A Developed Graphical User Interface to Improve Power System Stability Study

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Abstract— *This paper present the realization and development of a graphical user interface (GUI) to studied the stability and robustness of power systems (analysis and synthesis), using Conventional Power System Stabilizers (CPSS - realized on PID scheme) or advanced controllers (based on adaptive and robust control), and applied on automatic excitation control of powerful synchronous generators, to improve dynamic performances and robustness. The GUI is a useful average to facilitate stability study of power system with the analysis and synthesis of regulators, and resolution of the compromise: results precision / calculation speed. The obtained Simulation results exploiting our developed GUI realized under MATLAB shown considerable improvements in static and dynamic performances, a great stability and enhancing the robustness of power system, with best precision and minimum operating time. This study was performed for different types of powerful synchronous generators.*

Keywords— *Synchronous generators, AVR and PSS, GUI-Matlab, analysis and synthesis, stability and robustness.*

I. INTRODUCTION

Power system stability continues to be the subject of great interest for utility engineers and consumers alike and remains one of the most challenging problems facing the power community .The electric power system is a complex system with highly non-linear dynamics. Its stability depends on the operating conditions of the power system and its configuration. Low frequency oscillations are a common problem in large power systems. Excitation control or Automatic Voltage Regulator (AVR) is well known as an effective means to improve the overall stability of the power system. Power System Stabilizers (PSS) are added to excitation systems to enhance the damping during low frequency oscillations [1, 2]. The output of the PSS is applied as a supplementary control signal to the machine voltage regulator terminal. Oscillations of small magnitude and low frequency often persist for long periods of time and in some cases can cause limitations on the power transfer capability.

GUI (graphical user interface) creates graphical display in one or more windows containing controls, called components that enable a user to perform interactive tasks. The user of the GUI does not have to create a script or type commands at the command line to accomplish the tasks [3, 4]. Unlike coding programs to accomplish tasks, the user of a GUI need not understand the details of how the tasks are performed. The graphical user interface (GUI) can make the understanding of the effects of stability study of power system with the analysis and synthesis of regulators, and resolution of the compromise: results precision / calculation speed.

II. DYNAMIC POWER SYSTEM MODELLING

2.1. Description of the studied Power System

A single machine-infinite bus system (SMIB) is considered for the present investigation. A machine connected to a large system through a transmission line may be reduced to a SMIB system, by using the venin's equivalent of the transmission network external to the machine (figure 1). The synchronous machine is described as the fourth order model. The two-axis synchronous machine representation with a field circuit in the direct axis but without damper windings is considered for the analysis. The system dynamics of the synchronous machine can be expressed as a set of four first order linear differential equations given in equations below [5].

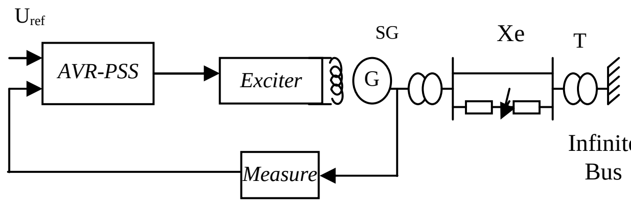

Fig. 1. Standard system IEEE type SMIB with excitation control of SG

A. *Modeling of powerful synchronous generators*

In this paper we based on the permeances networks modeling of synchronous generators to eliminating simplifying hypotheses and testing the control algorithm. The SG model is defined by equations 1-5 and figure 2 below [6]:

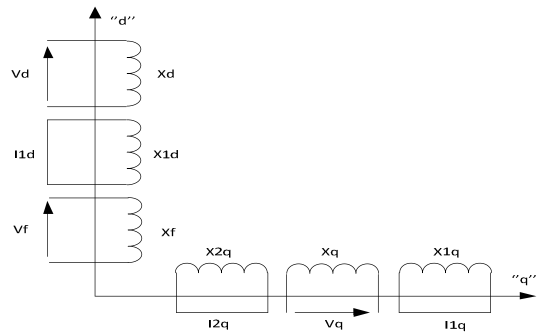

Fig. 2. Park Gariov Transformation of the synchronous machine

B. *Currants equations:*

$$I_q = (U_q - E''_q)/X''_d \qquad I_{1q} = (\Phi_{1q} - \Phi_{aq})/X_{sr1q}$$
$$I_d = -(U_d - E''_d)/X''_q \qquad I_{2q} = (\Phi_{2q} - \Phi_{aq})/X_{sr2q} \qquad (1)$$
$$I_{1d} = (\Phi_{1d} - \Phi_{ad})/X_{srd} \qquad I_f = (\Phi_f - \Phi_{ad})/X_{sr}$$

$$E''_q = \frac{\frac{1}{X_{sf}} \cdot \frac{X_f}{X_{ad}} E'_q + \frac{1}{X_{sfd}} \cdot \frac{X_{fd}}{X_{ad}} E'_{fq}}{\frac{1}{X_{ad}} + \frac{1}{X_{sf}} + \frac{1}{X_{sfd}}} \qquad E''_d = \frac{\frac{1}{X_{sfq}} \cdot \frac{X_{fq}}{X_{aq}} E'_{fd}}{\frac{1}{X_{ad}} + \frac{1}{X_{sfq}}} \qquad (2)$$

C. *Field equations*

$$\Phi_{ad} = E''_q + (X''_d - X_s) I_d \; ; \; \Phi_{aq} = E''_d + (X''_q - X_s) I_q$$
$$\Phi_{1q} = \omega_s \int_0^{\Phi_{1q}} (-R_{1q} I_{1q}).dt \quad \Phi_{2q} = \omega_s \int_0^{\Phi_{2q}} (-R_{2q} I_{2q}).dt \qquad (3)$$
$$\Phi_f = \omega_s \int_0^{\Phi_f} (-R_f I_f + U_{f0})dt \quad \Phi_{1d} = \omega_s \int_0^{\Phi_{1d}} (-R_{1d} I_{1d}).dt$$

D. *Mechanical equations*

$$d\delta = (\omega - \omega_s)dt \;,\quad s = \frac{\omega - \omega_s}{\omega_s} \qquad (4)$$

$$M_T + M_j + M_e = 0 \quad avec\ M_j : \text{moment d'inertie} \quad \left(M_j = -j\frac{d\omega}{dt} \right)$$
$$T_j \frac{d}{dt} s + (\Phi_{ad}.I_q - \Phi_{aq}.I_d) = M_T \quad \text{ou} \quad T_j \frac{d}{dt} s = M_T - M_e \qquad (5)$$
$$j\frac{d\omega}{dt} + \frac{P_e}{\omega_s} = M_T$$

B. *MODEL OF REGULATOR AVR*

The AVR (Automatic Voltage Regulator), is a controller of the PSG voltage that acts to control this voltage, thought the exciter .Furthermore, the PSS was developed to absorb the generator output voltage oscillations [1].

In our study the synchronous machine is equipped by a voltage regulator model "IEEE" type – 5 [7, 8], as is shown in Figure 4.

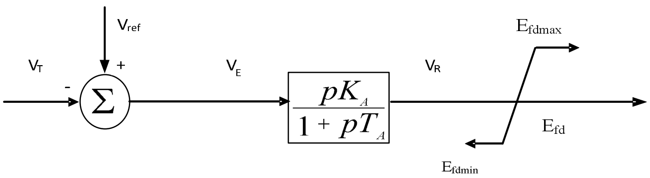

Fig. 4. A simplified ” IEEE type-5” AVR

$$V_R = \frac{K_A V_E - V_R}{T_A} \quad , \quad V_E = V_{ref} - V_F \qquad (6)$$

C. CONVENTIONAL POWER SYSTEM STABILIZER

The basic function of CPSS is to damp electromechanical oscillations. To achieve the damping, the CPSS proceeds by controlling the AVR excitation using auxiliary stabilizing signal. The CPSS's structure is illustrated in Figure 5 [9, 10].

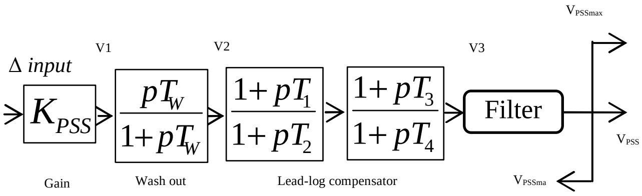

Fig.5. A functional diagram of the used CPSS

1. Gain

The gain determines the amount of damping introduced by the stabilizer. Therefore, increasing the gain can move unstable oscillatory modes into the left – hand complex plane. Ideally, the gain should be set to a value corresponding to a maximum damping. However, in practice the gain Kpss is set to a value satisfactory to damp the critical mode without compromising the stability of other modes.

2. Washout

The washout stage is a High Pass Filter (HPF) with purpose to respond only to oscillations in speed and block the dc offsets. The Washout filter prevents the terminal voltage of the generator to drift away due to any steady change in speed.

3. Phase compensation

This stage consists of two lead – lag compensators as shown in Figure 5 (lead – lag compensation stage*)*. The lead stage is used to compensate for the phase lag introduced by the AVR and the field circuit of the generator. The lead – lag parameters T1-T4 are tuned in such as way that speed oscillations give a damping torque on the rotor. When the terminal voltage is varied, the PSS affects the power flow from the generator, which efficiently damps the local modes.

4. Torsional Filter

This stage is added to reduce the impact on the torsional dynamics of the generator while preventing the voltage errors due to the frequency offset.

5. Limiter

The PSS output requires limits in order to prevent conflicts with AVR actions during load rejection. The AVR acts to reduce the terminal voltage while it increases the rotor speed and the bus frequency. Thus, the PSS is compelled to counteract and produce more positive output. As described in by P. Kundur in [7], the positive and negative limit should be around the AVR set point to avoid any counteraction. The positive limit of the PSS output voltage contributes to improve the transient stability in the first swing during a fault. The negative limit appears to be very important during the back swing of the rotor.

- ***SINGLE INPUT of the CPSS***

The input signals include deviations in the rotor speed ($\Delta\omega=\omega_{mech} - \omega o$), the frequency ($\Delta f$), the electrical power (ΔPe) and the accelerating power (ΔPa)

In this paper the PSS signal used, is given by: [5]

$$\dot{V}_1 = \frac{V_2 - V_1}{T_1} + \frac{T_2}{T_1}\dot{V}_2 \;; \qquad \dot{V}_2 = \frac{V_3 - V_2}{T_2} + \frac{T_3}{T_2}\dot{V}_2 \;; \qquad \dot{V}_3 = \frac{V_3}{T_W}\dot{V}_1 ;\; \dot{V}_1 = K_{PSS} \cdot \Delta input$$

$$\Delta input = \begin{cases} \Delta P \;,\; \int p \\ or \\ \Delta\omega = \omega_{mach} - \omega_0 \\ and \\ \Delta I_f = I_f - I_{f0} \\ and \\ \Delta U_f = U_f - U_{f0} \end{cases} \qquad (7)$$

III. CREATION OF THE CALCULATING CODE UNDER MATLAB / SIMULINK

The “SMIB” system used in our study includes:

- A powerful synchronous generator (PSG) ;
- Tow voltage regulators: AVR and AVR-PSS connected to;
- A Power Infinite network line

We used for our simulation in this paper, the SMIB mathematical model based on permeances networks model culled Park-Gariov, and shown in Figure 6 [11]

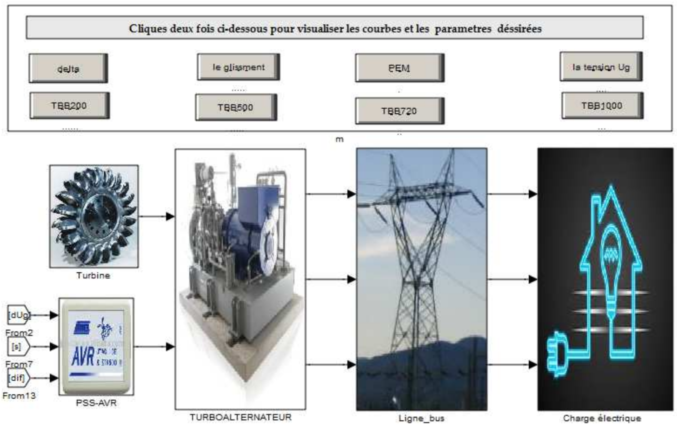

Figure 6. Structure of the synchronous generator (PARK-GARIOV model) with the excitation control.

IV. THE DEVELLOPPED GUI UNDER MATLAB

A. Introduction

GUIDE, the MATLAB graphical user interface development environment, provides a set of tools for creating graphical user interfaces (GUIs). These tools greatly simplify the process of designing and building GUIs. You can use the GUIDE tools to perform the following tasks:

B. Lay out the GUI.

Using the GUIDE Layout Editor, you can lay out a GUI easily by clicking and dragging GUI components—such as panels, buttons, text fields, sliders, menus, and so on—into the layout area. GUIDE stores the GUI layout in a FIG-file.

C. Program the GUI.

“GUIDE automatically generates a MATLAB program file that controls how the GUI operates. The code in that file initializes the GUI and includes function templates for the most commonly used callbacks for each component—the commands that execute when a user clicks a GUI component. Using the MATLAB editor, you can add code to the callbacks to perform the functions you want.

D. Starting GUIDE

Start GUIDE by typing guide at the MATLAB command prompt. This command displays the GUIDE Quick Start dialog box, as shown in the following figure 7.

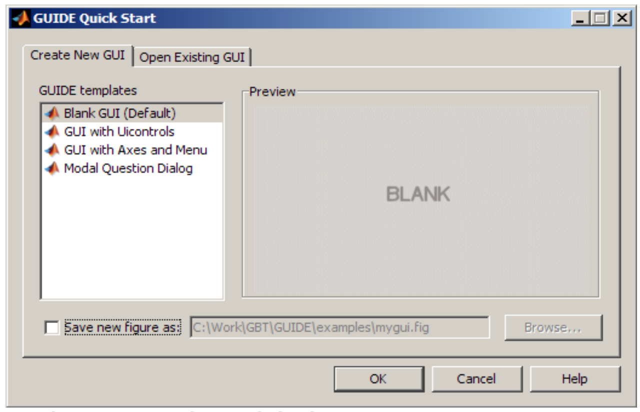

Fig 7. the GUIDE Quick Start dialog box

From the GUIDE Quick Start dialog box, you can perform the following tasks:

• Create a new GUI from one of the GUIDE templates prebuilt GUIs that you can modify for your own purposes.

• Open an existing GUI.

E. The Layout Editor

When we open a GUI in GUIDE, it is displayed in the Layout Editor, which is the control panel for all of the GUIDE tools. The following figure shows the Layout Editor with a blank GUI template.

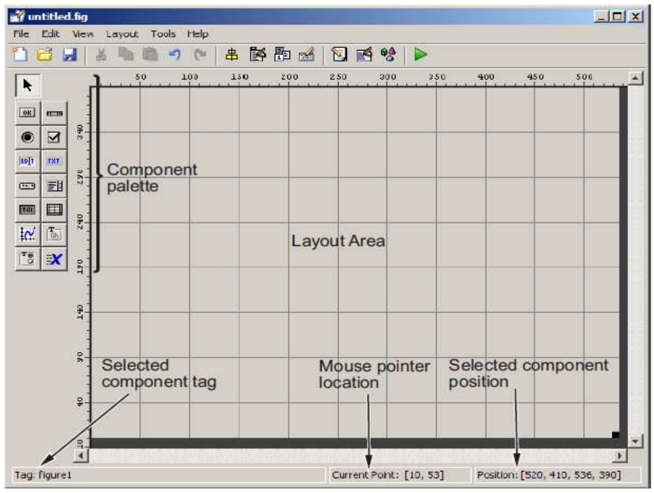

Fig 8. the Layout Editor

V. IMPLEMENTATION OF THE SYSTEM UNDER REALIZED GUI – MATLAB

To analyzed and visualized the different dynamic behaviors we have creating and developing a “GUI” under MATLAB .This GUI allows as to:

- Perform control system from PSS controller;
- View the system regulation results and simulation;
- Calculate the system dynamic parameters ;
- Test the system stability and robustness;
- Study the different operating regime (under-excited, rated and over excited regime).

The different operations are performed from GUI realized under MATLAB and shown in Figure 9.

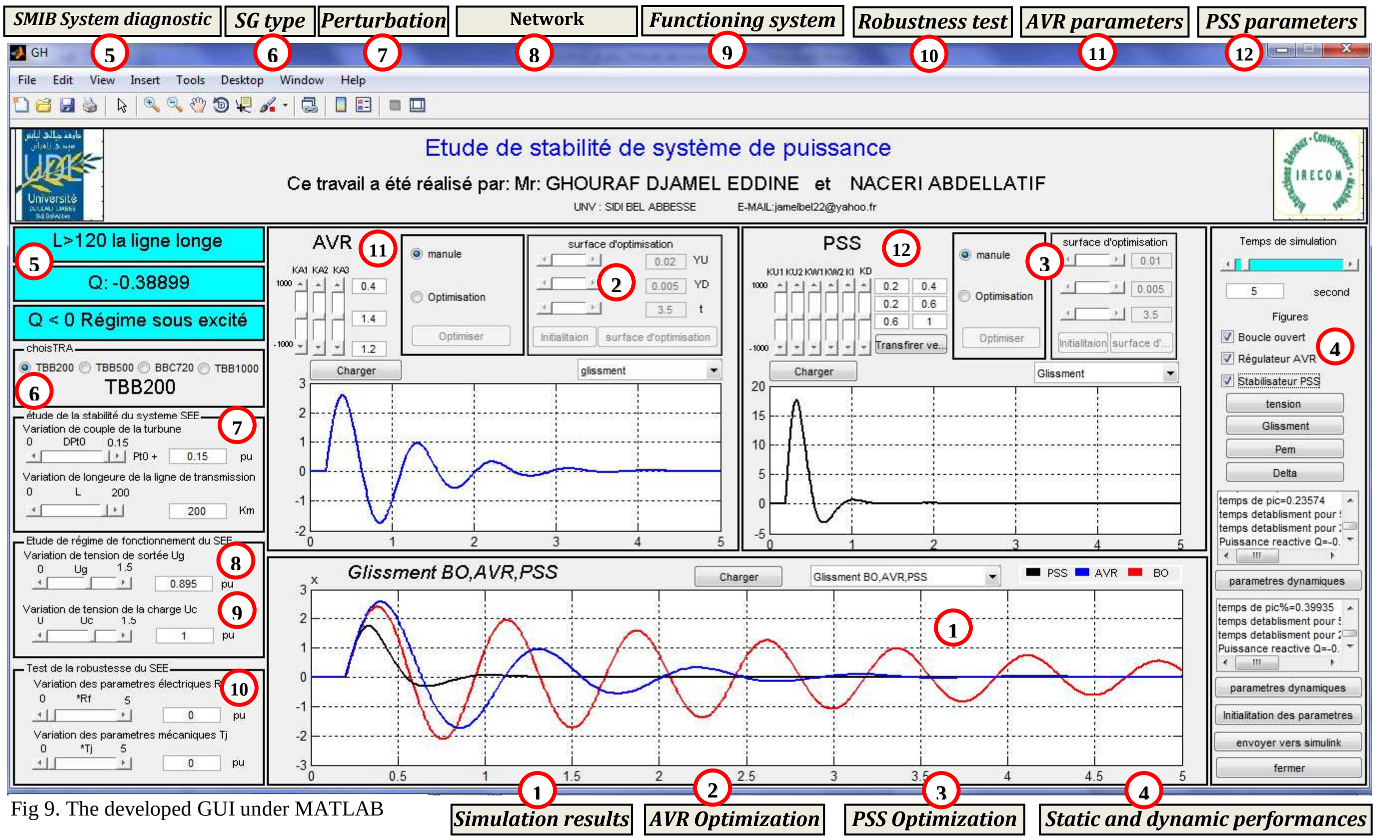

Fig 9. The developed GUI under MATLAB

VI. SIMULATION RESULTS AND DISCUSSION

The Stability study of the SMIB system was performed by mechanical perturbation (variation of turbine torque ΔTm of 15% at t = 0.2s).

The following results (Table 1 and Figures 10-13) were obtained using our developed graphical interface under Matlab in this paper, by studying the SMIB static and dynamic performances in the following cases:

1- The Open Loop (OL) without regulation;

2- Closed Loop System with AVR;

3- Closed Loop with the conventional stabilizer CPSS.

We have simulated three functioning mode of the used generators: under-excited, nominal and over-excited modes.

Our study interested different synchronous generators types [11]: TBB-200, TBB-500 BBC-720, TBB-1000 (the parameters shown in Appendix).

Table 1 presents the simulation results of static and dynamic performances applied on powerful synchronous generators in CL and OL for an average line Xe = 0.3 pu, and active power P=0.85 p.u.

More details about the calculating parameters of realized GUI-MATLAB given in Appendix 2.

α: Damping coefficient; ε %: the static error,

d%: the maximum overshoot; t_s: the setting time

Figures 10 to 13 show obtained simulation results, with: 'delta': the internal angle; 'Pe': the electromagnetic power system; 's': variable speed; 'Ug': the stator terminal voltage.

The electromechanical damping oscillations of synchronous generators parameters in under-excited mode with OL (green) and the controllable power system equipped by PSS (Black) and AVR (Bleu) are given in figures10 to 13. The stability Study of simulation results, it can be observed that the use of PSS improves considerably the dynamic performances (static errors negligible so better precision), and very short setting time so very fast system (table 1), and we found that after few oscillations, the system returns to its equilibrium state even in critical situations (the under-excited regime) and granted the stability of the studied SMIB system.

VII. CONCLUSION

The computer simulation results obtained by the realized GUI have proved a high efficiency of PSS, in comparison using AVR, showing stable system responses almost insensitive under different modes of the station. This PSS controller has the capability to improve its performance over time by interaction with its environment.

In This paper we proposed and developed a graphical user interface GUI under Matlab for acceleration and improve transient stability study of power system with regulation applied for powerful synchronous generators (analysis and synthesis), with best precision and minimum operating time.

Note that, our developed GUI was exploited and applied for other study (stability and robustness) using advanced adaptive and robust Controllers. As Perspective of this work, the implementation of realized GUI in real-time.

TABLE 1 THE “SMIB “STATIC AND DYNAMIC PERFORMANCES

SG 1: TBB-200												
Damping coefficient α				static error %			The setting time for 5%			maximum overshoot %		
Q(pu)	OL	AVR	PSS	BO	AVR	PSS	BO	AVR	PSS	BO	AVR	PSS
-0.1801	instable	-0.709	-1.761	instable	-2.640	-1.620	instable	4,231	1,704	9.572	9,053	7,892
-0.2016	instable	-0.708	-1.751	instable	-2.673	-1.629	instable	4,237	1,713	9.487	9,036	7,847
0.1896	-0.2442	-0.791	-1.855	-5.038	-2.269	-1.487	-	3,793	1,617	10,959	9,447	8,314
0.2847	-0.2354	-0.634	-1.759	-5.202	-1.807	-1.235	-	4,732	1,706	10,564	8,778	7,883
0.6896	-0.2095	-0.403	-1.470	-3.777	-0.933	-0.687	14,320	7,444	2,041	9,402	6,851	6,588
0.7173	-0.2080	-0.396	-1.442	-3.597	-0.900	-0.656	14,423	7,576	2,080	9,335	6,732	6,463
SG 2: TBB-500												
Damping coefficient α				static error %			The setting time for 5%			maximum overshoot %		
Q(pu)	OL	AVR	PSS	BO	AVR	PSS	BO	AVR	PSS	BO	AVR	PSS
-0.1801	instable	-0.765	-1.956	instable	-4.197	-1.459	instable	3,922	1,534	9.458	9,405	8,766
-0.2016	instable	-0.758	-1.926	instable	-4.230	-1.461	instable	3,958	1,558	9.254	9,137	8,632
0.1896	-0.2061	-0.761	-1.966	-5.933	-3.460	-1.386	-	3,942	1,526	9,249	9,635	8,811
0.2847	-0.2245	-0.691	-1.850	-5.802	-2.525	-1.170	-	4,342	1,621	9,075	9,500	8,292
0.6896	-0.3577	-0.492	-1.412	-4.903	-1.205	-0.659	8,387	6,098	2,125	8,053	7,380	6,328
0.7173	-0.3660	-0.484	-1.401	-4.597	-1.157	-0.683	8,197	6,198	2,141	7,426	7,260	6,279
SG 3: BBC-720												
Damping coefficient α				static error %			The setting time for 5%			maximum overshoot %		
Q(pu)	OL	AVR	PSS	BO	AVR	PSS	BO	AVR	PSS	BO	AVR	PSS
-0.2202	instable	-0.736	-1.858	instable	-2.640	-1.577	instable	4,076	1,349	9.956	9,776	8,955
-0.2464	instable	-0.728	-1.818	instable	-2.673	-1.579	instable	4,121	1,323	9.935	9,648	8,762
0.1489	-0.2810	-0.790	-2.049	-6.350	-2.269	-1.496	-	3,797	1,408	10,717	9,964	9,876
0.2726	-0.2651	-0.714	-2.017	-6.260	-1.807	-1.262	-	4,202	1,630	10,110	9,424	8,721
0.6552	-0.2377	-0.428	-1.704	-5.058	-0.933	-0.783	14,118	7,009	1,877	9,065	7,848	7,213
0.6892	-0.2365	-0.421	-1.398	-4.617	-0.900	-0.758	14,218	7,126	1,801	9,020	7,736	6,738
SG 4: TBB-1000												
Damping coefficient α				static error %			The setting time for 5%			maximum overshoot %		
Q(pu)	OL	AVR	PSS	BO	AVR	PSS	BO	AVR	PSS	BO	AVR	PSS
-0.160	instable	-0.766	-1.761	instable	-2.302	-1.530	instable	3,916	1,704	9.456	8,490	7,892
-0.222	instable	-0.762	-1.731	instable	-3.787	-1.517	instable	3,937	1,713	9.412	8,430	7,847
0.2139	-0.2442	-0.785	-1.855	-5.214	-3.195	-1.432	-	3,822	1,617	10,127	8,775	8,314
0.1634	-0.2354	-0.677	-1.759	-5.111	-2.565	-1.222	-	4,431	1,706	10,342	8,155	7,883
0.5746	-0.2095	-0.444	-1.470	-3.711	-1.312	-0.701	14,000	6,757	2,041	9,127	6,660	6,588
0.5663	-0.2080	-0.433	-1.442	-3.432	-1.266	-0.665	14,675	6,928	2,080	9,428	6,495	6,463

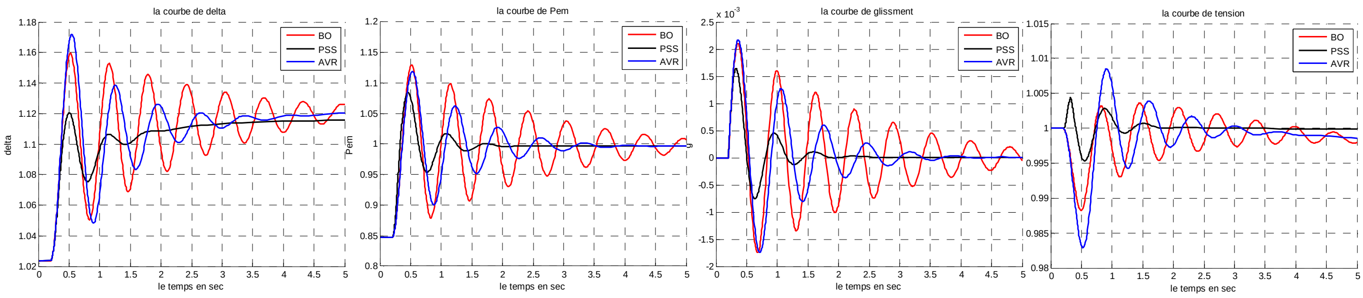

Fig .10. functioning system in the under-excited used of TBB 200 connected to a long line with AVR , PSS and OL

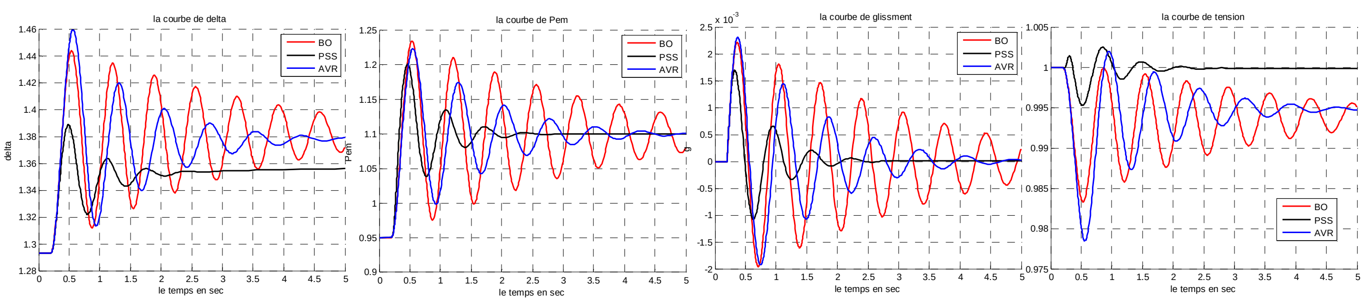

Fig .11. functioning system in the under-excited used of TBB 500 connected to a long line with AVR , PSS and OL

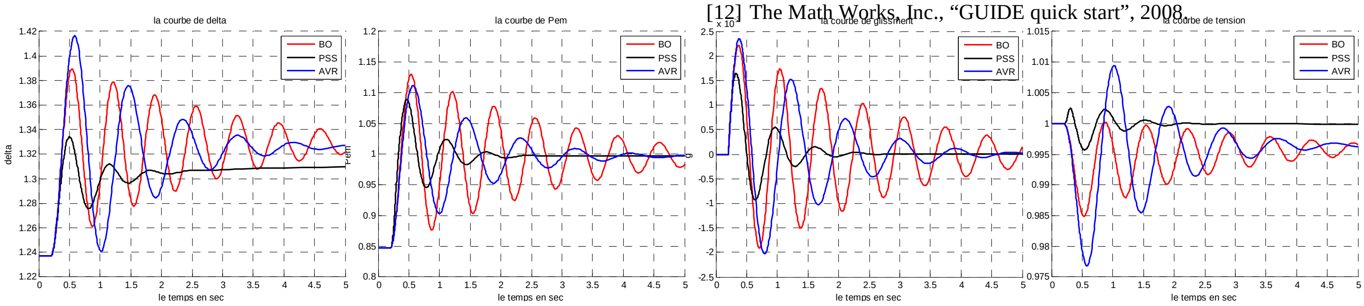

Fig .12. functioning system in the under-excited used of BBC 720 connected to a long line with AVR , PSS and OL

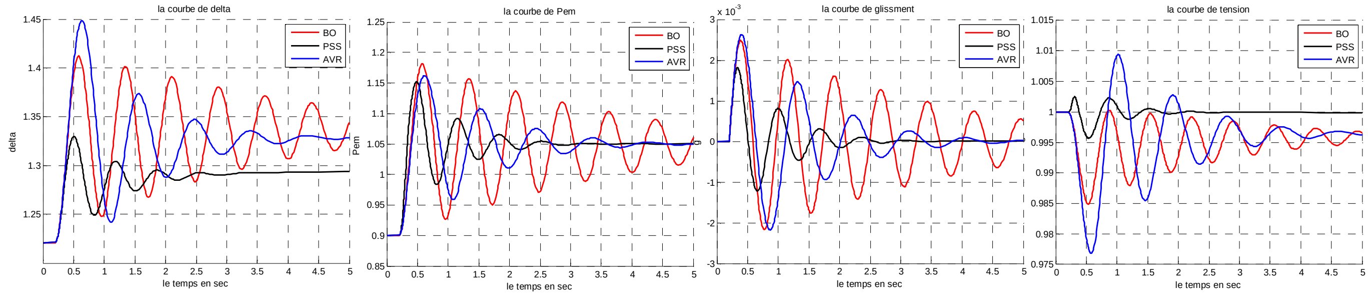

Fig .13. functioning system in the under-excited used of TBBC 1000 connected to a long line with AVR , PSS and OL

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APPENDIX

1. Parameters of the used Synchronous Generators

Parameters	***TBB-200***	***TBB-500***	***BBC-720***	***TBB1000***	Units of measure
power nominal	**200**	**500**	**720**	**1000**	**MW**
Factor of power nominal.	**0.85**	**0.85**	**0.85**	**0.9**	**p.u.**
X_d	**2.56**	**1.869**	**2.67**	**2.35**	**p.u.**
X_q	**2.56**	**1.5**	**2.535**	**2.24**	**p.u.**
X_s	**0.222**	**0.194**	**0.22**	**0.32**	**p.u.**
X_f	**2.458**	**1.79**	**2.587**	**2.173**	**p.u.**
X_{sf}	**0.12**	**0.115**	**0.137**	**0.143**	**p.u.**
X_{sfd}	**0.0996**	**0.063**	**0.1114**	**0.148**	**p.u.**
X_{sf1q}	**0.131**	**0.0407**	**0.944**	**0.263**	**p.u.**
X_{sf2q}	**0.9415**	**0.0407**	**0.104**	**0.104**	**p.u.**
R_a	**0.0055**	**0.0055**	**0.0055**	**0.005**	**p.u.**
R_f	**0.000844**	**0.000844**	**0.00176**	**0.00132**	**p.u.**
R_{1d}	**0.0481**	**0.0481**	**0.003688**	**0.002**	**p.u.**
R_{1q}	**0.061**	**0.061**	**0.00277**	**0.023**	**p.u.**
R_{2q}	**0.115**	**0.115**	**0.00277**	**0.023**	**p.u.**

2. Dynamics parameters calculated through GUI-MATLAB