A Robust PID-PSS Using Evolutionary Algorithms Implemented Using Developed Interface

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Abstract: Power System Stabilizer (PSS) is a supplementary control signal of a generator's excitation system based on Automatic Voltage Regulator (AVR), are now routinely used in the industry to damp out power system oscillations. Optimal tuning gain of AVR - PSS is necessary for satisfactory performance of power system. Genetic algorithms (GA) have been widely used for global optimization problems. This paper presents a systematic approach for designing and optimal tuning an advanced Conventional AVR-PSS gains, realized on PID-schemes (called AVR-SA), to improve the effectiveness and investigates its robustness under uncertainly constraints on a SMIB system, using Genetic Algorithms. The proposed approach employs GA search for optimal setting of AVR-PSS parameters. The performance of the proposed GA-PSS under small and large disturbances, loading conditions and system parameters variations are tested. The simulation results have proved that GA are powerful tools for optimizing the AVR-PSS parameters, and obtained more robustness of the studied power system. This present work was performed and simulated using our graphical interface 'GUI' realized under MATLAB.

Keywords: AVR-PSS, genetic algorithms, GUI-MATLAB, synchronous generators , stability and robustness.

1 Introduction

LOW frequency oscillations are observed when large power systems are interconnected by relatively weak tie lines.

These oscillations may sustain and grow to cause system separation if no adequate damping is available. Power system stabilizers (PSS) are now routinely used in the industry to damp out oscillations. An appropriate selection of PSS parameters results in satisfactory performance during system disturbances. The problem of PSS parameter tuning is a complex exercise. A number of conventional techniques have been reported in the literature pertaining to design problems of conventional power system stabilizers namely: the eigenvalue assignment, mathematical programming, gradient procedure for optimization and also the modern control theory [9].

Unfortunately, the conventional techniques are time consuming as they are iterative and require heavy computation burden and slow convergence. In addition, the search process is susceptible to be trapped in local minima and the solution obtained may not be optimal [4]. Most of the proposals on PSS parameter tuning are based on small disturbance analysis that required linearization of the system involved. However, linear methods cannot properly capture complex dynamics of the system, especially during major disturbances. This presents difficulties for tuning the PSS in that the controller tuned to provide desired performance at small signal condition do not guarantee acceptable performance in the event of major disturbances. In order to overcome the above short comings, this paper uses Park - Gariov models of power system components [4] and to optimally tune the Conventional PID-PSS parameters [1]. Also, the controller should provide some degree of robustness to the variations loading conditions, and configurations as the machine parameters change with operating conditions. A set of controller parameters which stabilize the system under a certain operating condition may no longer yield satisfactory results when there is a drastic change in power system operating conditions and configurations. The evolutionary methods constitute an approach to search for the optimum solutions via some form of directed random search process. A relevant characteristic of the evolutionary methods is that they search for solutions without previous problem knowledge. Recently, Genetic Algorithm (GA) appeared as a promising evolutionary technique for handling the optimization problems. GA has been popular in academia and the industry mainly because of its intuitiveness, ease of implementation, and the ability to effectively solve highly nonlinear, mixed integer optimization problems that are typical of complex engineering systems. In view of the above, this paper proposes to use GA optimization technique for the design of robust PSS. A comprehensive assessment of the effects of PSS-based damping controller for both single-machine infinite-bus (SMIB) and multi machine power system has been carried out in this paper. The design problem of the proposed controller is transformed into an optimization problem. The design objective is to improve the stability the power system, subjected to severe disturbances. GA based optimal tuning algorithm is used to optimally tune the parameters of the PSS. The proposed controller has been applied and tested under wide range of operating conditions; disturbances at different locations as well as for various fault clearing sequences to show the effectiveness and robustness of the proposed controller and their ability to provide efficient damping of low frequency oscillations.

2 Dynamic Power System Model

2.1. Power System description

In this paper the dynamic model of an IEEE - standard SMIB was considered [4]. 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.

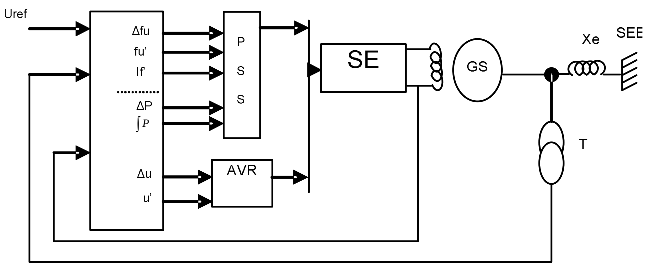


Fig. 1. Standard system IEEE type SMIB with excitation control of powerful synchronous generators

2.2. The Park-Gariov Model of synchronous generators

In this paper we based on the permeances networks modeling of powerful synchronous generators called *Park-Gariov,* for eliminating simplifying hypotheses and testing our designing control algorithm. The PSG model is defined by equations (1-8) and figure (2, 3) [4]:

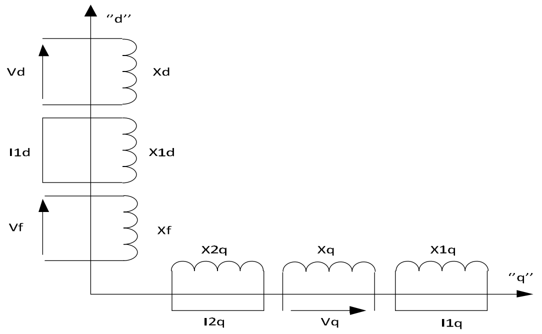


Fig. 2. PARK Transformation of the synchronous machine

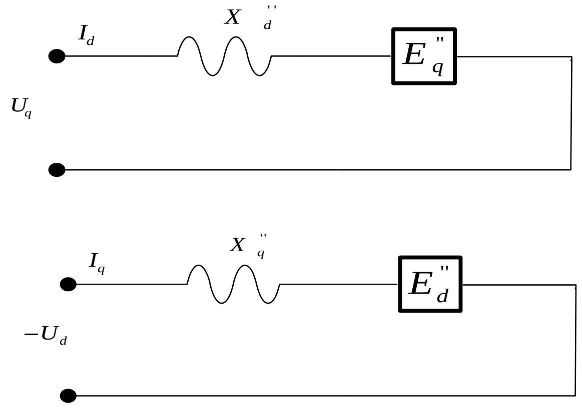


Fig. 3. Equivalent diagrams simplifies of the synchronous machine with damping circuits (PARK-GARIOV model)

a. *Currants equations:*

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

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

b. *Flow equations:*

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

c. *Mechanical equations*

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

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

2.3. Mathematical Model of the used PID –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 [1].

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

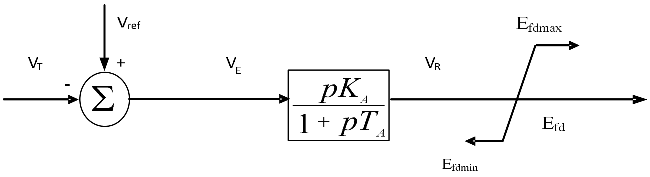


Fig. 4. A simplified" IEEE type-5" AVR

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

In this paper a Conventional PID-PSS [1], was used as a test controller.

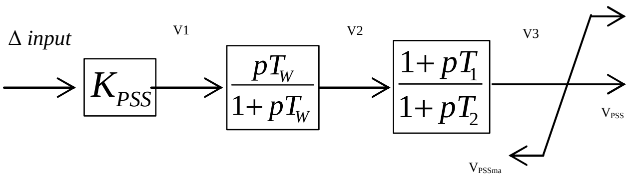


Fig. 5. A functional diagram of the conventinnel PSS

The PSS signal is given by [9]:

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

2.4. Simplified model of the studied SMIB system

We consider the system show in figure 6. The synchronous machine is connected by a transmission line to infinite bus type SMIB, where: Re - Resistor and Le - inductance of the transmission line [4].

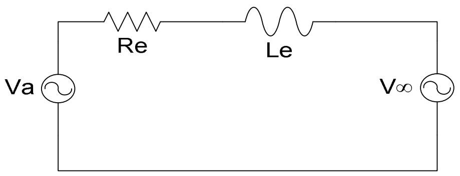


Fig. 6. Synchronous machine connected to an infinite bus network

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 Steps of the Used Genetic Algorithms

A Genetic Algorithm handles the potential solutions of a given problem, to achieve the optimum solution, or a solution considered as satisfactory .the algorithm is organized into several steps and works iteratively. The figure 7 shows the simplest GA introduced by Holland [6].

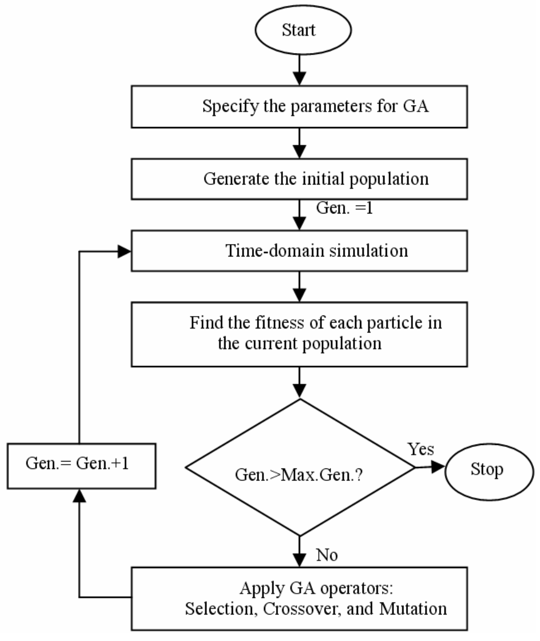


Fig. 7. The genetic algorithm organization

We describe in more detail the various steps of the used genetic algorithm (figure 7) in our work [9]:

1) Coding and initialization

The first step is the problem parameters coding in order to constitute the chromosomes. The most used type of coding is the binary one, but other coding can be also used for example: ternary, integer, real…etc. The passage from the actuary representation to the coded one is done through encoding and decoding functions.

2) Evaluation

It's to measure the performance of each individual in the population; this is done using a function directly related to the objective function which is called "fitness function". This is positive real function that reflects the strength of the individual. An individual with a high fitness value is a good solution to the problem, whereas individual with low fitness value represents a worse solution.

3) Selection

Selection in genetic algorithms plays the same role as natural selection. It follows the survivals Darwinian principle of those most adapted, it decide what are the individuals that survive and which ones disappear ,this selection is according to their fitness functions. a Population called intermediate is then formed by selected individuals.

There are several methods of selection. We mention two of the best known:

- Lottery roulette Method ;
- Tournement Method.

4) Crossover

Crossing enables a pair of individuals among those selected, to share their genetic information e. d. their genes. Its principle is simple: two individuals are randomly taken, and they are called "parents", then we draw a random"P" number in the interval [0, 1], after that it will be compared to some crossing probability "Pc".

- If P>Pc, there will be no crossing, and the parents are copied into a new generation.
- If else; P≤ Pc, crossing occurs and the chromosomes parents are crossed to produce tow children replacing their parents in the next generation.

There are different crossing types, the most known are:

- The multipoint crossover
- The uniforme crossover

5) Mutation

The mutation operator enables to explore new points in the search space and ensures the possibility to leave local optima; mutation applies to each individual gene with a mutation probability (Pm) following the same crossing principle.

- If P> Pm, there will be no mutation will and the gene remains as it is.

- If P ≤ Pm mutation occurs, and the gene will replaced with another gene randomly drawn among the possible values. In the case of a binary coding, it is simply to replace a”0” by a “1” and vice versa.

6) *Terminaison criteria*

As in any iterative algorithm, we must define a stopping criteria, this can be formulated in various ways, among which we can mention:

- Stop the algorithm when the result reached a satisfactory solution;
- Stop if there is no improvement for some number of generations;
- Stop if a certain number of generations is exceeded.

We consider the simple case of function with tow variables “X1, X2” belonging to the natural numbers set:

Maximise

$$F_{obj}(X1, X2) = (1 - X1)^2\exp(-X1^2 - (X2 + 1)^2) - (X1 - X1^3 - X2^5)\exp(-X1^2 - X2^2)$$

Subject to $3 > X1 \geq -3$

$3 > X2 \geq -3$

The used parameters are:

- A 8 bits binary encoding ;
- The search interval :X1 ϵ [-3,3], X2 ϵ [-3,3], ;
- Tournement Method;
- A simple crossing (to one point),with crossing probability Pc=0.7 ;
- A mutation probability Pm=0.3

To calculate the GA operations (Coding and initialization, Evaluation, Selection, Crossover and mutation), and to display graphically the problem solution, this is shown on figures 9 and 10

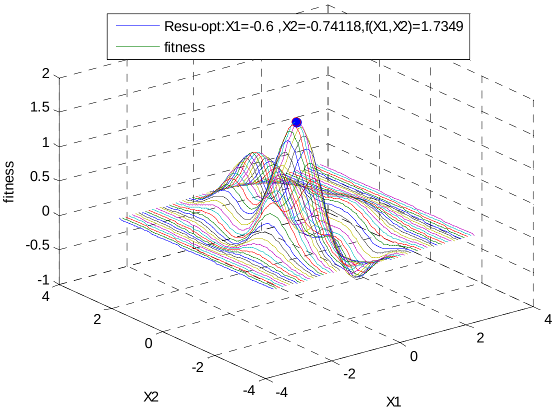


Fig. 9. Optimization result using GA

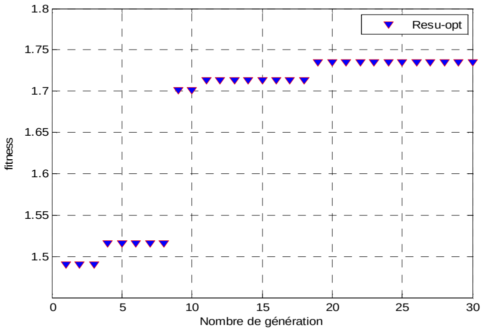
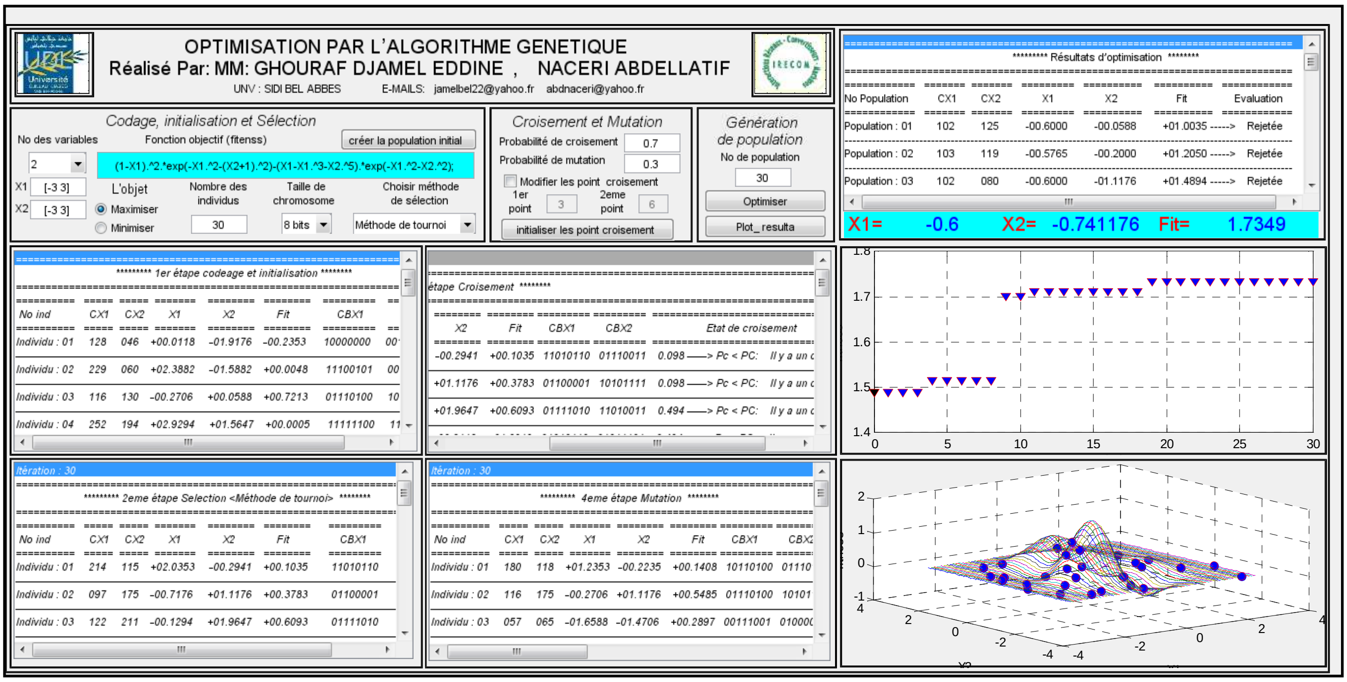


Fig. 10. Convergences of the objective function for the GA optimization



OPTIMISATION PAR L’ALGORITHME GENETIQUE
Réalisé Par: MM: GHOURAF DJAMEL EDDINE , NACERI ABDELLATIF
UNV : SIDI BEL ABBES E-MAILS: jamelbel22@yahoo.fr abdnaceri@yahoo.fr

Codage, initialisation et Sélection
No des variables: 2
Fonction objectif (fitenss): (1-X1).^2.*exp(-X1.^2-(X2+1).^2)-(X1-X1.^3-X2.^5).*exp(-X1.^2-X2.^2);
X1 [-3 3]
X2 [-3 3]
L'objet: ● Maximiser ○ Minimiser
Nombre des individus: 30
Taille de chromosome: 8 bits
Choisir méthode de sélection: Méthode de tournoi

Croisement et Mutation
Probabilité de croisement: 0.7
Probabilité de mutation: 0.3
☐ Modifier les point croisement
1er point: 3
2eme point: 6

Génération de population
No de population: 30

```
================================================================
                ********* Résultats d’optimisation  ********
================================================================
============ ======= ======= ========= ========== ========== ============
No Population   CX1     CX2      X1         X2         Fit      Evaluation
============ ======= ======= ========= ========== ========== ============
Population : 01  102     125   -00.6000   -00.0588   +01.0035 ----->  Rejetée
-------------------------------------------------------------------------
Population : 02  103     119   -00.5765   -00.2000   +01.2050 ----->  Rejetée
-------------------------------------------------------------------------
Population : 03  102     080   -00.6000   -01.1176   +01.4894 ----->  Rejetée
```

X1= -0.6 X2= -0.741176 Fit= 1.7349

```
==============================================================
          ********* 1er étape codeage et initialisation ********
==============================================================
========== ===== ===== ======= ======== ======== ========= ==
 No ind     CX1   CX2    X1       X2       Fit      CBX1
========== ===== ===== ======= ======== ======== ========= ==
Individu : 01  128  046  +00.0118  -01.9176  -00.2353  10000000  00
Individu : 02  229  060  +02.3882  -01.5882  +00.0048  11100101  00
Individu : 03  116  130  -00.2706  +00.0588  +00.7213  01110100  10
Individu : 04  252  194  +02.9294  +01.5647  +00.0005  11111100  11
```

```
==============================================================
étape Croisement  ********
==============================================================
 ======== ======== ========= ========= ========================
    X2       Fit      CBX1      CBX2           Etat de croisement
 ======== ======== ========= ========= ========================
 -00.2941  +00.1035  11010110  01110011  0.098 ——> Pc < PC:   Il y a un c
 +01.1176  +00.3783  01100001  10101111  0.098 ——> Pc < PC:   Il y a un c
 +01.9647  +00.6093  01111010  11010011  0.494 ——> Pc < PC:   Il y a un c
```

```
Itération : 30
==============================================================
     ********* 2eme étape Selection <Méthode de tournoi>  ********
==============================================================
========== ===== ===== ======= ======== ======== =========
 No ind     CX1   CX2    X1       X2       Fit      CBX1
========== ===== ===== ======= ======== ======== =========
Individu : 01  214  115  +02.0353  -00.2941  +00.1035  11010110
Individu : 02  097  175  -00.7176  +01.1176  +00.3783  01100001
Individu : 03  122  211  -00.1294  +01.9647  +00.6093  01111010
```

```
Itération : 30
==============================================================
            *********  4eme étape Mutation  ********
==============================================================
========== ===== ===== ======= ======== ======== ========= ======
 No ind     CX1   CX2    X1       X2       Fit      CBX1     CBX2
========== ===== ===== ======= ======== ======== ========= ======
Individu : 01  180  118  +01.2353  -00.2235  +00.1408  10110100  01110
Individu : 02  116  175  -00.2706  +01.1176  +00.5485  01110100  10101
Individu : 03  057  065  -01.6588  -01.4706  +00.2897  00111001  010000
```

Fig. 8. Genetic algorithm operation under a developped GUI / MATLAB

The problem solutions are:
$X1$= -00.6000, $X2$= -00.7412, $F(X1, X2)$ = +01.7349

The differents and various operations developed and runing using our realized GUI / Matlab (shown in figure 8):

4 Application of Genetic Algorithm to Optimezed the used AVR-PSS

4.1. The Linear System Stability -analytical study

Recall that the damping factor ζ of method represented by its complex eigenvalue "λ" is given by:

$$\zeta = \frac{-\sigma}{\sqrt{\sigma^2 + \omega^2}} \tag{9}$$

With $$\lambda = \sigma \pm j\omega \tag{10}$$

A damping factor ζ leads to a significant well-damped dynamic response; all eigenvalues must be located in the left area of the complex plane defined by two half-lines. For a critical value of the damping factor ζcr: we impose a relative stability margin [10].

The real part of the eigenvalue σ determines the rapid decay / growth exponential dynamic response of the component system. Thus, σ very negative results in a fast dynamic response. To do this, all the eigenvalues must be located in the left area of the complex plane defined by a vertical through a critical value of the portion real (σ_{cr}: we defined as the absolute stability margin when setting the parameters of PSS, it is desirable that these two criteria are taken into account for proper regulation. The combination between these two criteria leads to an area called D; stability area [11], show in figure 11. Moving eigenvalues in this area ensures robust performance for a large number of points operated [12].

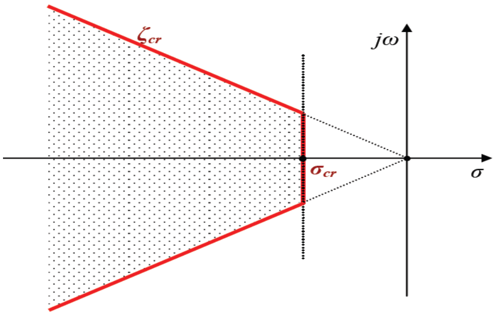


Fig. 11. D-Stability area

4.2. objective function

The purpose of the PSS use is to ensure satisfactory oscillations damping, and ensure the overall system stability to different operation points. To meet this goal, we using a function composed of two multi-objective functions [13]. This function must maximize the stability margin by increasing damping factors while minimizing the system real eigenvalues. Therefore, all the eigenvalues are in the D stability area, the multi-objective function calculating steps are:
1-formulate the linear system in an open –loop (without PSS);
2-locate the PSS and its parameters initialized by the G.A through an initial population;
3- Calculate the closed loop system eigenvalues and take only the dominant modes: $\lambda = \sigma \pm j\omega$
4- Find the system eigenvalues real parts (σ) and damping factor ζ;
5- Determine the (ζ) minimum value and the (- σ) maximum value, which can be formulated respectively as: (minimum (ζ)) and (maximum - (σ));
6- Gather both objective functions in a multi-objective function F as follows:

$$F_{obj} = -\max(\sigma) + \min(\zeta)$$

7- Return this Multi-objective function value the to the AG program to restart a new generation.

Figure 8 shows the proposed in this paper the GA for the AVR-PSS parameters optimization.

4.3. Application To AVR-PSS

The optimized parameters for PSS are: K_{0w}, K_{1w}, T_{1w}, and T_{0w} , and the PSS-AVR model used shows in figure 13
With:

$0 \le K_{0w} \le 10$
$0 \le K_{1w} \le 10$
$0.0005 \le T_1 \le 0.1$
$0.0001 \le T_2 \le 0.1$

Number of Individuals = 100
Maximum Generation = 120
A crossing probability Pc = 0.7
A mutation probability Pm = 0.3

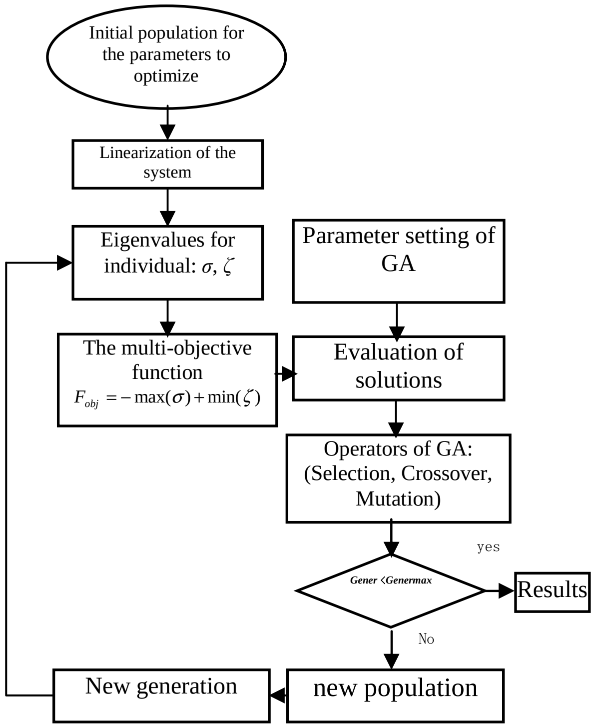


Fig. 12. The multi-objective function and AG program Flowchart for the PSS

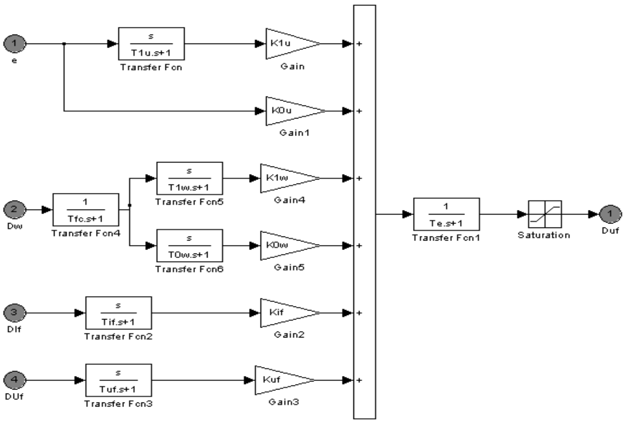


Fig. 13. Model of the used conventional PID-PSS

Table 1 give a simulation result optimized PSS parameters with different SG :

TABLE I. THE PSS OPTIMIZED PARAMETERS

parameters	**TBB-200**	**TBB-500**	**BBC-720**	**TBB-1000**
T_1	**0.0321**	**0.029**	**0.0445**	**0.0234**
T_2	**0.054**	**0.0322**	**0.0356**	**0.0214**
K_{0W}	**4.074**	**5.011**	**3.034**	**5.0142**
K_{1w}	**5.43**	**6.45**	**9.548**	**1.506**

5 Implementation of the Robust GA-PSS Under a realized GUI/ Matlab

5.1. Creation of a calculating code under MATLAB / SIMULINK

The “SMIB” system used in our study includes:

- A powerful synchronous generators (PSG) ;
- Tow voltage regulators: AVR and PSS

Connected to a power infinite network line

I this paper, We used for our simulation in this paper, the SMIB mathematical model based on permeances networks model culled Park-Gariov [4], shown in Figure 14 [14]:l

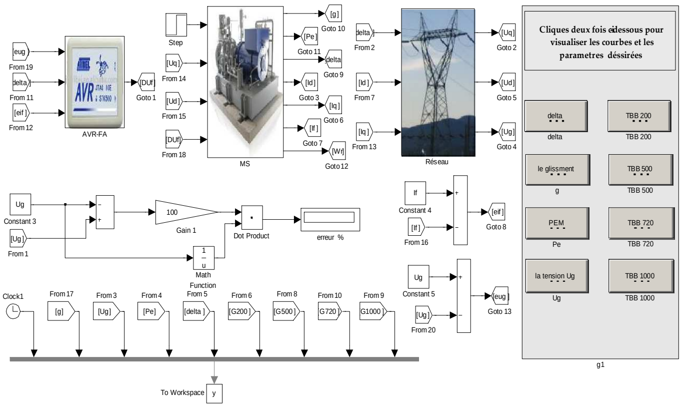


Fig. 14. Structure of the synchronous generator (PARK-GARIOV model) and his excitation controller

5.2. The developped grphicfal interface ‘GUI’ under MATLAB for PSS tuning parameters using GA

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 controller;
- To optimized the controller parameters by Genetic Algorithm;
- View the system regulation results and simulation (see GUI-MATLAB in the Appendix 3 created);
- Calculate the system dynamic parameters ;
- Test the system stability and robustness;
- Study the different operating regime (under-excited, rated and over excited regime).

We present an Example for optimization and tuning the parameters of the GA-PSS using our realized GUI, with:

Number of individuals=10 , Number of population =10

```
         ********* Creation of initial population ********
        ********* 1st step coding and initialization ********
==========================================
N ind      K0W        K1W       T1       T2      Sigma      ksi
_____________________________________________________
Indi:01  +01.2471 +00.8431  0.0828  0.0828  -0.2217  +0.0225
--------------------------------------------------------------------------------
Indi:02  +01.4824  +00.3765  0.0590  0.0600  -0.5294  +0.0538
--------------------------------------------------------------------------------
Indi:03  +00.5647  +00.2706  0.0145  0.0816  -0.1603  +0.0168
--------------------------------------------------------------------------------
Indi:04  +04.2353  +00.1216  0.0594  0.0953  -0.5294  +0.0538
--------------------------------------------------------------------------------
Indi:05  +05.1294  +00.6902  0.0727  0.0647  -0.5294  +0.0538
--------------------------------------------------------------------------------
Indi:06  +04.7294  +00.5529  0.0430  0.0628  -2.4673  +0.2311
--------------------------------------------------------------------------------
Indi:07  +04.4471  +00.0078  0.0212  0.0643  -2.4172  +0.2425
--------------------------------------------------------------------------------
Indi:08  +00.6118  +00.4157  0.0266  0.0060  -0.2397  +0.0255
--------------------------------------------------------------------------------
Indi:09  +03.1059  +00.4353  0.0992  0.0937  -0.4707  +0.0453
--------------------------------------------------------------------------------
Indi:10  +05.0588  +00.7843  0.0481  0.0898  -1.8467  +0.1662
--------------------------------------------------------------------------------
              ********* 2sd step selection ********
==============================================
N ind       K0W        K0W        T1       T2      Sigma       ksi
_____________________________________________________
Indi:01  +01.4824  +00.3765  0.0590  0.0600  -00.5294  +0.0538
-----------------------------------------------------------------------------------
Indi:02  +01.4824  +00.3765  0.0590  0.0600  -00.5294  +0.0538
-----------------------------------------------------------------------------------
Indi:03  +04.2353  +00.1216  0.0594  0.0953  -00.5294  +0.0538
-----------------------------------------------------------------------------------
Indi:04  +04.7294  +00.5529  0.0430  0.0628  -02.4673  +0.2311
-----------------------------------------------------------------------------------
Indi:05  +04.7294  +00.5529  0.0430  0.0628  -02.4673  +0.2311
-----------------------------------------------------------------------------------
Indi:06  +04.7294  +00.5529  0.0430  0.0628  -02.4673  +0.2311
-----------------------------------------------------------------------------------
Indi:07  +04.4471  +00.0078  0.0212  0.0643  -02.4172  +0.2425
-----------------------------------------------------------------------------------
Indi:08  +03.1059  +00.4353  0.0992  0.0937  -00.4707  +0.0453
-----------------------------------------------------------------------------------
Indi:09  +05.0588  +00.7843  0.0481  0.0898  -01.8467  +0.1662
```

```
---------------------------------------------------------------------------------
Indi:10  +04.7294  +00.5529  0.0430  0.0628  -02.4673  +0.2311
---------------------------------------------------------------------------------
            ********* 3th step crossover********
==================================================
N ind        K0W      K1W       T1       T2      Sigma      ksi       Pc
_____________________________________________________
Indi:01  +01.4824  +00.3765  0.0590  0.0600  -00.5294  +0.0538  0.695
 Pc < PC: There is a crossover  0011111101100000100101101001 1001
------------------------------------------------------------------------------
Indi:02  +01.4824  +00.3765  0.0590  0.0600  -00.5294  +0.0538  0.695
  Pc < PC: There is a crossover  00111111011000001001011010011001
------------------------------------------------------------------------------
Indi:03  +03.2000  +00.0588  0.0688  0.0890  -00.5294  +0.0538  0.310
 Pc < PC: There is a crossover  1000100000001111101011111110 0011
------------------------------------------------------------------------------
Indi:04  +05.7647  +00.6157  0.0337  0.0691  -00.5294  +0.0538  0.310
 Pc < PC: There is a crossover 11110101100111010101010110110000
------------------------------------------------------------------------------
Indi:05  +04.7294  +00.5529  0.0430  0.0628  -02.4673  +0.2311  0.344
 Pc < PC: There is a crossover  11001001100011010110110110100000
------------------------------------------------------------------------------
Indi:06  +04.7294  +00.5529  0.0430  0.0628  -02.4673  +0.2311  0.344
 Pc < PC: There is a crossover  11001001100011010110110110100000
------------------------------------------------------------------------------
Indi:07  +03.1294  +00.1804  0.0243  0.0675  -01.5648  +0.1580  0.076
 Pc < PC: There is a crossover  10000101001011100011110110101100
------------------------------------------------------------------------------
Indi:08  +04.4235  +00.2627  0.0961  0.0906  -00.7595  +0.0702  0.076
 Pc < PC: There is a crossover  10111100010000111111010111100111
------------------------------------------------------------------------------
Indi:09  +04.7765  +00.8000  0.0434  0.0882  -01.8779  +0.1716  0.520
 Pc < PC: There is a crossover  11001011110011000110111011100001
------------------------------------------------------------------------------
Indi:10  +05.0118  +00.5373  0.0477  0.0643  -02.5061  +0.2294  0.520
 Pc < PC: There is a crossover  11010101100010010111100110100100


              ******** 4th step Mutation ********
==================================================
N ind      K0W        K1W      T1       T2        Sigma      ksi
_____________________________________________________
Indi:01  +02.6118  +00.4235  0.0579  0.0538  -01.1364  +0.1126
    0 1 1 0 1 1 1 1 0 1 1 0 1 1 0 0 1 0 0 1 0 0 1 1 1 0 0 0 1 0 0 1
---------------------------------------------------------------------------------
Indi:02  +01.2941  +00.9412  0.0313  0.0361  -00.6357  +0.0664
    0 0 1 1 0 1 1 1 1 1 1 1 0 0 0 0 0 1 0 0 1 1 1 1 0 1 0 1 1 1 0 0
---------------------------------------------------------------------------------
Indi:03  +00.6118  +00.3059  0.0028  0.0882  -00.1824  +0.0191
    0 0 0 1 1 0 1 0 0 1 0 0 1 1 1 0 0 0 0 0 0 1 1 0 1 1 1 0 0 0 0 1
---------------------------------------------------------------------------------
Indi:04  +02.7529  +00.5843  0.0454  0.0600  -01.2761  +0.1266
    0 1 1 1 0 1 0 1 1 0 0 1 0 1 0 1 0 1 1 1 0 0 1 1 1 0 0 1 1 0 0 1
---------------------------------------------------------------------------------
Indi:05  +05.2471  +00.3882  0.0992  0.0961  -00.7749  +0.0702
     1 1 0 1 1 1 1 1 0 1 1 0 0 0 1 1 1 1 1 1 1 1 0 1 1 1 1 1 0 1 0 1
---------------------------------------------------------------------------------
Indi:06  +04.7294  +00.5529  0.0938  0.0628  -01.2761  +0.1266
    1 1 0 0 1 0 0 1 1 0 0 0 1 1 0 1 1 1 1 0 1 1 1 1 1 0 1 0 0 0 0 0
---------------------------------------------------------------------------------
Indi:07  +03.1294  +00.6353  0.0489  0.0064  -01.2761  +0.1266
    1 0 0 0 0 1 0 1 1 0 1 0 0 0 1 0 0 1 1 1 1 1 0 0 0 0 0 1 0 0 0 0
---------------------------------------------------------------------------------
Indi:08  +05.2706  +00.2627  0.0727  0.0616  -01.2761  +0.1266
    1 1 1 0 0 0 0 0 0 1 0 0 0 0 1 1 1 0 1 1 1 0 0 1 1 0 0 1 1 1 0 1
---------------------------------------------------------------------------------
Indi:09  +03.6941  +00.8000  0.0426  0.0248  -02.0490  +0.2142
    1 0 0 1 1 1 0 1 1 1 0 0 1 1 0 0 0 1 1 0 1 1 0 0 0 0 1 1 1 1 1 1
---------------------------------------------------------------------------------
Indi:10  +02.0000  +00.5137  0.0481  0.0424  -00.9589  +0.0980
    0 1 0 1 0 1 0 1 1 0 0 0 0 0 1 1 0 1 1 1 1 0 1 0 0 1 1 0 1 1 0 0
---------------------------------------------------------------------------------
              ********* Optimization results ********
=========================================================
N Pop     K0W     K1W        T1       T2       Sigma    ksi    Evaluation
____________________________________________________________
Pop:01  +05.8588  +00.5059  +00.0555  0.0075  -2.4821 +0.2719--> Acceptée
  Pop:02  +04.2588  +00.1804  +00.0325  0.0365  -1.8625  +0.2010 --> Rejetée
------------------------------------------------------------------------------------------
  Pop:03  +04.6824  +00.4510  +00.0372  0.0448  -2.0675  +0.2158 --> Rejetée
------------------------------------------------------------------------------------------
  Pop:04  +04.4000  +00.1608  +00.0052  0.0534  -1.8033  +0.1992 --> Rejetée
------------------------------------------------------------------------------------------
  Pop:05  +05.6235  +00.6863  +00.0590  0.0307  -2.4880 +0.2517--> Acceptée
------------------------------------------------------------------------------------------
  Pop:06  +06.0000  +00.3216  +00.0516  0.0150  -2.6346 +0.2859--> Acceptée
------------------------------------------------------------------------------------------
  Pop:07  +05.9294  +00.3451  +00.0887  0.0115  -2.2553  +0.2275--> Rejetée
------------------------------------------------------------------------------------------
  Pop:08  +05.5529  +00.3137  +00.0637  0.0475  -2.1573  +0.2082--> Rejetée
------------------------------------------------------------------------------------------
  Pop:09  +05.2706  +00.4392  +00.0263  0.0444  -2.3655  +0.2535--> Rejetée
------------------------------------------------------------------------------------------
  Pop:10  +05.3176  +00.4392  +00.0579  0.0444  -2.2063  +0.2176--> Rejetée
------------------------------------------------------------------------------------------
                 Optimization is finished.......
The obtained optimizing parameters are:
K0W= +06.0000   K1W= +00.3216   T1=+00.0516   T2= 0.0150   with Sigma= -2.6346
```

The different operations are performed from GUI realized under MATLAB and shown in Figure 15.

6 Simulation results and discussion

The following results (Table 2 and Figures 16 to 18) were obtained by study and simulation of static and dynamic performances in the following cases:

1. SMIB in open loop without regulation (OL)
2. Closed Loop System with the regulator AVR and conventional stabilizer PSS [14].

3 - Optimization and tuning parameters of the robust AVR-PSS using genetic algorithm (PSS-GA).

We simulated in this work three cases: the under-excited, the nominal regime and the over-excited modes.

In this work we interested in the Powerful Synchronous Generators types: TBB-200, TBB-500 BBC-720, TBB-1000 (given parameters in Appendix 1) [14].

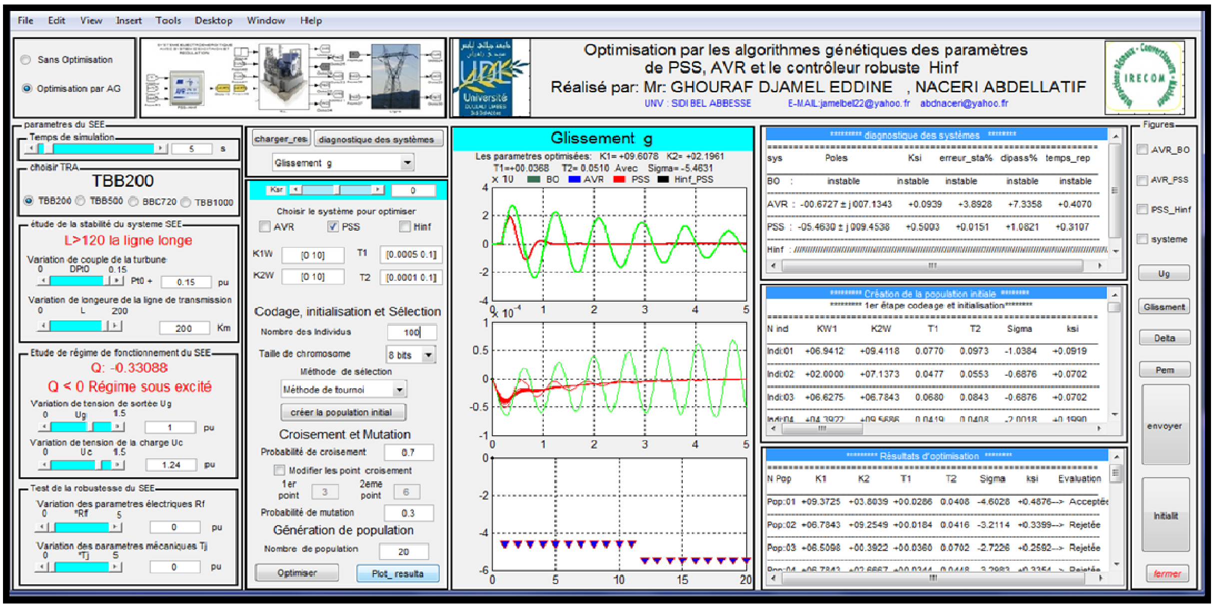
Table 2 presents the static and dynamic performances results in (OL) and (CL) with PSS and PSS-GA, for an average line (Xe = 0.3 pu), and an active power P=0.85 p.u.(generator BCC-720)

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

For more details about the calculating parameters the realized GUI-MATLAB is shown in Appendix 2.

TABLE II. THE "SMIB "STATIC AND DYNAMIC PERFORMANCES

Damping coefficient α					**the static error**			
Q	**OL**	**AVR**	**PSS**	**PSS-OPT**	**OL**	**AVR**	**PSS**	**PSS-GA**
-0.1372	**Unstable**	**-0.709**	**-1.6201**	**-2.3283**	**Unstable**	**-2.640**	**-1.620**	**-1.234**
-0.4571	**Unstable**	**-0.708**	**-1.6503**	**-2.3463**	**Unstable**	**-2.673**	**-1.629**	**-1.241**
0.1896	**-0.0813**	**-0.791**	**-1.6865**	**-2.3906**	**-5.038**	**-2.269**	**-1.487**	**-1.267**
0.3908	**-0.1271**	**-0.634**	**-1.5379**	**-2.3906**	**-5.202**	**-1.807**	**-1.235**	**-1.129**
0.5078	**-0.1451**	**-0.403**	**-0.9432**	**-1.9582**	**-3.777**	**-0.933**	**-0.687**	**-0.604**
0.6356	**-0.1588**	**-0.396**	**-0.9283**	**-1.9803**	**-3.597**	**-0.900**	**-0.656**	**-0.567**
the setting time for 5%					**the maximum overshoot %**			
Q	**OL**	**AVR**	**PSS**	**PSS-OPT**	**OL**	**AVR**	**PSS**	**PSS-GA**
-0.1372	**Unstable**	**4,231**	**1,704**	**1,349**	**Unstable**	**9,053**	**7,892**	**4,237**
-0.4571	**Unstable**	**4,237**	**1,713**	**1,323**	**Unstable**	**9,036**	**7,847**	**4,219**
0.1896	**-**	**3,793**	**1,617**	**1,408**	**10,959**	**9,447**	**8,314**	**4,928**
0.3908	**-**	**4,732**	**1,706**	**1,630**	**10,564**	**8,778**	**7,883**	**4,659**
0.5078	**14,320**	**7,444**	**2,041**	**1,877**	**9,402**	**6,851**	**6,588**	**3,269**
0.6356	**14,423**	**7,576**	**2,080**	**1801**	**9,335**	**6,732**	**6,463**	**3,012**



Optimisation par les algorithmes génétiques des paramètres
de PSS, AVR et le contrôleur robuste Hinf
Réalisé par: Mr: GHOURAF DJAMEL EDDINE , NACERI ABDELLATIF
UNV : SIDI BEL ABBESSE E-MAIL:jamelbel22@yahoo.fr abdnaceri@yahoo.fr

○ Sans Optimisation
● Optimisation par AG

parametres du SEE

Temps de simulation: 5 s

choisir TRA: TBB200
● TBB200 ○ TBB500 ○ BBC720 ○ TBB1000

étude de la stabilité du systeme SEE
L>120 la ligne longe
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): 200 Km

Etude de régime de fonctionnement du SEE
Q: -0.33088
Q < 0 Régime sous excité
Variation de tension de sortée Ug (0 Ug 1.5): 1 pu
Variation de tension de la charge Uc (0 Uc 1.5): 1.24 pu

Test de la robustesse du SEE
Variation des parametres électriques Rf (0 *Rf 5): 0 pu
Variation des parametres mécaniques Tj (0 *Tj 5): 0 pu

Ksr: 0

Choisir le système pour optimiser
☐ AVR ☑ PSS ☐ Hinf
K1W [0 10] T1 [0.0005 0.1]
K2W [0 10] T2 [0.0001 0.1]

Codage, initialisation et Sélection
Nombre des Individus: 100
Taille de chromosome: 8 bits
Méthode de sélection: Méthode de tournoi

Croisement et Mutation
Probabilité de croisement: 0.7
☐ Modifier les point croisement
1er point: 3 2ème point: 6
Probabilité de mutation: 0.3

Génération de population
Nombre de population: 20

Glissement g
Les parametres optimisées: K1= +09.6078 K2= +02.1961
T1=+00.0368 T2= 0.0510 Avec Sigma= -5.4631

```
********* diagnostique des systèmes ********
=====================================================================
sys        Poles                  Ksi      erreur_sta%  dipass%  temps_rep
---------------------------------------------------------------------
BO  :      instable               instable  instable     instable instable
---------------------------------------------------------------------
AVR :  -00.6727 ± j007.1343     +0.0939   +3.8928      +7.3358  +0.4070
---------------------------------------------------------------------
PSS :  -05.4630 ± j009.4538     +0.5003   +0.0151      +1.0821  +0.3107
---------------------------------------------------------------------
Hinf  : //////////////////////////////////////////////////////////////
```

```
******** Création de la population initiale ********
********* 1er étape codeage et initialisation*********
=====================================================================
N ind     KW1       K2W       T1       T2       Sigma     ksi
---------------------------------------------------------------------
Indi:01  +06.9412  +09.4118  0.0770   0.0973   -1.0384   +0.0919
---------------------------------------------------------------------
Indi:02  +02.0000  +07.1373  0.0477   0.0553   -0.6876   +0.0702
---------------------------------------------------------------------
Indi:03  +06.6275  +06.7843  0.0680   0.0843   -0.6876   +0.0702
---------------------------------------------------------------------
```

```
********* Résultats d'optimisation ********
=====================================================================
N Pop    K1        K2        T1        T2      Sigma    ksi      Evaluation
---------------------------------------------------------------------
Pop:01  +09.3725  +03.8039  +00.0286  0.0408  -4.6028  +0.4876--> Acceptée
---------------------------------------------------------------------
Pop:02  +06.7843  +09.2549  +00.0184  0.0416  -3.2114  +0.3399--> Rejetée
---------------------------------------------------------------------
Pop:03  +06.5098  +00.3922  +00.0360  0.0702  -2.7226  +0.2592--> Rejetée
---------------------------------------------------------------------
```

Fig. 15. The realised GUI / MATLAB for parameters tunnining of a Robust GA-PSS

In the Figures 16,17 and 18 show an example the obtained simulation results, with respectively 'Ug' the stator terminal voltage; 'Pe' the electromagnetic power system, 's' variable speed, 'delta' The internal angle of turbo-generator BBC 720.

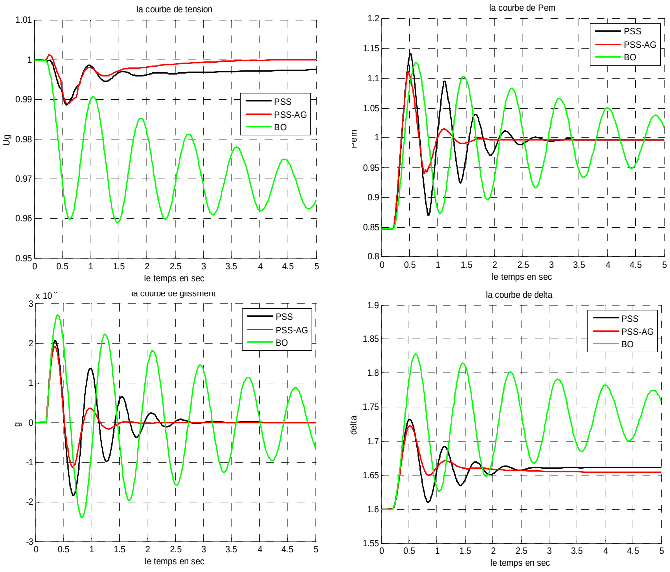


Fig. 16. functioning system in the under-excited of BBC 720 connected to a long line with PSS , PSS- AG and OL

From the simulation results, it can be observed that the use of PSS optimized by AG 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), granted a large stability and more robustness of the studied system.

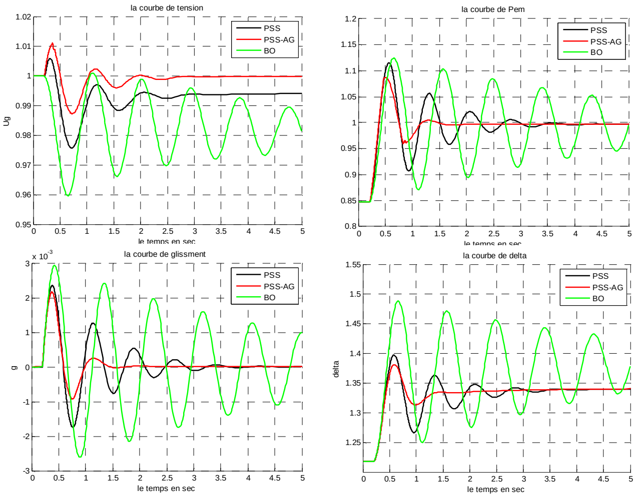


Fig. 17. system response under nominal mode with generator BBC 720 connected to a long line with PSS , PSS- AG and OL

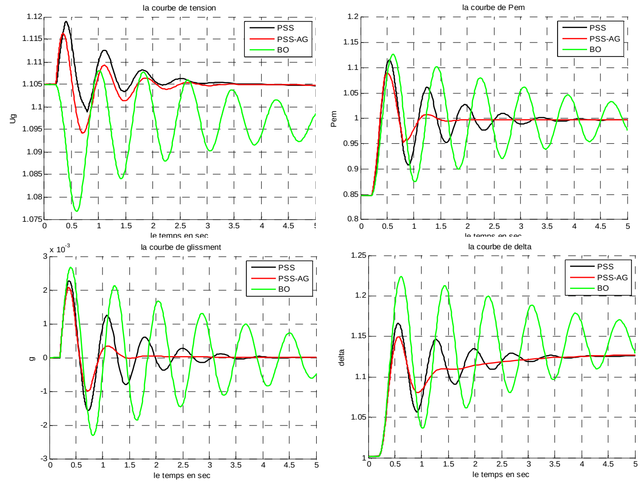


Fig. 18. functioning system in the over-excited used of BBC 720 connected to a long line with PSS , PSS- AG and OL

7 Conclusion

In this article, we have optimized conventional AVR-PSS parameters using genetic algorithms. The optimized PSS are used for powerful synchronous generators exciter voltage control in order to improve static and dynamic performances of power system.

This Genetic Algorithm optimization technique (GA) allows us to obtain a considerable improvement in dynamic performances and robustness stability of the studied power system.

All results in this work are implemented and obtained by using our developed graphical interface GUI under MATLAB.

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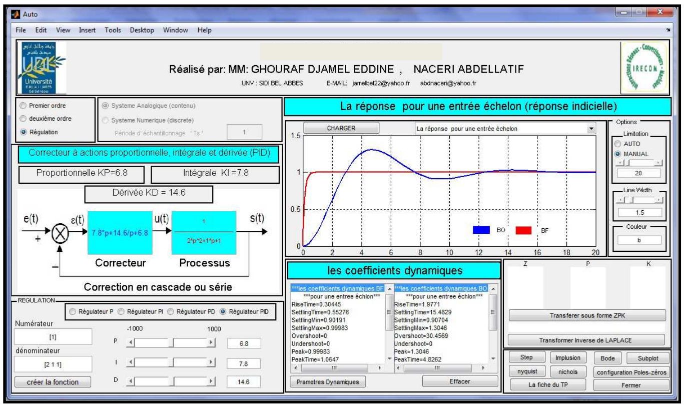
Appendix

1. 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**	**.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 using realized GUI-MATLAB



Réalisé par: MM: GHOURAF DJAMEL EDDINE , NACERI ABDELLATIF
UNV : SIDI BEL ABBES E-MAIL: jamelbel22@yahoo.fr abdnaceri@yahoo.fr

○ Premier ordre
○ deuxième ordre
● Régulation

● Systeme Analogique (contenu)
○ Systeme Numerique (discrete)
Période d' échantillonnage 'Ts' 1

La réponse pour une entrée échelon (réponse indicielle)

Limitation: ○ AUTO ● MANUAL 20
Line Width 1.5
Couleur b

Correcteur à actions proportionnelle, intégrale et dérivée (PID)
Proportionnelle KP=6.8
Intégrale KI =7.8
Dérivée KD = 14.6

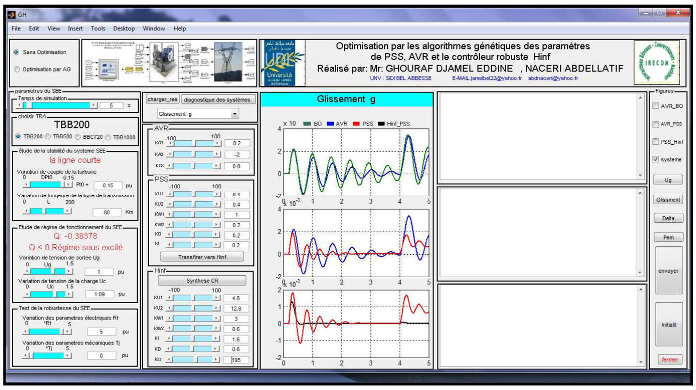
REGULATION
○ Régulateur P ○ Régulateur PI ○ Régulateur PD ● Régulateur PID
Numérateur [1]
dénominateur [2 1 1]
-1000 1000
P 6.8
I 7.8
D 14.6

les coefficients dynamiques

```
***les coefficients dynamiques BF
    ***pour une entree échlon***
RiseTime=0.30445
SettlingTime=0.55276
SettlingMin=0.90191
SettlingMax=0.99983
Overshoot=0
Undershoot=0
Peak=0.99983
PeakTime=1.0647
```

```
***les coefficients dynamiques BO
    ***pour une entree échlon***
RiseTime=1.9771
SettlingTime=15.4829
SettlingMin=0.90704
SettlingMax=1.3046
Overshoot=30.4569
Undershoot=0
Peak=1.3046
PeakTime=4.8262
```

3. The system regulation results and simulation under GUI-MATLAB



● Sans Optimisation
○ Optimisation par AG

Optimisation par les algorithmes génétiques des paramètres de PSS, AVR et le contrôleur robuste Hinf
Réalisé par: Mr: GHOURAF DJAMEL EDDINE , NACERI ABDELLATIF
UNV : SIDI BEL ABBESSE E-MAIL:jamelbel22@yahoo.fr abdnaceri@yahoo.fr

parametres du SEE
Temps de simulation 5 s
choisir TRA
TBB200
● TBB200 ○ TBB500 ○ BBC720 ○ TBB1000
étude de la stabilité du systeme SEE
la ligne courte
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 80 Km
Etude de régime de fonctionnement du SEE
Q: -0.38378
Q < 0 Régime sous excité
Variation de tension de sortée Ug 0 Ug 1.5 1 pu
Variation de tension de la charge Uc 0 Uc 1.5 1.09 pu
Test de la robustesse du SEE
Variation des parametres électriques Rf 0 *Rf 5 5 pu
Variation des parametres mécaniques Tj 0 *Tj 5 0 pu

Glissement g

AVR -100 100
KA1 0.2
KA2 -2
KA3 0.8

PSS -100 100
KU1 0.4
KU2 0.4
KW1 1
KW2 0.2
KD 0.2
KI 0.2

Hinf -100 100
KU1 4.8
KU2 12.8
KW1 3
KW2 0.6
KI 1.6
KD 0.6
Ksr 195

☐ AVR_BO
☐ AVR_PSS
☐ PSS_Hinf
☑ systeme