# An Enhanced PID-PSS Based Robust Frequency H2 and H∞ Approachs under A Developed interface

KABI Wahiba[1], GHOURAF Djamel Eddine[1], NACERI Abdellatif[1]
[1]IRECOM Laboratory, Department of Electrical Engineering, University of SBA, BP 98 22000 Algeria
Corresponding Authors E-mail: abdnaceri@yahoo.fr

*Abstract:* This article present a comparative study between two advanced robust frequency control strategies and their implementation using our created Graphical User Interface (GUI) under MATLAB: the first method based on loop-shaping $H_\infty$ optimization technique and the second on robust $H_2$ control method (LQG controller associated with KALMAN filter), and applied on automatic excitation control of synchronous generators, to improve transient stability and robustness of a single machine- infinite bus (SMIB) system operating in different several conditions. 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 robust $H_\infty$ controller in comparison with $H_2$ approach by exploiting our developed GUI interface in this work.

*Key words:* Synchronous machines and Excitations, AVR and PSS, advanced frequency control techniques, LQG control, Kalman filter, robust loop-shaping H∞ approach, stability and robustness, GUI/MATLAB.

## 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 Eigenvalue 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].

The first stabilizer of this new generation for the system AVR – PSS, aimed to improving power system stability, was developed using the robust loop-shaping H∞ approach [14 15].This has been advantage of maintaining constant terminal voltage and frequency irrespective of conditions variations in the system study. The closed loop is available for H∞ control. This loop is dedicated for regulating the terminal voltage of the Synchronous Generator to a set point by controlling the field voltage of the machine. The H∞ control design problem is described and formulated in standard form with emphasis on the selection of the weighting function that reflects robustness and performances goals [8]. The proposed system has the advantages of robustness against model uncertainty and external disturbances, fast response and the ability to reject noise.

The second regulator was suggested in this paper was developed by using the Linear Quadratic - Gaussian (LQG) control scheme (has the same structure as the traditional Russian type PID AVR-PSS [9]), consists of an optimal state feedback gain and a KALMAN state estimator, and equivalently in this paper on a robust $H_2$ controller '$H_2$PSS', was applied as a test control system

Simulation results shown the evaluation of the proposed linear control methods based on advanced frequency techniques applied in the automatic excitation regulator of synchronous generators: the robust loop-shaping H∞ linear stabilizer and robust $H_2$ control schemes against system variation in the SMIB power system, with a test of robustness against parametric uncertainties of the synchronous machines, and make a comparative study between these two new generations of control techniques for AVR – PSS systems.

## 2 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 [10]. 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.

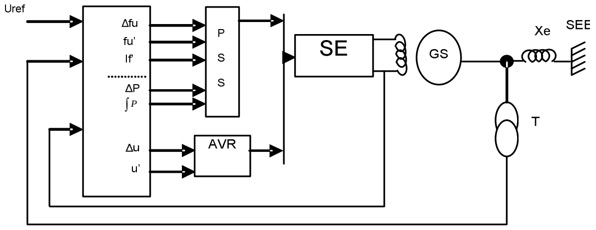


Fig. 1. Standard system IEEE type SMIB with excitation control of powerful synchronous generators

### *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 [10]:

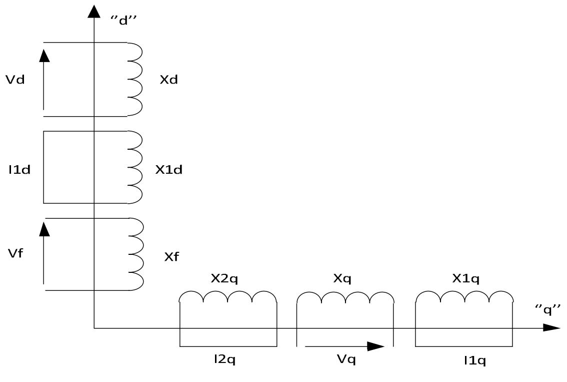


Fig. 2. PARK Transformation of the synchronous machine

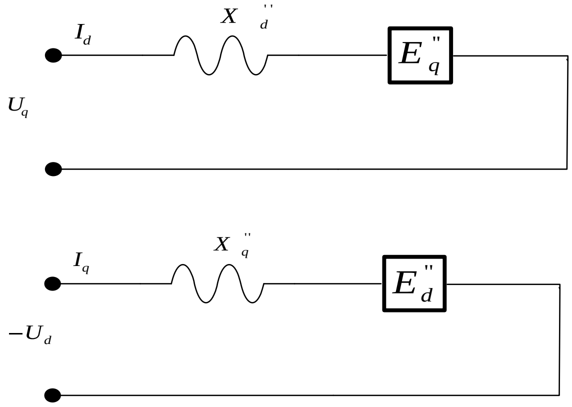


Fig.3. Equivalent diagrams simplifies of the synchronous machine with damping circuits (PARK-GARIOV model)

*A. Currants equations:*

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

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

*B. Flow equations:*

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

*C. Mechanical equations*

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

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

### *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 [11].

In our study the synchronous machine is equipped by a voltage regulator model "IEEE" type – 5 [12, 13], as is shown in figure 4.

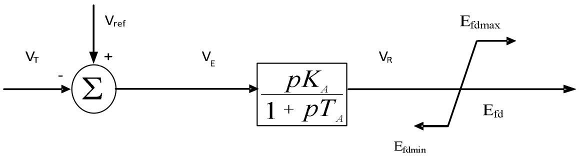


Fig. 4. A simplified" IEEE type-5" AVR

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

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 [10,11, 14].

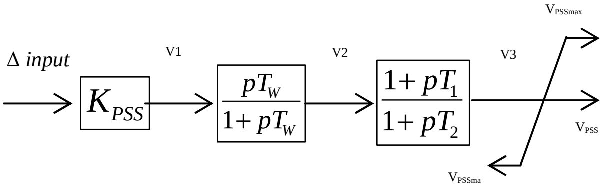


Fig.5. A functional diagram of the PSS used [8]

In this paper the PSS signal used, is given by: [15]

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

*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. Re: A resistance and Le: an inductance of the transmission line [10].

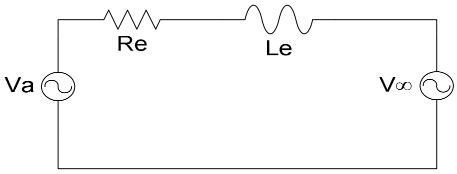


Fig.6. Synchronous machine connected to an infinite bus network

We define the following equation of SMIB system

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

*3.3 Structure of the power system with robust controllers $H_\infty$ and $H_2$*

The basic structure of the control system a powerful synchronous generator with the robust controller shown in Figure 7 [15]

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 regulate.

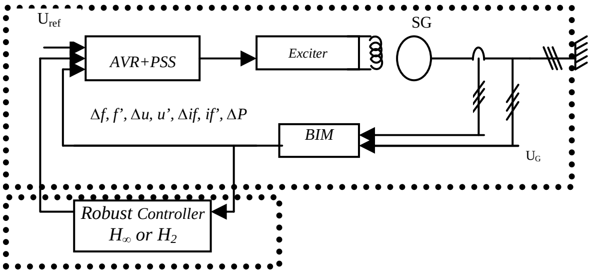


Fig. 7. structure of the power system withe the robust controllers H∞

## III. THE ROBUST PSS BASED ON LOOP –SHAPING $H_\infty$ OPTIMIZATION

### *3.1. The $H_\infty$ 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 [16, 17, 18], robust $H_2$ (linear quadratic Gaussian with KALMAN filter) and robust $H_\infty$ control [19,20].

$H_\infty$ approach is particularly appropriate for the stabilization of plants with unstructured uncertainty [20]. 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.However, $H_\infty$ 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 $H_\infty$ controllers based on a polynomial system philosophy has been introduced by Kwakernaak [19].

$H_\infty$ synthesis is carried out in two phases. The first phase is the $H_\infty$ 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 $H_\infty$ standard plant. The second phase is the $H_\infty$ 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 $H_\infty$ optimization problem is found.

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 $H_\infty$ PSS at different operating conditions of power system study [23]

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 [19].

The $H_\infty$ theory provides a direct, reliable procedure for synthesizing a controller which optimally satisfies singular value loop shaping specifications [24-8]. 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 $H_\infty$ synthesis is carried in two stages:

a. *Formulation*: Weighting the appropriate input – output transfer functions with proper weighting functions. This would provide robustness to modeling 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 $H_\infty$ optimization problem is found.

Figure 8 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.

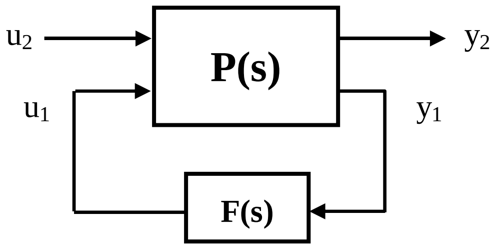


Fig.8. General setup of the loop-shaping $H_\infty$ design

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 $H_\infty$ 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 $H_\infty$ 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 9. 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 $H_\infty$ 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 $H_\infty$ problem.

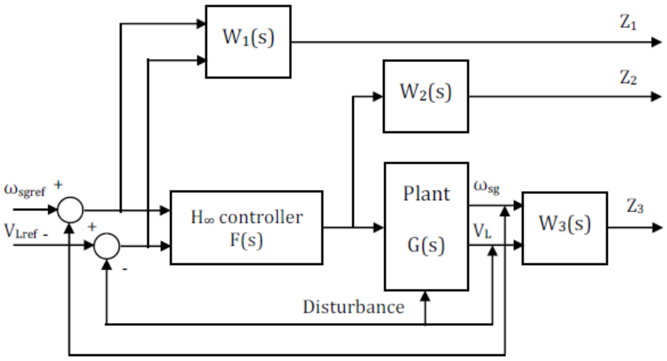


Fig.9. Simplified block diagram of the augmented plant including $H_\infty$ controller

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 [25,26].

## 3. 2 GLOVER - DOYLE algorithm to synthesize a robust stabilizer $H_\infty$-PSS

Problem solving of standard control is proposed as follows [24]:
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 weighting 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 $H_\infty$ 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 10

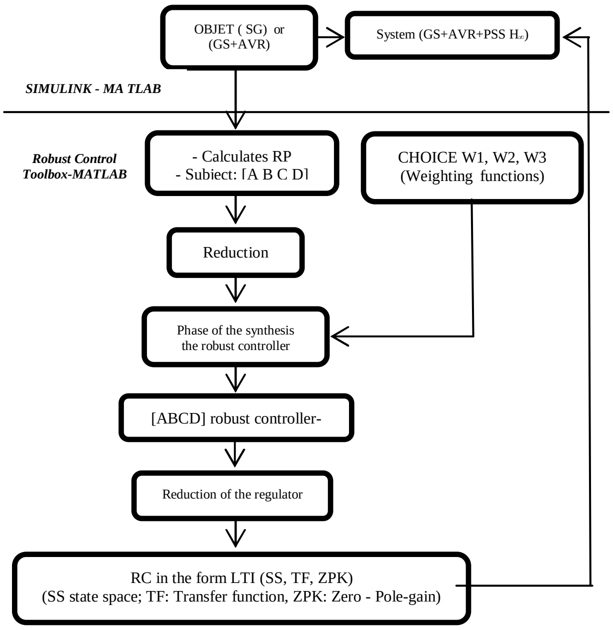


Fig.10. Synthesis algorithm robust controller of the excitation for a single machine

## 4 The Robust $H_2$-PSS Design Based on LQG Control and Kalman Filter

The control system design method by means of modern FSM algorithms is supposed to have some linear test regulator. It is possible to collect various optimal adjustment of such a regulator in different operating conditions into some database. Linear – Quadratic – Gaussian (LQG) control technique is equivalent to the robust $H_2$ regulator by minimizing the quadratic norm of the integral of quality .In this work, the robust quadratic $H_2$ controller (corrector LQG) was used as a test system, which enables to trade off regulation performance and control effort and to take into account process and measurement noise [27,28]. LQG design requires a state-space model of the plant:

$$\begin{cases} \dfrac{dx}{dt} = Ax + Bu \\ y = Cx + Du \end{cases} \tag{9}$$

Where *x, u, y* is the vectors of state variables, control inputs and measurements, respectively.

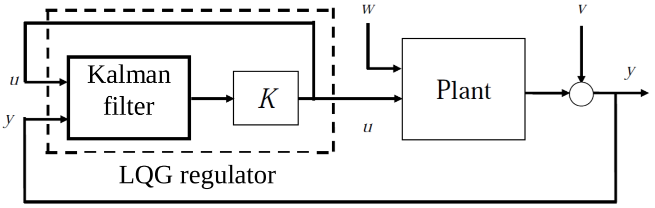


Fig.11. Optimal LQG regulated system with Kalman filter.

The goal is to regulate the output *y* around zero. The plant is driven by the process noise *w* and the controls *u*, and the regulator relies on the noisy measurements $y_v = y+v$ to generate these controls. The plant state and measurement equations are of the form:

$$\begin{cases} \dot{x}(t) = A(t)x(t) + B(t)u(t) + v(t) \\ y_v(t) = C(t)x(t) + w(t) \end{cases} \tag{10}$$

Both *w* and *v* are modeled as white noise.

In LQG control, the regulation performance is measured by a quadratic performance criterion of the form:

$$J(u) = \int_0^\infty (x^T Qx + u^T Ru + 2x^T Nu)dt \tag{11}$$

The weighting matrices *Q, N* and *R* are user specified and define the trade-off between regulation performance and control effort.

The LQ-optimal state feedback $u=-kx$ is not implemental without full state measurement. However, a state estimate $\hat{x}$ can be derived such that $u = -k\hat{x}$ remains optimal for the output-feedback problem.

This state estimate is generated by the Kalman filter:

$$\frac{d\hat{x}}{dt} = A\hat{x} + Bu + L(y_v - C\hat{x} - Du) \tag{12}$$

Thus, the LQG regulator consists of an optimal state-feedback gain and a Kalman state estimator (filter), shown in figure 7

On the basis of investigation carried out, the main points of fuzzy PSS automated design method were formulated [17]. The nonlinear model of power system can be represented by the set of different linearized models (10). For such models, the linear compensator in the form of $u = -Kx$ can be calculated by means of LQG - method. The family of test regulators is transformed into united fuzzy knowledge base with the help of hybrid learning procedure (based variable structure sliding mode). In order to solve the main problem of the rule base design, which called "the curse of dimensionality", and decrease the rule base size the scatter partition method [29] was used. In this case, every rule from the knowledge base is associated with some optimal gain set. The advantage of this method is the practically unlimited expansion of rule base. It can be probably needed for some new operating conditions, which are not provided during learning process. Finally, the robust $H_2$ stabilizer was obtained by minimizing the quadratic norm $\|M\|_2^2$ of the integral of quality *J(u)* in (11), where

$$Z(s) = M(s)x_0 \quad and \quad Z = \left[x^T Q^{1/2} u^T R^{1/2}\right], s = j\omega. \text{ [17].} \tag{13}$$

## 5 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 [10, 15], and shown in Figure 12.

### 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, $H_\infty$-PSS and $H_2$-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 using our realized Graphical interface GUI-MATLAB and shown in Figure 13.

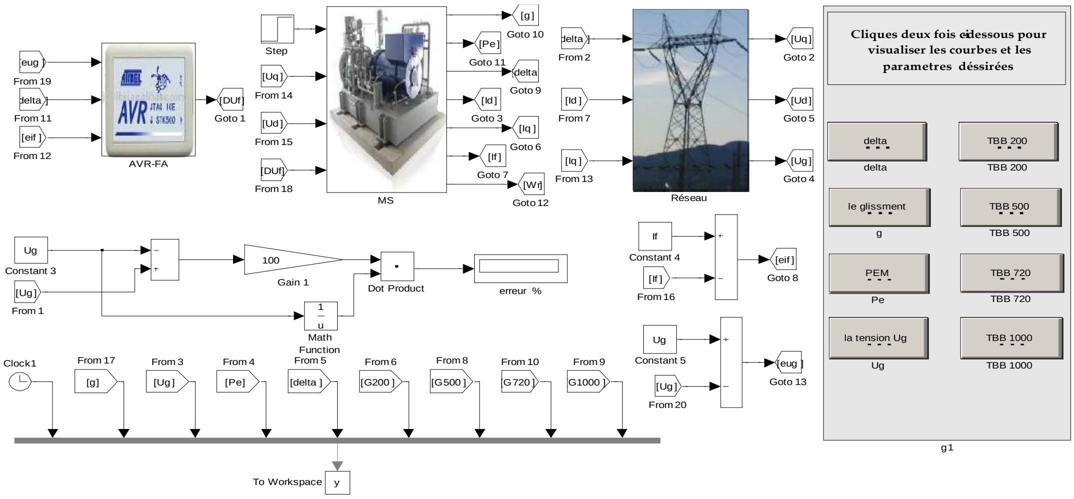
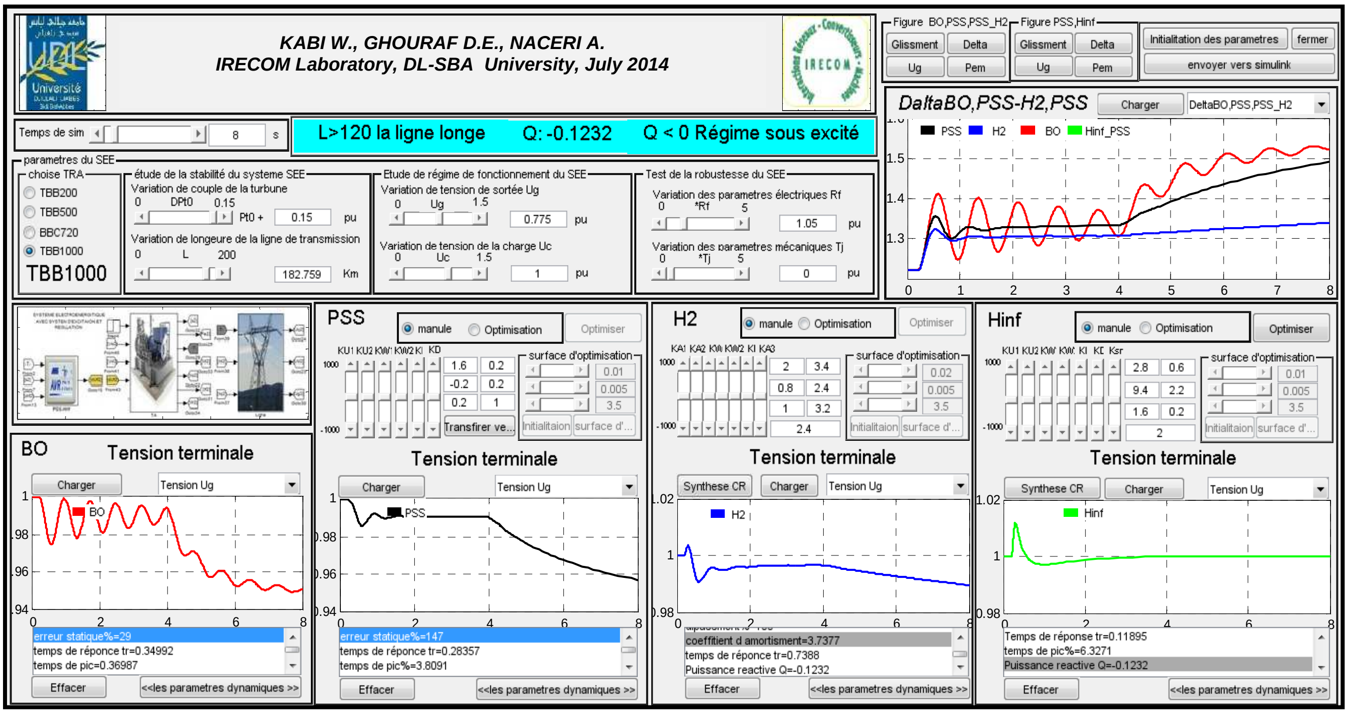


Fig12. Structure of the synchronous generator (PARK-GARIOV model) with the excitation controller under [13].



***KABI W., GHOURAF D.E., NACERI A.***
***IRECOM Laboratory, DL-SBA University, July 2014***

Temps de sim 8 s

L>120 la ligne longe Q: -0.1232 Q < 0 Régime sous excité

parametres du SEE

choise TRA: ○ TBB200 ○ TBB500 ○ BBC720 ● TBB1000

TBB1000

étude de la stabilité du systeme SEE

Variation de couple de la turbune (0 DPt0 0.15): Pt0 + 0.15 pu

Variation de longeure de la ligne de transmission (0 L 200): 182.759 Km

Etude de régime de fonctionnement du SEE

Variation de tension de sortée Ug (0 Ug 1.5): 0.775 pu

Variation de tension de la charge Uc (0 Uc 1.5): 1 pu

Test de la robustesse du SEE

Variation des parametres électriques Rf (0 *Rf 5): 1.05 pu

Variation des parametres mécaniques Tj (0 *Tj 5): 0 pu

PSS: ● manule ○ Optimisation

KU1 KU2 KW1 KW2 KI KD: 1.6, 0.2, -0.2, 0.2, 0.2, 1

surface d'optimisation: 0.01, 0.005, 3.5

H2: ● manule ○ Optimisation

KA1 KA2 KW KW2 KI KA3: 2, 3.4, 0.8, 2.4, 1, 3.2, 2.4

surface d'optimisation: 0.02, 0.005, 3.5

Hinf: ● manule ○ Optimisation

KU1 KU2 KW KW KI KD Ksr: 2.8, 0.6, 9.4, 2.2, 1.6, 0.2, 2

surface d'optimisation: 0.01, 0.005, 3.5

BO Tension terminale

erreur statique%=29
temps de réponce tr=0.34992
temps de pic=0.36987

PSS Tension terminale

erreur statique%=147
temps de réponce tr=0.28357
temps de pic%=3.8091

H2 Tension terminale

coeffitient d amortisment=3.7377
temps de réponce tr=0.7388
Puissance reactive Q=-0.1232

Hinf Tension terminale

Temps de réponse tr=0.11895
temps de pic%=6.3271
Puissance reactive Q=-0.1232

Fig.13. the comparative study using the developed GUI under MATLAB

### *C) Simulation result and discussion*

- ***Stability study***

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 (OL)
2. Closed Loop System with the conventional stabilizer PSS-FA and robust control H∞ -PSS, $H_2$-PSS [15].

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

Our study is interested in the ppowerful synchronous Generators of type: TBB-200, TBB-500 BBC-720, TBB-1000 (parameters in Appendix) [15].

Table 1 presents the TBB-1000 static and dynamic performances results in (OL) and (CL) with PSS, H∞ -PSS, and $H_2$-PSS for an average line (Xe = 0.3 pu), and an active power P=0.85 p.u , for more details about the calculating parameters see GUI-MATLAB created in the Appendix .

Where: ε %: the static error,
$t_s$ : the setting time

TABLE 1 THE "SMIB "STATIC AND DYNAMIC PERFORMANCES

**The static error %**

| **Q** | **OL** | **PSS** | **PSS-$H_2$** | **PSS-H∞** |
|---|---|---|---|---|
| **-0.160** | **Unstable** | **-3.761** | **-1.620** | **negligible** |
| **-0.222** | **Unstable** | **-3.731** | **-1.629** | **negligible** |
| **0.2139** | **-9.2442** | **-3.855** | **-1.487** | **negligible** |
| **0.1634** | **-9.2354** | **-3.759** | **-1.235** | **negligible** |
| **0.5746** | **-8.2095** | **-3.470** | **-0.687** | **negligible** |
| **0.5663** | **-8.2080** | **-3.442** | **-0.656** | **negligible** |

**The setting time for 5%**

| **Q** | **OL** | **PSS** | **PSS-$H_2$** | **PSS-H∞** |
|---|---|---|---|---|
| **-0.160** | **Unstable** | **1,704** | **0.835** | **0.213** |
| **-0.222** | **Unstable** | **1,713** | **0.884** | **0.246** |
| **0.2139** | **-** | **1,617** | **0.805** | **0.222** |
| **0.1634** | **-** | **1,706** | **0.794** | **0.201** |
| **0.5746** | **14,320** | **2,041** | **0.964** | **0.315** |
| **0.5663** | **14,423** | **2,080** | **0.973** | **0.329** |

In the Figures 14,15 and 16 show an example of simulation result with respectively: 'Ug' the stator terminal voltage, 'Pe' the electromagnetic power system, 's' variable speed, 'delta' The internal angle; for powerful synchronous generators TBB-1000 with P = 0.85, Xe = 0.3, Q1 = -0.1372 (pu)

- ***robustness tests***

In a first step we performed a variations electrical parametric (increase 100% of R). Then, we performed a variations mechanical parametric (lower bound 50% of inertia J)
The simulation time is evaluated at 6 seconds.

We present in Figure 15 (for electrical uncertainties) and Figure 16 (For mechanical uncertainty)

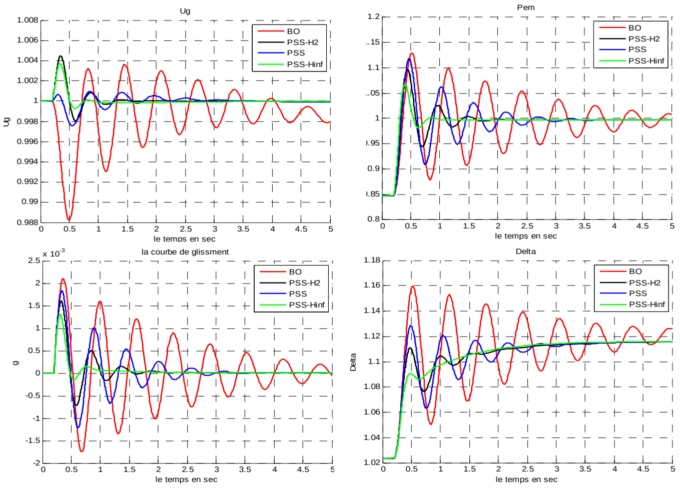


Fig .14. functioning system in the under-excited used of TBB-1000 connected to a average line with $H_2$-PSS , H∞ -PSS,PSS and OL (stability study)

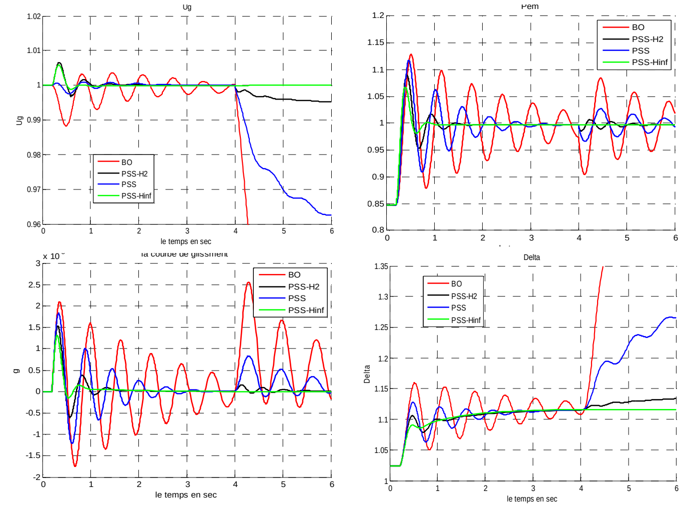


Fig .15. functioning system in the under-excited used of TBB-1000 connected to a average line with $H_2$-PSS , H∞ -PSS,PSS and OL (robustness tests)

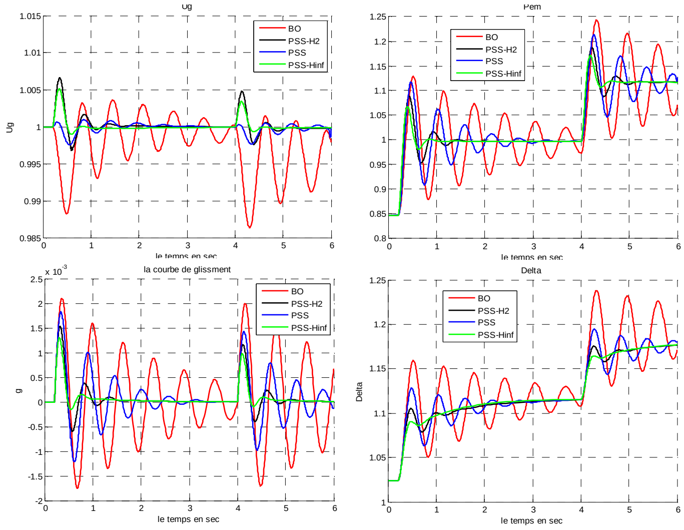


Fig .16.functioning system in the under-excited used of TBB-1000 connected to a average line with $H_2$-PSS , H∞ -PSS,PSS and OL (robustness tests)

From the simulation results, it can be observed that the use of $H_\infty$ -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.

## 6 Conclusion

This paper proposes tow advanced control methods based on frequency techniques: Robust loop shaping H∞ and robust $H_2$ approach's (an optimal LQG controller with Kalman Filter), applied on the system AVR - PSS of 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 have proved the efficiency and robustness of the Robust H∞ approach, in comparison with using robust $H_2$ Controller, showing stable system responses almost insensitive to large parameter variations. This robust control possesses the capability to improve its performance over time by interaction with its environment. The results proved also that good performance and more robustness in face of uncertainties (test of robustness) with the linear robust $H_\infty$ stabilizer ($H_\infty$ PSS), in comparison with using the linear robust $H_2$ controller (optimal LQG controller with Kalman Filter). After appearance of the real (non-linear) properties of the power system, especially in the under - excitation , the H2PSS quickly loses his effectiveness under condition of uncertainties; in the time where $H_\infty$ PSS improve its efficiency, enhance dynamics performances of power system and provides more robustness of its stability.

## *References*

[1] Apkarian, P., D. Noll (2006). "Nonsmooth Hinf-synthesis," IEEE Transactions on Automatic Control, vol. 51, no. 1, pp. 229-244.

[2] [20] P. Apkarian, D. Noll, A. Sim~oes (2009). "Time domain control design: a nonsmooth approach". IEEE Transactions on Control Systems Technology, vol. 17, no. 6, 1439 { 1445.

[3] Ramos, R.A., A.C.P. Martins and N.G. Bretas, 2005. An improved methodology for the design of power system damping controllers. IEEE Trans. Power Syst., 20(4): 1938-1945.

[4] Yorino N, Priyadi A, Kakui H, Takeshita M. A New Method for Obtaining Critical Clearing Time for Transient Stability. IEEE Transactions on Power Systems. 2010; 25(3): 1620-1626.

[5] Nimje AA, Panigrahi CK. Transient Stability Analysis Using Modified Euler's Iterative echnique. IEEE Conference on Power Systems. Kharagpur. 2009: 1-4.

[6] Graham J.W.Dudgeon, William E.Leithead,et al.The Effective Role of AVR and PSS in Power Systems Frequency Response Analysis [J]. IEEE Trans Action Sonpower Systems, 22(4), 2007: 1986-1994.

[7] Baros S., Ilic M. intelligent Balancing Authorities (iBAs) for transient stabilization of large power systems , IEEE PES General Meeting Conference & Exposition, National Harbor, MD, July 27-31, 2014.

[8] Kai Xu, Shanchao Liu, An online adaptive PSS based on RBF neural network identifier, WSEAS TRANSACTIONS on SYSTEMS and CONTROL, Volume 9, 2014, pp.379-387

[9] A. A.Abouelsoud, Abdullah Al-Odienat,Hany Abdelfattah Observer-Based Stabilizer of A single Machine Power System with Lossy Transmission Line Volume 9, 2014, pp.462-467

[10] Oleg N. Agamalov ,Excitation Control of the Synchronous Machines with use an Error Function of the Complex Argument. WSEAS TRANSACTIONS On POWER SYSTEMS, Issue 4, Volume 7, October 2012. pp.172-181

[11] . GROUZDEV, A.A. STARODEBSEV, S.M. OUSTINOV "Conditions for the application of the best amortization of transient processes in energy systems with numerical optimization of the controller parameters AVR-FA" Energy-1990-N ° ll-pp.21-25 (translated from Russian).

[12] P.M. ANDERSON, A. A. FOUAD "Power System control and Stability", IEE Press, 1991. .

[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] 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.

[15] KWAKERNAAK H. "Robust control and H∞ optimization, Tutorial paper", Automatica, vol. 29, № 2. June 1994, pp. 201-207.

[16] A.ANDERSON AND. A. FOUAD ,"Power System Control and stability". IEEE Power systems,1994.

[17] MATLAB Math library User's Guide, by the Math works Inc., 2006.

[18] R. Y. CHIANG, M. G. SOFONOV "Robust control Toolbox User's guid", the Mathworks, INC, 1992.

[19] 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.

[20] 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. 1989, vol.34, № 8, pp.834-847.

[21] 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