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Discrete Time Power System Stabilizer Tunning For Networked Control

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Abstract: **In this paper, a discrete time power system stabilizer is designed for silent-pole synchronous generator connected to infinite bus. In this study, the synchronous generator is represented by simplified transient model in qd rotating reference frame. In simplified model both the damper windings and changing in flux linkages are neglected during transient period. The rise of electricity demand in a power system and the widely spread of networked control systems require the use of discrete-time devices. Digital devices are widely spread and play an essential task in the operation and control of power systems. Several kinds of digital controlled devices have been put into practical use in power systems for the last decade, such as power system stabilizers PSS, proportional-integral plus derivative PID controllers and automatic voltage regulators AVR.The power system stabilizer is represented by a three-pole three-zero, lead-lag type PSS. The effects of sampling time and PSS parameters are simulated and examined. TRUETIME simulink library is used to implement the discrete PSS through networked control system.**

Keywords: **Power system stabilizer; discrete time; synchronous generator; excitation system; matlab; simulink; TrueTime library.**

I. INTRODUCTION

Analog PSS have been used widely in the field of power systems to improve dynamic performances and disturbance-rejection properties of a synchronous generator. However, it has been witnessed that digital control devices are replacing analog ones during the past decade or so due to their versatility and the availability of low cost digital computers. Digital control systems form a class of control system which is probably the most popular in current practice. In networked control system, a control algorithm is implemented in a software form, which requires a discrete-time formulation. The generating unit consists of a set of first order differential equations representing the models of the synchronous machine windings, the excitation system, the mechanical system, and another set of differential equations representing the PSS. This paper aims to replace the analog PSS by its digital version that is represented by a set of difference equations in order to compare the digital PSSs performances with the analog ones type.

The action of a PSS is to extend the angular stability limits of a power system by providing supplemental damping to the oscillation of synchronous machine rotors through the generator excitation. This damping is provided by a electric torque applied to the rotor that is in phase with the speed variation. Once the oscillations are damped, the thermal limit of the tie-lines in the system may then be approached. This supplementary control is very beneficial during line outages and large power transfers. However, power system instabilities can arise in certain circumstances due to negative damping effects of the PSS on the rotor. The reason for this is that PSSs are tuned around a steady-state operating point; their damping effect is only valid for small excursions around this operating point. During severe disturbances, a PSS may actually cause the generator under its control to lose synchronism in an attempt to control its excitation field.

The input signal for the PSSs in the system is also a point of debate. The signals that have been identified as valuable include deviations in the rotor speed, the frequency, the electrical power and the accelerating power. Since the main action of the PSS is to control the rotor oscillations, the input signal of rotor speed has been the most frequently advocated in the literature. Controllers based on speed deviation would ideally use a differential-type of regulation and a high gain. Since this is impractical in reality, the rotor speed deviation input-type lead-lag structure is commonly used. However, one of the limitations of the speed input PSS is that it may excite torsional oscillatory modes.

II. SYNCHRONOUS GENERATOR MODEL

The simplified synchronous generator transient model in qd rotating reference frame was considered. Now we will show the equations of the transient model in the q and d -axis for the transient period where the damper windings may be assumed to be no longer active and with changes in stator qd flux linkages are neglected.

Considering that x'_d, x'_q are q- and d-axis transient generator reactance, L'_q, L'_d are q- and d-axis transient generator inductances, E'_q, E'_d are q- and d-axis transient electromotive forces, λ'_q, λ'_d are q- and d-axis transient flux linkages and T'_{qo}, T'_{do} are the transient open circuit time constants, then the stator winding equations are:

$$v_q = -r_s i_q - x'_d i_d + E'_q \quad (1)$$

$$v_d = -r_s i_d - x'_q i_q + E'_d \quad (2)$$

Rotor winding equations are:

$$T'_{do}\frac{dE'_q}{dt} + E'_q = E_f - (x_d - x'_d)i_d \quad (3)$$

$$T'_{qo}\frac{dE'_d}{dt} + E'_d = E_g - (x_q - x'_q)i_q \quad (4)$$

$$\lambda'_q = \lambda_q - L'_q(-i_q) \quad (5)$$

$$\lambda'_d = \lambda_d - L'_d(-i_d) \quad (6)$$

Where E_f and E_g are the d and q field voltages respectively. The torque and motion equations are:

$$T_{em} = -\left\{E'_q i_q + E'_d i_d + (x'_q - x'_d)i_q i_d\right\} \quad (7)$$

$$2H\frac{d(\frac{\omega_r - \omega_e}{\omega_b})}{dt} = T_{em} + T_{mech} - T_{damp} \quad (8)$$

Where T_{em} is the electromagnetic torque, T_{mech} is the externally applied torque, T_{damp} is the friction torque, H is the inertia constant, ω_r is the rotor angular speed, ω_e is the electrical angular speed and ω_b is the base angular speed.

III. EXCITATION SYSTEM

The generator excitation system consists of an exciter and an automatic voltage regulator AVR. The AVR regulates the generator terminal voltage by controlling the amount of current supplied to the generator field winding by the exciter. A power system stabilizer (PSS) is added to the AVR subsystem to help damp power swings in the system.

Exciters have many types and models; generally they can be classified as either rotating or static exciters. Fig. 1 shows 1shows block diagram of excitation system with Automatic Voltage Regulator AVR and Power System Stabilizer PSS. Fig. 2 shows a functional block diagram of excitation system with DC exciter type. The block diagram of the main part of the excitation system can be formulated by combining the block diagram of the exciter with that of the regulator and the stabilizing feedback signal. The regulator is represented by a first-order transfer function with a time constant T_A and gain K_A. Typical values of these parameters are T_A = 0.05–0.2 s and K_A = 20–400.

The high regulator gain is necessary to ensure small voltage regulation of the order of 0.5%. Unfortunately, although this high gain ensures low steady-state error, when coupled with the length of the time constants the transient performance of the exciter is unsatisfactory. To achieve acceptable transient performance the system must be stabilized in some way that reduces the transient (high-frequency) gain. This is achieved by a feedback stabilization signal represented by the first-order differentiating element with gain K_F and time constant T_F . Typical values of the parameters in this element are

T_F = 0.35 – 1s and K_F = 0.01 – 0.1. Although the saturation function S_E can be approximated by any nonlinear function, an exponential function of the following form is commonly used:

$$S_E = A_{ex} e^{B_{ex}.E_f} \qquad (9)$$

As this function must model the saturation characteristic over a wide range of exciter operating conditions, the parameters A_{ex} and B_{ex} of the exponential function are determined by considering the heavily saturated region of the characteristic corresponding to high excitation voltage and high exciter field current.

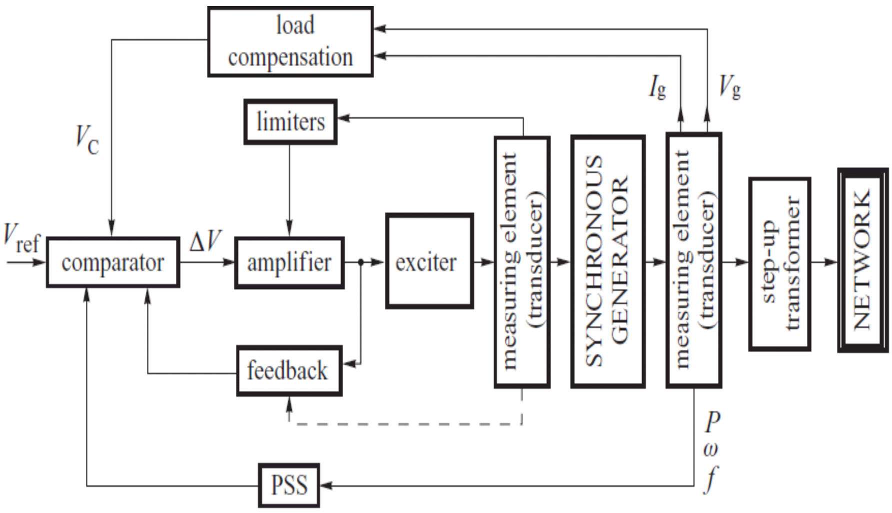

Fig. 1. Block Diagram of the Excitation System with AVR and PSS

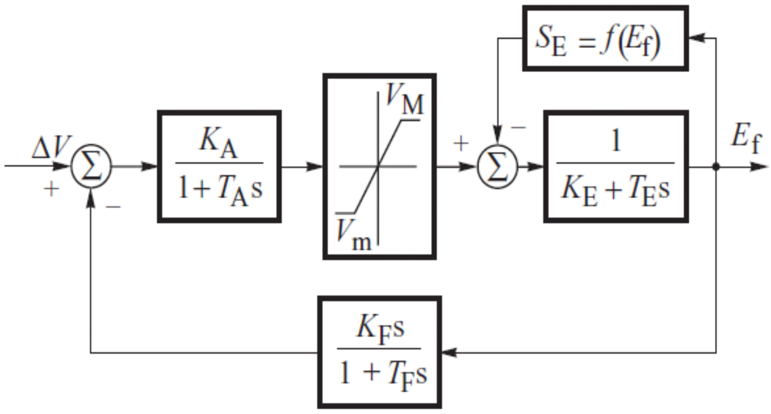

Fig. 2. Block diagram of the excitation system with DC exciter

IV. POWER SYSTEM STABILIZER PSS

Power System Stabilizer is the effective one for damping electromechanical oscillations especially in interconnected power system.. When the stabilizers are correctly tuned the resulting damping action will be robust. The main advantage of PSS is a cost effective one when compared to the power electronics based FACTS controller when used for damping application. PSS have been used for over 20 years in the western part of United States of America Ontario Hydro [55]. In United Kingdom it was reported that PSS have been used for damping of oscillations when the power is transmitted for long distance with weak AC tie-lines like connecting Scotland and England. However PSS is not used under normal operating condition it will be service at abnormal or unusual condition which may occur sometimes. Therefore PSS is necessary to operate along with modern excitation systems to damp out the oscillations effectively and also to enhance the system stability.

A. Analog PSS Structure:

Fig. 3 shows a block diagram of power system stabilizer. This particular controller structure contains a washout block, $\frac{T_w s}{T_w s+1}$ used to reduce the over-response of the damping during severe events. Since the PSS must produce a component of electrical torque in phase with the speed deviation, phase lead blocks circuits are used to compensate for the lag (hence, "lead-lag') between the PSS output and the control action, the electrical torque. The number of lead-lag blocks needed depends on the particular system and the tuning of the PSS. The PSS gain K_s is an important factor as the damping provided by the PSS increases in proportion to an increase in the gain up to a certain critical gain value, after which the damping begins to decrease. All of the variables of the PSS must be determined for each type of generator separately because of the dependence on the machine parameters. The power system dynamics also influence the PSS values. The determination of these values is performed by many different types of tuning methodologies.

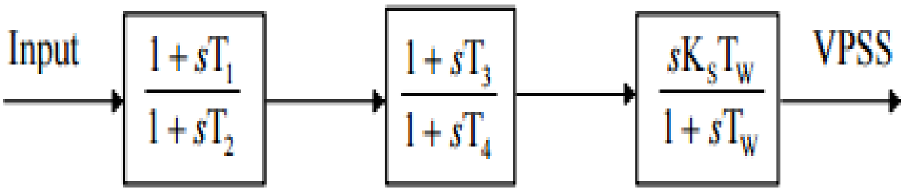

Fig. 3. Lead-Lag power system stabilizer

B. Discrete PSS Design:

For the design of a discrete PSS, the sampling interval T plays an important role. Discrete transfer function is approximated using zero-order hold (ZOH) equivalent. For this technique, the situation sketched in Fig. 4 is constructed. The samplers in Fig. 4(b) provide the samples at the input of $H_{ho}(z)$ and take samples at its output insuring that $H_{ho}(z)$ can be realized as a discrete transfer function.

The philosophy of the design is the following, we are asked to design a discrete system that, with an input consisting of samples of e(t), has un output that approximates the output of the continuous filter $H(s)$ whose input is the continuous e(t). The discrete hold equivalent is constructed by first approximating $e(t)$ from the samples $e(k)$ with a hold filter and then putting this $e_h(t)$ through the given $H(s)$. There are many techniques for taking sequence of samples and extrapolating or holding them to produce a continuous signal. The zero-order hold operation is a sketch of a piecewise constant approximation to $e(t)$ obtained by holding $e_h(t)$ constant at $e(k)$ over the interval from kT to $(k+1)T$. If a first order polynomial is used for extrapolation then it is called a first-order hold (FOH).

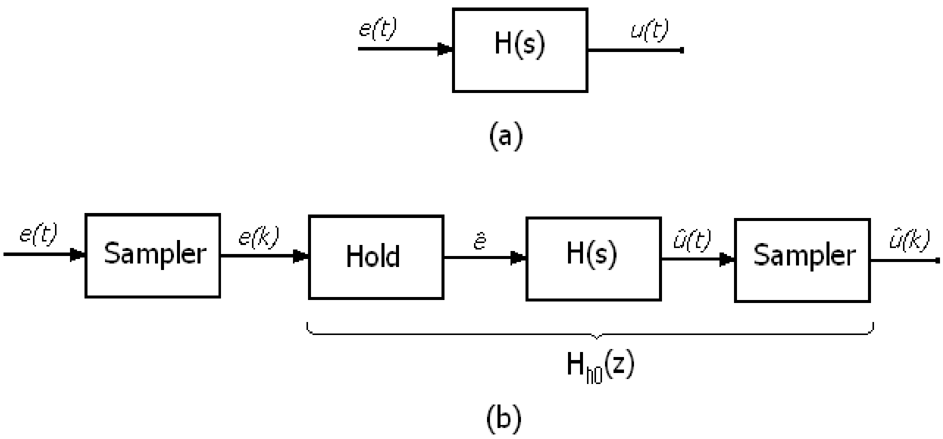

Fig. 4. System construction for hold equivalent. (a) A continuous transfer function. (b) Block diagram of an equivalent system

When the approximation hold is zero-order hold, then the discrete equivalent to $H(s)$ is given by:

$$H_{h0}(z) = (1 - z^{-1})\mathcal{Z}\left\{\frac{H(s)}{s}\right\} \qquad (10)$$

If we have H(s) is the phase lead function where:

$$H(s) = \frac{1 + sT_1}{1 + sT_2} \qquad (11)$$

Then the zero-order hold equivalent is:

$$H_{h0}(z) = \frac{\frac{T_1}{T_2} z - \left(\frac{T_1 - T_2}{T_2} + e^{-\frac{T}{T_2}}\right)}{z - e^{-\frac{T}{T_2}}} \qquad (12)$$

V. TRUETIME SIMULINK LIBRARY

TrueTime is a Matlab/Simulink-based simulator for networked and embedded control systems that has been developed at Lund University since 1999. The simulator software consists of a Simulink block library and a collection of MEX files. The kernel block simulates a real-time kernel by executing user-defined tasks and interrupt handlers. The various network blocks allow nodes (kernel blocks) to communicate over simulated wired or wireless networks. Fig. 5 shows TrueTime block library of Trutime 2.0 beta 6 2010 version. The TRUETIME blocks are connected with ordinary Simulink blocks to form a real-time control system. Before a simulation can be run, however, it is necessary to initialize kernel blocks and network blocks, and to create tasks, interrupt handlers, timers, events, monitors,.. etc for the simulation. The initialization code and the code that is executed during simulation may be written either as Matlab M-files or as C++ code. The execution of tasks and interrupt handlers is defined by code functions. A code function is further divided into code segments according to the execution model shown in Fig. 6. All execution of user code is done in the beginning of each code segment. The execution time of each segment should be returned by the code function. The standalone network blocks, named TrueTime Send and TrueTime Receive, as seen in Figure 1, can be used to send messages using the network blocks without using kernel blocks. This makes it possible to create TrueTime network simulations without having to initialize kernels. The TrueTime Battery block acts as a power source for the battery enabled kernel blocks. It uses a simple integrator model so it can be both charged and recharged. The only one parameter in its block mask is the initial power. TrueTime Ultrasound Network and TrueTime Wireless Network blocks are used to simulate wireless networks. The TrueTime Network block simulates medium access and packet transmission (physical and medium access layer) in a local area network. The following subsections describe TrueTime Network and TrueTime Kernel blocks in some detail.

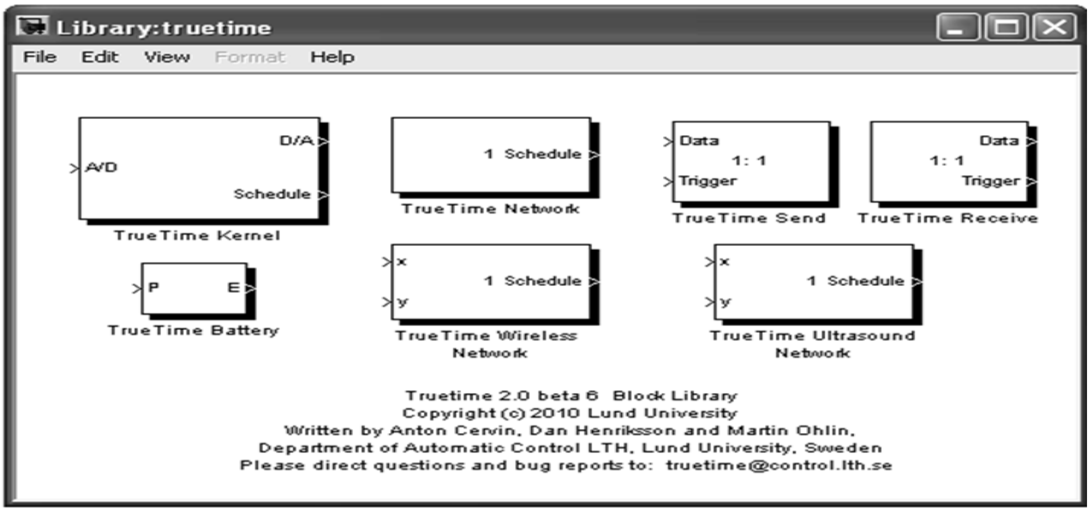

Fig. 5. TrueTime block library

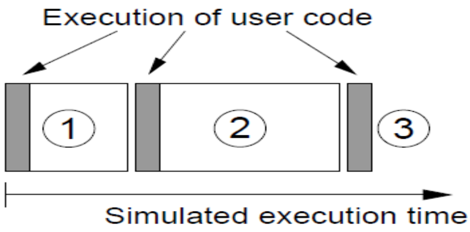

Fig. 6. Execution of user code and sequence of segments

A. TrueTime Kernel Block:

The kernel block is a Simulink S-function that simulates a computer with a real-time kernel, A/D and D/A converters, a network interface, and external interrupt channels. The kernel executes user-defined tasks and interrupt handlers. Internally, the kernel maintains several data structures that are commonly found in a real-time kernel: a ready queue, a time queue, and records for tasks, interrupt handlers, monitors and timers that have been created for the simulation. The block is configured by the block mask dialog as shown in Fig. 7.3. The main parameter is the name of the initialization function, because each kernel block has to be initialized at the start of the simulation. An optional argument for the initialization script can be set, also the battery option, the clock drift and the clock offset can be set.

B. The TrueTime Network Block:

The TRUETIME network block simulates medium access and packet transmission in a local area network. When a node tries to transmit a message (using the primitive ttSendMsg), a triggering signal is sent to the network block on the corresponding input channel. When the simulated transmission of the message is finished, the network block sends a new triggering signal on the output channel corresponding to the receiving node. The transmitted message is put in a buffer at the receiving computer node. A message contains information about the sending and the receiving computer node, arbitrary user data (typically measurement signals or control signals), the length of the message, and optional real-time attributes such as a priority or a deadline. Six simple models of networks are supported: CSMA/CD (e.g. Ethernet), CSMA/ AMP (e.g. CAN), Round Robin (e.g. Token Bus), FDMA, TDMA (e.g. TTP), and Switched Ethernet. The propagation delay is ignored, since it is typically very small in a local area network. Only packet-level simulation is supported, it is assumed that higher protocol levels in the kernel nodes have divided long messages into packets, etc.

VI. SIMULATION AND RESULTS

Fig.7 shows overall diagram of synchronous generator model and excitation system with networked control PSS. TrueTime simulink library is used for simulating the network and controlling the PSS signal. TrueTime Simulink library, illustrated in chapter V, was used to simulate the internet network. Network type Switched Ethernet was used in this simulation.

Parameters of the synchronous machine used in simulation are illustrated in Table I, while Table II shows the excitation system parameters and Table III shows the continuous PSS parameters.

TABLE I. SYNCHRONOUS GENERATOR PARAMETERS USED IN SIMULATION

Parameter	Value
S	310 MVA
V	13.8 kv
F	60 Hz
Poles	56
r_s	0.008 pu
x_{ls}	0.11 pu
x_d	1.14 pu
x_q	0.63 pu
x'_d	0.33 pu
x'_q	0.63 pu
x''_d	0.25 pu
x''_q	0.33 pu
T'_{do}	6.6 s
T''_{do}	0.05 s
T'_{qo}	2.2 s
T''_{qo}	0.1 s

TABLE II. EXCITATION SYSTEM PARAMETERS

Parameter	Value
T_A	0.06 s
K_A	50
T_E	0.052 s
K_E	-0.0465
K_F	0.0832
T_F	1 s
VRmax	1
VRmin	-1
A_{ex}	0.33 pu
B_{ex}	0.63 pu

TABLE III. PSS PARAMETERS

Parameter	Value
T_W	1s
K_S	120
T_1	0.024 s
T_3	0.024 s
T_4	0.24 s
PSS limit	0.1

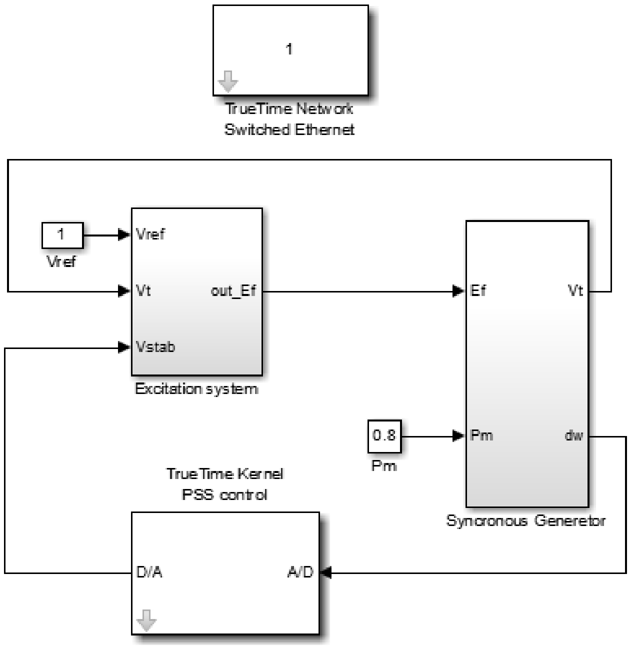

Fig. 7. **Overall Diagram of simulated system**

The following figures, Fig.8 to Fig.19, show the speed division and rotor angel results of system transient response to a three phase fault at the generator terminals, the fault duration is 0,1 second. Results are shown for different values of time constant T2 of the continuous PSS and also for different sample time T of discrete equivalent PSS. Results of non-use PSS situation is also compared with the situations of using both discrete and continuous PSS. Three values of the time constant T2 are considered for continuous PSS, which are 0.002, 0.02 and 0.08 second. Then different sample times are used to design the equivalent discrete PSS for each value of T2.

Results show that for small time constants T2, it is butter to use small sample times, less than 0.01 second. Higher values of sampling time may cause the system to be unstable, so the continuous PSS is preferred in this case. For the higher values of time constant T2, the equivalent discrete PSSs perform better than continuous ones, so they are recommended in this cases. In this situation, when using small sampling times, less than 0.001s, then the results of discrete PSS are close to continuous one, and when using long sampling times, more than 0.1s, then the system may unstable, so a suitable sampling time must be chosen.

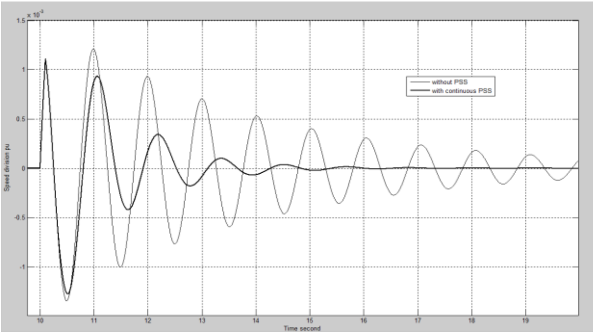

Fig. 8. Speed division results for T2=0.002 second, without PSS and with continuous PSS

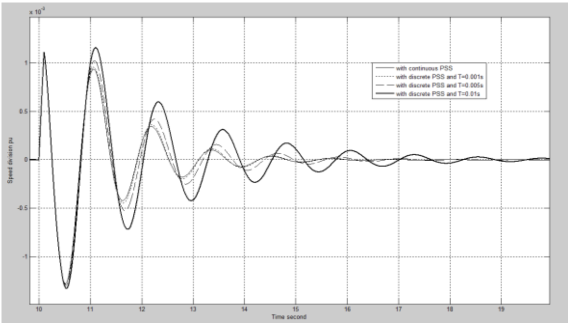

Fig. 9. Speed division results for T2=0.002 second, with continuous PSS and discrete PSS with sample times T=0.001, 0.005, 0.01 second

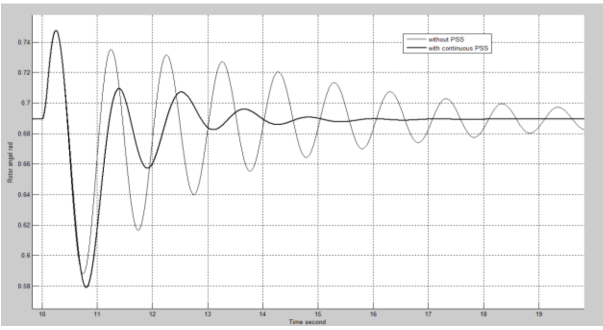

Fig. 10. Rotor angel results for T2=0.002 second, without PSS and with continuous PSS

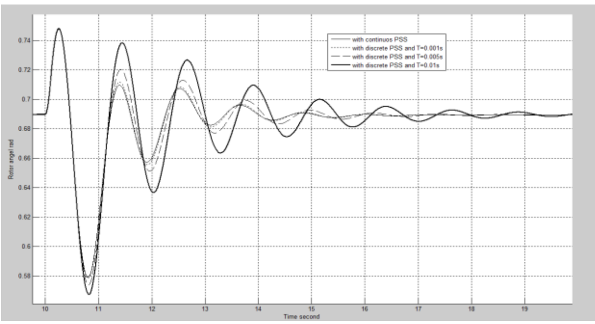

Fig. 11. Rotor angel results for T2=0.002 second, with continuous PSS and discrete PSS with sample times T=0.001, 0.005, 0.01 second

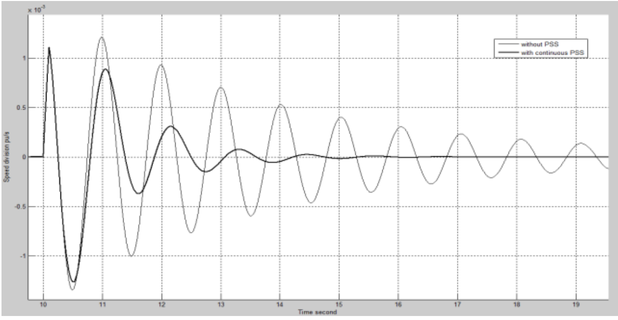

Fig. 12. Speed division results for T2=0.02 second, without PSS and with continuous PSS

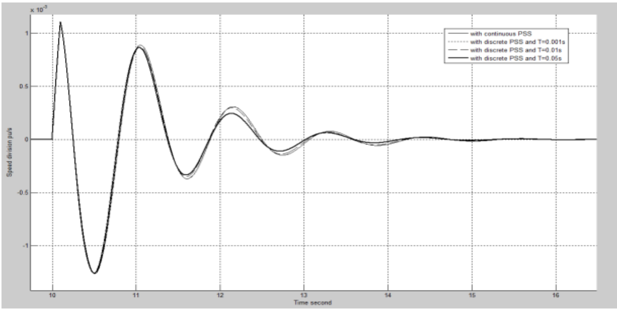

Fig. 13. Speed division results for T2=0.02 second, with continuous PSS and discrete PSS with sample times T=0.001, 0.01, 0.05 second

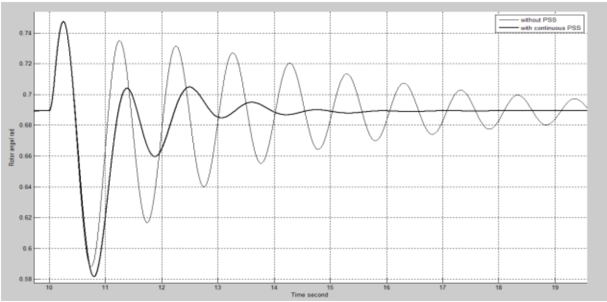

Fig. 14. Rotor angel results for T2=0.02 second, without PSS and with continuous PSS

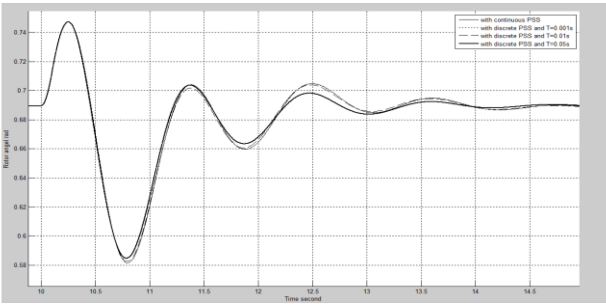

Fig. 15. Rotor angel results for T2=0.02 second, with continuous PSS and discrete PSS with sample times T=0.001, 0.01, 0.05 second

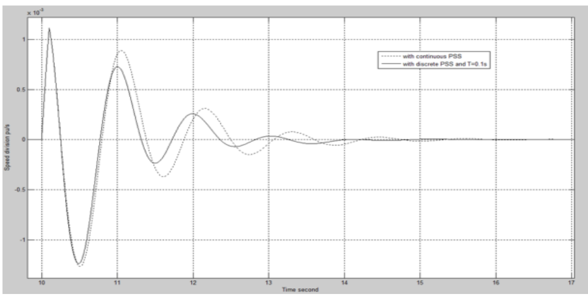

Fig. 16. Speed division results for T2=0.02 second, with continuous PSS and discrete PSS with sample time T=0.1 second

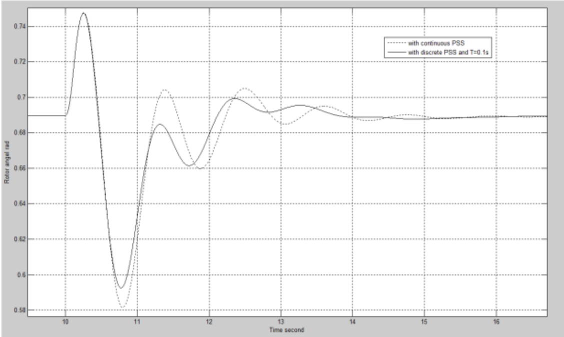

Fig. 17. Rotor angel results for T2=0.02 second, with continuous PSS and discrete PSS with sample time T=0.1 second

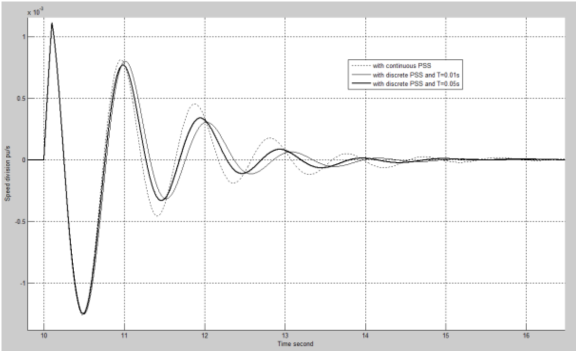

Fig. 18. Speed division results for T2=0.08 second, with continuous PSS and discrete PSS with sample time T=0.01, 0.05 second

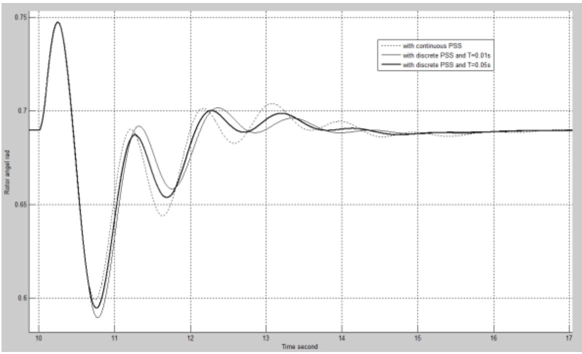

Fig. 19. Rotor angel results for T2=0.08 second, with continuous PSS and discrete PSS with sample time T=0.01, 0.05 second

VII. CONCLUSION

In this paper, a discrete time power system stabilizers were designed to enhance the power system stability and were implemented using networked control system. The networked control system was simulated with TrueTime Matlab library using switched Ethernet network type. TrueTime library is a Matlab/Simulink library developed by the Department of Automatic Control, Faculty of Engineering, Lund University in Sweden since 1999.

To examine the continuous and discrete time power system stabilizers types, a synchronous generator model with excitation system model were developed. The simplified transient model of the synchronous generator in qd rotating reference frame was used. A system of one generator-infinite bus was simulated and examined.

Results of using different values of the time constant T_2 of the continuous PSS and equivalent discrete PSS with different sample times were shown and discussed. Comparing the presented results help to tune the PSS parameters and to choose the best value of sampling time of the discrete PSS.

In the future, a discrete and continuous PSS effects on multi parallel generators system may be studied, and the sub-transient model may be developed

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