Power Imbalance Reduction Solution with the Digital Grid System

OKABE Toshiya, Shantanu Chakraborty, OGATSU Toshinobu

Abstract

Japan's imminent liberalization of electricity sales and subsequent deregulation of the electric power industry in Japan will create huge opportunities for businesses in the electric power sector, while creating a host of new issues. In particular, finding a way to reduce the cost of power imbalances is considered crucial for companies trying to break into the new field of electric power retailing business. This paper introduces Digital Grid - a next-generation electric power system integrating information and communications - and our imbalance reduction solution.

Keywords
Digital Grid, smart grid, power storage system, energy management system, imbalance, electric power deregulation

1. Introduction

The Digital Grid[1), 2)] is an Internet-like power distribution system that connects asynchronous, autonomous small-and-medium-scale microgrids. The design of time system enables individual cells to support one another by exchanging electric power, while at the same time making possible local production and consumption of power within microgrids using available energy storage and renewable energy. What makes this all possible is a device called a Digital Grid Router (DGR) that uses software control to manage and regulate power demands by facilitating dynamic, real-time power exchange within and between cells in the grid.

Invented by Rikiya Abe, Project Professor at the University of Tokyo Graduate School, this new concept of power distribution has the potential to significantly enhance conventional power distribution systems while collaborating with mature national grids. Some of the major technologies underlying this concept - including the Digital Grid router - will be operational in the near future.

Power exchange technology makes it possible to transmit and receive power by designating a partner via a power line that already exists or to be installed in the future. As the overall power distribution evolves, distributed generation systems such as energy storage

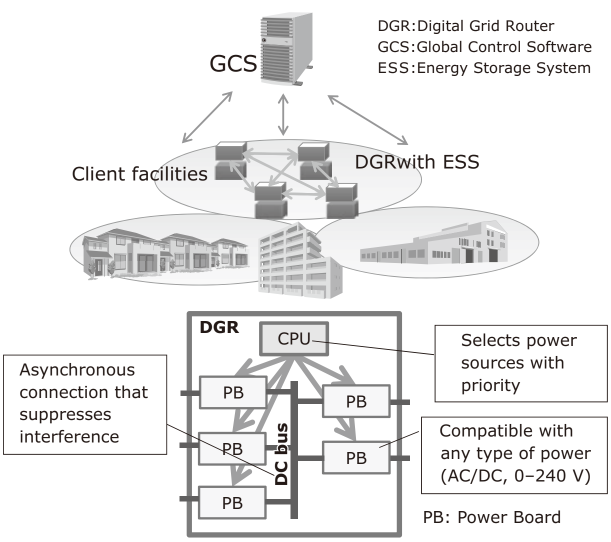


Fig. 1 Digital Grid system and DGR.

installed on the customer side are expected to play an increasingly greater role. However, in many cases those systems are owned by different people and enterprises. By assigning identifiers to individual users, it will be possible to exchange power explicitly between multiple users.

The brain of the Digital Grid system is the Global Control Software (GCS), which controls multiple DGRs remotely and is provided with power storage capability.

The GCS features an original algorithm that selects and coordinates transmitters and receivers, as well as managing the timing when power is exchanged (**Fig. 1**). It will be possible to implement various applications in the GCS.

2. Imbalance Reduction Solution

An example of a solution that is made possible by the application implemented in the GCS is the imbalance reduction solution. This is a solution targeted at companies that are starting up new PPS (Power Producer and Supplier) businesses.

Power imbalance is the difference between the power consumed and the power generated. New PPS need to be able to balance the generation and consumption of power in 30-minute units. In practice, however, there will be occasions when too much or too little power is generated relative to the demand. This is a power imbalance. Depending on how much excess or deficient power is produced, these providers will have to pay a fee to electric power companies. These fees are called imbalance fees. Higher fees are imposed when the imbalance exceeds the range of +3% and -3% of the peak. When the amount of deficiency exceeds 3%, they have to pay a high out-of-variation-range generation fee.

With the imminent liberalization and deregulation of electric power retailing, imbalance fees are expected to become unavoidable costs for new PPS trying to enter the electric power business. For providers who purchase power from existing power companies, costs can be roughly divided into four types - power purchasing costs, wheeling costs, imbalance costs, and management and other costs[3] (**Fig. 2**). Although imbalance costs account for only a small percentage of total costs, they are nonetheless expected to have a significant impact on the profits of PPS.

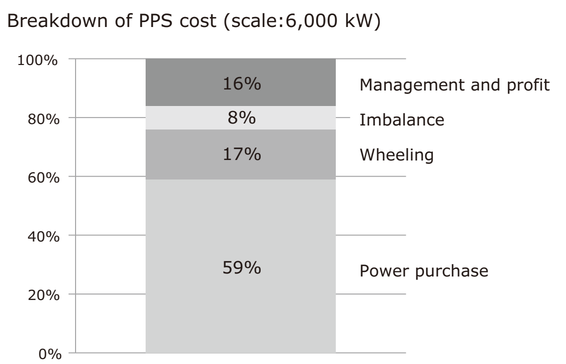


Fig. 2 Breakdown of new power cost (scale: 6,000 kW).

3. Demand-Fix Technology

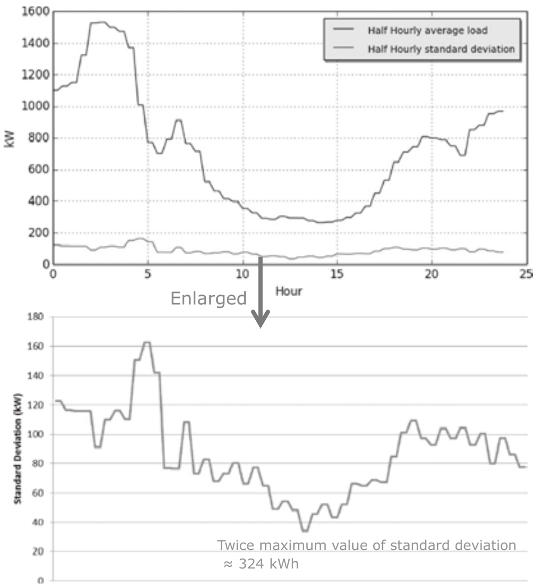
Demand-fix technology makes it possible to fix or forecast (plan) intrinsically fluctuating demands by remote-controlling batteries.

To reduce power imbalances, Demand-fix technology absorbs fluctuating power demands using batteries that can be externally charged and discharged. This makes it possible to synchronize the power demands of multiple customers with the planned values based on the forecast. Procurement plans based on demand forecast make it possible to procure accurate wholesale power. Technologies including a battery charge/discharge control algorithm fill the gap between the plans and actual consumption.

3.1 Imbalance Analysis

A power imbalance is the difference between the amount of power consumed and the amount generated. Now let's see how large the imbalance is in practice. Power generation is typically based on a variety of policies, including generator operation plans and market procurement. Power consumption can be estimated relatively easily by calculating the capacities of energy storage required, although the resulting estimate is not very accurate. An example of this can be seen in the analysis results published by the Architectural Institute of Japan shown in **Fig. 3**, which are based on power consumption data[4]. The analysis calculates the average for each hour and the standard deviation of data on the power consumed during the winter in about 1,000 households in the Kanto region for 31 days from January to February.

It is clear from this graph that demand peaked in the early morning and the standard deviation reached a maximum of 162 kWh. Twice the maximum standard deviation value is 324 kWh. Assuming that the distribution here is normal, then, based on the definition of standard deviation, about 68% of the power demand can be covered by 324 kWh battery capacity, which corresponds to about 0.3 kWh per household. From this, it is clear that a battery with a relatively small capacity can handle



Note: The analysis used demand data corresponding to about 1,000 households that was created by repeating the same set of data multiple times as the number of actual customers in the published data was limited.

Fig. 3 Demand analysis of the winter in the Kanto region.

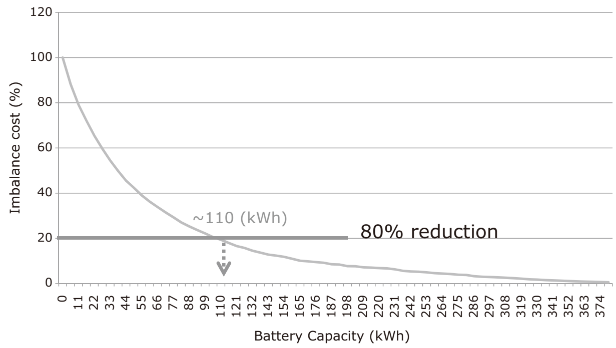


Fig. 4 Imbalance reduction effect using batteries (in winter in Kanto region).

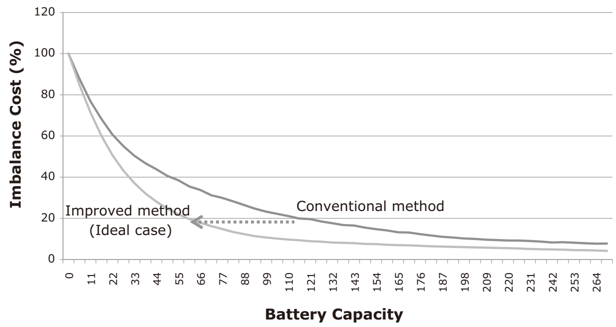


Fig. 5 Effect of Demand-fix control method.

most variations in power demand. As Fig. 3 shows, the standard deviation reaches its narrow peak in the early morning. This means that in practice it would be possible to obtain satisfactory results with about half of that value - 162 kWh for example.

3.2 Imbalance Reduction Effect Using Batteries

Now, let's take a look at the imbalance reduction effect using batteries. Here, we need mathematical model for the amount of imbalance created. As a simple example, let's assume that there is a 10% deviation on average (uniform random numbers from 0 to 20%) between the generation planned on the previous day and the actual demand. Let's also assume that the deficit imbalance fee over 3% is 45 yen/kWh and the deficit fee under 3% is 15 yen/kWh, as well as that the surplus fee under 3% is −10 yen/kWh and the surplus fee over 3% is 0 yen/kWh. For the power consumed, we used the same demand data as in Fig. 3, corresponding to 1,000 households in the Kanto region in the winter. The results of the analysis when a relatively simple charge/discharge algorithm are shown in **Fig. 4**. From these results, it is clear that the battery capacity required for the reduction of the 80% imbalance cost is 110 kWh. Basically, the greater the battery capacity, the greater the reduction of the imbalance; however, the degree of improvement tends to decrease. In other words, it is important that the battery storage capacity corresponds to the desired reduction effect, rather than attempting to maximize the reduction.

3.3 Charge/Discharge Algorithm Based on Demand Forecasts

The results shown above are based on an analysis of the effects when a very simple control method is applied. However, a large imbalance reduction effect can be obtained even with a small battery capacity by applying a more sophisticated control method.

In our trial calculation, a forecast of short-term demand is generated. By calculating the optimum battery charge/discharge of the battery while that forecast is taken into consideration, we've found that the same imbalance reduction effect can be achieved even with a battery that has 30 to 40% less capacity than conventional method (**Fig. 5**).

4. Conclusion

The Digital Grid, like the Internet, is a means of connecting multiple independent nodes and managing and directing traffic between them. In the case of the Digital Grid, that traffic is electric power. As an example of how this works, we have shown how this technology can be applied to reduce power imbalances that arise in dispersed power distribution systems. The anticipated move towards renewables, along with deregulation of the power industry, will increase demand for this technology and expand the range of applications.

As the amount of renewable energy such as photovoltaics (PV) entering the system increases, the feed-in tariff system (fixed-price purchase system) used to subsidize less reliable forms of energy is expected to be phased out. The value of surplus power that up to now has been purchased on an unconditional basis is also expected to decrease in the future. Under these conditions, it makes sense for locally generated power to be consumed locally.

However, out of the power produced in households in Japan that own 4 kW class PV devices, only about 40% or so is locally consumed, while the remaining 60% is apparently sold[5]. The reason why the percentage of power consumed locally is so small is that the timing of power generation differs from the timing of consumption.

However, when batteries are used, the gap created by the deviation between the time when power is generated and when it is consumed can be eliminated. According to our calculations, the use of batteries can significantly reduce the imbalance, leading to greater local consumption of the power generated. However, the cost will increase relative to the number of batteries used.

Power exchange technology take this a step further by redistributing power among multiple households so that any deviations up or down can be mutually absorbed. Collaborative operation between multiple households can be expected to further reduce the amount of power that needs to be purchased.

These solutions are based on the assumption that the initial clients will be providers - companies seeking to enter the electricity retail business without owning electric power infrastructure.

The electric power retail market is generally regarded as an independent and well-established commercial field. In the future, however, it is entirely possible that much more eclectic ranges of businesses will be active in this field, including, for example, stores that sell physical merchandise or facility management companies. In other words, we expect that these solutions will be adapted to meet the needs of customers from a wide range of businesses.

* Digital Grid is a registered trademark of the Digital Grid Consortium, a nonprofit corporation.

Reference

1) ABE Rikiya, "The Digital Grid: The Convergence of Power and Information, and Its Application," NEC Technical Journal, Vol.65 No.1, pp.14-18, 2012.2
2) Rikiya Abe, et al., "Digital Grid: Communicative Electrical Grids of the Future," IEEE Trans. on SG, Vol.2, No.2, June 2011.
3) PPS-NET, Points of PPS operation (In Japanese), (http://pps-net.org/aboutpps/process/theme)
4) The Architectural Institute of Japan, Energy consumption database in house (In Japanese) (http://tkkankyo.eng.niigata-u.ac.jp/HP/HP/database/index.htm)
5) NEDO, Renewable energy technology white paper2nd edition (In Japanese), December 2013 (http://www.nedo.go.jp/content/100544817.pdf)

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