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Hybrid system based on constructive heuristic and integer programming for the solution of problems of fault section estimation and alarm processing in power systems

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ABSTRACT

This paper presents a tool capable of performing alarms processing to diagnose faults in electrical power systems. The purpose is to filter alarms generated during a shutdown and indicate which equipment is at fault. To solve this problem, it was proposed an integrated use between constructive heuristic methods (CH) and integer programming (IP) by establishing a methodology for its completion. Initially, CH method performs through alarms signaled by protective relays, an analysis with relation to direction of fault in each equipment of power system. Thus, CH in possession of as much information as possible, and signals coming from trip of each relay equipment (busbars, power transformers and transmission lines), can identify direction in which disturbance occurred. The final processing is done by IP, which analyzes the response of protection system as a whole, using signs of opening triggers of circuit breakers along with response of CH, indicating at fault section and possible failures of opening in circuit breaker.

1. Introduction

Protection relays are designed and applied in power systems to protect equipment and maintain system integrity and stability. The substantial growth in power systems, either in complexity or size, requires fast protective algorithms to avoid the fault propagation and, consequently, blackouts.

At the instant that disturbances in electric power systems occur a surprising number of alarm messages to the operators of the centers of control and supervision may arise, making it essential to use computational tools to support decision making, to allow a speedy restoration of system and consequent recovery in energy supply.

In recent years, the number of monitored equipment in substations has been increasing together with the number of alarms reported during a shutdown. Depending on the event, the volume of alarm messages can reach the order of hundreds per minute.

According to [1] the intelligent electronic devices (IEDs) use and capacity have grown explosively over the last 20 years along with the amount of available data; furthermore, currently electromechanical relays are moved by microprocessor-controlled devices, each of which has hundreds of settings and thousands of internal variables. This makes the amount of data available for analysis be enormous. All of these alarms shall be analyzed in a timely manner by operators, just at moments of stress, so as to restore the system to its normal and secure operating condition. Thus, a model capable of dealing with uncertainties in problem of classification of events is extremely necessary.

The function of an alarm processor is: grouping, selecting and presenting the most important alarms to the operator [2]. Moreover, it should also suggest corrective control actions when necessary.

In recent years several methods have been developed for fault section estimation and alarm processing in power systems, and it was used information about operation of relays and circuit breaker performance in identifying fault sections. Some of these methods are based on theory of fuzzy sets or fuzzy logic [3,4], neural networks [5,6], under rules of expert systems [7,8], genetic algorithms [9,10], Petri nets [11] and Bayesian networks [12,13] or on the combination of methods, for example, neural-fuzzy [14], expert systems with neural network [15], genetic algorithm with neural network [16,17], genetic algorithm with Tabu Search [18]. In addition to these papers, the work [19] presents two new options for alarm processing. One model is based on diagnostic reasoning fuzzy and Petri nets, and the other is an advanced alarm processor that combines processing techniques, either at substation or at control centers.

Solutions based on computational intelligence have been widely proposed in recent years. But now, with advances in performance of generic solvers for integer programming (IP) problems, it became

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feasible to use analytical formulas to solve the problem of alarm processing. Recent developments in solvers for IP have improved ability to solve these large-scale instances of different types of problems. Currently, the use of IP has gained acceptance and is considered a powerful computational tool for finding optimal or near-optimal solutions for real problems of strategic or operational planning.

The constructive heuristic algorithms (CH) are robust, easy to understand and require a low computational effort; however, for large systems they have a low quality of solutions obtained in addition to having trouble finding the global optimum.

This approach follows the line of research [20] as well as [21], in which exact and heuristic methods work in cooperation or in an integrated manner in order to obtain optimal solutions with smaller execution times or better heuristic solutions.

This paper proposes a new method for development of intelligent processor alarms and fault section estimation, where problem is treated in two parts, one at local level, in equipment, and the other at system-level aiming to identify which regions were affected by a particular contingency. The first stage is based on CH where it is proposed a mathematical model with information from the relays to solve problem of alarm handling at equipment level in order to find a locally optimal solution of excellent quality. The second stage is based on a mathematical model that uses IP information from first stage of circuit breakers and information that defines topology of system globally.

2. Characterization of the problem

To ensure perfect operation of electric power systems is necessary to use devices that will protect the equipment during a contingency, guaranteeing the integrity and allowing its re-establishment of normal operating conditions.

The protection schemes are designed to isolate a particular fault as quickly as possible, by turning off the least amount of equipment. During a fault, alarms are triggered in order to signal operation of protective relays, sending codes with information to operation and control centers.

The electric system operators may be surprised by a devastating number of alarms reported due to occurrence of contingencies in a large electrical system. The operator, based on information from alarms, must use his experience and decide what exactly happened with the system. This task may often not be trivial, as there is a possibility of multiple events, failure or undue operation of relays, circuit breaker failure and failure in remote units of data acquisition.

The use of computational tools to support decision making has become indispensable to operation and control centers of electric power systems for rapid restoration to normal state of operation. It should be emphasized that as alarm signals are of informative nature, it is natural to use resources provided by methods of computational intelligence.

In an attempt to reduce the possibility of error during the task of analyzing the alarms raised due to operation of protective relays, computational tools for alarm processing and fault diagnosis are developed [22]. These tools should assist operator in decision making by reducing the amount of information to be processed and analyzed through the discharge of redundant and irrelevant information. In addition, they should improve form and content of messages presented to operator as well as suggest corrective actions to be taken.

It is widely accepted that the parsimony theory should be used in the analysis of multiple faults in electric power systems. The premise considered is that the smallest number of events which are able to explain alarms received should be selected. Finding these events is an optimization problem, in which the aim is to minimize the number of events associated with alarms. In this process some alarms can be considered flawed, i.e., they should be active to explain a particular event. There is still a more remote possibility that the alarm may be false, i.e., although active, it is not considered in the solution.

This article proposes a mathematical model with dummy variables to solve the problem of alarm processing. This method dispenses parameter settings such as heuristics and metaheuristics, which makes it easy its application in a wide range of instances of problems. Even in cases where computational time to prove optimality is prohibitive for practical purposes desired, you can truncate process and obtain a near-optimal solution.

The problem discussed was characterized by demonstrating difficulties encountered in task of creating an algorithm capable of performing estimation of section on faults in electric power systems. An algorithm for this purpose should be able to handle such problems in a timely manner so operator can restore system, or at least a portion thereof, without failures occurring again.

3. Constructive heuristic

The minimization of human effort has been one of the objectives of engineering, which has been developing techniques and implementations that can realize the same tasks as men. Constructive heuristic (CH), which can be utilized in pattern recognition and modeling, is among these techniques and implementations.

A proceeding based on cognitive model that takes into account the experience of developers can be defined as heuristics. It usually has some degree of knowledge about behavior of the problem, generating a much smaller number of solutions, which does not happen with the exact methods that seek to find an optimal solution.

Constructive heuristic, or myopic, in general, consists of trying to find a good answer to a problem, considering at each iteration only the next step, i.e., criterion of choice is basically local. The starting point is an empty solution and at each step of construction, a dataset is considered, always inserting one data at a time, until the solution is complete. Constructive algorithms have no backtracking scheme, i.e., after entering one data, it is not possible to remove it from solution.

4. Integer programming

An integer programming problem (IP) is a special case of optimization problems, whose variables can only take integer values (discrete). A mixed integer programming problem is another special case in which some but not all the variables are restricted to be integers. A subset of this class of problems occurs when variables of problem are restricted to only two values (zero or one, for example), making binary or zero-one programming.

There are different approaches to solving integer programming problems. Among exact methods of resolution are branch-and-bound, dynamic programming, methods based on Lagrangean relaxation, and methods based on integer linear programming such as branch-and-cut, branch-and-price, and branch-and-cut-and-price. These techniques are designed to be flexible and independent of domain in order to be applicable to a wide variety of practical problems with no need to design specific strategies. In fact, in real environments, flexibility is often a critical factor to respond promptly to changes of requirements.

Many of the above methods are implemented in optimization solvers such as CPLEX, LINDO, Xpress and MINTO. Currently these applications can handle efficiently, instances of integer programming problems with dimensions large enough to be useful