Study and Application of the Advanced Frequency Control Techniques H∞ in the Voltage Automatic Regulator of Powerful Synchronous Generators (Application under Gui/Matlab)

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Abstract— This article presents a study of of the advanced frequency control techniques based on loop-shaping H∞ optimization method applied on automatic excitation control of powerful synchronous generators (AVR and PSS), to improve transient stability and its robustness of a single machine- infinite bus system (SMIB).The computer simulation results (static and dynamic stability), with test of robustness against machine parameters uncertainty (electric and mechanic), have proved that good dynamic performances, showing a stable system responses almost insensitive to large parameters variations, and more robustness using the robust H-infinity controller, in comparison with the classical Russian PID power system stabilizer . Our present study was performed using a GUI realized under MATLAB in our work.

Keywords— powerful synchronous generators and Excitations, AVR and PSS, , stability and robustness, GUI.

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. Power system oscillations are damped by the introduction of a supplementary signal to the excitation system of a power system. This is done through a regulator called power system stabilizer. Classical PSS rely on mathematical models that evolve quasi-continuously as load conditions vary. This inadequacy is somewhat countered by the use of fuzzy logic in modeling of the power system. Fuzzy logic power system stabilizer is a technique of incorporating expert knowledge in designing a controller [1].

The Power System Stabilizer (PSS) is a device that improves the damping of generator electromechanical oscillations. Stabilizers have been employed on large generators for several decades; permitting utilities to improve stability constrained operating limits. The input signal of conventional PSS is filtered to provide phase lead at the electromechanical frequencies of interest (ie , 0.1 Hz to 5.0 Hz). The phase lead requirement is site-specific, and is required to compensate for phase lag introduced by the closed-loop voltage regulator.

The PSS conventional and the PSS control based on root locus and eigen value assignment design techniques have been widely used in power systems. Such PSS ensure optimal performance only at a nominal operating point and do not guarantee good performance over the entire range of the system operating conditions due to exogenous disturbances such as changes of load and fluctuations of the mechanical power. In practical power system networks, a priori information on these external disturbances is always in the form of a certain frequency band in which their energy is concentrated. Remarkable efforts have been devoted to design appropriate PSS with improved performance and robustness. These have led to a variety of design methods using optimal control [2] and adaptive control [3]. The shortcoming of these model-based control strategies is that uncertainties cannot be considered explicitly in the design stage. More recently, robust control theory has been introduced into PSS design which allows control system designers to deal more effectively with model uncertainties [4, 5, 6 and 7].H∞ based control approach is particularly appropriate for plants with unstructured uncertainty.

In this paper, a PSS based on H∞ robust control techniques is introduced and results are displayed in time response approach for studying stability of electric power system under different conditions.

Simulation results shown the evaluation of the proposed linear control methods based on this advanced frequency techniques applied in the automatic excitation regulator of powerful synchronous generators: the robust H∞ linear stabilizer and conventional PID control schemes against system variation in the SMIB power system, with a test of robustness against parametric uncertainties of the synchronous machines (electric and mechanic), and make a comparative study between these two control techniques for AVR – PSS systems.

II. DYNAMIC POWER SYSTEM MODEL:

2.1. Power System description

In this paper the dynamic model of an IEEE - standard of power system, namely, a single machine connected to an infinite bus system (SMIB) was considered [8]. It consists of a single synchronous generator (turbo-Alternator) connected through a parallel transmission line to a very large network approximated by an infinite bus as shown in figure 1.

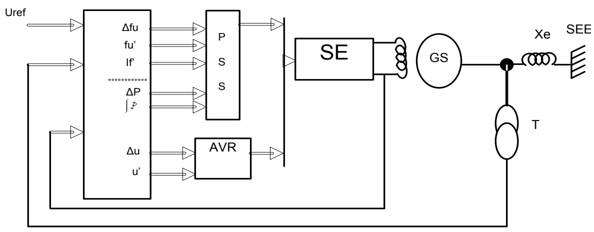


Fig. 1. Standard system IEEE type SMIB with excitation control of powerful synchronous generators

2.2. The permeances networks modeling (Park-Gariov) of powerful synchronous generators

In this paper we based on the permeances networks modeling of powerful synchronous generators for eliminating simplifying hypotheses and testing the control algorithm. The PSG model is defined by equations and Figure 2 and 3 below [8]:

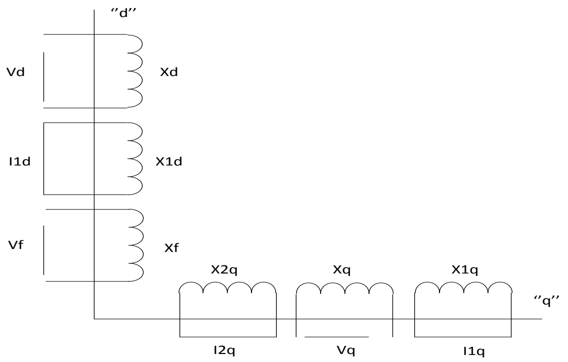


Fig. 2. PARK Transformation of the synchronous machine

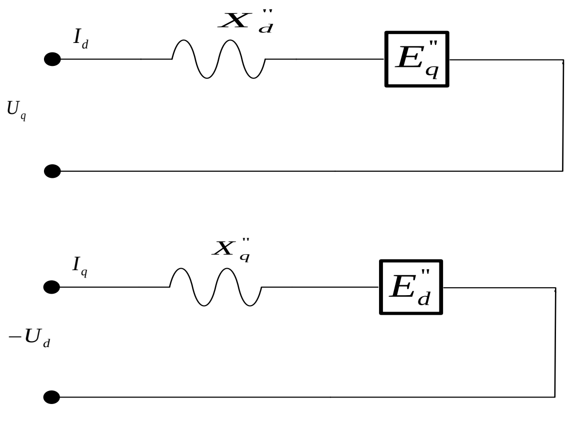


Fig.3. Equivalent diagrams simplifies of the synchronous machine with damping circuits (PARK-GARIOV model)

A. Currants equations:

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

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

B. Flow equations:

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

C. Mechanical equations

$$d\delta = \left(\omega - \omega_s\right) dt \;,\; s = \frac{\omega - \omega_s}{\omega_s} \tag{4}$$

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

2.3. Models of regulators AVR and PSS:

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 [9].

In our study the synchronous machine is equipped by a voltage regulator model "IEEE" type – 5 [10, 11], as is shown in figure 4.

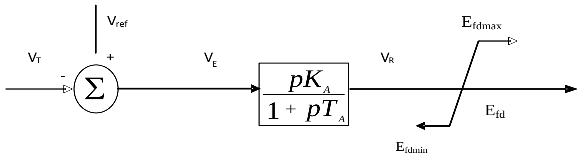


Fig. 4. A simplified " IEEE type-5" AVR

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

About the PSS, considerable's efforts were expended for the developpement of the system. The main function of a PSS is to modulate the SG excitation to [9, 12, 8].

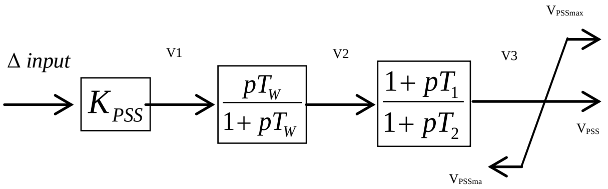


Fig.5. A functional diagram of the PSS used [8]

In this paper the PSS signal used, is given by: [13]

$$\dot{V}_1=\frac{V_2-V_1}{T_1}+\frac{T_2}{T_1}\dot{V}_2 \;; \quad \dot{V}_2=\frac{V_3-V_2}{T_2}+\frac{T_3}{T_2}\dot{V}_2 \;; \quad \dot{V}_3=\frac{V_3}{T_w}\dot{V}_1;\ \dot{V}_1=K_{PSS}\cdot\Delta input \qquad \Delta input=\begin{cases}\Delta P\ ,\ \int p \\ or \\ \Delta\omega=\omega_{mach}-\omega_0 \\ and \\ \Delta I_f=I_f-I_{f0} \\ and \\ \Delta U_f=U_f-U_{f0}\end{cases} \quad (7)$$

2.4. Simplified model of system studied SMIB

We consider the system of figure 6. The synchronous machine is connected by a transmission line to infinite bus type SMIB. The transmission line with a resistance Re, and an inductance Le [8].

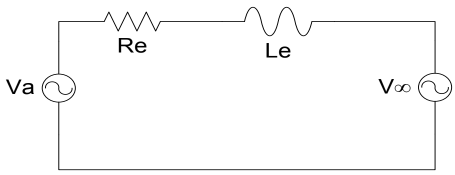


Fig.6. Synchronous machine connected to an infinite bus network

We define the following equation of SMIB system

$$V_{\infty odq}=Pv_{\infty abc}=\sqrt{2}\,V_\infty\begin{bmatrix}0\\-Sin\left(\delta-\alpha\right)\\\cos\left(\delta-\alpha\right)\end{bmatrix}+L_e I'_{odq}+X_e\begin{bmatrix}0\\-i_q\\i_d\end{bmatrix} \quad (8)$$

III. THE ROBUST PSS BASED ON LOOP –SHAPING H_∞ OPTIMIZATION

3.1. The H_∞ theory:

Advanced control techniques have been proposed for stabilizing the voltage and frequency of power generation systems. These include output and state feedback control, variable structure and neural network control, fuzzy logic control [14,15, 16], Robust H_2 (linear quadratic Gaussian with KALMAN filter) and robust H_∞ control [17,18].

H_∞ approach is particularly appropriate for the stabilization of plants with unstructured uncertainty [18]. In which case the only information required in the initial design stage is an upper band on the magnitude of the modeling error. Whenever the disturbance lies in a particular frequency range but is otherwise unknown, then the well known LQG (Linear Quadratic Gaussian) method would require knowledge of the disturbance model [17]. However, H_∞ controller could be constructed through, the maximum gain of the frequency response characteristic without a need to approximate the disturbance model. The design of robust loop – shaping H_∞ controllers based on a polynomial system philosophy has been introduced by Kwakernaak and Grimbel [19, 20].

H_∞ synthesis is carried out in two phases. The first phase is the H_∞ formulation procedure. The robustness to modelling errors and weighting the appropriate input – output transfer functions reflects usually the performance requirements. The weights and the dynamic model of the power system are then augmented into an H_∞ standard plant. The second phase is the H_∞ solution. In this phase the standard plant is programmed by computer design software such as MATLAB [21-22], and then the weights are iteratively modified until an optimal controller that satisfies the H_∞ optimization problem is found [23].

Time response simulations are used to validate the results obtained and illustrate the dynamic system response to state disturbances. The effectiveness of such controllers is examined and compared with using the linear Robust H_∞ PSS at different operating conditions of power system study.

The advantages of the proposed linear robust controller are addresses stability and sensitivity, exact loop shaping, direct one-step procedure and close-loop always stable [17].

The H_∞ theory provides a direct, reliable procedure for synthesizing a controller which optimally satisfies singular value loop shaping specifications [24-23]. The standard setup of the control problem consist of finding a static or dynamic feedback controller such that the H-INFINITY norm (a uncertainty) of the closed loop transfer function is less than a given positive number under constraint that the closed loop system is internally stable.

The robust H_∞ synthesis is carried in two stages:

a. *Formulation*: Weighting the appropriate input – output transfer functions with proper weighting functions. This would provide robustness to modelling errors and achieve the performance requirements. The weights and the dynamic model of the system are hen augmented into H-INFINITY standard plant.
b. *Solution:* The weights are iteratively modified until an optimal controller that satisfies the H_∞ optimization problem is found.

Fig.7 shows the general setup of the problem design where: P(s): is the transfer function of the augmented plant (nominal Plant G(s) plus the weighting functions that reflect the design specifications and goals),

u_2: is the exogenous input vector; typically consists of command signals, disturbance, and measurement noises,

u_1: is the control signal, y_2: is the output to be controlled, its components typically being tracking errors, filtered actuator signals, y_1: is the measured output.

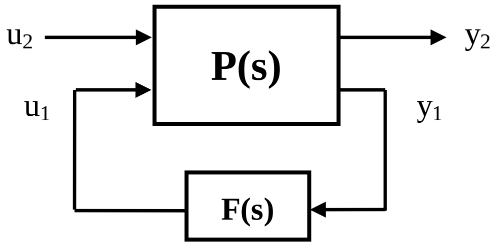


Fig.7. General setup of the loop-shaping H_∞ design

The objective is to design a controller F(s) for the augmented plant P(s) such that the input / output transfer characteristics from the external input vector u_2 to the external output vector y_2 is desirable. The H_∞ design problem can be formulated as finding a stabilizing feedback control law $u_1(s)$-$F(s).y_1(s)$ such that the norm of the closed loop transfer function is minimized.

In the power generation system including H_∞ controller, two feedback loops are designed; one for adjusting the terminal voltage and the other for regulating the system angular speed as shown on figure 8. The nominal system G(s) is augmented with weighting transfer function $W_1(s)$, $W_2(s)$, and $W_3(s)$ penalizing the error signals, control signals, and output signals respectively. The choice proper weighting functions are the essence of H_∞ control. A bad choice of weights will certainly lead to a system with poor performance and stability characteristics, and can even prevent the existence of solution to the H_∞ problem.

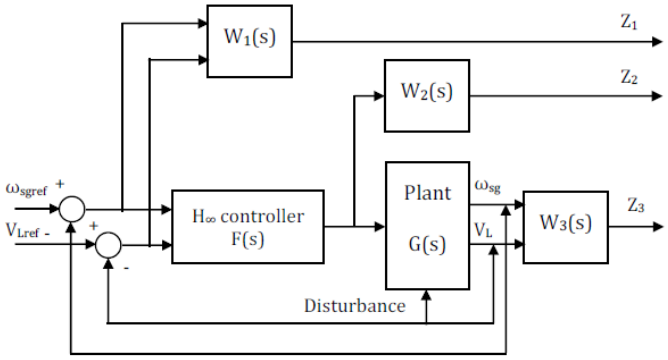


Fig.8. Simplified block diagram of the augmented plant including H_∞ controller

The control system design method by means of modern robust H-infinity algorithm is supposed to have some linear conventional PID test regulator.

It is possible to collect various optimal adjustment of such a regulator in different operating conditions into some database. Traditional Russian Power system stabilizer (realized on PID schemes) was used in this work as a test system, which enables to trade off regulation performance, robustness of control effort and to take into account process and measurement noise [17].

3. 2 GLOVER - DOYLE algorithm to synthesize a robust stabilizer PSS- H ∞

Problem solving of standard control is proposed as follows [22]:

1. Calculates the Standing regime established (RP) ;
2. Linearization of the control object (GS+PSS+AVR)
3. The main problem in H ∞ control and the definition of the control object increased P(s) in the state space:
   3-1. Choice of weighting functions: W_1, W_2, W_3
   3-2. The obtaining of the command object increased from weighting functions $W_{1,2,3}$.
4. Verify if all conditions to the ranks of matrices are satisfied, if not we change the structure of the weightings functions;
5. Choosing a value of γ (optimization level) ;
6. Solving two Riccati equations which defined by the two matrices H and J of HAMILTHON;
7. Reduction of the regulator order if necessary
8. By obtaining optimum values and two solutions of Riccati equations we get the structure of controller H ∞ and the roots of the closed loop with the robust controller;
9. We get the parameters of robust controller H_∞ in linear form 'LTI (SS state space, TF transfer function or ZPK zeros - pole - gains)
10. The simulation and realization of the stability study and robustness of electro-energy system under different functioning conditions.

The synthesis algorithm of the robust controller H∞ proposed in this work is clearly shown schematically by the flow chart of Figure 9

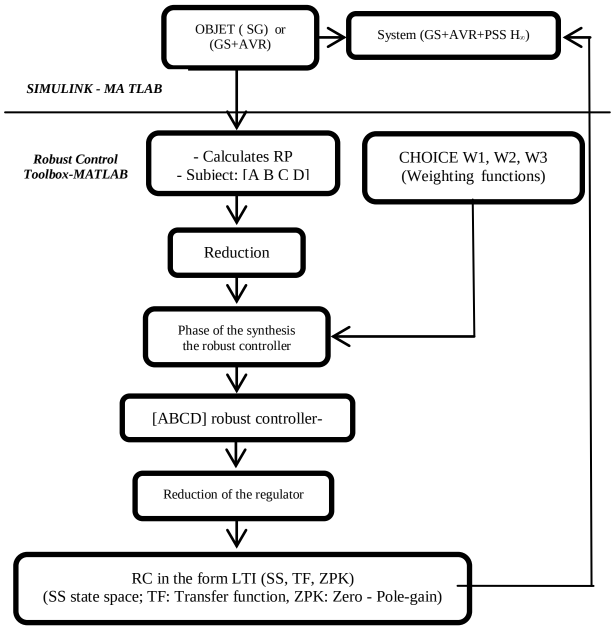


Fig.9 Synthesis algorithm robust controller of the excitation for a single machine

3.3 Structure of the power System withe Robust Controllers H∞

The basic structure of the control system a powerful synchronous generator with the robust controller shown in Figure 10 [3]

As command object we have synchronous generator with regulator AVR-FA (PID with conventional PSS), an excitation system (exciter) and an information block and measures (BIM) of output parameters to regulated.

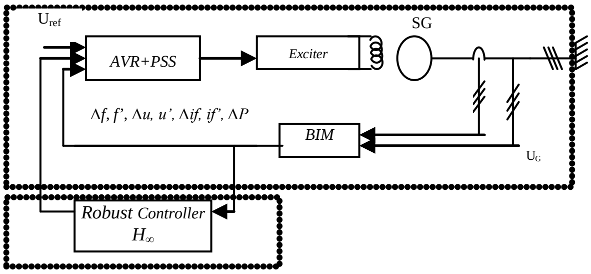


Fig 10. structure of the power system withe robust controllers H∞

IV . The Simulation Result Under GUI/ Matlab

A) Creation of a 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 11[13]

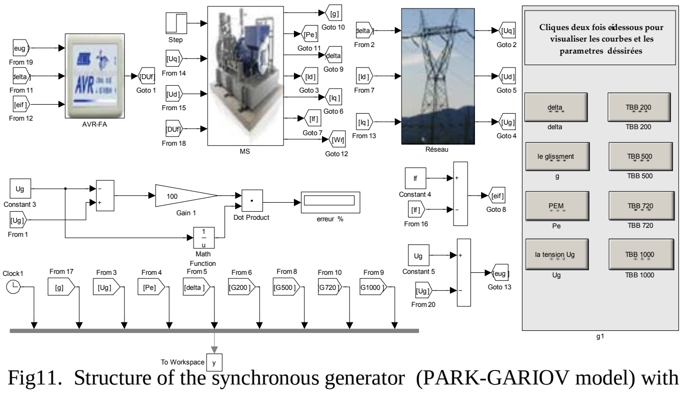


Fig11. Structure of the synchronous generator (PARK-GARIOV model) with the excitation controller under [13].

B) A Created GUI/MATLAB

To analyzed and visualized the different dynamic behaviors we have creating and developing a "GUI" (Graphical User Interfaces) under MATLAB .This GUI allows as to:

- Perform control system from PSS and H∞ -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 12.

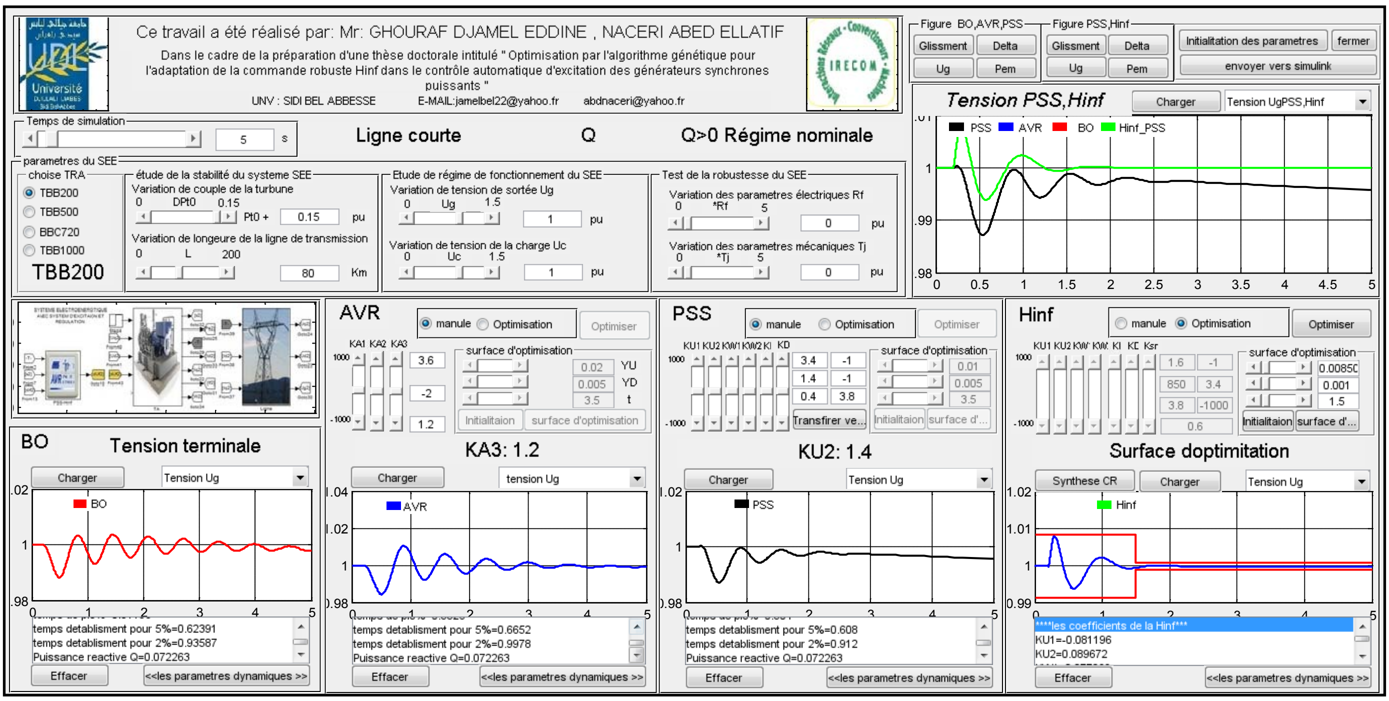


Fig.12.The realised GUI / MATLAB

C) Simulation result and discussion

- ***Stability study***

We performed an perturbations by abrupt variation of turbine torque ΔTm of 15% at t = 0.2s,

The following results (Table 1 and figure 13, 14 and 15) were obtained by studying the "SMIB" static and dynamic performances in the following cases:

1. SMIB in open loop (without regulation) (OL)
2. Closed Loop System with the conventional stabilizer PSS-FA and robust control H∞ -PSS [13].

We simulated three operating: the under-excited, the rated and the over-excited.

Our study is interested in the powerful synchronous Generators of type: TBB-200, TBB-500 BBC-720, TBB-1000 (parameters in Appendix) [13].

Table 1 presents the TBB-1000 static and dynamic performances results in (OL) and (CL) with PSS and H∞ -PSS, for an average line (Xe = 0.3 pu), and an active power P=0.9 p.u , for more details about the calculating parameters see GUI-MATLAB in the Appendix created.

Where: α: Damping coefficient ε %: the static error, d%: the maximum overshoot, t_s: the setting time

TABLE 1 THE "SMIB "STATIC AND DYNAMIC PERFORMANCES

Damping coefficient α				The static error		
Q	OL	PSS	H∞ -PSS	OL	PSS	H∞ -PSS
-0.1372	Unstable	-1.956	-3.767	Unstable	1.459	negligible
-0.4571	Unstable	-1.926	-3.659	Unstable	1.461	negligible
0.1896	-0.2061	-1.966	-3.876	-5.933	1.386	negligible
0.3908	-0.2245	-1.850	-3.769	-5.802	1.170	negligible
0.5078	-0.3577	-1.412	-3.211	-4.903	0.659	negligible
0.6356	-0.3660	-1.401	-3.109	-4.597	0.683	negligible
The setting time for 5%				The maximum overshoot %		
Q	OL	PSS	H∞ -PSS	OL	PSS	H∞ -PSS
-0.1372	Unstable	1,534	rapid	9.458	8,766	3.768
-0.4571	Unstable	1,558	rapid	9.254	8,632	3.548
0.1896	-	1,526	rapid	9,249	8,811	4.691
0.3908	-	1,621	rapid	9,075	8,292	4.773
0.5078	8,387	2,125	rapid	8,053	6,328	3.729
0.6356	8,197	2,141	rapid	7,426	6,279	3,612

In the Figures 13,14 and 15 show an example of simulation result with respectively: 's' variable speed , 'delta' The internal angle, 'Pe' the electromagnetic power system, 'Ug' the stator terminal voltage; for powerful synchronous generators TBB-1000 with P = 0.9, Xe = 0.3, Q1 = -0.1372 (pu)

- ***robustness tests***

In a first step we performed an variations electrical parametric (increase 100% of R). then, we performed an variations mechanical parametric (lower bound 50% of inertia J)

The simulation time is evaluated at 8 seconds.

We present in Figure 13 (For electrical uncertainties) and Figure 14 (For mechanical uncertainties)

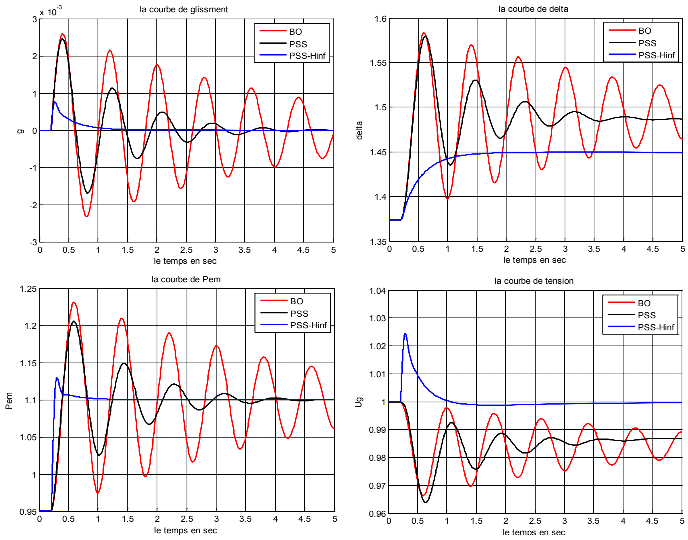


Fig .13. functioning system in the under-excited used of TBB-1000 connected to a average line with PSS , H∞ -PSS and OL (stability study)

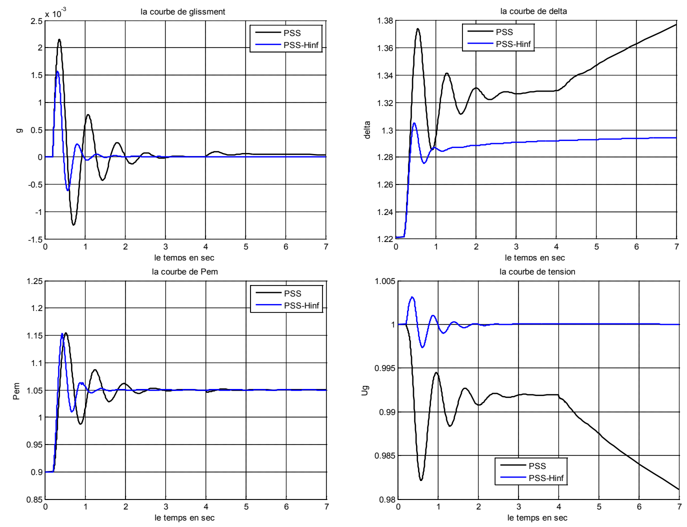


Fig .14.functioning system in the under-excited used of TBB-1000 connected to a average line with PSS , H∞ -PSS and OL (robustness tests)

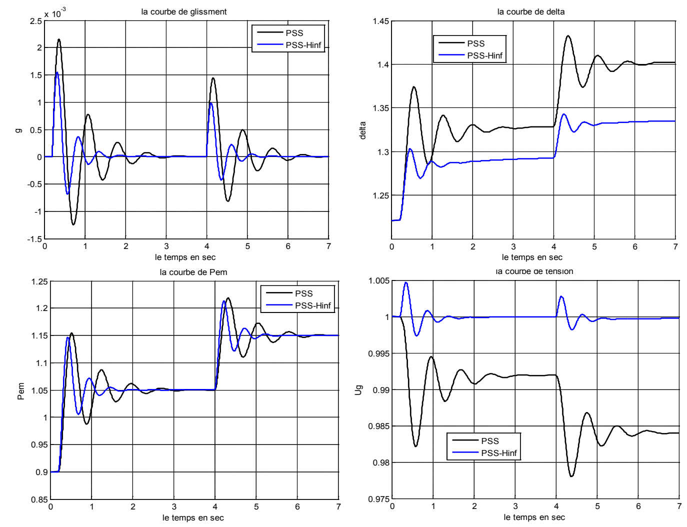


Fig .15. functioning system in the under-excited used of TBB-1000 connected to a average line with PSS , H∞ -PSS and OL (robustness tests)

From the simulation results, it can be observed that the use of H_∞ -PSS improves considerably the dynamic performances (static errors negligible so better precision, and very short setting time so very fast system, and we found that after few oscillations, the system returns to its equilibrium state even in critical situations (specially the under-excited regime) and granted the stability and the robustness of the studied system.

V. Conclusion

This paper proposes an advanced control method based on advanced frequency techniques: a Robust H_∞ Power system stabilizer based on loop-shaping optimization methods applied on the system AVR - PSS of powerful synchronous generators, to improve transient stability and its robustness of a single machine- infinite bus system (SMIB). This concept allows accurately and reliably carrying out transient stability study of power system and its controllers for voltage and speeding stability analyses. It considerably increases the power transfer level via the improvement of the transient stability limit.

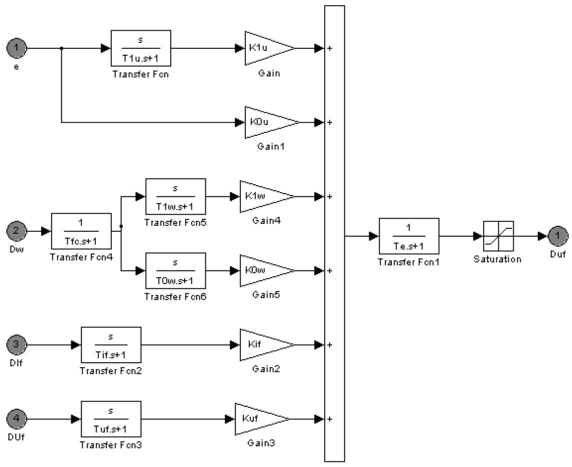
The computer simulation results (with test of robustness against electric and mechanic machine parameters uncertainty), have proved a high efficiency and more robustness with the Robust H_∞ PSS, in comparison using a Conventional Test stabilizer (with a strong action) realized on PID schemes, showing stable system responses almost insensitive under different modes of the station. This robust loop shaping H_∞ generator voltage controller has the capability to improve its performance over time by interaction with its environment.

References

[1] Ali.Z.M, and ELsherbiny M.," effect of both mechanical and excitation system on power system and methods of improvement.", M.sc, Egypt, Assuit university,2003.
[2] ABIDO, M. A.—ABDEL-MADJID, Y.L.: Coordinated Design of PSS and SVC Based Controller to Enhance Power System Stability, Electrical Power and Energy Systems 25 (2003), 695-704.
[3] GUPTA, R.—BANDYO, B.—KULKARNI, A. M.: Design of Power System Stability forSingle Machine System Using Robust Fast Output Sampling Feedback Technique, Electrical Power Systems Research 65 (2003), 247-257.
[4] BOUHAMIDA, M.—DENAI, M. A.—MOKHTARI, A.—BOU-HENNA, A.: GH∞ Robust Power System Stabilizer Design with Parametric Uncertainty, International Conference on Electrical and Electronics Engineering (ELECO'99), 1-5 December 1999, Bursa, Turkey.
[5] ZIAD M. M. ALI , ALEXANDER I.: ROBUST TECHNIQUES FOR DESIGNING POWER SYSTEM STABILIZER Journal of Theoretical and Applied Information Technology 2009
[6] CHEN, S.—MALIK, O. P.: H∞ Optimisation- Based Power System Stabiliser Design, IEE Proc. Gener. Trans. Distr. 142 No. 2 (1995), 179-184.
[7] FOLLY, K.—NAOTO, Y.—HIRISHI, S.: Design of Hinf -PSS Using Numerator- Denominator Uncertainty Representation, IEEE Trans. on Energy Conversion, 12 No. 1 (1997), 45-50.
[8] S. V. SMOLOVIK "Méthodes de modélisation mathématique des processus transitoires des générateurs synchrones plus usuels et non traditionnels dans les systèmes électro -énergétiques" Thèse doctorat d'état, Institut polytechnique de Leningrad, 1988 (traduit du Russe).
[9] LA. GROUZDEV, A.A. STARODEBSEV, S.M. OUSTINOV "Conditions d'application des meilleurs amortissements des processus transitoires dans les systèmes énergétiques avec optimisation numérique des paramètres du régulateur AVR-FA" Energie -1990-N°ll-pp.21-25 (traduit du russe).
[10] P.M. ANDERSON, A. A. FOUAD "Power System control and Stability", IEE Press, 1991.
[11] Hong Y.Y. and Wu W.C., « A new approach using optimization for tuning parameters of power system stabilizers », IEEE Transactions on Energy Conversion, vol. 14, n°. 3, pp. 780–786, Sept. 1999.
[12] DeMello F.P., Flannett L.N. and Undrill J.M., « Practical approach to supplementary stabilizing from accelerating power », IEEE Trans., vol. PAS-97, pp, 1515-1522, 1978.
[13] GHOURAF D.E., "Study and Application of the advanced frequency control techniques in the voltage automatic regulator of Synchronous machines', Magister Thesis, UDL-SBA, 2010 (In French).
[14] Kwakernaak H., Sivan R. Linear Optimal Control Systems, Wiley-Interscience, 1972.
[15] NACERI A., SMOLOVIK S.V. 'Estimation des lois de commande robustes H2 et Hinf dans les contrôleurs automatiques d'excitations des générateurs synchrones puissants' // Proc. VI conférence internationale ''problèmes scientifiques et techniques'', St. Petersbourg, 6 – 7 Juin 2002 (Tom. 1), édition SPBSPU, pp. 222 -228 (in Russain).
[16] Felix R. A., Sanchez E.N, Loukianov A.G., "Synchronous generator control combining sliding modes and neural networks" . American Control Conference, Vol. 5, Issue 4-6, June 2003, No. 4, pp. 4065-4070.
[17] Kwakernaak H. "Robust control and H∞ optimizatio n, Tutorial paper", Automatica, vol. 29, № 2. June 1994, pp. 201-207.
[18] A. Anderson and. A. Fouad ,"Power System Control and stability". IEEE Power systems,1994.
[19] MATLAB Math library User's Guide, by the Math works Inc., 2006.
[20] R. Y. Chiang, M. G. Sofonov "Robust control Toolbox User's guid", the Mathworks, INC, 1992.
[21] M. Sofonov , D. J. Limbeer, R. Y. Chiang "Simplifing the H∞ PSS theory via loop shaping matrix pencil and descriptor concept ", INT. J. Of control, vol. 50, № 6.1994, pp 2467-2488.
[22] K. Glover, J.C. Doyle, P.P. Khargonekar, B.A. Francis "State-space solutions to standard H2 and H∞ control problems", IEEE Trans. On A.C. 19 89, vol.34, № 8, pp.834-847.
[23] Grimbel M.J., "New direction in adaptive control theory and application". IFAC – IFIP- IMACS Conf., Control of industrial systems, Belfort, France 1997, pp. 95 – 110.
[24] Naceri, A. N Belaev, S. V Smolovik "rational Choices of the weight functions in the process of construction of the robust H∞ regulators for synchronous generators", the IX international conference "High intellectual technology of sciences", SaintPetersburgg, January - February 2002, pp. 251-257.

Appendix

1. The PSS-AVR model



2. Parameters of the used Turbo –Alternators

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.**

3. Dynamics parameters calculated through GUI-MATLAB