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COMBINED CONTROLS OF STATCOM DEVICE AND MULTI-BAND POWER SYSTEM STABILIZER (MB-PSS) IN POWER SYSTEM

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This paper solves the problem of power system stabilization by using the advanced static synchronous shunt compensator (STATCOM) to increase the damping of electromechanical oscillations of the power system and regulates the system voltage by absorbing or generating reactive power to the system. Also, a multi-band power system stabilizer (MB-PSS) is developed in this paper to get a moderate phase advance at all frequencies of interest in order to compensate for the inherent lag between the field excitation and the electrical torque induced to ensure robust oscillation damping. A combined control of (STATCOM) with (MB-PSS) is proposed also in this paper to give more increase of the oscillation damping that improves power system stability. All these controllers are supplied to the multi-machine two-area power system.

KEYWORDS: *STATCOM, MB-PSS, Power System Stability, Oscillation Damping*

1. INTRODUCTION

Recent development of power electronics introduces the use of FACTS devices in power systems. FACTS devices are capable of controlling the network condition in a very fast manner and this unique feature of FACTS devices can be exploited to improve the transient stability of a system. Reactive power compensation is an important issue in electrical power systems and shunt FACTS devices play an important role in controlling the reactive power flow to the power network and hence the system voltage fluctuations and transient stability [1].

STATCOM is a member of FACTS family that is connected in shunt with the system. Even though the primary purpose of shunt FACTS devices is to support bus voltage by injecting (or absorbing) reactive power, they are also capable of improving the transient stability by increasing (decreasing) the power transfer capability when the machine angle increases (decreases), which is achieved by operating the shunt FACTS devices in capacitive (inductive) mode [2]. Power system oscillations can be classified into local oscillations between a unit and the rest of generating stations [3, 4] in the order of (0.8 to 4.0) Hz, interplant oscillations occur between two electrically close generation plants of the order (1.0 to 2.0) Hz [3] and inter-area oscillation between two major groups oscillations of frequency (0.2 to 0.8) Hz [5]. These oscillations may lead to synchronous or angle or inertia instabilities [6]. Several cases have been recorded in literature [4-7].

Damping of these oscillations is reported to be done by power system stabilizers (PSS) [8, 9]. Conventional PSS's are installed in many power plants. They are all based on single mass turbine-generator and two motion equations one for the speed deviation d ($\Delta\omega$/dt) and the other for the rotor angle deviation d ($\Delta\delta$/dt), derived for one mass model. Multi-Band Power System Stabilizer (MB-PSS) is based on multi-frequency variables that this stabilizer can obtain to cope with all low, intermediate, and high frequencies oscillations. The MB-PSS is developed in such a manner that it can be capable of introducing moderate phase advance at all oscillations frequencies of interest in order to compensate for the inherent lag between the field excitation and the electrical torque [7].

2. STUDIED SYSTEM AND MODELING

The studied system (Kundur's four-machine two-area test system) consists of two fully symmetrical areas linked together by two 230 kV lines of 220 km length as shown in fig. (1). Despite its small size, it mimics very closely the behavior of typical systems in actual operation [3, 5]. Each area is equipped with two identical round rotor generators rated 20kV/900MVA. The synchronous machines have identical parameters [5, 9], except for inertias which are H=6.5s in area 1 and H=6.175s in area 2 [5]. The parameters of the generators, turbines and exciters data are given in Appendix.

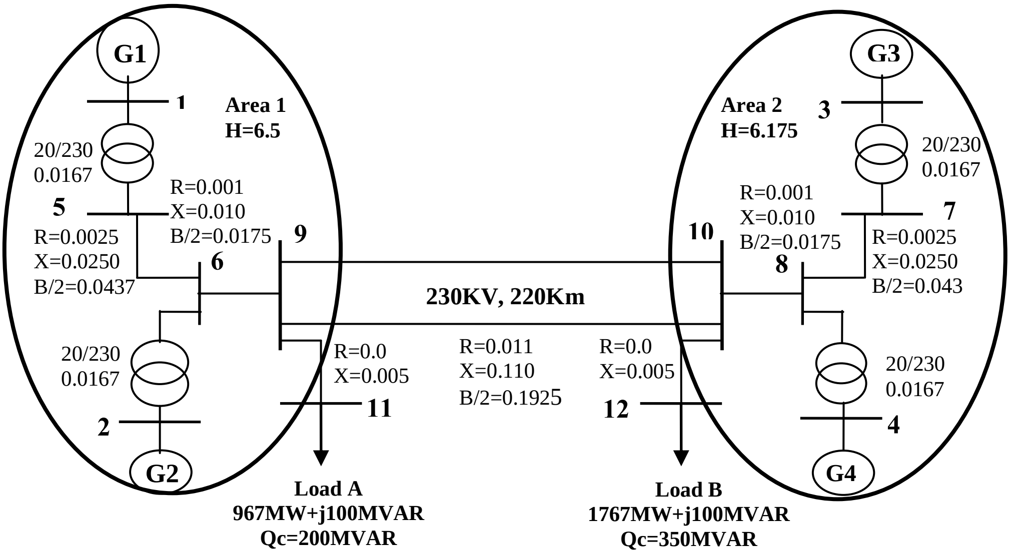


Fig. (1) The single line diagram of four-machine two-area test system.

Thermal plants having identical speed regulators are further assumed at all locations, in addition to fast static exciters with a gain on 200 [5, 9]. The load is represented as constant impedances and is split between the areas in such a way that area 1 is exporting 413MW to area 2. Since the surge impedance loading of a single line is about 140 MW [5], the system is somewhat stressed, even in steady-state.

2.1 Static Synchronous Compensator (STATCOM)

The STATCOM is based on a solid state synchronous voltage source which generates a balanced set of three sinusoidal voltages at the fundamental frequency with rapidly controllable amplitude and phase angle. The configuration of a STATCOM is shown in Fig. (2). it consists basically of a voltage source converter (VSC), a coupling transformer and a dc capacitor. Control of reactive current and hence the susceptance presented to power system is possible by variation of the magnitude of output voltage (VVSC) with respect to bus voltage (VB) and thus operating the STATCOM in inductive region or capacitive region [10].

When the STATCOM is used for reactive power generation, the inverter itself can keep the capacitor charged to the required voltage level. This is accomplished by making the output voltages of the inverter lag the system voltages by a small angle. In this way the inverter absorbs a small amount of real power from the AC system to cover its internal losses and to keep the capacitor voltage at the desired level. The same control mechanism can be used to increase or decrease the capacitor voltage, and thereby the amplitude of the output voltage of the inverter, for the purpose of controlling the VAR generation or absorption [13].

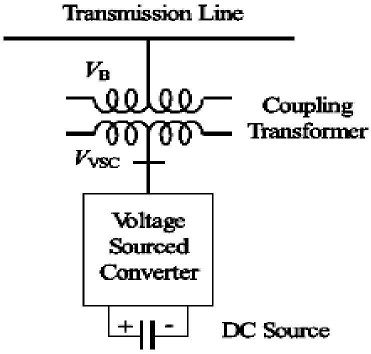


Fig. (2) STATCOM connected to a transmission line.

This study examines the application of STATCOM for damping electromechanical oscillations in a power system. When a disturbance occurs, the STATCOM controller can provide a damping torque signal to improve the system stabilization to make the system return to a steady-state quickly, make the system damping large enough to decrease the oscillations, and pre-specify the system eigen-values to a stable range for the desired relative stability [11].

2.2 Multi-Band Power System Stabilizer (MB-PSS)

The need for effective damping of a wide range of electromechanical oscillations motivated the concept of the multi-band power system stabilizer (MB-PSS). As its name reveals, the MB-PSS structure is based on multiple working bands. The main idea of the MB-PSS is that three separate bands are used, respectively dedicated to the low, intermediate, and high frequency modes of oscillations. The low band is typically associated with the power system global mode, the intermediate band with the inter-area modes, and the high band with the local modes. Each of the three bands is made of a differential band-pass filter, gain, and limiter as shows fig. (3). The outputs of the three bands are summed and passed through a final limiter producing the stabilizer output V_{stab}. This signal then modulates the set point of the generator voltage regulator so as to improve the damping of the electromechanical oscillations. Usually, a few of the lead-lag blocks should be used in MB-PSS's circuits [12].

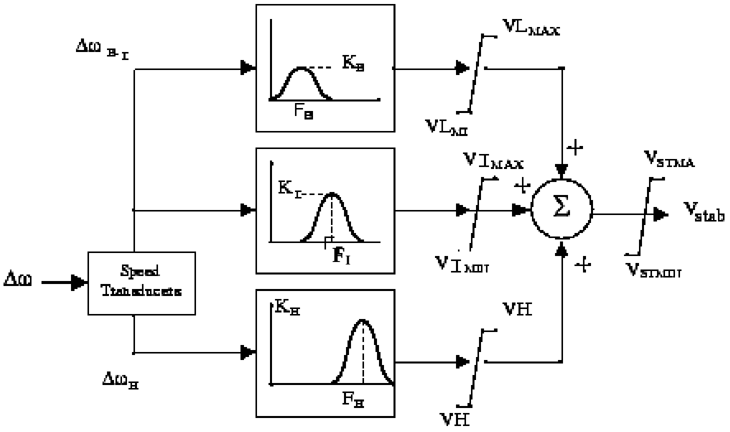


Fig. (3) Multi-band power system stabilizer (MB-PSS) conceptual representation

Two different approaches are available to configure the settings during MB-PSS tuning process:

(a) Simplified Settings:

Only the first lead-lag block of each frequency band is used to tune the MB-PSS. The differential filters are assumed to be symmetrical band-pass filters respectively tuned at the center frequency F_B, F_I, and F_H shown in fig. (3). The peak magnitude of the frequency responses can be adjusted independently through the three gains K_E, K_I, and K_H. Only six parameters are therefore required for a simplified tuning of the MB-PSS. They are F_B, F_I, F_H, K_E, K_I, and K_H. This method is adopted in this study.

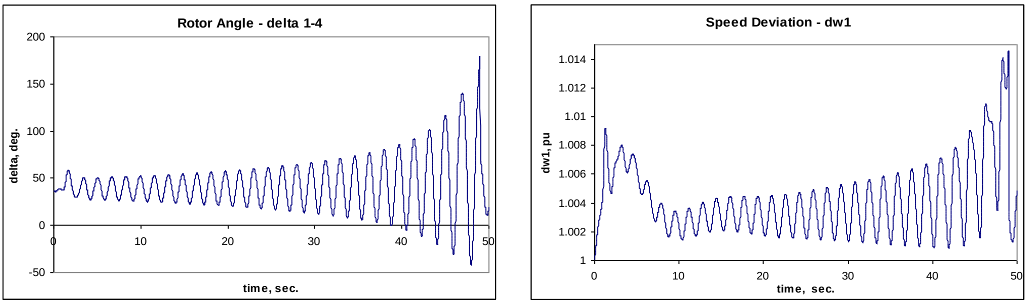
(b) Detailed Settings:

The designer is free to use all the flexibility to built into the MB-PSS structure to achieve nontrivial controller schemes and to tackle even the most constrained problem (for example, multi unit plant including an inter-machine mode, in addition to a local mode and multiple inter-area modes).

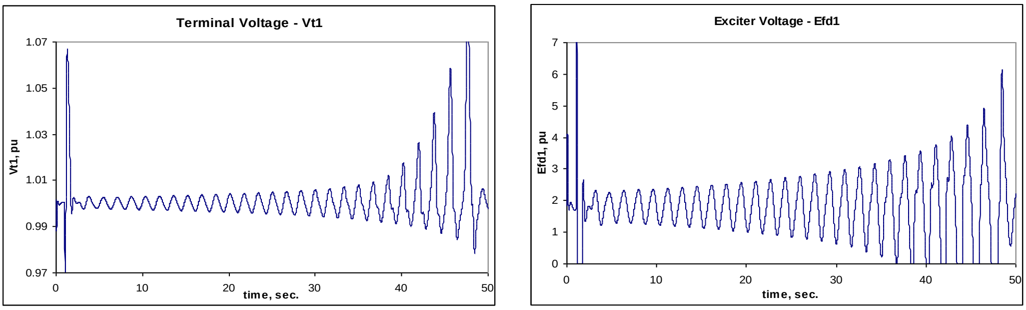
3. RESULTS AND DISCUSSIONS

3.1 System without STATCOM or MB-PSS:

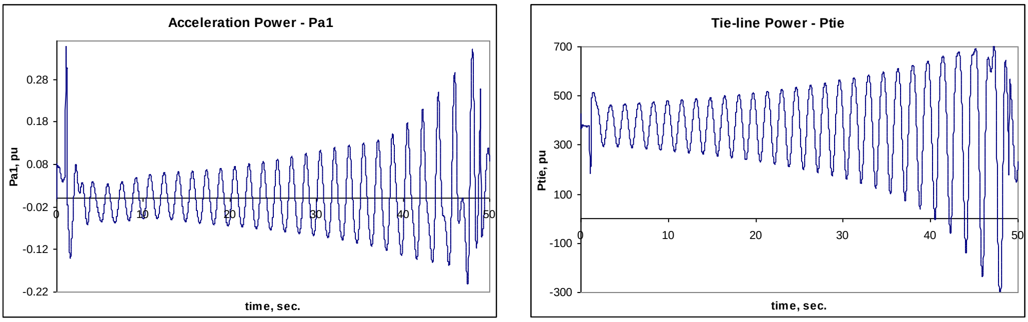
The 4-machine 2-area test system was subjected to a three phase fault at the mid point of the one transmission lines and cleared after 200 ms. In this case, the system didn't have any stabilizer such as power system stabilizer (PSS) or FACTS devices. Therefore, the system stability was affected by this three-phase fault and led the system to be unstable. The responses of the test system are shown in fig. (4). The performance of the rotor angle (δ), speed deviation (dω), the terminal voltage (V_t), the field excitation voltage (E_{fd}), acceleration power (P_a) and tie line power (P_{tie}) in the two area system are shown below.



(a) Rotor angle δ_{14}, in deg. (b) Speed Deviation $d\omega_1$, pu.



(c) Voltage Terminal V_{t1}, pu. (d) Exciter Voltage E_{fd1}, pu.



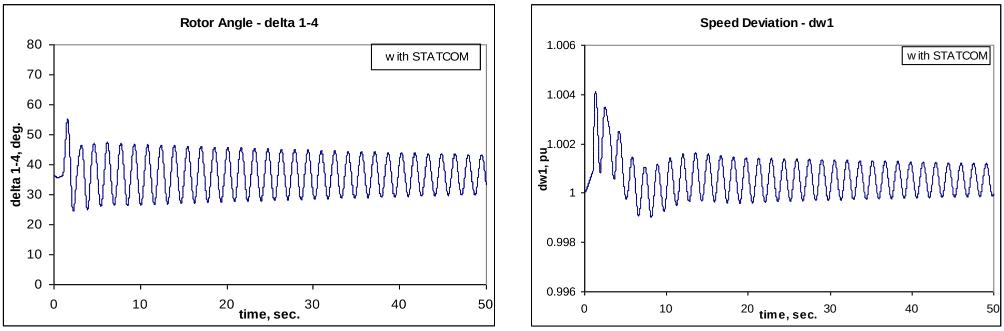
(e) Acceleration Power P_{a1}, pu. (f) Power Tie Line P_{tie}, MW

Fig. (4) Four-machine two-area test system with 3-Φ fault and without MB-PSS or STATCOM

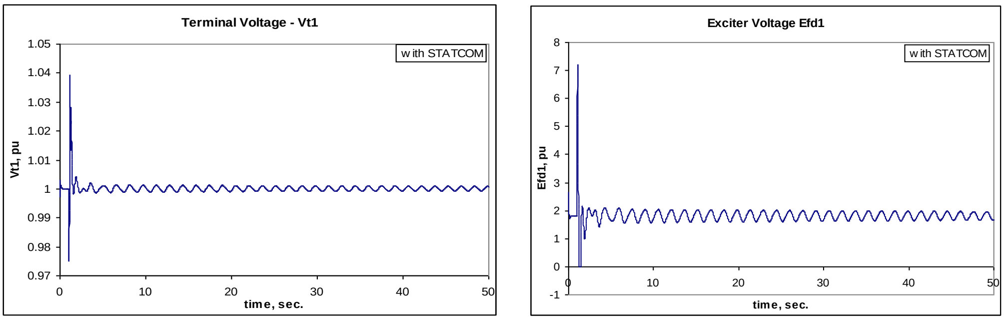
3.2 System with STATCOM device and without MB-PSS

If the STATCOM controller is added to the above test system (4-machine 2-area system) and subjected to the same 3-Φ fault, then the system response maintain to be stable and the oscillations nearly damped. Figure (5) shows the performance of the rotor angle (δ), speed deviation (dω), the terminal voltage (V_t), the field excitation voltage (E_{fd}), acceleration power (P_a) and tie line power (P_{tie}) when the disturbance of

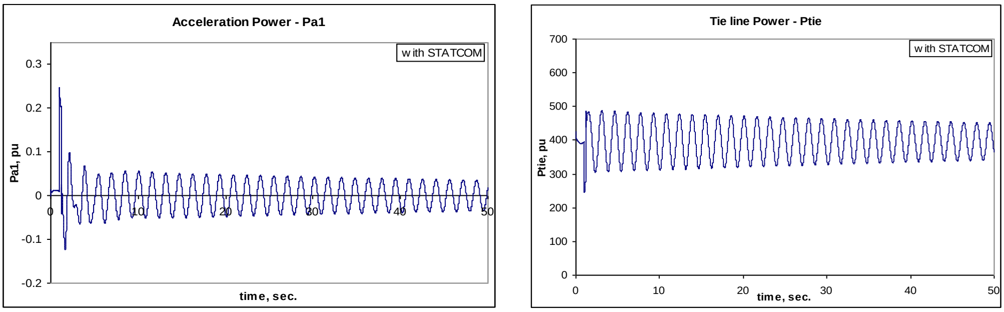
3-Φ fault has occurred in the two-area system with STATCOM controllers of +/- 500MVA converter rating fixed at each end of the two areas.



(a) Rotor angle δ_{14}, in deg. (b) Speed Deviation $d\omega_1$, pu.



(c) Voltage Terminal V_{t1}, pu. (d) Exciter Voltage E_{fd1}, pu.

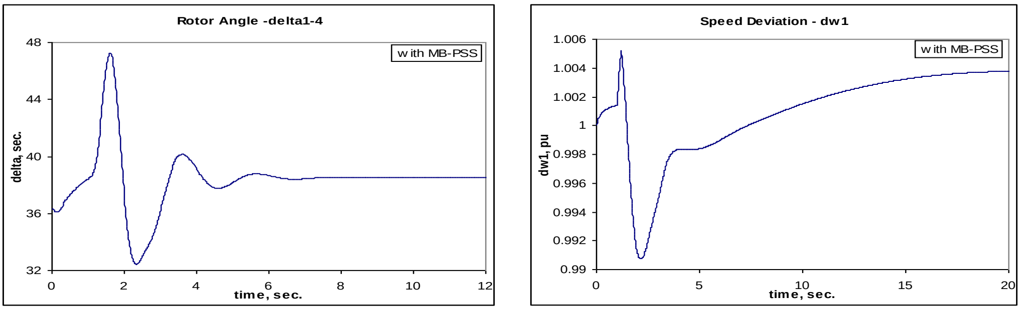


(e) Acceleration Power P_{a1}, pu. (f) Power Tie Line P_{tie}, MW

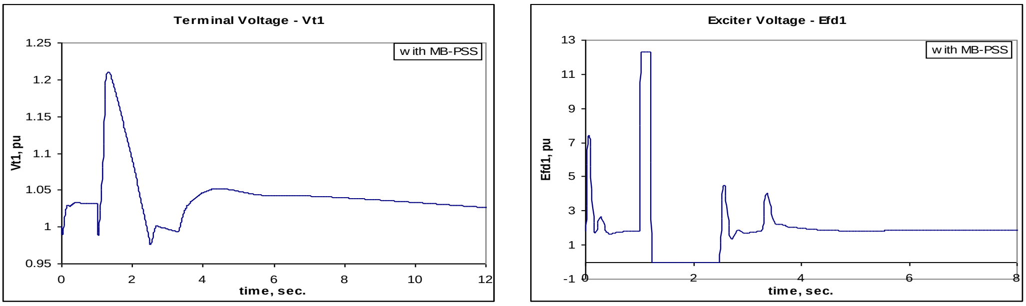
Fig. (5) Four-machine two-area test system with STATCOM controller under 3-Φ fault

3.3 System with MB-PSS and without STATCOM

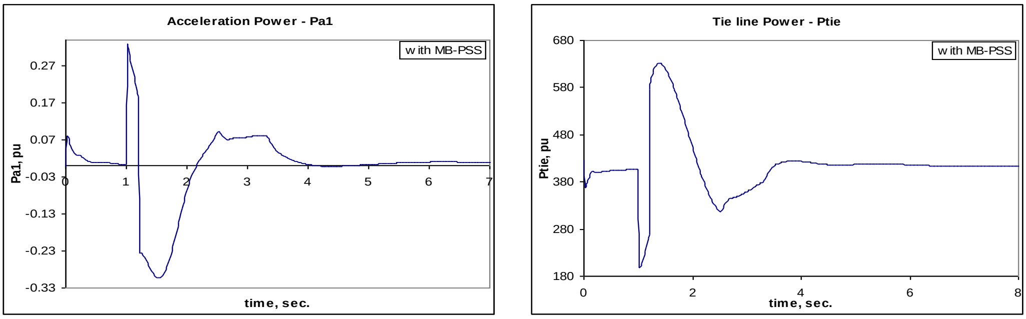
If the multi-band power system stabilizer (MB-PSS) is used with the exciter of each machine in the test system (4-machine 2-area system), and the system is subjected to the same 3-Φ fault, then the system response maintain to be stable and the oscillations are damped. Figure (6) shows the performance of the rotor angle (δ), speed deviation ($d\omega$), the terminal voltage (V_t), the field excitation voltage (E_{fd}), acceleration power (P_a) and tie line power (P_{tie}) when the disturbance of 3-Φ fault has occurred in the two-area system which have excitation control by multi-band power system stabilizer (MB-PSS)[12].



(a) Rotor angle δ_{14}, in deg. (b) Speed Deviation $d\omega_1$, pu.



(c) Voltage Terminal V_{t1}, pu. (d) Exciter Voltage E_{fd1}, pu.

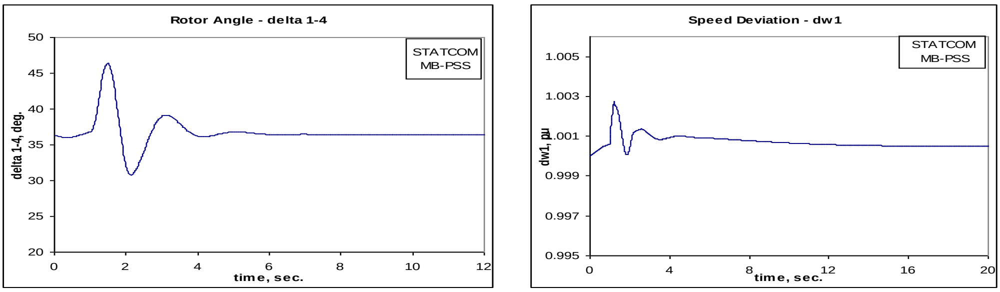


(e) Acceleration Power P_{a1}, pu. (f) Power Tie Line P_{tie}, MW

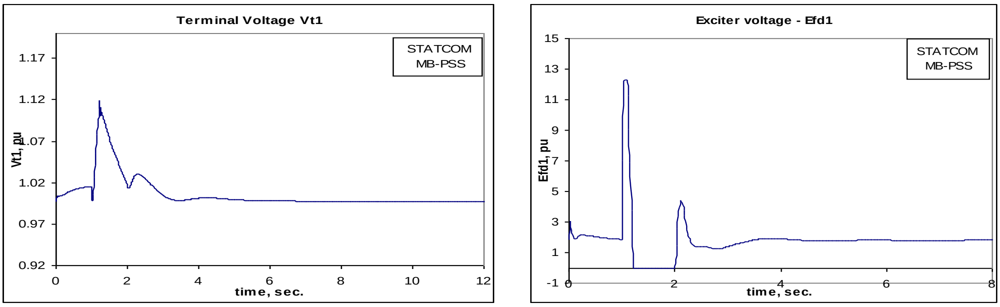
Fig. (6) Four-machine two-area test system with multi-band power system stabilizer (MB-PSS) under 3-Φ fault

3.4 System with Combined Control of STATCOM Controller and with Excitation Control of (MB-PSS)

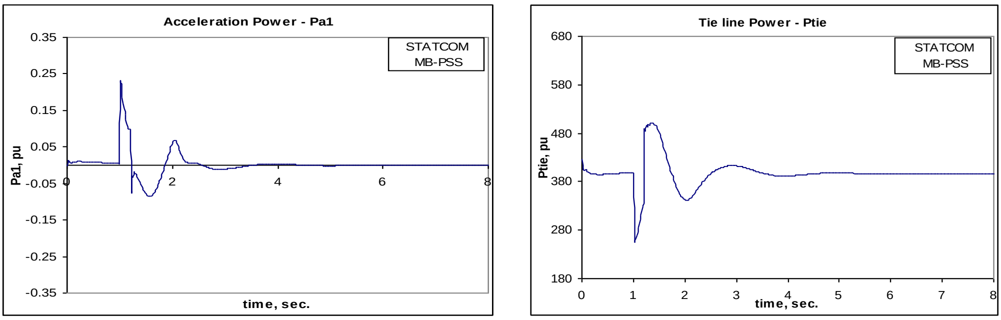
When the combination of the static synchronous compensator (STATCOM) and the multi-band power system stabilizer (MB-PSS) were added to the two-area system, this results in a significant increase of the oscillation damping and leads to the improvement of the power system stability. Comparing with the previous results, the combination between STATCOM and MB-PSS gives more stable performance of the system parameters. Figure (7) shows the performance of the disturbance of 3-Φ fault occurred in the two-area system which have combined control of multi-band power system stabilizer (MB-PSS) and static synchronous compensator (STATCOM).



(a) Rotor angle δ_{14}, in deg. (b) Speed Deviation $d\omega_1$, pu.



(c) Voltage Terminal V_{t1}, pu. (d) Exciter Voltage E_{fd1}, pu.

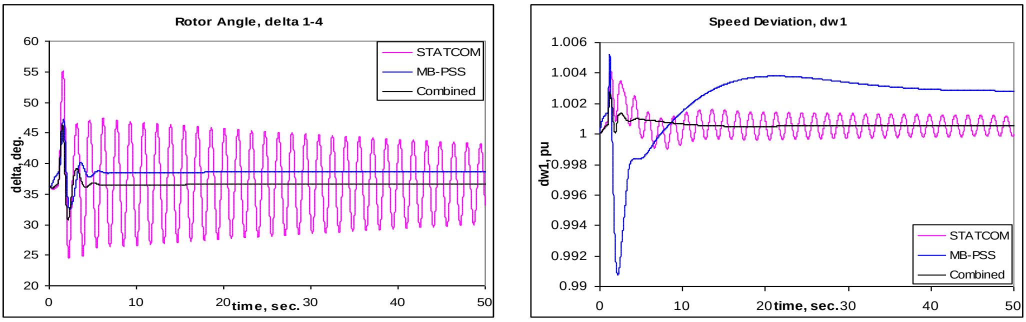


(e) Acceleration Power P_{a1}, pu. (f) Power Tie Line P_{tie}, MW

Fig. (7) Four-machine two-area test system with combined STATCOM controller and MB-PSS under 3-Φ fault

3.5 Comparison between the Three Cases (STATCOM, MB-PSS, and Combined)

When the combination between the static synchronous compensator (STATCOM) and the multi-band power system stabilizer (MB-PSS) is added to the two-area system, this results in a significant increase of the oscillation damping and leads to improve the power system stability. Comparison between the three cases (STATCOM, MB-PSS, and Combined) is shown in Fig. (8) for the rotor angle (δ), and speed deviation (dω). The combination STATCOM and MB-PSS gave more stable performance of the system parameters.



(a) Rotor angle δ_{14}, in deg. (b) Speed Deviation $d\omega_1$, pu.

Fig. (8) Four-machine two-area test system with combined STATCOM controller and MB-PSS under 3-Φ fault

CONCLUSION

In this study, the power system stability enhancement via STATCOM device and MB-PSS are presented and discussed. The coordination between the STATCOM controller and the MB-PSS is taken into consideration to improve the system transient stability as well as the system voltage regulation. The electromechanical mode is more controllable through based stabilizers. The proposed stabilizers have been tested on a Kundur's four-machine two-area power system with three-phase fault disturbance and loading conditions. The nonlinear simulation results show the effectiveness and robustness of the proposed STATCOM controller and power system stabilizer to enhance the system stability.

Appendix

1- Multi-Band-Power System Stabilizer (MB-PSS) Simplified Settings Mode [3]:

$K=1$, $F_B=0.2Hz$, $K_E=20$, $F_I=0.9Hz$, $K_I=25$, $F_H=12Hz$, $K_H=145$, $V_{Lmax}=0.075pu$, $V_{Imax}=0.15pu$, $V_{Hmax}=0.15pu$, $V_{Smax}=0.15pu$

2- STATCOM parameters [10]: 230 KV, ±500 MVAR

$R=0.0073pu$, $L=0.22pu$, $V_{dc}=40KV$, $C_{dc}=\pm 375\mu F$, $V_{ref}=1.0pu$, V_{ac} regulator gains $K_p = 5$, $K_i = 1000$, V_{dc} regulator gains $K_p = 0.1e\text{-}3$, $K_i = 20e\text{-}3$

3- Synchronous Generator [3, 5]:

$X_d=1.8pu, X_d'=0.3pu, X_d''=0.25pu, X_q=1.7pu, X_q'=0.55pu, X_q''=0.25pu, X_l=0.2pu, R_s=0.0025pu, T_{do}'=8sec, T_{do}''=0.03sec, T_{qo}'=0.4sec, T_{qo}''=0.05sec, H=6.5sec, p=4$

4- Excitation System [5, 6]:

$T_r=0.02sec$, $K_a=300$, $T_a=0.001$, $K_e=1$, $T_e=0$, $T_b=0$, $T_c=0$, $K_f=0.001$, $T_f=0.1sec$, $E_{fmin}= -11.5$, $E_{fmax}=11.5$

5- Steam Turbine and Governor [14]:

$K_p=1$, $R_p=0.05$, $D_z=0$, $T_{sr}=0.001$, $T_{sm}=0.15$, and $V_{gmin}=-0.1$, $V_{gmax}=0.1pu/s$, $g_{min}=0$, $g_{max}=4.496$, and $T_2=0$, $T_3=10$, $T_4=3.3$, $T_5=0.5$, and $F_2=0.5$, $F_3=0.5$, $F_4=0$, $F_5=0$, and $H_3=0.24897$, $H_4=0$, $H_5=0$, and $K_{12}=83.47$, $K_{23}=42.702$, $K_{34}=0$, $K_{45}=0pu/rad$, and $D_2=2.4832$, $D_3=0.4$, $D_4=0$, $D_5=0pu$, torque/pu speed deviation.

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تحكم مركب من مكثف تزامنى أستاتيكى و نظام القوي متعدد الترددات

يقدم البحث نظام التحكم باستخدام مكثف متزامن استاتيكي (STATCOM) لاخماد التذبذبات الكهربائية في نظام القوي الكهربية مع نظام القوي المتعدد الترددات (MB-PSS). وهذا البحث يتم الحصول على مرحلة متقدمة في جميع الترددات من أجل تعويض عن الفارق الزمني بين ميدان الإثارة الكهربائية الناجمة عن عزم الدوران لضمان إخماد قوي التذبذب. اتضح السيطرة المشتركة ل(STATCOM) مع (MB-PSS) ويقترح أيضا في هذا البحث إعطاء المزيد من زيادة اخماد التذبذب في تحسين استقرار نظام الطاقة.