Expert Systems With Applications 56 (2016) 131–142

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

An artificial immune system with continuous-learning for voltage disturbance diagnosis in electrical distribution systems

Fernando P.A. Lima, Mara L.M. Lopes, Anna Diva P. Lotufo, Carlos R. Minussi*

Electrical Engineering Department, Faculty of Engineering of Ilha Solteira (FEIS), UNESP, Univ Estadual Paulista "Júlio de Mesquita Filho", Av. Brasil 56, PO Box 31, 15385-000 Ilha Solteira, SP, Brazil

A R T I C L E I N F O

Article history:
Received 6 November 2014
Revised 21 January 2016
Accepted 6 March 2016
Available online 15 March 2016

Keywords:
Diagnosis
Voltage disturbances
Artificial immune systems
Negative selection algorithm
Clonal selection algorithm
Continuous-learning
Electrical distribution systems

A B S T R A C T

This paper presents a new artificial immune algorithm with continuous-learning, which is inspired by the biological immune system, to realize the voltage diagnosis in electrical distribution systems. This conception allows one to compose a diagnosis system that can continuously learn without reinitialization when new disturbances occur due to the evolution of the electrical system. Two artificial immune algorithms, which are the negative selection algorithm and the clonal selection algorithm, are used for the pattern recognition process and the learning process, respectively. The principal application of this new method aids the operation during failures, supervises the protection system, and can evolve with the power systems to continuously acquire new knowledge. This new methodology has a direct impact in the area of diagnosis in electrical systems, as well as, in the pattern recognition problem, because the main contribution and novelty of this method is the continuous learning capability, which enables the system to learn unknown patterns without having to restart the knowledge. This is the major advantage of this methodology. To evaluate the efficiency and performance of this new method, failure simulations were performed in a real distribution system with 134 buses using the EMTP software. The results show robustness and efficiency.

1. Introduction

Nowadays, a new concept of electrical power systems called Smart Grids requires several investments to transform the electrical systems that provide modern technologies to generate, transmit and principally distribute electrical energy systems (Dongli, Meng, & Song, 2011), (Gungor et al., 2011). The smart grid concept is based on an intense usage of automation, computation and telecommunication technologies to monitor and control electrical systems that allow the implementation of new control, communication, protection and optimization strategies to improve the efficiency of the currently available systems (Gungor et al., 2011).

Thus, several technologies are used, particularly digital and information technology (Alag et al., 2001), which allow the development of integrated systems that combine acquisition, analysis and data processing techniques, to provide the necessary assistance to automation, control and decision-making processes (Northcote-Green & Wilson, 2007).

Considering the failure diagnosis for the smart grid, those systems must be based on auto-restoration idea, i.e., they must be able to automatically detect, analyze, respond and restore failures (Dongli et al., 2011) without human intervention. Thus, using intelligent techniques (artificial neural networks, fuzzy logic, artificial immune systems, etc.) is an alternative to the diagnosis problem. Several techniques based on this concept have been used to aid the operators in executing routines in electrical systems, which provides security, velocity and efficiency in planning corrective actions.

However, most failure-diagnosis methods based on intelligence proposed to the actual electrical systems have a learning strategy to obtain the knowledge, on which all efficiency and robustness depend. Normally, these strategies (training or learning algorithms) must always reinitialize the learning process when the system is executed or a new disturbance occurs; therefore, the system is not significantly intelligent. The system does not constantly learn, and when a new pattern appears, every learning process is executed again.

A modern and intelligent failure-diagnosis system to the smart grids must continuously learn, follow innovations and modernizations of the electrical system, which include new types of prominent failures, learn with experience and constantly evolve.

* Corresponding author. Tel.: +5501837431225.
E-mail addresses: engfernandoparra@gmail.com (F.P.A. Lima), mara@mat.feis.unesp.br (M.L.M. Lopes), annadiva@ieee.org (A.D.P. Lotufo), minussi@dee.feis.unesp.br, crminussi@gmail.com (C.R. Minussi).

http://dx.doi.org/10.1016/j.eswa.2016.03.010
0957-4174/

Developing a system with these characteristics is a complex task. In the literature, many studies present methods to solve the problem of the diagnosis of disturbances, as in (Uyar, Yildririm, & Gencoglu, 2008), (Oleskovicz et al., 2009), (Zhang, Li, & Hu, 2011), (Lima, Lotufo, & Minussi, 2014), (Lima, Minussi, Bessa, & Fidalgo, 2015), however these approaches do not consider the minimum requisites to the smart grids, i.e., the objective to provide continuous-learning to a pattern recognition system. This requisite based on auto-restoration idea, i.e., continuous learning provide the ability to perform the detection, analyze, respond and classify failures without human intervention.

In the literature, there are a few approaches that propose methodologies to develop a system with continuous training to realize diagnosis. For example, in Pham and Cham (2007) is proposed an online learning asymmetric boosted classifiers for object detection. This approach is one of the first to try the continuous learning in techniques of pattern recognition. In the reference (Marchiori, Silveira, Lotufo, Minussi, & Lopes, 2011) the authors presents a methodology to analyze the transient stability in electrical energy systems using, a Euclidean ARTMAP neural network with continuous training. In this paper the Euclidean ARTMAP neural network was modified to learning continuously and identify novelties in the analysis of the transient stability in electrical systems, i. e., the Euclidean ARTMAP neural network was able to identify unknown patterns, which were not learned yet in the training process. In Barros, Tonelli-Neto, Decanini, and Minussi (2015) the authors present a method to detection and classification of voltage disturbances in electrical power systems using a modified Euclidean ARTMAP neural network with Continuous Training. In this strategy the neural network is initially trained to obtain the knowledge. In the online process, if a pattern in analysis is unknown by the diagnostic system, is executed an online learning phase, and starting this, the diagnostic system is able to identify and classify the pattern that was unknown to the system. This method presents a precision of 90.32% in the voltage disturbance diagnosis.

In this sense, this work aims to propose a new approach to develop a system with continuous training to realize the voltage disturbances diagnosis in electrical distribution systems based on the Biological Immune System (BIS). Two immune algorithms were used to compose this system: the Negative Selection Algorithm (NSA) (Forrest, Perelson, Allen, & Cherukuri, 1994) and the clonal selection algorithm (CLONALG) (de Castro & Von Zuben, 2000).

The artificial immune algorithm, which is inspired by the BIS, is a promising technique in Intelligent Computing (IC). The BIS computationally reproduces the principal characteristics and the propriety functionalities and abilities. It has a stable, reliable, and adaptive architecture, allowing the continuous inclusion of the training module. This propriety allows the system to introduce new experiences and knowledge without the need to reinitialize the immune memory of the system. This is one advantage of using Artificial Immune Systems, which allow the possibility of continuous training unlike in other techniques such as using Artificial Neural Networks (ANNs). In some ANNs, to improve the training, it is necessary to reinitialize the process, consequently destroying the knowledge previously acquired, except for a few architectures that have the plasticity propriety as in the neural networks of the ART (Adaptive Resonance Theory) family (Carpenter, Grossberg, Markuzon, Reynold, & Rosen, 1992). The main contribution and novelty of the approach proposed in this paper is the paradigm shift, that is, enable continuous learning for the pattern recognition methods. This ability allows great evolution to intelligent systems, where the methods are able to learn in online mode, acquiring knowledge of the unknown patterns for the system.

To evaluate and validate the efficiency of this new approach, the results were compared with a conventional diagnosis system based only in the NSA, proposed and presented in Lima, Lotufo, and Minussi (2013).

This paper is organized as follows. Section 2 discusses the BIS, Section 3 focuses on the NSA, and Section 4 tackles the CLONALG. The modeling and simulations is presented in Section 5. The proposed methodology is presented in Section 6, and the applications and results are discussed in Section 7. The conclusions are presented in Section 8.

2. Biological immune system

The BIS is the principal defense of organisms against several infective agents that invade/infect the human body. In this case, the BIS must instantaneously act by effectively responding to the invading agents and identifying them to protect the human body (indicating the disease). There are two types of responses: the innate immune system and the adaptive immune system.

The innate immune system is the first defense line with a fast response characterized by dendritic cells (APC- Antigen Presenting Cell) and phagocyte (Granulocytes, Macrophages, etc.), which are responsible for ingesting strange particles to the organism and other types of defenses, such as physical barriers (skin) and chemicals (de Castro, 2001).

The adaptive immune system is the second level, which can recognize microorganisms, such as viruses, bacteria, fungi, protozoa, helminthes, and some types of worms. The adaptive immune system is responsible for realizing the learning process on the infective agents on the first contact with the antigens, i.e., the first exposure to the infective agent. In addition, it is responsible for creating memory immune cells from the first exposure to the infective agent to accelerate a response to this type of infective agent in future exposure (de Castro & Timmis, 2002).

2.1. Operation of the pattern recognition of the BIS

The biological organism, particularly the human body, is composed of several cells and molecules that work in harmony and respond to strange agents that enter the organism, which are called antigens.

The BIS has fundamental characteristics such as pattern recognition, learning and neutralization of infective agents. These steps represent an immune response, which is illustrated on Fig. 1.

Step (I) represents the BIS exposure to an antigen (infective agent). The BIS can react with two types of responses: the innate immune response, which begins at step (II), and the adaptive immune response, which begins at step (VII). If the process begins with the innate immune system (step (II)), the infective agent is considered to be an unknown agent by the BIS, and the infective cell in the organism must be identified and informed *a posteriori*; then, the adaptive immune system begins an adaptive response (learn and generate antibodies to neutralize the antigen). If the process begins with the adaptive immune system (step (VII)) the antigen is known by the BIS, and the detection process is realized by the memory lymphocytes in the organism.

In step (II), the innate immune process begins when some antigen (infective agent) is ingested by a dendritic cell (APC- Antigen Presenting Cell). At this phase, the antigens are ingested and disintegrated into antigen peptides. In step (III), the pieces of peptides are linked to the MHC (Major Histocompatibility Complex) molecules and presented to the surface of the dendritic cell.

In step (IV), the T lymphocytes, which have receptive molecules at the surface, can recognize/identify different antigen MCH/peptides that are processed by the dendritic cells, i.e., when there is a link (combination), the antigen is recognized,