



New genetic algorithms for contingencies selection in the static security analysis of electric power systems



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ABSTRACT

The importance of a reliable supply of electric power in industrial society is unquestionable. In control centers of electrical utilities, an important task is the security analysis, even for those companies that already have the modern smart grids. In this task, a contingency is the operation outage of one or more devices, while contingencies selection is the determination of the most severe contingencies on the system. Despite the current technological advances, an analysis of all possible contingencies is impracticable. In this paper, a method to efficiently perform the selection of multiple contingencies is presented. The issue is modeled as a combinatorial optimization problem and solved by genetic algorithms, developed for this application. A robust method, which considers power flow and voltage, is presented and tested over IEEE-30 test system and over a large real life system, considering double outages of branches. The results showed accuracy close to 100%, when compared with an exact method.

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1. Introduction

Electricity is an important benefit to society, making social and economic development indicators. Therefore, the quality and continuity of electric energy supply are nowadays essential to our way of life (León et al., 2011; Bompard, Huang, Wu, & Cremenescu, 2013). In this context, the security analysis in power systems (SA) is important to identify the contingencies that can lead to alterations in the current operating status of the system (Kalyani & Swarup, 2013; Monticelli, Pereira, & Granville, 1987). These contingencies considered critical are those which can compromise the supply of electricity.

In the SA, a contingency is the operation outage of one or more devices, such as transmission lines, generators, and transformers – (Matarucco, Bonini Neto, & Alves, 2014; Balu, 1992). The Contingency Analysis is an important step in SA. It consists in identifying, on a list of possible contingencies, which ones, in case of occurrence, would lead the network to an unsafe operating state (Ciapessoni et al., 2013; Srivani & Swarup, 2008). There are, in the electrical network operation, severe time limitation imposed on the control tasks, including SA. In order to solve this problem, several methods have been proposed and used in recent decades – (Matarucco et al., 2014; Javan, Mashhadi & Rouhani, 2013; Ciapessoni et al., 2013; Kalyani & Swarup, 2011b; Chakrabarti &

Jeyasurya, 2008; Chen & Bose, 1989; Devaraj, Yegnanarayana, & Ramar, 2002; Galiana, 1984; Nims, El-keib, & Smith, 1997). Some of these methods aim at performing the Contingency Analysis, while others are used in the Contingency Selection step. Contingency Selection is a previous stage to the Contingency Analysis. Its function is to eliminate from the list of contingencies to be evaluated, those that are not critical. A robust method for the Contingency Selection must be able to effectively eliminate from the contingency list, the largest possible amount of non-serious cases. Moreover, a good Contingency Selection method must keep the serious cases on the contingency list. The SA is divided into two parts: Static Analysis and Dynamic Analysis. The first one considers the equilibrium system, the so-called steady state of operation. The second one considers the transitory state, associated with electromagnetic phenomena that occur during changes in system topology. There are studies in the literature that focus only on static analysis, such as: (Matarucco et al., 2014; Javan, Mashhadi, & Rouhani, 2013), only on dynamic analysis – (Chakrabarti & Jeyasurya, 2008; Nims et al., 1997) and a smaller number of proposals that deal with both analyzes – (Ciapessoni et al., 2013; Kalyani & Swarup, 2013). Another important aspect is the size of an electric grid that the SA method is able to deal. Most existing work only presents tests and results for small systems, typically IEEE test systems. Real systems usually are very large, with thousands of buses and branches, which leads to natural processing difficulties even with current computer resources. These systems also have electrical characteristics that need specific treatment. On the

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extensive search, which has been done through several decades to the present, it has not been found any studies that show methods capable of performing the two parts of SA in real time to real and large networks. A great example of this reality is found in the work of [Matarucco et al. \(2014\)](#) which is quite recent and that presents results obtained only for the IEEE test systems of 14, 57 and 118 bars. Another example is the work of [Kalyani and Swarup \(2013\)](#) which presents a fairly comprehensive proposal in terms of methodology, but that has only been tested to a standard 39-bar system. The same researchers previously showed ([Kalyani & Swarup, 2011a](#)) results for the IEEE test system of 30, 57, 118 and 300 bars in an article that presented an approach based on K-means method to the problem of SA. The work demonstrated how the traditional grouping algorithm can be transformed into a classification algorithm combined with the optimization method known as Particle Swarm Optimization (PSO).

This paperwork proposes a method that considers the static aspect of the Contingency Selection which is able to solve, in real time, cases of single and multiple contingencies and that was also designed to treat real and large systems. The problem of Contingency Selection was addressed as a combinatorial optimization problem and solved by using two genetic algorithms. Therefore, the main contribution of this paper is to present a robust and efficient method for the selection of multiple contingencies that was effective in tests with a large real life system. Among the features of the developed methods are: selection of multiple contingencies; selection accuracy close to 100%, even when assessing a few cases and absence of off-line calculations and facility to handle with topological changes and there is no need for off-line calculations. The structure of the paper is: after this introduction, Section 2 presents the essential concepts to understand the article, through a brief literature review. In Section 3, the aspects related to the implementation of the proposed method are detailed. Section 4, in its turn, contains information on the methodology of the experiments conduction. In Section 5, the results are presented. Section 6, finally, describes the conclusions of the work.

2. Basic concepts

2.1. Security analysis

The electric power systems are assembled structures to generate, transmit and distribute electricity. They are composed of large, complex and strongly connected equipment networks. In these networks, generators operate in synchronous way, and in a dynamic equilibrium, adapting power generation at existing loads. The electrical network operation control occurs conventionally in the control centers, which are structures where professionals observe and control a power system to keep the stability and security of the system ([Tomsovic, 2005](#)). An important task performed in the control centers is the SA. This task involves the network data assessment to estimate its current operating status, as well as possible changes of this status ([Balu, 1992](#)). The importance of the SA comes from the current context, which includes ([Ilie, Hernando-Gil, & Djokic, 2014](#)):

- (a) The relevance of electric power to society – the more evolved a society is the greater consumption of electricity.
- (b) The growth of power demand and the restructuring of the electricity sector – nowadays we can highlight new technologies with many possibilities for generating electricity.
- (c) Insufficient investment in the system, which brings the operation point of the systems close to the limits of its equipment – which can lead in case of severe contingencies to blackout occurrences.

2.2. Contingency Analysis and selection

Contingency is the outage of operation, expected or unexpected, from some network equipment, such as a generator, a transformer or a transmission line. Concerning its order, contingencies can be simple (one device) or multiple (two or more devices).

The Contingency Analysis is a task that aims to figure out which contingency would lead the network to a state of unsafe operation, among the possible ones – ([Kalyani & Swarup, 2013](#)). This task should be performed at regular and usually short intervals. Despite the increase in computing power in recent decades, an exhaustive analysis of all possible contingencies during operation is impracticable. This is due to the fact that in the conventional method it is necessary to know the operating status of the system for each simulated contingency, by calculating the non-linear model of the power flow. Thus, the size and characteristics of the current electric networks, as well as severe time restrictions imposed on the Contingency Analysis, make the problem difficult to be computationally treated. To resolve this problem, several methods have been developed in recent decades. Among the published papers, the highlighted ones are: Performance Index ([Chen & Bose, 1989](#)), topological approaches ([Galiana, 1984](#)), hybrid methods and metaheuristics ([Nims et al., 1997](#); [Kalyani & Swarup, 2011a](#)), and artificial neural networks and machine learning techniques ([Devaraj et al., 2002](#); [Chakrabarti & Jeyasurya, 2008](#); [Javan, Mashhadi & Rouhani, 2013](#); [Kalyani & Swarup, 2013](#)).

Direct classification methods generate disguised and false alarms – non-serious contingencies classified as serious ([Meliopoulos, Cheng, & Xia, 1994](#)). These problems have been fixed in recent works, but not for the selection of multiple contingencies. Methods based on neural networks or machine learning techniques were effective, but require an earlier stage of training the network ([Devaraj et al., 2002](#)), and therefore may be sensitive to topological changes ([Kalyani & Swarup, 2013](#); [Chakrabarti & Jeyasurya, 2008](#)), which does not occur in the metaheuristics methods studied. The metaheuristics based methods have found good results for test network, but its use has not been studied in real size networks ([Saitoh, Takano, & Toyoda, 1996](#); [Nims et al., 1997](#); [Kalyani & Swarup, 2011a](#)). The topological approaches, in its turn, reduce the calculations of the influence area of the contingencies, making the selection more efficient without the need of off-line calculation. Although the topological approaches make calculations more efficient, a performance for all possible contingencies is still prohibitive concerning time.

Contingency Selection is a previous stage to Contingency Analysis, which aims to reduce the list of contingencies to be evaluated in Contingency Analysis, gaining efficiency. Among the methods used in the Contingency Selection, the screening can be highlighted. The screening is a method based on solutions of a power flow. The screening methods are effective, but the need for calculating the power flow makes it less efficient from the computational point of view ([Meliopoulos et al., 1994](#)). In order to resolve this, it is possible to use more efficient methods for calculating power flow, as the Fast Decoupled Load Flow (FDLF) ([Stott & Alsac, 1974](#); [Monticelli, Garcia, & Saavedra, 1990](#)).

2.3. Fast Decoupled Load Flow

The FDLF proposed by [Stott and Alsac \(1974\)](#) and better explained by [Monticelli et al. \(1990\)](#) is a particularization of the Newton–Raphson method. In it, only the dependencies between the voltage and reactive power, and between active power and voltage angle of each bus are considered. It is a simple, reliable and efficient method to calculate the power flow. These characteristics make it suitable for the calculation of online contingencies in

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