DINCON 2017
CONFERÊNCIA BRASILEIRA DE DINÂMICA, CONTROLE E APLICAÇÕES
30 de outubro a 01 de novembro de 2017 – São José do Rio Preto/SP

# Optimization of synchronous machines controllers using metaheuristics

Natã Franco Soares de Bem[1]
Centro Federal de Educação Tecnológica de Minas Gerais – CEFET-MG, Leopoldina, MG
Control and Automation Engineering, CEFET-MG – Leopoldina, MG
Lorrana Faria da Rocha[2]
Control and Automation Engineering, CEFET-MG – Leopoldina, MG
Marlon José do Carmo[3]
Department of Electroeletronics, CEFET-MG – Leopoldina, MG

**Abstract**. EPS problems are usually difficult to find its best result, due to lack of precise resolution models or because of its complexity and high number of variables. Metaheuristics are a good resolution process, being not only robust, but also simple and adaptable to the nature of the problem. Therefore, in this paper we propose the use of three different metaheuristic algorithms to solve an infinite bus problem when a short-circuit is applied to the system. Genetic Algorithm, Particle Swarm Optimization and Cuckoo Search are implemented and their tuning of the controller is discussed.
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**Keywords**. Metaheuristics, Optimization, Control, Tuning, Electric Power System.

## 1 Introduction

The Electric Power System (EPS) is a complex circuit formed by the generation, transmission (and subtransmission) and distribution of electric power, as well as of its respective devices, such as generators, transformers and distribution and transmission buses [1].

To operate satisfactorily, with the lowest cost, environmental impact and reliability, the EPS operates interconnected [2], [1]. The interconnection of the system (National Grid – NG) also

[1] natan.franco.s@gmail.com
[2] lorrana_faria@yahoo.com.br
[3] marloncarmo@ieee.org

allows alternative paths for the passage of electric energy [2], which, in a problem situation in the transmission line, can be more easily bypassed. In order to operate interconnected, the generators must be in synchronous operation, with equal frequency and angle output. Typically, synchronous machines are used because of their intrinsic synchronous characteristic. Some exceptions exist, such as in wind power plants where the machine that is used is an induction generator. Contingencies in the system can lead to instabilities throughout the EPS.

System instability can be achieved in different ways, depending on the configuration, interconnection and reliability of the system and its equipment. However, this instability can cause the system to operate at a power output beyond the capacity of the generators, which can lead to physical damage to the EPS equipment [3].

Despite the advantages of a NG, there are consequences arising from this union, such as the possible energy loss of a significant part of the system, when the instability of an area is not controlled and, therefore, is spread. Stability analysis techniques arise as a means of studying the behavior of the system or part of it when contingencies occur.

The Electric System National Operator (ONS) analyzes the NG power flow and performs the decision making based on EPS behavior simulations according to applied study techniques, such as modal analysis and small signal stability.

Stability in steady state or small signals is defined as the ability of a system to remain stable when a small disturbance occurs [4]. Small disturbances are common in the NG and may be due to variations in load, i.e., increase or decrease in power demand, for example, during the day or generation variations, which may occur as a consequence of variations in the water reservoir, for example. When controlling systems based on small signals stability, the set of equations describing the system can be linearized, which makes possible the use of linear control [5].

With the Brazilian EPS in constant expansion, the ONS must coordinate it, always in order to keep the NG in balance and stable. New tools and techniques are constantly studied and implemented to improve the standards and reliability of electric power distribution [6]. Given the complexity of the NG, analytical techniques sometimes become costly and complex with the size of the NG, which makes it difficult to analyze the whole system. The metaheuristic algorithms show promising potential in analyzing and obtaining the necessary quasi-optimal response, especially when one does not have more detailed information on the problem situation.

When working with power systems in relation to their stability and joint analysis, metaheuristics algorithms are an interesting tool because they have a simple algorithm structure, with a high power of problem processing, almost independently of the number of variables to be optimized. Thus, this work aims to implement algorithms for controlling the parameters of the controllers of the synchronous generating machines to keep the electrical system in balance and, mainly, stable in relation to its permanent regime.

Several problems requiring solution are difficult to obtain and cannot be solved or achieve the optimal solution by traditional methods of resolution. Such problems can be solved through metaheuristics. Metaheuristics are algorithms developed with the purpose of solving a wide range of problem of difficult solution without the need to adapt the algorithm excessively to the problem. These algorithms are widely applied in complex problems ranging from problem situations in financial sectors to production management [7].

A good metaheuristic algorithm should explore the response domain and benefit from possible exploit responses. However, there must be a balance between these two concepts: while the former is connected to the response search field, thus allowing a more complete scan, the latter is linked to the exploration of promising areas, that is, they show good results. The difference between the various algorithms of metaheuristics are linked, mainly to this equilibrium [7].

The algorithms used in this work are population-based, that is, this type of algorithm works with several solutions, trying to find the best among them, instead of working with only one answer. This type of algorithm has its chances of reaching the answer to the problem increased, since several possible answers are used. Several algorithms of this category are based on Evolutionary Computation, which are based on the principles of Natural Evolution, or Swarm Intelligence, that take as base the social or collective behavior of several species of the animal kingdom [7]. There are several metaheuristics algorithms, such as Genetic Algorithm, Firefly, Dragonfly, Cuckoo Search and others.

This paper is divided as follows: in Section 2, it is presented the objectives of the paper, in Section 3, the methods that were used for the execution of the simulations, while Section 4 discusses and presents the results obtained and Section 5 concludes our work and conclusions we came across while developing this project.

## 2 Objectives

This paper aims to study the effectiveness of metaheuristics algorithms applied to a infinite bus. Three algorithms are implemented here: GA (Genetic Algorithm), PSO (Particle Swarm Optimization) and CS (Cuckoo Search).

## 3 Methods

For this simulation, it was used a Windows 10 Home laptop, with 16 Gb of RAM and Intel® Core i7 -6500 CPU, 2.5 GHz, mathematic simulation software MATLAB 2006b, ANATEM and ANAREDE for circuit design and simulation of the system and Plot Cepel for plotting the graphics.

The EPS in study is an infinite bus circuit. This system is composed of two generators and two buses, one being infinite. When there is more than one generator in the system and the presence of the others does not cause significant difference in the frequency and voltage in the generator under study, it is said that this system behaves like an infinite bus in relation to the other generators [8]. In Figure 1 it is shown the infinite bus circuit in study.

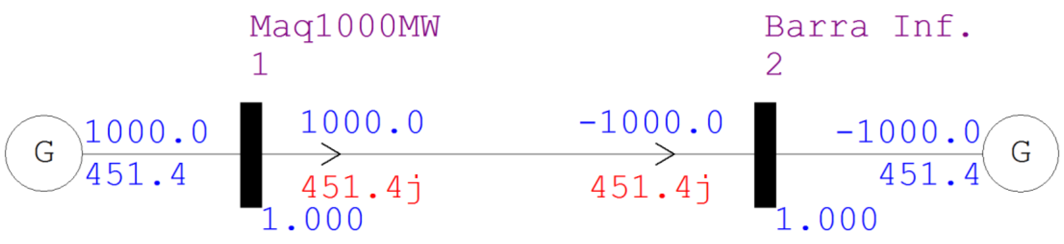


Figure 1: Infinite bus circuit designed using ANATEM software.

A short-circuit is applied in the system and we controlled one generator response, for the infinite bus does not interfere with the rest of the system. The controller modeling has eight parameters to be tuned and hence, to be optimized.

After the design of the system, a MATLAB code is run for each of the algorithms. Plot Cepel plots the waveforms for each answer and MATLAB reads the angle of the generator and calculates the error based on this angle. A MSE (Mean Squared Error) function is used to find the error based on the mean of the response. The metaheuristics have the function to minimize the error.

Each answer is composed of eight numbers, from 0.01 to 90.0, forming a vector. The vectors together form a population matrix, which is updated at each iteration or generation, depending on the algorithm. Figure 2 shows the flowchart and how each software communicates with each other.

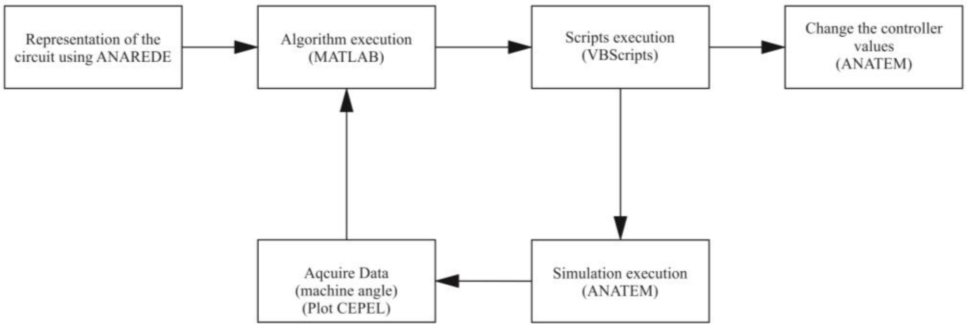


Figure 2: Flowchart of the actions needed in order to run the algorithms.

Each algorithm had 50 individuals or particles and 50 iterations or generations were set. Several simulations were run and the best answer for each algorithm was considered.

Table 1: Equations used for the algorithms.

| **Algorithm** | **Equations** | |
|---|---|---|
| PSO | $velocity_{t+1} = w \cdot velocity_t + c_1 \cdot \gamma_1 \cdot (p_{best} - p_t) + c_2 \cdot \gamma_2 \cdot (g_{best} - p_t)$ | $p_{t+1} = p_t + velocity_{t+1}$ |
| GA | $offspring_{t+1} = p \cdot parent1_t + (1 - p) \cdot parent2_t$ | $mutation = random\ value\ equation$ |
| CS | $nestArea_{t+1} = neatArea_t + s \cdot (bestArea_t - nestArea_t)$ | $eggs_{t+1} = neatArea_{t+1} + p \cdot ELR_{t+1}$ |

The algorithms have different equations that update the values, as shown in Table 1. GA uses recombination and mutation (random small values that are added or subtracted from the answers), while PSO uses velocity and position movement towards the best answer from each particle and from the global best. Lastly, CS uses Lèvy Flights to update the areas to be exploited, which allows a better exploration of the search space. PSO answer is given by $p_{t+1}$, GA is given by $offspring_{t+1}$, with a change of its values being altered by a mutation equation (1% mutation rate) and CS answer is given by $eggs_{t+1}$.

# 4 Results and Discussions

In Table 2 it is shown the best error for each of the algorithms. It is also compared to the standard response of ANATEM, which already represents a good tuning for the parameters.

Table 2: Final Error of each algorithm.

| **Algorithm** | **Final Error** |
|---|---|
| ANATEM Standard | 3.59E+04 |
| PSO | 5.79E+03 |
| GA | 8.79E+03 |
| CS | 2.19E+03 |

CS algorithm found the best response for the parameters of the controller. Its response is 16 times smaller than the standard response given by the parameters of ANATEM. It should be noted that all the algorithms discovered better parameters than the standard ones, as PSO and GA showed a response 6.2 and 4.0 times smaller. Although GA showed the worst results, its parameters are still better than the standard values.

In Table 3 it is shown the values for each of the eight parameters for the controller found by the algorithms and by ANATEM.

Table 3: Values of each parameter

| **Algorithm** | **P1** | **P2** | **P3** | **P4** | **K** | **T1** | **T1** | **Tw** |
|---|---|---|---|---|---|---|---|---|
| ANATEM | 100 | 0 | 1 | 0.05 | 20 | 0.08 | 0.01 | 3 |
| PSO | 34.9 | 50.0 | 8 | 0.23 | 47.54 | 71.8 | 78.6 | 3.97 |
| GA | 34.7 | 49.9 | 9.45 | 0.3 | 47.0 | 71.0 | 79.3 | 4.42 |
| CS | 1.54 | 87.9 | 0.05 | 0.96 | 90.0 | 90.0 | 90.0 | 88.7 |

We can see that the PSO and GA found similar values to parameters and that the CS got very different values. Its search space was better exploited than PSO and GA. In fact, GA has a known problem that is to get locked in a local optimum, which can be mitigated by elevating the mutation rate, which, on the other hand, can make the algorithm excessively oscillate.

In Figure 3 we have the response over time for the machine angle controlled with the parameters found by the algorithms. It is visible the improvement provided by the algorithms, especially by the CS.

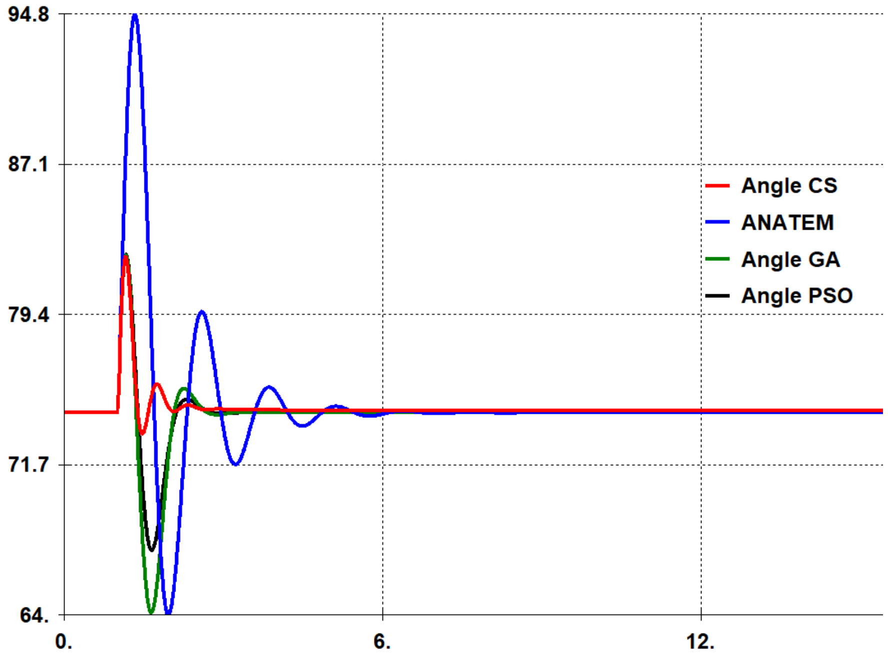


Figure 3: Machine Angle over time for the parameters found by the algorithms.

The transient response was also improved, as shown in Table 4, where we can see that the settling time was significantly reduced, as well as the overshoot.

Table 4: Response characteristics of the algorithms

| Algorithm | Settling Time (s) | Overshoot (%) | Peak Time (s) |
|---|---|---|---|
| ANATEM | 4.69 | 27.45 | 1.34 |
| PSO | 2.65 | 10.89 | 1.17 |
| GA | 2.60 | 10.88 | 1.17 |
| CS | 2.51 | 10.61 | 1.16 |

The greatest difference lies on the overshoot, with a reduction of about 60% in all algorithms.

## 5 Conclusions

All the algorithms showed very good results, although CS has the best results. While GA presented a step-up compared with the standard response, this algorithm may be lock itself in a local optimum and therefore, not explore all its search space towards better results. This technique is simpler than classical analysis for EPS once there is no need to know the system precisely, only to represent it in a simulation software, such as the one used in this paper. Future work includes application of the algorithms in more complex systems to push forward its capabilities of optimization.

## Acknowledgement

We would like to express our deepest appreciation to all those who provided the possibility to complete this work. We would like to express special gratitude to CEFET-MG and FAPEMIG for their support in this project.

## References

[1] J. P. A. SILVA, “AVALIAÇÃO DE OPERAÇÃO ILHADA DE SISTEMAS ELÉTRICOS DE POTÊNCIA,” Juiz de Fora, 2014.

[2] B.M. Weedy, B.J. Cory, N. Jenkins, J.B. Ekanayake, G. Strbac, Electric System Power, Quinta ed., Wiley, 2012, pp. 1-50.

[3] I. J. S. Lourinho, “Estudo dos índices de estabilidade e controlabilidade de tensão em sistemas elétricos de potência multimáquinas,” Florianópolis, 2001.

[4] R. R. Silva, “ANÁLISE DINÂMICA FRENTE A PEQUENAS E GRANDES PERTURBAÇÕES DO SISTEMA ELÉTRICO ACRE-RONDÔNIA,” Rio de Janeiro, 2011.

[5] T. J. M. A. Parreiras, “METODOLOGIA E IMPLEMENTAÇÃO COMPUTACIONAL PARA ANÁLISE DA ESTABILIDADE A PEQUENOS SINAIS EM MÚLTIPLOS CENÁRIOS,” Rio de Janeiro, 2012.

[6] Frederique Augusto Lisboa, Rodrigo da Cunha Santos, “Ferramenta computacional para análise de estabilidade a pequenos sinais de sistemas elétricos de potência,” Brasília, 2010.

[7] Ilhem Boussaïd, Julien Lepagnot, Patrick Siarry, "A survey on optimization metaheuristics," *Information Sciences,* vol. 237, pp. 82-117, 2013.

[8] P. Kundur, Power System Stability and Control, Palo Alto: McGraw-Hill, 1994.

[9] Prabha Kundur, John Paserba, Venkat Ajjarapu, Göran Andersson, Anjan Bose, Claudio Canizares, Nikos Hatziargyriou, David Hill, Alex Stankovic, Carson Taylor, Thierry Van Cutsem, Vijay Vittal, "Definition and Classification of Power System Stability," *IEEE TRANSACTIONS ON POWER SYSTEMS,* vol. 19, no. 2, pp. 1387-1401, maio 2004.

[10] A. Jalilvand, M. Azari, "ROBUST TUNING OF PSS CONTROLLER BASED ON IMPERIALIST COMPETITIVE ALGORITHM," *International Journal on “Technical and Physical Problems of Engineering” (IJTPE),* vol. 4, no. 13, pp. 5-10, dezembro 2012.