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Emergency rush repair task scheduling of distribution networks in large-scale blackouts

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ABSTRACT

This paper focuses on the emergency rush-repair task scheduling of distribution networks in power grid emergencies. As there are many characteristics in distribution network emergency rush-repair such as large number of rush repair points, diverse but with limited repair resources and urgent repair time, this paper takes constraint conditions, such as a variety of execution modes and repair resources into consideration during the model building process of the emergency rush repair scheduling, and we study emergency repair strategies, such as using the emergency generator vehicle, nearby repair strategy and ordinary repair strategy. In order to obtain the optimal solution and satisfy the constraints of the distribution network repair model, this paper improves the traditional serial schedule generation mechanism to a distribution network repair serial schedule generation mechanism by using improved SA algorithm and hierarchical optimization method to search the optimal solution. Finally, we use the model to an example and analyze it. It is validated that the two schedule generation mechanisms that use nearby repair strategy and ordinary repair strategy are both effective. Both the advantages and disadvantages of two mechanisms, and the feasibility and rationality of the model are analyzed in this paper.

Introduction

The emergencies of large power network are called large-scale power failures, which indicate those power network emergencies have great impacts on users or societies especially. Many factors may lead to these large unexpected accidents, but most of them are recently caused by natural disasters. The power failures caused by natural disasters not only badly threat people's daily life and the normal operation of public facility causing heavy economic losses, but also result in further damage on infrastructures of the power system, which makes the restoration of the power system more difficult. However, in order to imply emergency rescues or repairing works in time and reduce economic losses, even save lives, power enterprises need recover electric power supply to meet requirements of repair works after failures as soon as possible. And distribution network, as the last link of the power transmission and distribution system, is the key to achieve effective delivery of power resources. Therefore, it is significant to take research on emergency rush-repair task scheduling of distribution network in power grid emergencies to improve the quality and efficiency of emergency treatment.

The problem of distribution network emergency task scheduling can be traced back to the problem of the power system restoration after distribution network outages. Power system restoration after large-scale blackouts is a sophisticated control and decision problem. It's fairly difficult to build its mathematical model, and almost all the mathematical models have their own shortcomings [1]. Currently, many scholars carry on related optimized researches and pay attention to emergency rush-repair problems in the distribution network. However, most of them just focused on controlling and optimizing problems of the power grid itself, such as adding the switching operation or optimizing the network structure. These researches were lack of system analysis and consideration for the entire repair process, such as consideration of the distance between the place of each repair, limitations of each repair resources and other factors. Meanwhile, they also did not present effective strategies to shorten the repair time or to reduce social and economic losses. In addition, the selection of the optimal target function and other aspects are still not complete and comprehensive.

Researchers have proposed a number of models and methods. For examples, in the area of maintenance task scheduling on the distribution network and power system, several scholars proposed various kinds of repair plan models and methods based on both the view of formulating long-term maintenance plan, shortening

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repair time and reducing risks and costs of maintenance, and the consideration on repair distribution network as a multi-objective problem. However, in these maintenance plan models, most of them do not consider some main problems, including resource allocation, the use of emergency resources, as well as the electric voltage grade of power-losing and social economic losses, which is not consistent with actual situation and just is suited for small and regular troubleshooting in general.

Janjic [2] proposed a methodology for optimal long-term maintenance schedule of distribution networks. And the methodology is based on risk management approach and the new model of decoupled risk factors and state transition based on decision tree diagram. Zhang [3] established a multi-resource and multi-center dispatching model with the objective of "the shortest repair start-time" and "the least number of the repair centers", and a "proximity degree method" is used to calculate the optimal resource dispatching plan. Abbasi [4] optimized long-term maintenance scheduling of overhead distribution networks using dynamic programming approach. And the proposed approach is based on risk management approach and utilizes the model of decoupled risk factors. Leou [5] presented a new formulation considering both reliability and cost reduction by using a hybrid algorithm that combined simulated annealing algorithm and genetic algorithm to solve the problem of power grid maintenance scheduling. Canto [6] solved preventative maintenance scheduling and optimization problem of power system using Benders' Decomposition Method. Edwin [7] found a new way to calculate the annual best maintenance scheduling of power generating equipment among power system. Jafarian [8] proposed a new aggregative indicator, ordered the priority of distribution line based on market factors for reducing emergency repair time. Berrichi [9] formulated an algorithm based on Ant Colony Optimization paradigm to solve the joint production and maintenance scheduling problem. Gomes [10] worked out alternative contingency plan for achieving loss minimization in case of large-scale blackout in Rio de Janeiro, based ISO power system recovery standard in Brazil. Kuntz [11] founded a vegetation failure rate model which quantifies the impact of the maintenance schedule on the reliability of a distribution system. Street [12] proposed an energy and reserve scheduling approach to solve the problem of transmission flow limits, with the purpose of minimizing total cost of energy reserves, and simultaneously, supporting every emergency repair plan. Saraiva [13] used Simulated Annealing Algorithm to calculate the power system maintenance scheduling. Digalakis [14] proposed a method to solve the maintenance scheduling problem, called the parallel cooperating cultural algorithm (PARCA). El-Amin [15] proposed a new heuristic algorithm based on the Tabu search for the maintenance schedule (MS) of electric generation units. The model used two criteria: minimizing the total generator operating cost and levering the reserve. Li [16] introduced a risk-based optimal strategy for distribution asset management preventive maintenance resource allocation.

After power failure, on the one hand, it is required to concentrate resources on emergency repairs, meanwhile it also need as soon as possible to restore power supply and reduce losses due to power-losing. Rush-repair and recovery should be coordinated. More scholars are enthusiastic about adopting technical means to study distribution recovery strategies and methods after network fault, such as using the method of dynamic programming, expert system and so on to research some problems including switch operation and system reconfiguration, while research less on the emergency rush-repair task scheduling problems.

Such as Carvalho [17] proposed to address the problem of fault restoration in distribution systems in a two phase approach. In the first phase, a network optimization evolutionary approach is proposed to find the optimal post-fault configuration. In the second phase, a dynamic programming approach is proposed to determine the optimal sequence of switching operations. Ma [18] introduced a power restoration strategy for the distribution network based on the weighted ideal point method. Manjunath [19] presented a new hybrid multi-objective quick service restoration (QSR) technique for electrical power distribution systems (EPDS). Huang [20] proposed a new algorithm to construct the optimal radial basic function (RBF) neural network for fast restoration of distribution systems with load variations. El-Zonkoly [21] introduced simultaneous single step restoration of transmission and distribution networks with the help of distributed generation (DG) units optimally sited and sized by particle swarm optimization (PSO) algorithm. Huang [22] developed a rule-based expert system with a colored Petri net (CPN) inference model. Ciric [23] described an efficient and robust method and a developed software package for the restoration of radial distribution networks for the purpose of reconstructing normal operating conditions. Singh [24] presented a sequential switch opening method for minimum loss feeder reconfiguration. Fotouhi [25] proposed short-term security-constrained scheduling. Mixed Integer non linear programming was applied to mid-term maintenance. Operation cost optimization considered maintenance of distributed energy resources. Fattahia [26] introduced a new practical GMS for centralized electrical power systems, in which the outage periods are scheduled based on operational hours of units. Geetha [27] maintain gird lines by using Bender's decomposition technique which is based on Lagrangian relaxation method.

Because the distribution network and power system emergency repair plan models or restoring models involve more variables and constraints, which is a complex and multidimensional constrained optimization problems. Especially, the large-scale distribution network repair model, the traditional optimization method is generally difficult to work out the best solution, thus, some scholars also carried out some beneficial research on the optimal solution for models, and proposed some intelligent optimization. However, most of these algorithms are relatively complicated, the optimization effects are also not ideal. For examples, Schlünz [28] presented the simulated annealing (SA) method for solving the generator maintenance scheduling problem. The hybrid SA algorithm performs very well by compared to other methods on the benchmark test system from the literature, and an improved lower bound on the objective function value is presented for this test system. Sanches [29] proposed a new approach results from the combination of MEAN with characteristics from the mutation operator of the differential evolution (DE) algorithm. Stępień [30] presented the co-evolutionary algorithm with memory at the population level. Irving [31] employed a genetic algorithm to solve this multi-objective constrained optimization problem. Nagata [32] used multi-agent method to restore power system. Augugliaro [33] proposed ES and the fuzzy MO formulation of the SR problem.

This paper presented a standardized and systematic description of the task scheduling problem in the distribution network rush-repair based on project scheduling theories and methods. In the case of large-scale power failures caused emergency events, it takes the effect of using emergency generator vehicles, the diversity of resource type, the variability of resource quantity and the actual situation of emergency repair into considerations and presents a multi-objective repair model of distribution network aiming at minimizing economic losses and repair time. Meanwhile, it proposes a two-step model to optimize the solution path within multiple constraints including network structure, limited resource requirements and the nearby repair strategy, which generates repair task scheduling scheme by using the serial schedule generation mechanism and being combined with SA algorithm to find the optimal solution.