

The power system stabilizers synthesis by the genetic algorithms

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Abstract— This paper presents the use of genetic algorithms (GA) to synthesize the optimal parameters of Power System Stabilizer (PSS), this later is used as auxiliary of turbo generator excitation system in order to damp electro mechanicals oscillations of the rotor (inductor), and consequently, improve the Electro Energetic System (EES). In this study, we started with the linearization of a system around the operating point, then, we analyzed its stability in slight movement, after that, we have optimized the PSS parameters using the Genetic Algorithms (G.A), these later are researches technical's based on natural selection mechanism, genetics and evolution. The obtained results have proved that (G.A) are a powerful tools for optimizing the PSS parameters. Our present study was performed using a GUI realized under MATLAB in our work.

Keywords— AVR-PSS, Electro Energetic System, genetic algorithm, GUI, powerful synchronous generators, stability.

I. INTRODUCTION

The Electro Energetic System stability is viewed as the most necessary condition to regular operating electrical network control systems are required to ensure this stability by identifying the main factors that influence on this one. The Classical controllers AVR and PSS [1,2] (PI or PID) have a leading role in increasing static and dynamic stability degree, and damping electro mechanicals oscillations generated by the rotor (the inductor). However, a robustness test (a disturbance injected on the EES) showed that PID-AVR and PSS are hardly robust, so, in order to improve their efficiency (robustness), we used the (G.A) for the optimization and the adjusting of PSS parameters [3,4].

The genetic algorithms is a global research technical and an optimization procedure based on natural inspired operators such as crossing, and selection [5,6]. Unlike other optimization methods, the (G.A) operate under several encodings parameters (binary, ternary, real...), to be optimized and not the parameters themselves. In addition, to better guide the

AVR-PSS optimal parameters search, the (G.A) use a performed index to approach this solution [6].

II. DYNAMIC POWER SYSTEM MODEL:

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 [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.

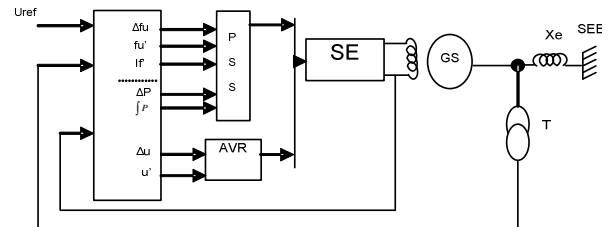


Fig. 1. Standard system IEEE type SMIB with excitation control of powerful synchronous generators

The AVR (Automatic Voltage Regulator), is a controller of the PSG voltage that acts to control this voltage, through the exciter. Furthermore, the PSS was developed to absorb the generator output voltage oscillations [4].

In our study the synchronous machine is equipped by a voltage regulator model "IEEE" type - 5 [7, 8], as is shown in Figure 2.

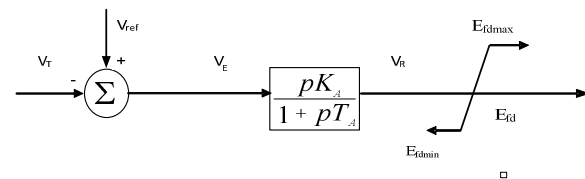


Fig. 2. A simplified "IEEE type-5" AVR diagram

$$V_R = \frac{K_A V_E - V_R}{T_A}, \quad V_E = V_{ref} - V_F \quad (1)$$

About the PSS, considerable's efforts were expended for the developpement of the system. The main function of a PSS is to modulate the PSG excitation to [1, 2, 4].

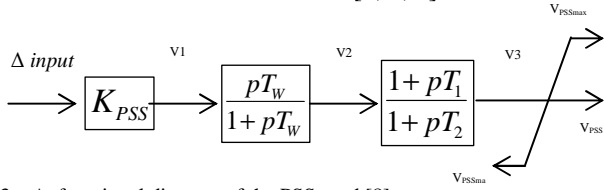


Fig. 3. A functional diagram of the PSS used [8]

The PSS signal is given by:[8]

$$\begin{aligned} \dot{V}_1 &= \frac{V_2 - V_1}{T_1} + \frac{T_2}{T_1} \dot{V}_2; \\ \dot{V}_2 &= \frac{V_3 - V_2}{T_2} + \frac{T_3}{T_2} \dot{V}_3; \\ \dot{V}_3 &= \frac{V_3}{T_w} \dot{V}_1; \quad \dot{V}_1 = K_{PSS} \Delta input \end{aligned} \quad \Delta input = \begin{cases} \Delta P, \int p \\ \text{or} \\ \Delta \omega = \omega_{mach} - \omega_0 \\ \text{and} \\ \Delta I_f = I_f - I_{f0} \\ \text{and} \\ \Delta U_f = U_f - U_{f0} \end{cases} \quad (2)$$

III. THE GENETICS ALGORITHMS THEORY

A. Introduction

Overall, 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 4 shows the most simple genetic algorithm introduced by Holland [6].

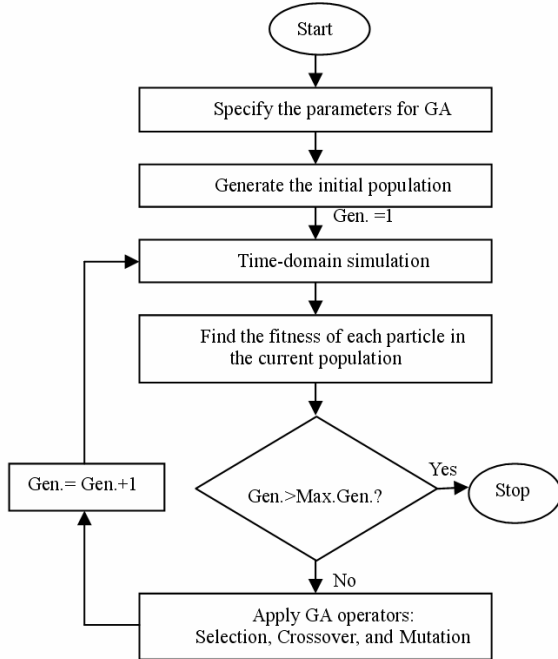


Fig. 4. The genetic algorithm organization

B. The genetic algorithm steps description

In what follows, we will describe in more detail the various steps of a simple genetic algorithm Figure 4

1) Coding and initialization [9]

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...the passage from the actual 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 Méthod ;
- Tournament 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 $P > P_c$, there will be no crossing, and the parents are copied into a new generation.
- If else; $P \leq P_c$, 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 $P > P_m$, there will be no mutation will and the gene remains as it is.
- If $P \leq P_m$ mutation occurs, and the gene will be 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.

Example:

We consider the simple case of function with one variable "x" belonging to the natural numbers set:

$$\text{Maximise } F_{obj} = 15x - x$$

$$\text{Subject to } 0 > x \geq 15$$

The used parameters:

- A 8 bits binary encoding ;
- The search interval [0,15] ;
- A Lottery roulette Method;
- A simple crossing (to one point),with crossing probability $P_c=0.7$;
- A mutation probability $P_m=0.1$.

To run and view the various steps of genetic algorithm, we created and developed a "GUI" (Graphical User Interfaces) in MATLAB software, this latter allows:

- To calculate and display the AG operations (Coding and initialization, Evaluation, Selection, Crossing and mutation);
- To display graphically the problem solution, as is shown in figure 5.

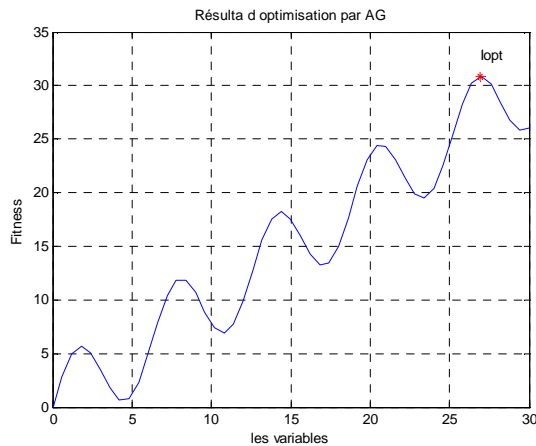


Fig. 5. Optimization result by AG

The problem solution:

$$x = 26.9412. \quad F(x) = 30.8288$$

The various operations are developed by the realized "GUI" (shown in figure 6).

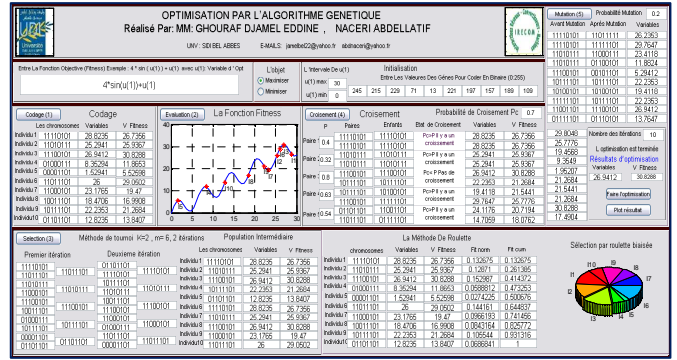


Fig. 6. The genetic algorithm in GUI / MATLAB

IV. APPLICATION OF THE ALGORITHM GENETIC TO PSS

A) The Linear System Stability -analytical study

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

$$\zeta = \frac{-\sigma}{\sqrt{\sigma^2 + \omega^2}} \quad (3)$$

$$\text{With } \lambda = \sigma \pm j\omega \quad (4)$$

A damping factor ζ leads to a significant well-damped dynamic response. To do this, 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 ζ_{cr} : 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], figure 7. Moving eigenvalues in this area ensures robust performance for a large number of points operations [12].

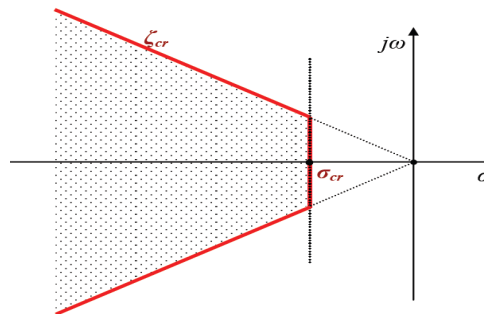


Fig. 7. D. Stability zone

B) objective function [13]

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. This function must maximize the stability margin by increasing damping factors while minimizing the system real eigenvalues . Therefore, all 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 ($-\sigma$) 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 PSS parameters synthesis algorithm

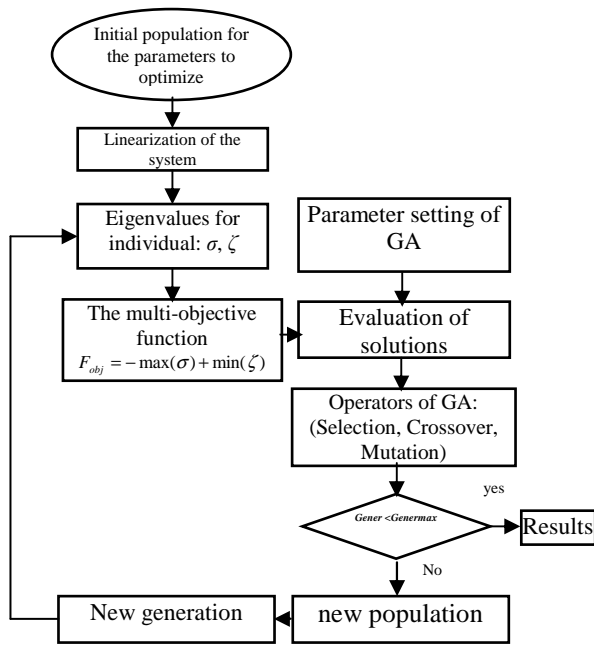


Fig. 8. The multi-objective function and AG program Flowchart

The optimized parameters used for PSS: K_{PSS} , T_w , T_1 , T_2

$$5 \leq K_{PSS} \leq 150$$

$$0.01 \leq T_w \leq 0.05$$

$$0.01 \leq T_1 \leq 0.06$$

$$0.01 \leq T_2 \leq 0.065$$

Number of Individuals = 120

Maximum Generation = 100

A crossing probability $P_c = 0.7$

A mutation probability $P_m = 0.01$

TABLE I. THE PSS OPTIMIZED PARAMETERS

parameters	TBB-200	TBB-500	BBC-720	TBB-1000
T_w	0.0321	0.029	0.0445	0.0234
T_1	0.054	0.0322	0.0356	0.0214
T_2	0.074	0.011	0.034	0.0142
K_{PSS}	51.43	15.45	100.548	15.506

V. THE SMIB SYSTEM SIMULATION WITH MATLAB

A) Creation of a calculating code under MATLAB / SIMULINK

The “SMIB” system used in our study includes:

- A synchronous machine (MS) ;
- Tow voltage regulators: AVR and AVR-PSS connected to;
- A Power Infinite network line

The SMIB’s mathematical model simulation (the Park-Gariv with permeances networks Model), is shown in Figure 9 [14].

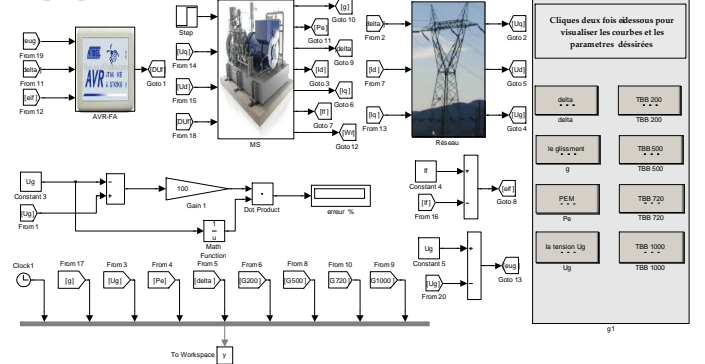


Fig. 9. Structure of the synchronous machine (PARK-GARIOV model) with the excitation controller under MATLAB –SIMULINK

B) The GUI Created

To analyze and visualize the different dynamic behaviors we have creating and developing a “GUI” (Graphical User Interfaces) in MATLAB .this GUI allows as to:

- Perform control system from PSS controller;
- To optimize the controller parameters by Genetic Algorithm;
- 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 (shown in Fig. 10).

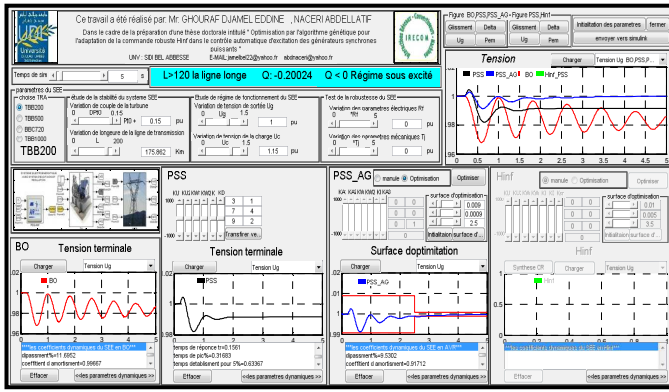


Fig. 10. The system applications under GUI / MATLAB

C) Simulation result and discussion

The following results (Table 2 and Figure 11) were obtained by studying the “SMIB” static and dynamic performances in the following cases:

1. SMIB in opened loop without regulation recorded (OL)
2. Closed Loop System with the stabilizer PSS-FA; recorded (CL)
- 3 - Optimization of gains Regulators PSS-AVR by genetic algorithm.

We suddenly disrupted the SMIB by changing the turbine torque ($\Delta T_m = 15\%$) at the instant: $t = 0.2s$, with changes in network configuration outside;

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

Our study is interested in the Powerful Synchronous Generators of type: TBB-200, TBB-500 BBC-720, TBB-1000 (parameters in Appendix A).

Table 2 presents the TBB -200 static and dynamic performances results in (OL) and (CL) with PSS and PSS-optimized, for an average line ($X_e = 0.3$ pu), and an active power $P=0.85$ p.u.

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

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	instable	-2.640	-1.620	-1.234
-0.4571	Unstable	-0.708	-1.6503	-2.3463	instable	-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	9,572	9,053	7,892	7,237
-0.4571	Unstable	4,237	1,713	1,323	9,487	9,036	7,847	7,219
0.1896	-	3,793	1,617	1,408	10,959	9,447	8,314	7,928
0.3908	-	4,732	1,706	1,630	10,564	8,778	7,883	7,659
0.5078	14,320	7,444	2,041	1,877	9,402	6,851	6,588	6,269
0.6356	14,423	7,576	2,080	1,801	9,335	6,732	6,463	6,012

In the Figures 11 and 12 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 TBB200 of Turbo-generator with $P = 0.85$, $X_e = 0.5$, $Q1 = -0.107$ (pu)

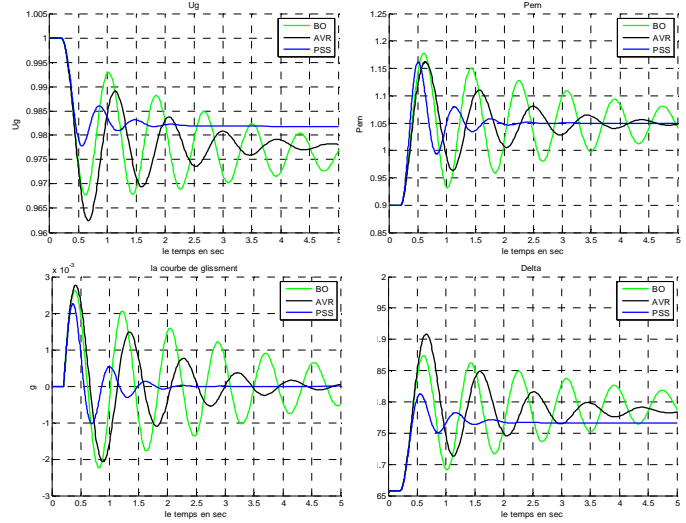


Fig. 11. functioning system in the under-excited of TBB 200 connected to a long line with AVR ,OL and PSS

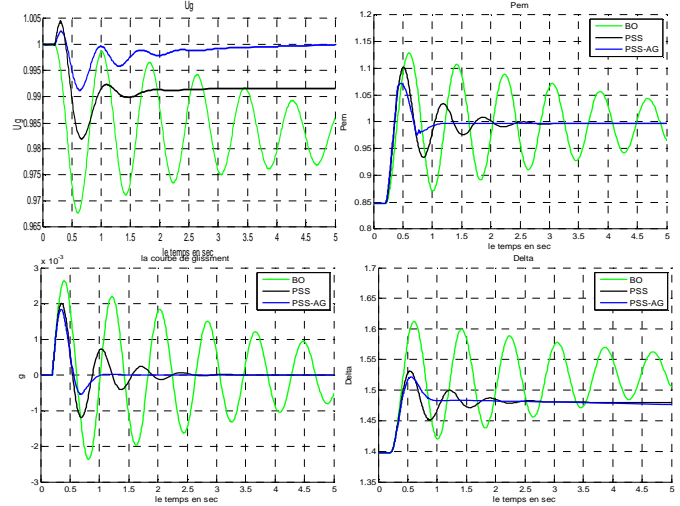


Fig. 12. functioning system in the under-excited of TBB 200 connected to a long line with PSS , PSS- AG and OL

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 (the under-excited regime for example).

VI. CONCLUSION

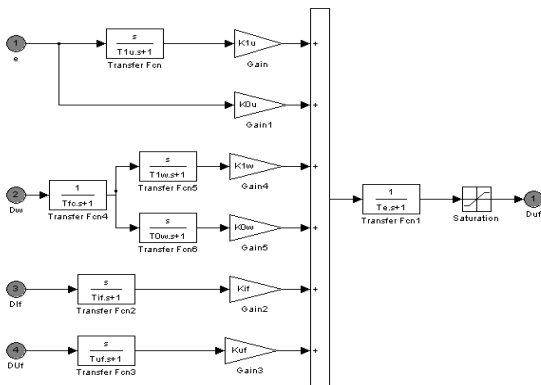
In this article, we have optimized the PSS parameters by genetic algorithms; these optimized PSS are used for powerful synchronous generators exciter voltage control in order to improve static and dynamic performances of the Electro-Energetic. This technique (GA) allows us to obtain a considerable improvement in dynamic performances and robustness stability of the SMIB studied.

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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	.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_{ld}	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. Power System model:

$$\dot{\delta} = \omega_0 \Delta \omega$$

$$\dot{\omega} = (P_m - P_e) / M$$

$$\dot{E}'_q = (E_{fd} - (x_d - x'_d)i_d - E'_q) / T'_{do}$$

$$\dot{E}_{fd} = \frac{1}{T_A} (K_A (V_{ref} - V_t + V_{PSS}) - E_{fe})$$

$$V_d = V_s \sin \delta + R_e i_d - x_e i_q$$

$$V_q = V_s \cos \delta + R_e i_q + x_e i_d$$

$$V_t = \sqrt{V_d^2 + V_q^2}$$

$$T_e = E'_q i_q - (x'_d - x_q) i_d i_q$$

NOMENCLATURES

- E_{fd} : The exciter output voltage
 V_f : The filter output voltage
 T_e : The electrical torque
 V_d/V_q : Components along the direct axis / quadrature axis voltage
 I_d/I_q : Components along the direct axis / quadrature axis current
 X_g/L_e : Reactance / inductance transmission line
 X_d/L_d : Reactance / inductance synchronous longitudinal
 X_q/L_q : Transversal Reactance / inductance synchronous