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Impacts of the SSSC on Damping Power System Oscillations

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Abstract: *The planning and operation condition of electrical power systems are changing due to a variety of causes. FACTS controller helps in raising dynamic stability limit and provide better power flow control. Static synchronous series compensator (SSSC) is one of the important members of series FACTS controller, which consists of a solid-state voltage source inverter coupled with a transformer that is connected in series with a transmission line. In this paper is presented the effect of SSSC for damping power system oscillation. The complete digital simulation is performed in the Matlab Simulink environment.*

Keywords: *Oscillation damping; FACTS controller; SSSC*

1. INTRODUCTION

From the steady-state point of view, FACTS devices operate by increasing or reducing voltage, supplying or absorbing reactive power and controlling the series impedance of transmission lines or phase angle [1-4]. FACTS controller can be classified in four main categories [5-7]: shunt controller, series controller, series-series controller and series-shunt controller [8-10]. A systematic classification of the FACTS devices is presented in Fig. 1 [11].

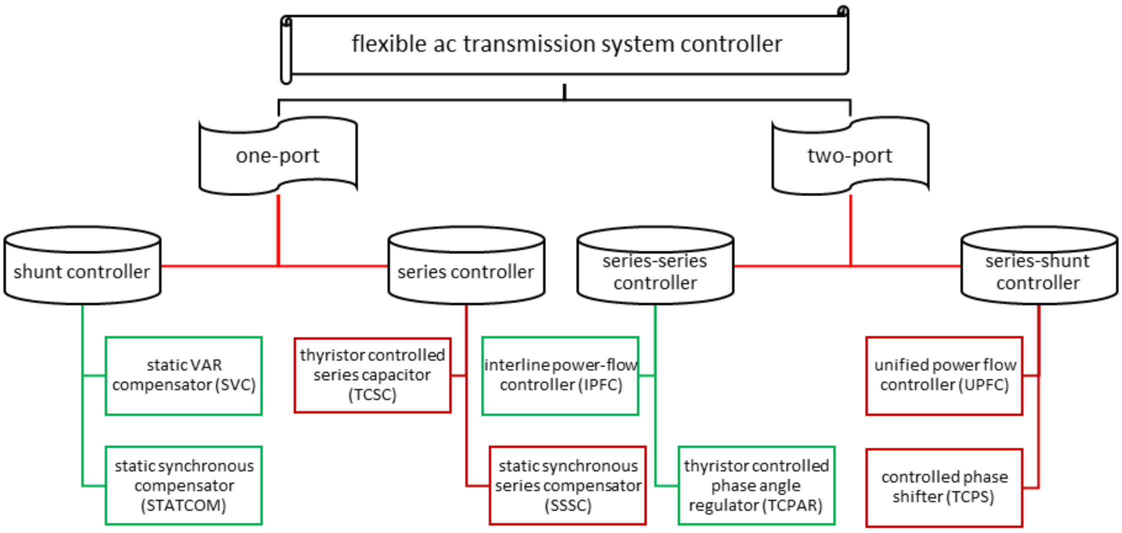

Fig1. *Classification of the FACTS controller*

In recent years, flexible ac transmission system (FACTS) devices equipped with a power oscillation damper (POD) have been also efficiently used for damping oscillations of power system [12-19]. Generally, there are two kinds of power oscillation damping controllers in power systems: power system stabilizer (PSS) [20-24] and FACTS POD controllers [25-28].

A method for designing of power system stabilizer (PSS) (lead-lag compensation type) based on sliding mode control technique is presented in [29], which the control objective is to enhance stability and improve the dynamic response of the multi-machine power system and, also, the main approach is to focus on the control performance which later is proven to have the degree of shorter reaching time and lower spike. For damping oscillations and to enhance the transient stability performance of power systems in [30] the UPFC is used, that the controller parameters are designed using an efficient version of the Takagi-Sugeno fuzzy control scheme. A design procedure for simultaneous coordinated designing of the static synchronous compensator controller parameters (STATCOM) and PSS in multi-machine power system is developed in [31], that the artificial bee colony algorithm is employed to search for optimal controller's parameters. To set the parameters of FACTS devices, genetics and particle swarm optimization with fuzzy logic techniques have been used in [32], which to optimize the reactive power consumption and reduce the line congestion, two types of FACTS devices; thyristor controlled series compensator (TCSC) and static var compensator (SVC), are used. To verify the capability of the distributed SSC as a member of DFACTS family in mitigating the sub-synchronous resonance is purposed in [33], that two controllers the particle swarm optimization-based conventional damping controller and the fuzzy logic based damping controller are designed and implemented in traditional controller of the distributed SSC in order to provide the effective damping. A multi-objective approach for daily scheduling of microgrids contributing to a higher penetration of photovoltaics is studied in [34], which the existing control devices including DSTATCOM and under-load tap changer are integrated in volt/var control process.

Static synchronous series compensator (SSSC) is one of the important members of FACTS family. It is able to providing the reactive power compensation of power system. Several references in technical literature can be found on the application of SSSC for power oscillation damping [35,36] and stability improvement in power system [37].

Power system stability enhancement via robust coordinated design based on an optimization problem with a time-domain simulation-based objective function and real-coded genetic algorithm of a PSS and a SSSC-based controller is show in [38]. A control scheme to damp the low-frequency oscillations and voltage deviations of a multi-machine power system using an ant colony optimization-based static synchronous compensator is developed in [39], which the control scheme incorporates two different proportional-integral controllers to control the gate signal in the SSC and, also, the time-domain results of the rotor dynamics and deviation in generator voltage for various test cases reveal the potential of the proposed controller in in alleviating the overall power system oscillations. The stability improvement and power-flow control results of a DFIG-based offshore wind farm connected to a one-machine infinite-bus system using a SSSC is presented in [40], which an oscillation damping controller is designed by using modal control theory. The sub-synchronous resonance characteristics of the hybrid series compensation using SSSC and passive series capacitor discussed in [41] and proposes a method for the extraction of sub-synchronous components of line current using filter. A hybrid firefly algorithm and pattern search technique for a SSSC-based power oscillation damping controller design is proposed in [42], which a modified signal equivalent to the remote speed deviation signal is constructed from the local measurements. The stability issues of the double fed induction generator based wind farm in the power system with variable wind speed in strong and weak grid is studied in [43], which the impact of PSS and SSSC on the stability of wind power system is analyzed by utilizing modified IEEE 14-bus test system.

The SSSC is an important device to control transmission line impedance, and so to power flow control independent of the line current. In this paper, the application of SSSC in damping power system oscillation is investigated. Matlab Simulink software package is used for the simulations.

2. STATIC SYNCHRONOUS SERIES COMPENSATOR

SSSC is a series connected FACTS devices which can be installed in series in the transmission lines. It is very effective in controlling power flow in a transmission line with the capability to change its reactance characteristic from capacitive to inductive [44]. When the SSSC operates in inductive mode, the injected voltage is leading the line current and therefore reactive power is absorbed. In capacitive mode, the injected voltage is lagging the line current and therefore reactive power is injected into the transmission line. The SSSC injects a series ac voltage to transmission line through a transformer as shown in Fig. 2.

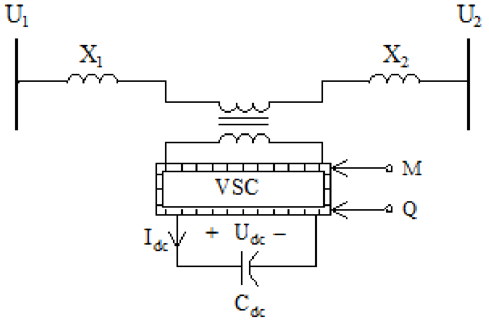

Fig2. *Power system with SSSC*

U_1 and U_2 are the bus voltages and U_{dc} is the dc voltage source. X_1 represents the equivalent reactance between the bus 1 and the SSSC, and X_2 represents the equivalent reactance between SSSC and the bus 2. The converter voltage is varied by changing the M is the amplitude modulation ratio and ϕ is the phase angle modulation ratio. A capacitor connected on the dc side of the VSC acts as a dc voltage source. The SSSC output voltage is defined by the following equation [45]:

$$U_S = M\,U_{dc}(\cos\phi + j\sin\phi) \tag{1}$$

The differential equation of the dc voltage is given below:

$$\frac{dU_{dc}}{dt} = \frac{M}{C_{dc}}(i_q\cos\varphi + i_d\sin\varphi) \tag{2}$$

where i_d and i_q are the d and q axes currents of transmission line. The structure of SSSC-based controller is shown in Fig. 3. The input signal of the proposed controller is the rotor angle deviation ($\Delta\delta$) and the output signal is the injected voltage Vs. The structure consists of a gain block with gain K_P, a signal washout block with the time constant T_W and two-stage phase compensation blocks.

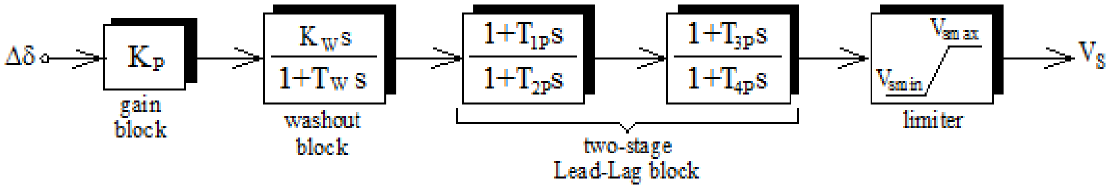

Fig3. *Structure of SSSC-based controller*

3. SYSTEM UNDER STUDY

The simulation bock diagram of the power system with a SSSC in Matlab/Simulink environment is shown in Fig. 4. The power grid consists of two power generation substations and one major load center at bus B3. The load center is modeled using a dynamic load model where the active and reactive power absorbed by the load is a function of the system voltage. Line L2 is split in two segments in order to simulate a three-phase fault at the midpoint of the line. The active power and reactive power measured at bus are shown in Figs. 5 and 6. When the SSSC is bypass, the power flow towards major load is as follows: 664 MW flow on L1, 563 MW flow on L2 and 990 MW flow on L3. There are measured at bus B2, B4 and B3, respectively. The SSSC, located at bus B1, is in series with line L1. It is capable of injecting up to 10% of the nominal system voltage. The SSSC injected voltage reference is normally set by a POD controller whose output is connected to the U_q input of the SSSC. The inputs to the POD controller are the bus voltage at B2 and the current flowing in L1.

4. SIMULATION RESULTS

The initially of the input of the POD controller (reference voltage U_q) is zero. At t=2 s, U_q is -0.08 pu (SSSC inductive) and at t=6 s, U_q is 0.08 pu (SSSC capacitive). The active power flow on line L1, measured at bus B2, is show in Fig. 7. Depending on the injected voltage, the power flow on line varies from 575 to 750 MW. A comparison of the SSSC operation with and without POD control is shoe in Fig. 8. Therefore, the SSSC with a POD controller is a very effective tool to damp power oscillation. The output active power of the machine M1 for two cases are shown in Figs. 9 and 10. Also the rotor speed are shown in Figs. 11 and 12, and the excitaion voltage are shown in Figs. 13 and 14 for two cases of machine M1.

5. CONCLUSION

Damped oscillations are contributing an important role in power system. The effect of SSSC for damping power system oscillation is presented. This work is carried out under Matlab environment using Simulink and PSB toolboxes. The simulation results show that the SSSC controller is efficient in damping power oscillations.

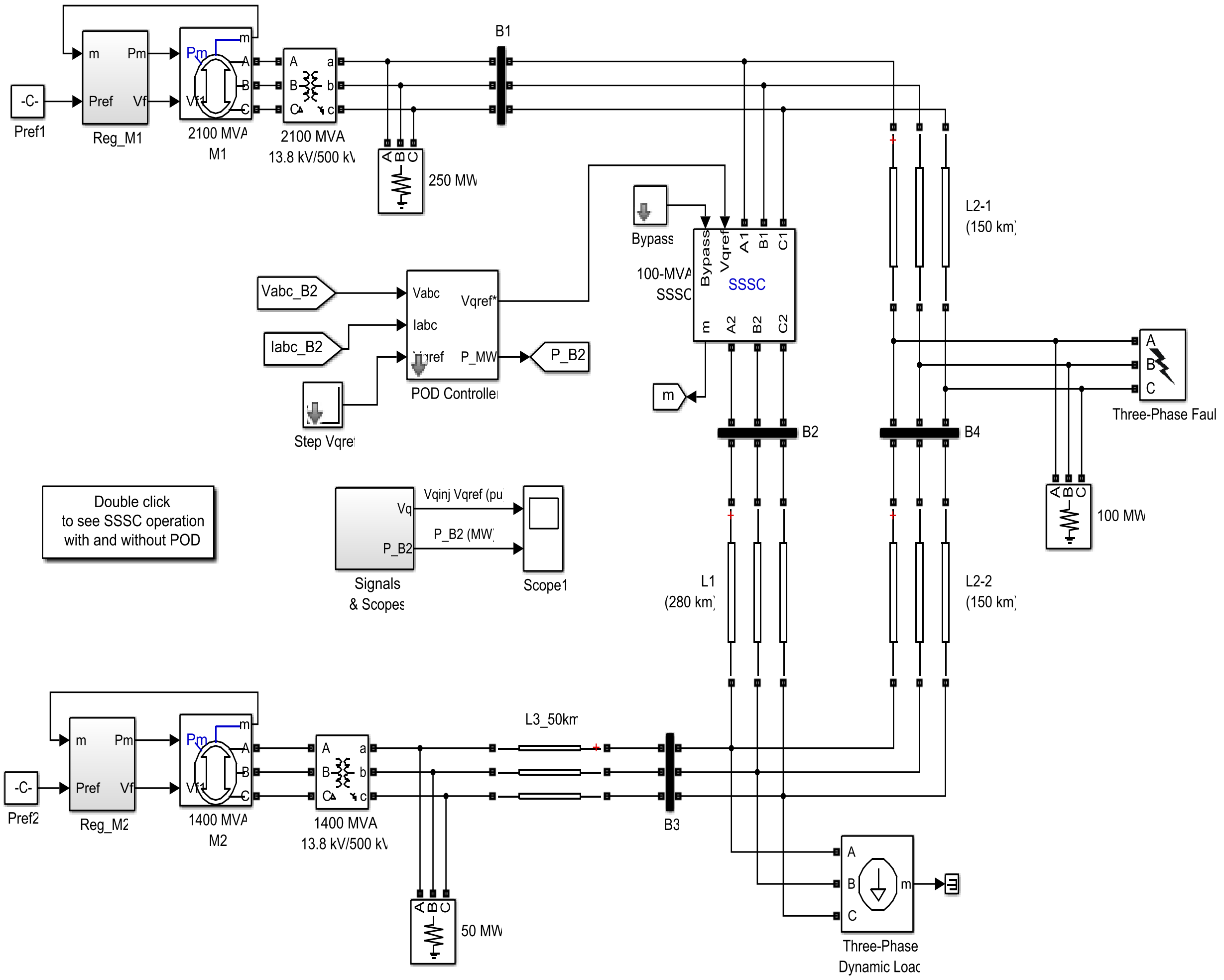

Fig4. *Simulation block diagram of the power system with a SSSC in Matlab/Simulink*

Table1. *System Parameters*

Components	Value
SSSC	S_n=100 MVA, U_{dc}=40 KV Cdc=375 µF, X_{eq}=0.16 pu
power generation substation (M1)	6×350 MW
power generation substation (M2)	4×350 MW
load center	2200 MW
line L_1	280 Km
line L_2	300 Km
line L_3	50 Km
POD	K_P=0.08, T_W=1 s, K_W=1, T_{P1}=1 s, T_{P2}=0.1 s, V_{smin}=-0.1, V_{smax}=0.1

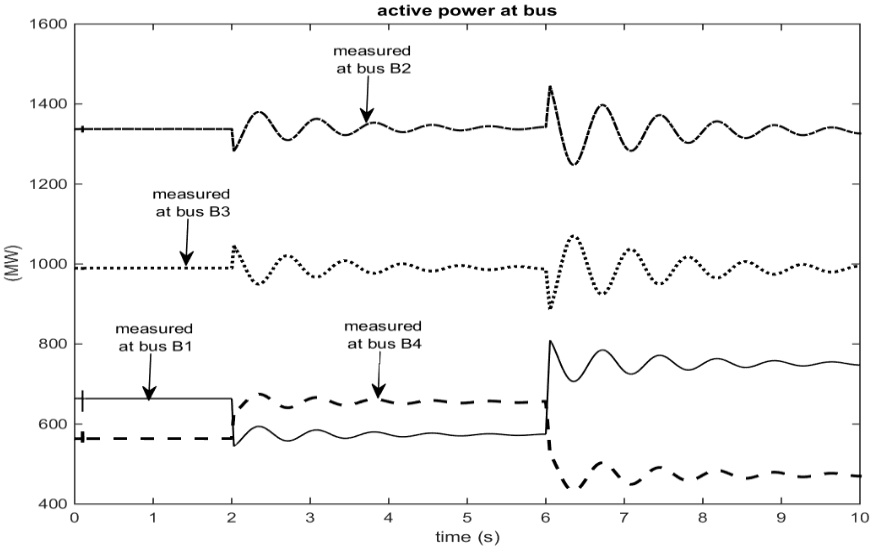

Fig5. *Active power measured at bus*

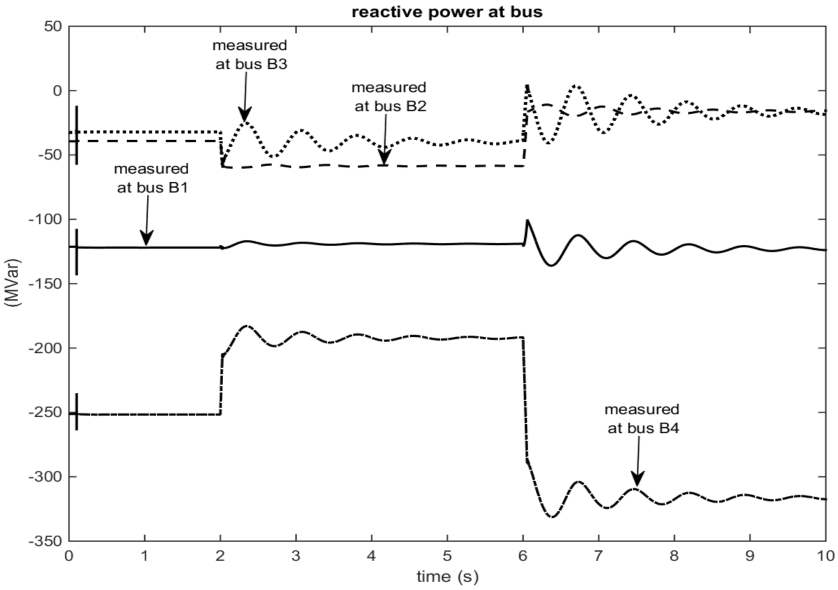

Fig6. *Reactive power measured at buses*

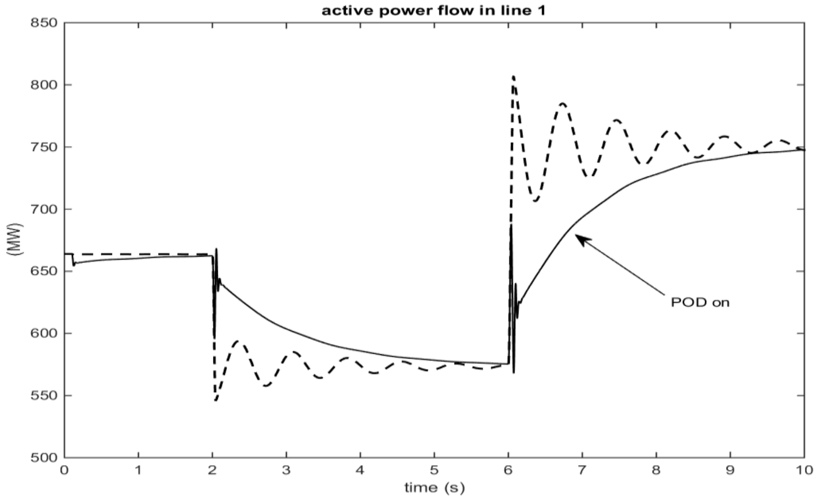

Fig7. *Active power flow on line 1 that the SSSC operation with and without POD*

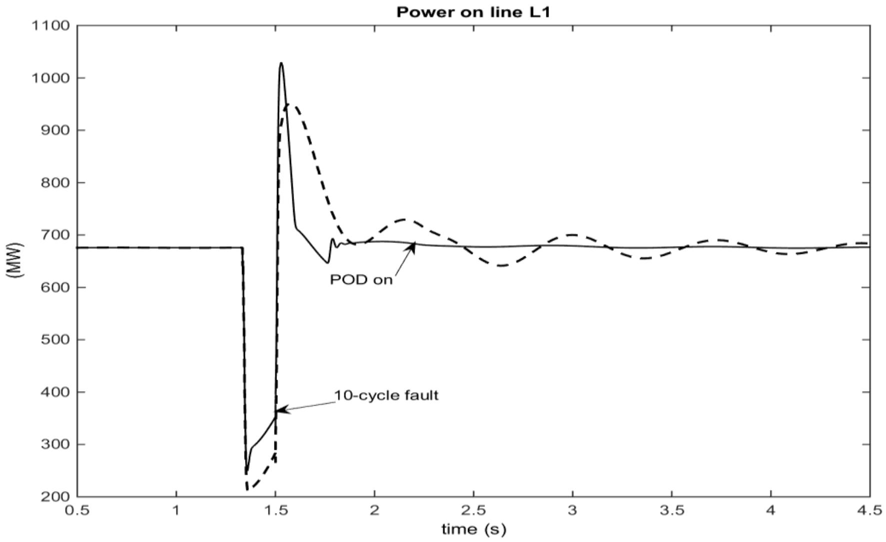

Fig8. *Power on line 1 that the SSSC operation with and without POD*

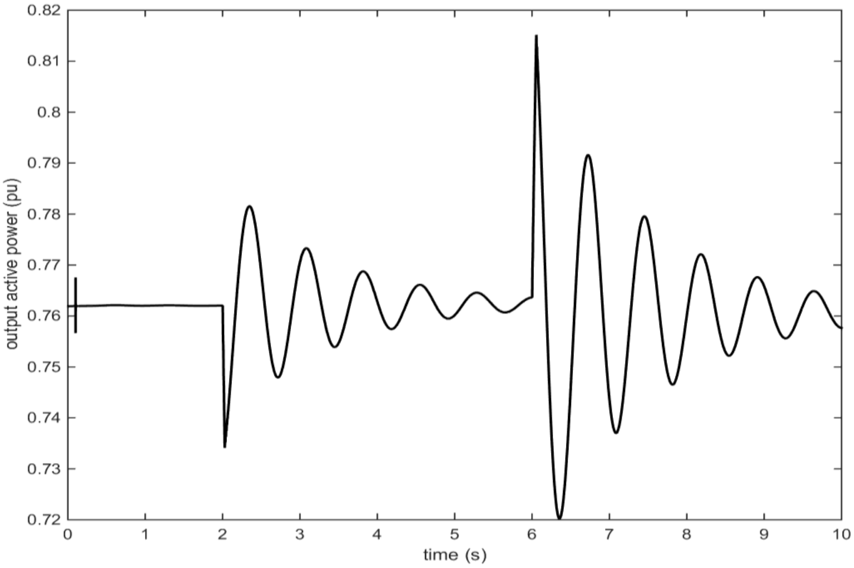

Fig9. *Output active power without POD*

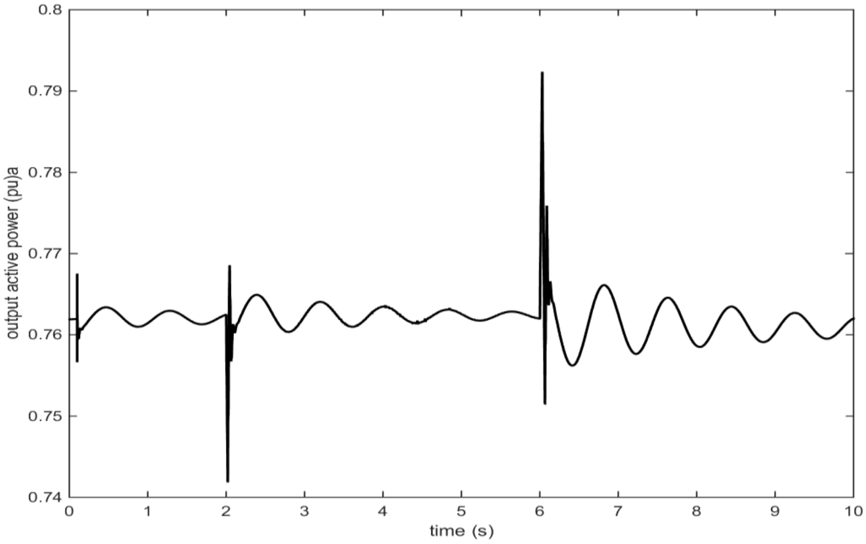

Fig10. *Output active power without POD*

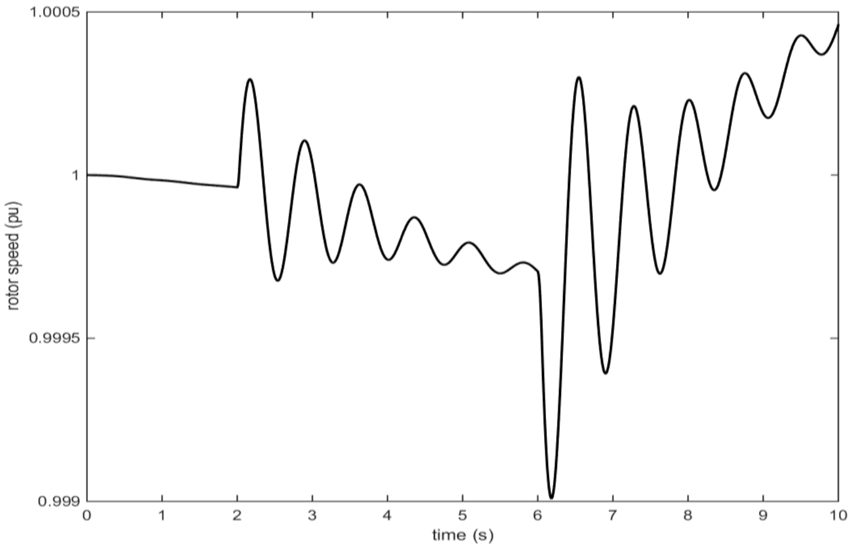

Fig11. *Rotor speed without POD*

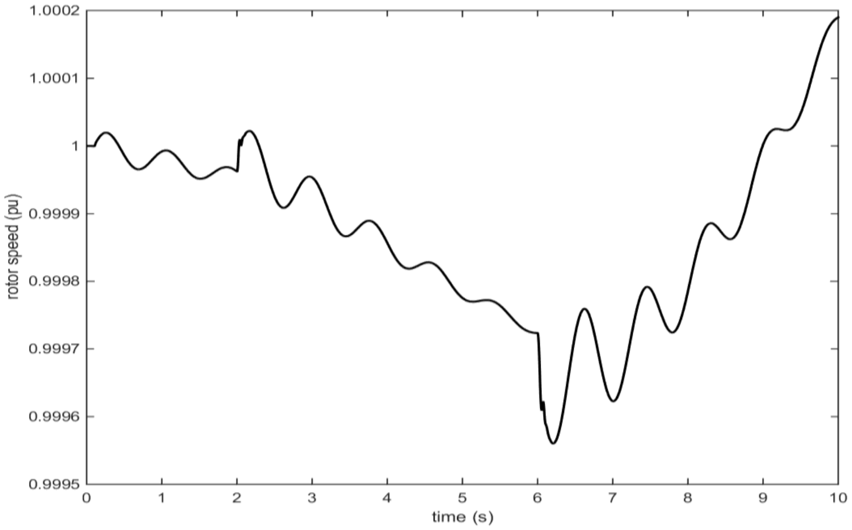

Fig12. *Rotor speed without POD*

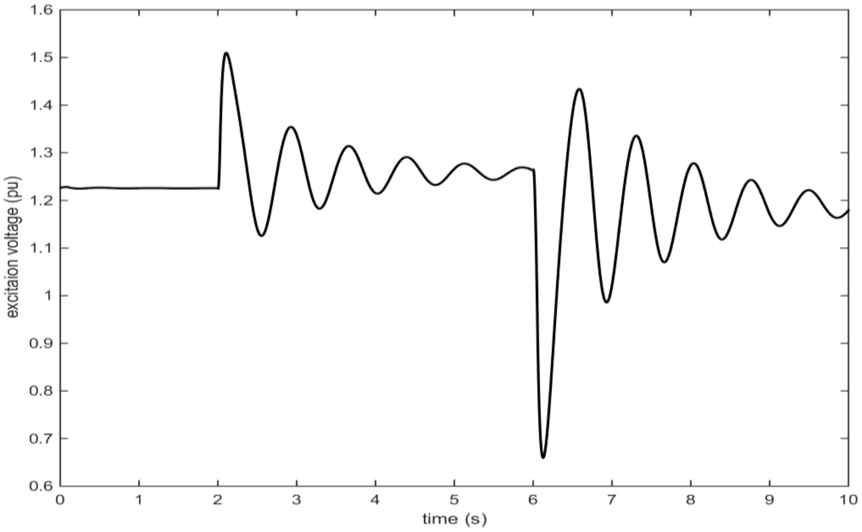

Fig13. *Excitaion voltage without POD*

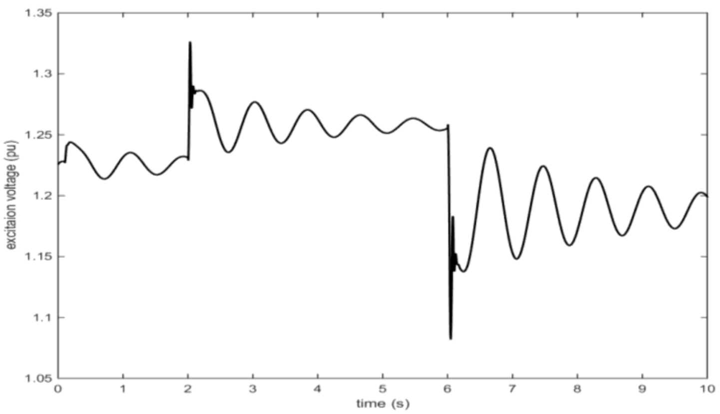

Fig14. *Excitaion voltage with POD*

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