A New Algorithm that Minimizes Distribution Loss and Calculates Switching Procedure

A team of researchers from Tohoku University and Meidensha Corporation (Meiden) has successfully developed an efficient algorithm to minimize power loss during distribution by changing the distribution network configuration. The team, which has been researching power distribution since 2015, has also submitted joint patent applications for the algorithm.

The algorithm calculates not only an optimal network configuration but also a procedure for switching to the configuration, allowing for wide-application to a variety of practical situations in existing power distribution systems. This was a joint research project carried out by Tohoku University's team (led by Xiao ZHOU, Takehiro ITO and Akira SUZUKI) and Meiden's Power Utility Sector Engineering Division, Power Utility & Energy Sector Business Unit. Tohoku University conducted the majority research on algorithms, with Meiden mainly doing the research on power systems technology.

In this study, we confirmed the effectiveness of our algorithm via experiment using a standard model of Japanese power distribution networks (*1) with 468 controllable switch gears. This network is known to have at least 10 to the 58th power possible network configurations. Our algorithm was able to find an optimal network configuration among such an incredibly large number of choices, as well as provide a switching procedure sometimes involving more than 100 steps. These calculations can be done in about 1 to 15 seconds, even using a commercially available desktop computer. This could improve distribution loss by about 13.7GWh per year across Japan (enough to power about 3,800 typical households for a year) according to rough estimates. This is also equivalent to an annual reduction in carbon dioxide emissions of about 6,800 tons (the amount absorbed by about 490,000 cedar trees).

The reduction of CO2 emissions is of course important in terms of fighting global warming. Additionally, the cost of wheeling services has attracted attention in Japan due to the upcoming legal separation of power generation and distribution in 2020. A major advantage of our method is that loss improvements can be achieved using existing equipment. Furthermore, our method could help support the operation and management of power distribution systems that are constantly growing more complex due to the spread of distributed generators such as photovoltaic generation systems.

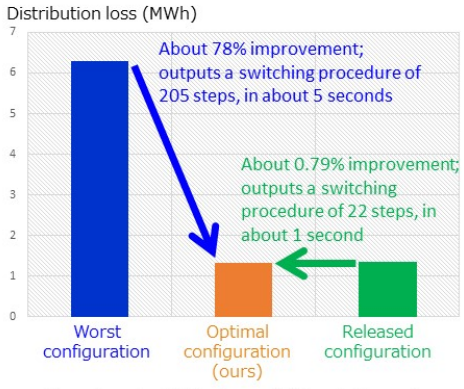
[Achievements]

A **new algorithm** for minimizing distribution loss that **simultaneously** outputs a switching procedure

→ Wide application to real power distribution systems

→ Expected to reduce carbon dioxide emissions and wheeling service costs using only existing equipment

[Experiment Using a Standard Model of Japanese Power Distribution Networks]



(Based on electricity demand data at 10 p.m.)

Rough estimate of energy-efficient improvements for 1 year in Japan:

- Losses reduced by about 13.7 GWh (= roughly 3,800 typical households)
- Reduces CO2 emissions by about 6,800 tons (= roughly the amount absorbed by 490,000 cedar trees)

* Compared with a network configuration released together with the standard model

[Detailed description]

Research background:
Power distribution networks are usually designed with several network configurations operating on radial configurations, which help ensure rapid restoration and reliability. The amount of distribution loss depends on the network configurations selected. Therefore, when choosing a network configuration, it is important not only to satisfy the various electrical constraints, but also to optimize several metrics, such as the distribution loss we examined in our study. In recent years, appropriately operating and managing network configurations has become much more complicated, due to the spread of distributed generators such as photovoltaic generation system.

Existing research and issues:
In general, distribution networks have a large number of switch gears, and hence an incredibly large number of possible network configurations, even if limited only to those that satisfy all the electrical constraints. For example, a research team led by Prof. Yasuhiro Hayashi (Waseda University, Japan) published a standard model of Japanese power distribution networks (*1) that has 468 controllable switch gears. For this network, the number of network configurations satisfying all the electrical constraints is at least 10 to the 58th power. Although research on finding an optimal network configuration among such a large number of choices has been conducted, problems remain in terms of how to apply solutions to real power distribution systems. For example, an efficient algorithm for finding an optimal network configuration to minimize distribution loss is already known; however, this algorithm does not calculate a switching procedure to reconfigure the current configuration to the optimal one. On the other hand, there are several algorithms that are known to both improve distribution loss and simultaneously output switching procedures; however, these algorithms do not always output an optimal network configuration.

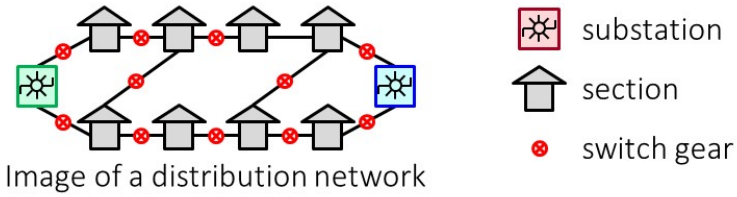
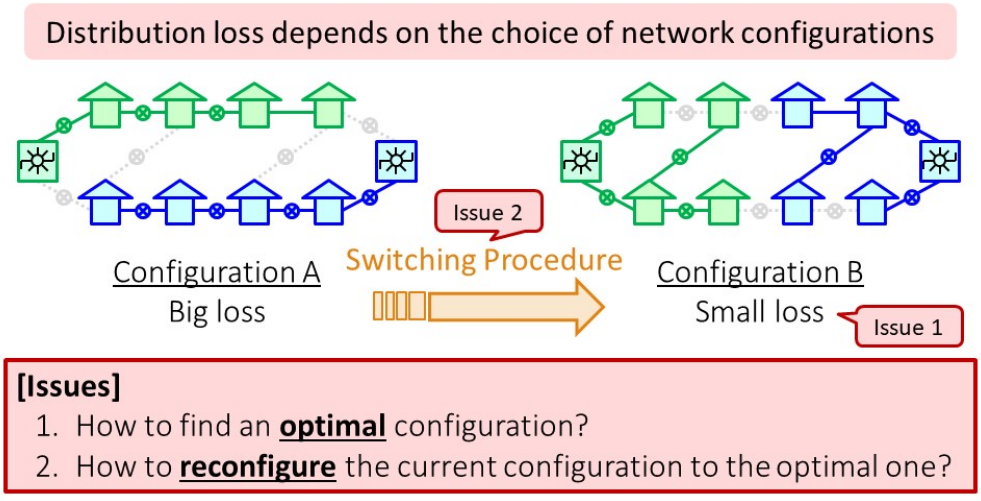


Image of a distribution network



Our achievements:
In this study, we successfully developed a new algorithm that not only minimizes distribution loss but also simultaneously outputs a switching procedure, using a technique called "combinatorial reconfiguration" (*2), which is becoming a new trend in algorithm theory. Theoretically, there may be no way to reconfigure an initial network configuration into an optimal one. Our algorithm can distinguish such cases and also output a

network configuration (along with its switching procedure) with the smallest distribution loss from among the available configurations.

As another advantage, although it may take a long time to determine an optimal solution depending on the size of the distribution network, our algorithm can be discontinued at any time. Recall that many existing algorithms force us to wait without providing any information as to when they will terminate. In this sense, our algorithm can be used flexibly depending on the computer equipment and purpose. If the algorithm is discontinued before it terminates, the optimality of the output is not guaranteed. However, it will provide the best network configuration available at that time together with its switching procedure. In addition, the algorithm can easily be parallelized, which could provide even faster service, depending on the computer equipment.

Experimental evaluation:
The effectiveness of our algorithm can be confirmed experimentally for the standard model of Japanese power distribution networks. Recall that the number of possible network configurations for this network is at least 10 to the 58th power, and that we found a network configuration with a switching procedure that requires at least 100 steps to optimize distribution loss. It is extremely difficult for existing algorithms to select an optimal network configuration from such an enormous number of choices, as well as simultaneously output a switching procedure. However, our algorithm can calculate both in about 1 to 15 seconds, even using a commercially available desktop computer. Below we explain two specific experimental results.

The first case considered an extreme situation: an initial network configuration that maximizes distribution loss of the standard model. The distribution loss of this worst configuration is about 6.28 MWh, while that of the optimal one is about 1.33 MWh (based on electricity demand data at 10 p.m.). Our algorithm was able to decrease distribution loss by about 78% and simultaneously calculate a switching procedure of 205 steps in about 5 seconds.

In the second case, the initial network configuration was the one released with the standard model of Japanese power distribution networks. This initial network configuration does not minimize distribution loss, but we reconfigured it to an optimal one that decreased loss by about 0.79% (based on electricity demand data at 10 p.m.). Our algorithm calculated a switching procedure of 22 steps to optimize distribution loss in about 1 second. A rough estimate of energy-efficient improvements for Japan (based on an analysis of electricity demand data over 24 hours) showed that loss could be reduced by about 13.7GWh per year (enough to power roughly 3,800 typical households for a year). This is also equivalent to an annual reduction in carbon dioxide emissions of about 6,800 tons (roughly the amount absorbed by 490,000 cedar trees).

[Glossary]
*1) Standard model of Japanese power distribution networks
A benchmark test network of practical scale that was designed based on a real distribution network in Japan. Investigated and published by a research team led by Prof. Yasuhiro Hayashi (Waseda University, Japan). This network contains 468 controllable switch gears, 72 feeders, has a total electricity demand of 73-170MWh, line capacity of 300A, feed voltage of 6.6kV, and voltage operation range of 6.3-6.9kV.
http://www.hayashilab.sci.waseda.ac.jp/RIANT/riant_test_feeder.html

*2) Combinatorial reconfiguration
A field of research that uses mathematical models of dynamic situations, such as the switching procedures for distribution networks, and analyzes the complexity of algorithms and computation. This field has been studied intensively over the past decade and has begun to attract worldwide attention in the field of algorithm theory.

[Contact information]
<Regarding research>
Takehiro ITO, Associate professor
Graduate School of Information Sciences, Tohoku University
E-mail: takehiro@ecei.tohoku.ac.jp

<Media department>
Tohoku University / Public Relations Office of Graduate School of Information Sciences
E-mail: koho@is.tohoku.ac.jp

Meidensha Corporation / Public Relations Division
E-mail: kouhou@mb.meidensha.co.jp