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Group decision support system for backbone-network reconfiguration

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ABSTRACT

Modern power system is unprecedentedly vulnerable and the society is exposed to higher blackout risks. Therefore restoration is a key issue to power systems. Reasonable backbone-network reconfiguration is necessary for re-establishing the network and restoring loads quickly. In order to speed up network reconfiguration under security constraints, a group decision support system (GDSS) is developed. A unified data platform based on data warehouse is constructed to resolve inconsistencies of data, information and models. A three-stage restoration strategy and a two-layer restoration path searching method are proposed to establish restoration schemes. Multiple attribute decision-making is implemented to evaluate alternatives and consider various attributes about restoration speed and system security comprehensively. Group decision-making provides an aggregated cardinal ranking of candidate restoration schemes. The GDSS uses expert rules for qualitative analysis and numerical computation programs for quantitative analysis, and it can resolve the semi-structured decision problem of network reconfiguration efficiently. Restoration plan of Shandong power grid is developed with the proposed method and it has been adopted by State Grid Shandong Electric Power Company. Performance results of Shandong power grid of China demonstrate the feasibility and flexibility of the method.

Introduction

Modern society is increasingly dependent on reliable power supply. But due to the deregulation of power industry, aging infrastructure and many other factors, power systems are pushed close to critical operating limits [1]. Meanwhile many new facilities are introduced into power system, network structure and dynamic behaviors of power system are becoming more and more complex. Especially in the market environment, generation companies are independent entities pursuing the maximum of profits, traditional management is replaced by distributed decision-making, and surely this will have a great impact on power systems [2]. For the above-mentioned reasons, the risk of blackouts is still existing or to some extent even increasing. In recent years, some widespread blackouts have occurred all over the world, including the well-known outages in North America and Canada (2003), Japan (2011) and India (2012). The restoration of power system is attracting more and more attention for the catastrophic results of blackouts. According to actual experience, probability of blackouts can be decreased through applying novel equipment and technologies, improving management measures and optimizing network structures. But blackout is inherently inevitable because of unforeseen circumstances, incompleteness of information, treacherous weather and increasing complication of power systems.

The impact of a blackout increases exponentially with the duration of restoration, once blackout occurs, it is imperative to take effective and secure measures to restore the power system as soon as possible [3–5]. Generally, power system restoration includes three phases: black-start, network reconfiguration and load restoration [1]. The objectives of restoration are to take the power system return to normal securely and rapidly, minimize losses and restoration duration, and diminish adverse impact on the society [2]. For network reconfiguration, the purpose is to restore the backbone network concerned, interconnect relevant subsystems and finally rebuild a stable skeleton network [6].

Backbone-network reconfiguration can be described as a multi-stage, multivariable, multi-objective, combinatorial, nonlinear and constrained optimization problem. There are no known mathematical methods for solving such a NP-complete problem exactly in polynomial time [7]. In order to speed up restoration without violating security constraints, many methods have been addressed. Expert system [8] has been employed extensively in making restoration schemes, it has promising prospects of application. But the establishment and maintenance of knowledge base is a

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key problem, especially when the system is becoming larger. The change of expert rules may lead to errors and conflicts. Different from expert system, which is based on expert rules, case based reasoning (CBR) [9] is dependent on typical scenarios. It is hard to establish an excellent case base because of the small probability of blackouts, and the difficulty of maintenance is also a bottleneck for its application. Besides, mathematical programming [10] is advantageous to obtain an optimal solution, but the application is rare due to its sheer difficulty, huge solution space and long execution time. With the development of computational intelligence, some heuristic algorithms like genetic algorithm [11], artificial neutral network [12] and fuzzy theory [13] are introduced into restoration field. However, the optimum of the methods cannot be guaranteed, and these algorithms need to be improved in some specific aspects respectively. Graph theory is also a popular algorithm for restoration, the switch operation and network topology is described with Petri net. This method is straightforward and accessible in a small system, but a little too complex in large systems [14]. The verification of constraints and disposal of uncertainties need further improvement.

In addition, more algorithms like multi-agent [15] have been proposed for backbone network reconfiguration. Each algorithm has its own merits, demerits and scope of application. According to former researches, hybrid intelligent algorithms perform quite excellently in restoration. As a function extension of expert system and heuristic rules, decision support system (DSS) is attracting more and more attention [16,17]. It can solve this semi-structured decision problem efficiently by means of man–machine interaction. The computer-aided system is of vital importance especially when time is pressing, operators are unfamiliar with decision situations, or the conditions are significantly different from assumptions when the plan was developed. The decision support system needs to be improved in practicality, man–machine interface, data interface and maintenance.

This paper presents a group decision support system (GDSS) for backbone-network reconfiguration. The system establishes a unified data platform based on data warehouse to analyze security issues and evaluate restoration schemes, and it avoids inconsistencies of data and equipment models. It produces candidate restoration schemes with corresponding restoration strategies and path searching method, and then evaluates and ranks these alternatives with multiple attribute decision-making (MADM) and group decision-making theories. The GDSS can provide online assistance to operators, supplement restoration plans efficiently, and achieve the trade-off between restoration speed and system security.

The remainder of the paper is structured as follows. Section 'Theory foundation of GDSS for backbone-network reconfiguration' describes restoration strategies, path searching method and theories of MADM. The group decision support system is realized in Section 'Realization of GDSS for backbone-network reconfiguration'; in Section 'Case study', a subsystem of western Shandong power system of China is utilized to demonstrate the feasibility and practicability of the proposed system. Finally, Section 'Conclusion' concludes all this paper.

Theory foundation of GDSS for backbone-network reconfiguration

Restoration spans over multiple stages, and a step-by-step restoration strategy is implemented in each stage. Goals of each step should be stated explicitly in a practical restoration plan. Probable effects of each restoration step on the rest of the system and the subsequent measures entail careful consideration before proceeding to the next step [18]. Several key issues such as sequence of switching and transient stability need to be focused on during restoration. Because of different backgrounds and positions of decision makers, it is hard to reach a consensus on the most applicable restoration plan. Different restoration schemes should be produced for evaluation and selection. And for each step of restoration, many factors will influence restoration speed and system security. Therefore every step of backbone-network reconfiguration pertains to a typical MADM problem.

In this section, the theory foundation of group decision support system is introduced. Section 'Determination of restoration schemes' presents a three-stage restoration strategy and path searching method to develop candidate restoration schemes. Section 'Evaluation of restoration schemes' discusses the theories of MADM and group decision-making for selecting a more applicable restoration scheme.

Determination of restoration schemes

The determination of restoration schemes consists of two parts: (1) determination of restoration goals and (2) path searching method. These two parts are described in the following two subsections respectively.

Three-stage restoration strategy

After a blackout, the whole system should be sectionalized into several subsystems to accelerate restoration process. The sectionalization is based on the distribution of black-start units, technical properties of units, network structure and management scope of regional power supply companies. Each subsystem should contain at least one black-start unit, one unit to be restarted, one feasible restoration path and one reliable synchronization point with other subsystems. And each subsystem should have adequate measures and capacities for controlling the voltage and frequency of the system.

The restoration after sectionalization includes two parts: subsystem restoration and coordination of subsystems. The subsystem restoration is comprised of three stages, and different stages focus on different goals. In the first stage, restoration of large units is of the most importance. In the second stage, more attention is paid to restoring important substations (the importance is determined by their load and network structure). In the third stage, synchronization of subsystems and interconnection assistance is the most significant. In these three stages, the restoration path is optimized dynamically to form candidate restoration schemes. There are no strict lines between these three stages. In the second and third stage, if some units which cannot be restored in the first stage meet the startup conditions, they should be restarted preferentially. And if some units do not reach the minimum load limitations, load pick-up is necessary to keep them stable. As for coordination of subsystems, it is responsible for analyzing synchronization conditions and available capacity of subsystems, and it makes decisions on synchronization and interconnection assistance.

Two-layer path searching method

The restoration path searching problem is a typical combinatorial optimization problem, and it can be resolved by graph theory. The energized network can be regarded as the start vertex, and the target vertex is decided by the above-mentioned three-stage restoration strategies, then the shortest path can be obtained with graph theory. However, this method gets a combination explosion in a large-scale power system, a two-layer path searching method based on Dijkstra algorithm is proposed in this paper. This algorithm can reduce computation burden and improve searching speed. It includes inner-layer path searching and outer-layer path searching. The inner layer is composed of equipment within substations and power plants, and the outer layer consists of transmission lines, terminals of substations and power plants. The terms of