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Preface

The field of artificial immune systems (AIS) is one of the most recent natural computing approaches to emerge from engineering, computer science and theoretical immunology. The immune system is an adaptive system that employs many parallel and complementary mechanisms to maintain homeostasis and defend the organism against pathological agents. It is a distributed system, capable of constructing and maintaining a dynamical and structural identity, learning to identify previously unseen invaders and remembering what it has learnt. Numerous immune algorithms now exist, based on processes identified within the vertebrate immune system. These computational techniques have many potential applications, such as in distributed and adaptive control, machine learning, pattern recognition, fault and anomaly detection, computer security, optimization, and distributed system design.

The International Conference on Artificial Immune Systems (ICARIS) started in 2002 with the goal of bringing together a number of researchers investigating forms of using ideas from the immune system to do engineering and computing and to solve complex problems. Some theoretically oriented researchers also joined this effort with ambitious goals such as modeling the immune system. There is a continued effort to strengthen the interaction among distinct research areas, aiming at supporting the multidisciplinary outline of the field. Table 1 indicates the number of submissions versus the number of published papers for each of the six ICARIS conferences up to now. From 2004 to 2007 the number of submissions and accepted papers has varied little with a slight increase in 2005, although one would probably expect these numbers to have increased more over time, due to the existence of mature textbooks and survey papers in the literature. Despite that, the submissions this year came from 24 countries (Lithuania, Switzerland, Luxemburg, Chile, Taiwan, Japan, Malaysia, Morocco, Iran, Portugal, Belgium, Algeria, Turkey, Poland, India, Pakistan, Colombia, USA, Hong Kong, Germany, Republic of Korea, P. R. China, UK and Brazil), and the range of innovative and well-succeeded applications of immune-inspired algorithms is increasing significantly. As we are with the field almost from its inception, we noticed that ICARIS conferences are playing a great role in bringing newcomers to the field. It is a challenge for us as a community to stimulate these newcomers and encourage others, so that the field may face sustainable growth and progress.

Concerning the event organization, for us it was a great pleasure to host ICARIS in Santos/SP, Brazil. This is a particularly interesting city in Brazil, for it contains the largest port in Latin America, it is surrounded by paradisiacal beaches and dense Atlantic forests, and it is the house of one of the most traditional Brazilian soccer teams: Santos Futebol Clube, the soccer team where Pele, the most famous soccer player around the world, developed his splendid career.

Table 1. Number of submissions versus number of accepted papers for each ICARIS conference

Year	Submissions	Acceptance (Rate%)
2002	—	26 (—%)
2003	41	26 (63%)
2004	58	34 (59%)
2005	68	37 (54%)
2006	60	35 (58%)
2007	58	35 (60%)

ICARIS 2007 provided a number of activities for its attendees, from lectures, to tutorials, software demonstrations, panel discussions, and paper presentations. We had the pleasure of bringing Rob de Boer (University of Utrecht, Netherlands), Jorge Carneiro (Instituto Gulbenkian de Ciências, Portugal), Hugues Bersini (IRIDIA, Brussels), and Uwe Aickelin (University of Nottingham, UK), for the event.

The organization of ICARIS 2007 would not have been possible without the support of a number of committed institutions and people. We are particularly indebted to our home institutions and company, UniSantos, Unicamp and NatComp, respectively, and to all the collaborators and sponsors that helped to make ICARIS 2007 a success.

August 2007

Leandro Nunes de Castro
Fernando Von Zuben
Helder Knidel

Organization

ICARIS 2007 was organized by the University of Santos (UNISANTOS), State University of Campinas (UNICAMP) and NatComp - From Nature to Business.

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A Gradient-Based Artificial Immune System Applied to Optimal Power Flow Problems

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Abstract. Mathematically, an optimal power flow (OPF) is in general a non-linear, non-convex and large-scale problem with both continuous and discrete control variables. This paper approaches the OPF problem using a modified Artificial Immune System (AIS). The AIS optimization methodology uses, among others, two major immunological principles: hypermutation, which is responsible for local search, and receptor edition to explore different areas in the solution space. The proposed method enhances the original AIS by combining it with a gradient vector. This concept is used to provide valuable information during the hypermutation process, decreasing the number of generations and clones, and, consequently, speeding up the convergence process while reducing the computational time. Two applications illustrate the performance of the proposed method.

Keywords: Artificial immune system, gradient-based algorithms, optimal power flow, transmission loss reduction.

1 Introduction

One of the most important areas in electric power systems is the study of optimal power flow problems. There are several relevant applications of this tool for planning the power network expansion, operation, maintenance and, most recently, for solving different problems in the emerging electricity markets [1]-[11]. Moreover, many applications in power system reliability use OPF as the major tool of their analyses [12], [13]. In general, an OPF is a non-linear, non-convex and large-scale problem involving several sets of continuous and discrete variables. This diversity makes the OPF problem to be divided, according to solution space, convexity, and types of control variables, into several broad categories such as linear, non-linear, combinatorial, dynamic, probabilistic, and others. In order to deal with these categories, different optimization concepts or methods have been employed [1]-[11], [14]-[19]: Simplex, Interior-Point, Conjugate Gradient, Hill Climbing, Tabu Search, Genetic Algorithm, Ant Colony, Particle Swarm Optimization, Artificial Immune System, etc.

These methodologies can further be divided into two major groups: numerical and intelligent-based. Regarding numerical-based methodologies, reference [5] shows a comparison among three interior-point-based methods, primal-dual (PD),

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predictor-corrector (PC) and multiple-centrality-correction (MCC). The results show good performance for all methods especially the MCC, although it needs accurate parametric adjustments to improve the convergence performance. Reference [9] uses the PC and PD to test different control actions and objective functions in order to enhance systems loadability.

Although these conventional methods have presented good results, some drawbacks have appeared in actual power system applications. Reference [7] shows that handling discrete variables as continuous ones, until they are close to the optimal solution, and then rounding them off to the nearest corresponding values, may provide significant higher cost results than the one present by the actual optimal solution. It also suggests that techniques capable of working properly with mixed-integer programming models may suffer from scalability and, therefore, are unsuitable for large-scale power systems. On the other hand, intelligent-based methodologies are interesting alternatives for some of the discussed OPF problems, as it can be seen recently in the power system literature: e.g., Particle Swarm [4], [10], Genetic-Algorithm [11], Greedy search [6], and many others. Several advantages can be linked to those methods; the software complexity is simple; they are able to mix integer and non-integer variables, and also present very appealing computational performance. However, the problem with many of these methodologies is the difficulty in establishing the Karush-Kuhn-Tucker conditions [3], [5], at the end of the optimization process. One method able to deal with this problem is the Artificial Immune System. Although very few AIS applications in power flow optimization can be found in the literature [14]-[16], results in other engineering fields [20]-[23] are very promising, and must encourage power engineers to further explore these techniques.

The AIS method is based on the biological principle of bodies' immune systems [20], [21]. An immunological system has major characteristics that can be used in learning and optimization [22]. For optimization problems, three topics are especially interesting: proliferation, mutation, and selection. While proliferation is the capability of generating new individuals making the optimization process dynamic, mutation is the ability of searching through the solution space for sub-optimum points. The selection is responsible for eliminating low-affinity cells. These three features make AIS a powerful optimization tool, enabling the search for several local-optima.

There are several variants among AIS methodologies, available in the literature, used to implement optimization algorithms. Reference [22] shows a very interesting approach by embedding a useful property of evolutionary algorithms, *niching,* which drives individuals to the most promising points in the solution space. Although this algorithm has exhibited very good results, the number of individuals used in the simulation processes is very high bearing in mind OPF problems. Since the purpose of this paper is to demonstrate the effectiveness of AIS concepts in OPF problems, some modifications in the referred algorithm are being proposed by adding more relevant information to individuals. In an electric power system, an individual can be related to an operating condition, which is characterized by the corresponding power flow equations that describes its electrical behavior [24], [25]. Therefore, when a modification in any control variable is performed, it is possible to predict the associated operating point by analyzing the behavior of the power flow equations. Mathematically, by using the information given by the tangent/Jacobian vector (i.e. gradient) associated with these equations, it is possible to lead the mutation process, which in the original AIS algorithm was made through a completely random approach, to generate better individuals, making the optimization much faster and more reliable. In order to demonstrate the effectiveness of the proposed Gradient-Based AIS, an optimal power flow aiming to minimize network transmission losses is implemented.

This paper is organized as follows. Section 2 describes the optimal power flow problem and formulation. Section 3 shows the implementation of the proposed Gradient-Based AIS and some tests using as benchmark reference [22]. Section 4 illustrates and discusses the OPF results, obtained with an IEEE standard test system.

2 The Optimal Power Flow Problem

It is not the purpose of this work to present a full explanation on electric power system static and dynamic behaviors; for that references [24] and [25] are much more appropriate. Instead, the main concepts and the corresponding mathematical models are summarized as follows.

An electric power system is composed of several electrical equipment such as generators, transmission lines, transformers, shunt capacitors, etc. Its main goal is to generate, transmit, and distribute electric power to costumers, through a high quality service at minimum cost. There are several constrains linked to this aim. The most important one is that it is not possible to store electrical power and, therefore, the amount of generated energy at any given time must be the same as the amount consumed, duly discounted the transmission losses. In order words, the power flow balance must be null. To fulfill these conditions, human operators must handle hundreds, sometimes thousands, of variables in order to control the system driving energy flow from sources to consumers. Moreover, during this process, the system must remain physically stable, from both static and dynamic points of view, technically reliable, and economically interesting for all market agents involved in this process.

The previously described balance conditions can be mathematically stated as follows:

$$\begin{aligned} &y = M(x_{cl}) \\ &g_I(V,\theta,y,x_{cb}) - g_G + g_L = 0 \end{aligned} \tag{1}$$

where: y is the system admittance matrix; x_{cl} is the control variables related to the models of the transmission elements (e.g. lines and transformers); x_{cb} the control variables related to the models of the buses (i.e., power stations); g_I, g_G and g_L are the vectors of power injections, power generations and power loads at each bus, respectively. If any change happens in the control variables, the system is driven into a different operating point, changing values of several measures such as voltage magnitudes V and angles θ (named as state variables), and also active/reactive flows, etc., spread along the power network. This leads to a condition where finding the best operation point under a desirable scenario is challenging. This problem is named as optimal power flow or simply OPF.