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Disturbance detection for optimal database storage in electrical distribution systems using artificial immune systems with negative selection

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ABSTRACT

This paper presents the development of an intelligent system named "normal pass filter" to generate a disturbance database in electrical distribution systems. This is a system that aims to extract examples (and proper registration) of real disturbances from voltage and current measurements that are available by SCADA system. This filter is developed based on negative-selection artificial immune systems. The negative selection algorithm of an immune system is used to determine the presence of abnormalities. If an abnormality is detected, the system records the abnormal signal in a database. This database is a set of disturbance examples (e.g., harmonic, sag, high-impedance fault) for use in many purposes, for example, for training artificial neural networks for intelligent fault diagnosis and prognosis of electrical distribution systems. Recently, these diagnosis systems have been emphasized, particularly in smart grid environments. To exemplify the efficiency of the method, two electrical distribution systems with 33, and 134 busses were examined.

1. Introduction

Recently, many investments and studies have been devoted to a new concept of electrical systems known as the smart grid [1,2]. This concept is being widely discussed, and the main objective is to transform the electrical energy systems by modernizing generation, transmission, and distribution systems. This new concept of intelligent electrical systems has the following motivations: climatic changes, the aging of the present installations, improving the quality of power and the possibility of allowing the final user to participate in electrical system planning and operation [1,2].

The smart grid concept is based on the intense use of automation, computation and telecommunication technologies for monitoring and controlling electrical systems to allow the use of new control, communication, protection and optimization strategies that improve the efficiency of the present systems [2]. The generation, transmission and distribution infrastructures must therefore be consistent with the telecommunication and data-processing systems infrastructure and the development of new forms of control, automation, protection, communication and optimization. The development aims to modify the operational methods and to improve the efficiency of these electrical systems [1].

Smart grids must have the following characteristics [1]:

- Self-recovery: Capacity to detect, analyze, answer and restore faults in the electrical systems automatically;
- Power quality: Provide energy with the quality that is demanded by the digital society;
- Environmental impact reduction: Create strategies to reduce the losses of the electrical system and energy sources with low environmental impact;
- Information filtering: Capacity to read, analyze, process and distinguish information that is important for solving problems;
- Empowering the users: Ability to include the equipment and the behavior of the users in network planning and operation;
- Tolerance to external offensives: Capacity to mitigate and resist physical and cyber offensives;
- Arrange several sources and demands: Capacity to clearly integrate (plug and play) several energy sources with different dimensions and technologies;
- Demand answer face to remote acting in user' devices; and
- Take advantage of retailer markets and micro-generation that allows and improves competitive energy markets.

The transformation of the present electrical network to a smart grid should be gradual. To increase the electrical power system

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protection and aid the decision-making process, every available resource must be employed to avoid or at least minimize the effects that are caused by perturbations, which occur frequently. Among these resources, preventive action is emphasized. The available resources include devices that monitor, analyze and develop corrective actions. To produce good results effectively, it is therefore necessary to understand the behavior of the electrical system from previous situations that aimed to aid decision making. This knowledge can be acquired from the database (historical data from the system operation). To record these data is a problem when the waves (current and voltage) are continuously filed, and the database is not used efficiently because of the quantity of information that is stored in this operation. An alternative procedure, which is usually adopted by electricity companies, is not to file continuously, i.e., the recording is effected in predefined periods such as two or three times per minute, where each register corresponds to a number of cycles, which is also predefined. The recording forms that are described above are inefficient because of the amount of data is too large and because the stored data do not recognize the situations that effectively occur one perturbation from the normal operation.

The motivation of this paper is thus to propose a more rational procedure to build the reference database, the recording of which is performed by a data filter that uses only the cases that effectively represent danger to the system integrity. The procedure in this paper is known as a normal pass filter (or disturbance detector filter). In this case, the registers are activated only when the filter understands that an abnormality or an imminent abnormality exists. This procedure represents a smaller quantity of information stored in the database and provides the exact discrimination of disturbances. This procedure satisfies one of the requirements of operating the system in a smart grid environment, i.e., the capacity to analyze, process and discriminate the data with the aim of storing only the effective abnormal data.

The principal objective of this work is the development of an intelligent system for disturbance detection for optimal database storage in electrical distribution systems based on artificial immune system (AIS) [3]. This database is a set of disturbance examples (e.g., harmonic, sag, high-impedance fault, and others fault type) for use in many purposes, for example, for training of the artificial neural networks for intelligent fault diagnosis and prognosis of electrical distribution systems. However, the AIS filter is developed based exclusively on information obtained by a digital simulator (EMTP) to define the detectors of the censor phase. This information is sufficient to extract the knowledge of the AIS, according to what is observed considering the quantity of tests and the matches obtained. It is an efficient procedure (precise, fast and robust).

After the AIS-filter has been implemented in the system, if there is interest, examples of faults (stored in the database) can be accessed and performed a more detailed study with the purpose of increasing the information quality.

Searching the specialized literature, there is no publication related to the proposal of this work (unless by mistake) that contributes to the failure monitoring and diagnosis, mainly to the development of smart grid systems, presenting a new approach to identify and file essential data in electric power systems using artificial immune systems. The AIS are promising algorithms in the artificial intelligence (AI) field. The concept of the AISs was based on biological immune systems (BISs) and aims to reproduce computationally the principal characteristics, proprieties and abilities [3]. According to [4], the AIS are adequate tools to be applied for identifying failures in electrical systems due to the natural characteristics of pattern recognition. Considering this information, the AIS was selected to be used in this work.

This paper presents the normal pass filter, developed based on AIS with negative selection [3,5], which aims to generate a database with information that can aid the decision-making process in electrical systems. From the voltage and the current oscillographs measured at a SCADA system [6] in a substation, the negative selection algorithm [7] was employed to detect the abnormalities based on the discrimination criterion proper/non-proper. If an abnormality is identified, this abnormality is filed in a database. This methodology allows electricity companies to employ disturbance databases that contribute to the smart grid concept. For example, these data can be used for training intelligent systems based on, for example, artificial neural networks [8] and fuzzy logic [9,10] to detect, classify and localize disturbances in real-time. The detection and classification methods use the oscillographs as electrical system data with disturbance effects, which are generally simulated. This proposal therefore allows the evaluation of new diagnosis methodologies using databases that are created in real situations where simulations are unnecessary, even when the simulations can be used as additional resources. With the data base generated by the abnormality detector filter, it is necessary the intervention of a specialist and analyzing the oscillographs classify every signal extracted by the filter, therefore building a database containing real patterns to train diagnosis systems. A didactic example has been formulated illustrating the step-by-step the development of the filter to provide more information to the readers. To validate and evaluate the efficiency of the proposed method, data simulated with the EMTP [11] software were used when real data were not available. Examples were created using the 33 bus test system [12] and 134-bus real system [13]. The method presents satisfactory results, with a high generalization capacity, reliability, precision and low computational effort.

This paper is organized as follows: Section 2 presents the negative selection algorithm (NSA). The disturbance modeling and simulations are described in Section 3. Section 4 presents the proposed methodology. The results are presented in Section 5, and Section 6 presents the conclusions from this work.

2. Negative selection algorithm

The NSA, which was proposed by Forrest [7] to detect changes in systems, is based on the negative selection of T lymphocytes over time. This process works with the discrimination of proper and nonproper cells. The algorithm is executed in two phases according to the following description [4,14]:

1. Censor
   a) Define a set of proper chains (S) to be protected;
   b) Generate the random chains and evaluate the affinity (match) with each chain and the proper chains. If the affinity is greater than a predefined value, reject the chain. Otherwise, file the chain in a detector set (R).
2. Monitor
   a) Given a set of chains to be protected (protected chains), evaluate the affinity between each chain and the detector set. If the affinity is superior to a predefined value, then a non-proper element is identified.

The censor phase of the NSA consists primarily of generating a detector set from the data that were randomly chosen and verifying which data can recognize a non-proper pattern. The detectors are similar to the mature T cells that can recognize pathogenic agents [3].

The monitoring phase consists of monitoring a system to identify a change in behavior; thus, this monitoring phase classifies the change using the detector set that was created in the censor phase.