Algorithmic Study for Power Restoration in Electrical Distribution Networks

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Abstract

We study the automated power restoration in electrical distribution networks, from the algorithmic viewpoint. During power outages, blackout sections without faults may be able to be recovered early using the capacity margins of surrounding supply sources. However, remote supply sources must be utilized in cases where the capacity margins of the neighboring supply sources are insufficient for the scale of the power outage, which is called multi-stage power restoration. In multi-stage power restoration, the distribution network subject to control becomes broader, and in addition, even healthy sections are subjected to control. In this study, we give an efficient algorithm which determines whether multi-stage power restoration is needed for power restoration, and in either case, the algorithm calculates the switching procedure which recovers power with the minimum number of switch operations. Our algorithm employs a novel algorithmic technique of combinatorial reconfiguration, which enables to maintain power supply to the healthy sections.

1. Introduction

Power distribution networks are usually designed to supply power from multiple routes so as to minimize blackout sections when faults occur. Distribution networks contain multiple switch gears, and the power supply route is determined based on their open/closed states.

When a fault on a distribution network causes a power outage, it takes time to restore the section that caused it. However, early power restoration may be able to be realized for the blackout sections where no fault occurred, using the capacity margins of surrounding supply sources. The capacity margins of remote supply sources must be utilized when those of the neighboring ones are insufficient for the scale of the power outage, which is known as multi-stage power restoration. Multi-stage power restoration is a power restoration method where supply route changes occur even in healthy sections without any power outages. (See Figure 1 as an example.) In multi-stage power restoration, the distribution network subject to control becomes broader. Additionally, even healthy sections are subjected to control; therefore, it is associated with difficulties in distribution system operations.

Power restoration is a crucial topic, and while research and development in practical aspects are taken for granted, research has also been progressing even in the theoretical field of algorithms (e.g., see (Ito, Zhou, & Nishizeki, 2009)). How-

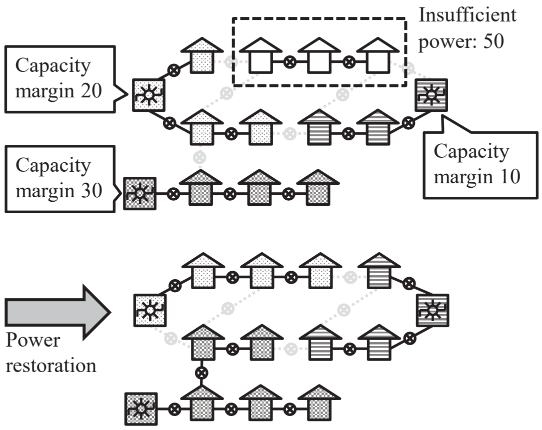

Figure 1. Image of multi-stage power restoration. Although the capacity margins of the two neighboring supply sources are insufficient for power restoration even if combined, power restoration is performed by switching healthy sections to the remote supply source.

ever, existing theoretical research on algorithms has primarily derived supply routes capable of power restoration, and it was difficult to derive the switching procedures for execution. In particular, multi-stage power restoration requires the control of supply routes for healthy sections, and the generation of new power outages in the course of the switching procedure must be avoided. Such switching procedures that consider availability are necessary to advance multi-stage power restoration. In fact, most existing theoretical research on algorithms was performed after having restricted itself to cases where multi-stage power restoration was not required.

In this study, we propose an algorithm that determines whether multi-stage power restoration is required for power restoration, and in either case, the shortest switching procedure is calculated to execute power restoration.

2. Algorithm and experimental result

Our algorithm employs a novel technique called "combinatorial reconfiguration" (Ito et al., 2011; Nishimura, 2018), which enables the calculation of a shortest switching procedure for power restoration while maintaining power supply to the healthy sections. We modify the algorithmic framework (Ito et al., 2022) that can be applied to various types of combinatorial reconfiguration problems. This framework efficiently uses a data structure called a "zero-suppressed binary decision diagram (ZDD)" (Minato, 1993), which can compress and maintain all the executable configurations of switch gears. Although we omit the details from this extended abstract, the idea is to maintain the status of healthy sections efficiently.

In this study, we check the effectiveness of our algorithm via experiment using a standard analytical model of Japanese power distribution networks (Hayashi et al., 2006). This

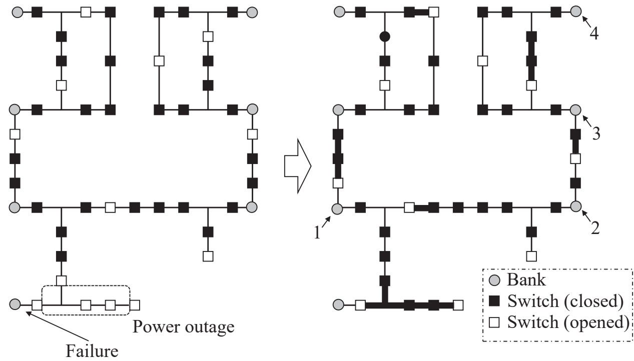

Figure 2. Example of four-stage power restoration.

benchmark data has 468 switch gears and 72 feeders, and there are more than 10^{53} feasible network configurations (power supply routes). We randomly choose one feasible network configuration as the initial configuration, and break one supply source (bank) to cause a power outage. Then, we found an example that requires 10 switch operations and four-stage power restoration as shown in Figure 2.

3. Conclusion

In this study, we developed an efficient algorithm for multi-stage power restoration. Modern society requires control of more widespread power distribution grids with guaranteed availability for situations such as large-scale power outages during major disasters and variation of electric demand density caused by lifestyle transformations. In response to such requests, our algorithm is anticipated to be applied to higher-order distribution system operations, such as automated power restoration, clearing grid congestion, and distribution system planning for downsizing.

Acknowledgments

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