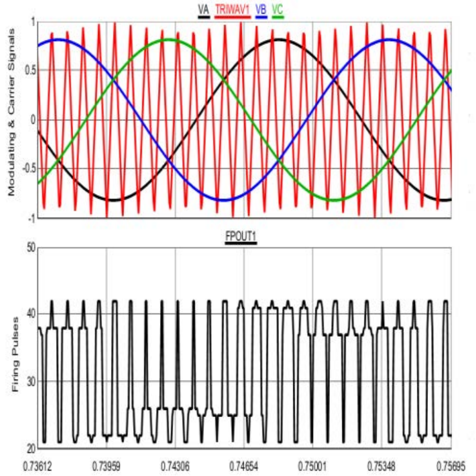

Fig. 14 The modulating and carrier signals of the system equipped with PSS and Φ -based stabilizer only.

VI. CONCLUSIONS

In this work the investigator researched the problem of enhancing the power system dynamic stability through individual and coordinated design of power system stabilizers and STATCOM-based stabilizers. The coordination between the various damping stabilizers and the STATCOM internal voltage PI controllers is taken into consideration to improve the system dynamic stability as well as the system voltage regulation. Such a study is very important as it laid the foundations of the requirements of the coordinated design problem. In this regard, the proposed objective function ensures the improvement in the system damping as well as the AC and DC voltage regulations. It is also aimed to improve the system response in terms of the settling time and overshoots. Individual design as well as coordinated design of the proposed stabilizers have been investigated and discussed.

VII. ACKNOWLEDGMENT

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