Potentiality of Demand Response and Curtailment for Wind Power Integration

－Implications for Demand Response Designing－

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Summary

This study evaluated the degree to which wind power can be integrated in Japan by adopting curtailment and demand response, subject to the ramping capability identified from the hourly electric demand variation, which can be interpreted as a "capability without additional effort" that the utilities are equipped with as aggregated dispatchable power plants. The required curtailment rate, demand response rate, number of demand response events and time of the year of the event were revealed.

The results show that the wind power integration potential, which is 10GW and 17TWh without any integration measures, increases as much as to 32GW to 51GW and 57 to 86TWh, equal to the potential yielded by strengthening interregional transmission lines, if 1% to 5% curtailment and demand response with 1% to 5% of the maximum reduction rate are introduced. The average demand response rate is no more than 1% to 2% and the number of events called in a year is only two to ten. A very small fractional wind curtailment and demand response can yield a wind power potential equivalent to the potential by strengthening interregional transmission lines. Since strengthening the interregional transmission lines, which are important not only for renewable integration but for power exchange in Japan, requires huge investment cost and a long lead time, it is important that the demand response and curtailment measures should also be strongly promoted.

Among challenges in designing a demand response is that the demand response should be incentive-based and equipped with an automatic control system, since certainty in response is sine qua non for absorbing variable renewables. Involvement of aggregators who can provide the optimum demand responses by controlling a variety of customers is highly recommended to assure response. Designing with regard to cost effectiveness, such as how much incentive should be offered for reduced electricity demand and/or standby capacity, is also one of the crucial issues.

Research and development of energy storage technologies such as batteries and hydrogen as one of the renewable integration measures are of importance for their future exploitation. Nevertheless, these technologies remain within the concept that energy supply should follow energy service demand and this concept is the same as that of the stock-type centralized energy system. In order to integrate massive flow-type renewable energy, it is important to encourage consumers to be much more involved, not just relying on the supply side measures. Demand

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response, being effectively employed by existing and proven technology, can be expected to play an important role in involving consumers. For the demand response to be widely implemented, further evaluations on the feasibility of demand response based on the detailed data of hourly electricity demand by sector and by type of use as well as on renewable energy power generation are the challenges.

Introduction

The ramping capability of dispatchable power plants is one of the governing factors that determines the wind power integration to the grid. If the ramp-down capability dominates, more wind power can be integrated by increasing the acceptable curtailment scale. However, from the viewpoint of cost effectiveness, the wind power capacity that can be integrated is determined by the capacity that maximizes the difference between the avoided power generation cost of utilities and the opportunity loss by curtailment on wind power generators. On the other hand, when the ramp-up capability is a dominant constraint, implementing demand response presumably increases the integration potential of wind power.

Though strengthening the interregional transmission lines, energy storage and hydrogen production and storage are important measures for more variable renewables to be integrated, their long lead times, huge investment costs and long term R&D planning are the challenges. As curtailment and demand response are proven measures realized by information and communication technologies, the feasibility of these measures in renewable integration should also be addressed. This study analyzes the wind power integration potential by curtailment and demand response, and also evaluates the feasible scale of demand response.

1. Conditions and Analysis Flow

1-1 Conditions

Following the existing study on the wind power integration potential via strengthening the interregional transmission lines subject to the ramping capability of the aggregated dispatchable power generation [1], the data used in this study also include the hourly electric demand and hourly wind power generation output in the nine utilities in Japan.

[Data Set]

- The hourly wind power output is estimated from AMeDAS (Automated Meteorological Data Acquisition System) wind speed data in 2010, 2011 and 2012 simulating the actual power generation pattern. The observatories of AMeDAS close to the existing wind turbine sites were selected.
- The hourly electric demand in 2012 was collected from the utilities websites. Therefore, analysis is carried out in three cases.

[Conditions]

- The ramping capability is figured out from the hourly electric demand variation, which can be interpreted as a “capability without additional effort” that the utilities are equipped with as aggregated dispatchable power plants. Accordingly, it should be noted that the wind power integration potential is underestimated. The ramping capability of the individual utilities figured out from 2012 electric load curve is presented in Table 1-1.

Table 1-1 Ramping Capability of Individual Utilities

	Electricity demand		Ramping capability		Ratio to peak demand	
	Peak demand (GW)	Bottom demand (GW)	Ramping-up (GW/h)	Ramping-down (GW/h)	Ramping-up capability	Ramping-down capability
Hokkaido	5.7	2.7	0.6	-0.4	11%	-7%
Tohoku	13.6	6.5	2.1	-1.0	15%	-8%
Tokyo	50.8	20.5	8.2	-4.5	16%	-9%
Hokuriku	5.3	2.0	0.8	-0.4	15%	-8%
Chubu	24.8	8.8	4.6	-2.2	18%	-9%
Kansai	26.8	11.0	3.6	-2.0	13%	-7%
Chugoku	10.9	4.4	1.6	-0.9	15%	-8%
Shikoku	5.3	2.0	0.8	-0.4	15%	-7%
Kyushu	15.2	5.8	1.6	-1.9	10%	-13%
Japan	154.5	66.0	21.7	-12.4	14%	-8%

Source : Shibata, “Evaluation of Wind Power Integration Potential in Japan by Strengthening of Interregional Transmission Lines and by Power Curtailment,” IEEJ Energy Journal Vol.8, No.3, 2013 [1]

- Strengthening interregional transmission lines is disregarded and the current interregional transmission lines capacity is presumed.

- The acceptable wind power output capacity is identified so that the largest increment/decrement of the hourly net load coincides with the ramping-up/ramping-down capability. The smaller acceptable wind power capacity identified based on the ramping-up capability and ramping-down capability is interpreted as the additional integration potential without measures (curtailment and demand response) in the individual region and the sum of the each region is the nationwide additional potential.

- With regard to the constraint caused by lack of dispatchable capacity that the sum of wind power output and base load power plant output should not exceed the electric demand, the bottom net load reduction rate is assumed to be 18% for the sake of comparison with the wind power integration potential by strengthening interregional transmission lines [1].

- Curtailment: Wind power output equivalent to the amount by which the net load variation exceeds the ramp-down capability and also to the amount by which it exceeds the reduction rate of the bottom net load is curtailed (Fig. 1-1).

- A demand response event is to be called to reduce the electric demand equivalent to the amount by which the net load variation exceeds the ramp-up capability (Fig. 1-1). Demand response, drawing much attention as one of the peak cut measures, is also expected to activate electricity demand to absorb the variability of renewable energy power output. Among the technologies (measures) to change the electric load curve following the variation of renewable energy power output are heat pump water heaters with heat storage and electric vehicles that are addressed in many of the existing studies [2][3], and also introduction of a time-of-use tariff to encourage customers to shift their electricity use pattern, on which a few research projects have been carried out [4]. Meanwhile, this study includes only demand response that encourages consumers to reduce electricity demand in an emergency. Both the demand response via energy storage technology and that with emergent electricity demand reduction accompany the change in the electric load curve observed from the power grid side. However, the former does not affect the hourly service demand of customers, but the latter does, which means that more active involvement of the customers (demand side) is required (Fig. 1-2). In addition, the latter generally requires less investment.

Fig. 1-1 Thumbnail of Renewable Integration by Curtailment and Demand Response

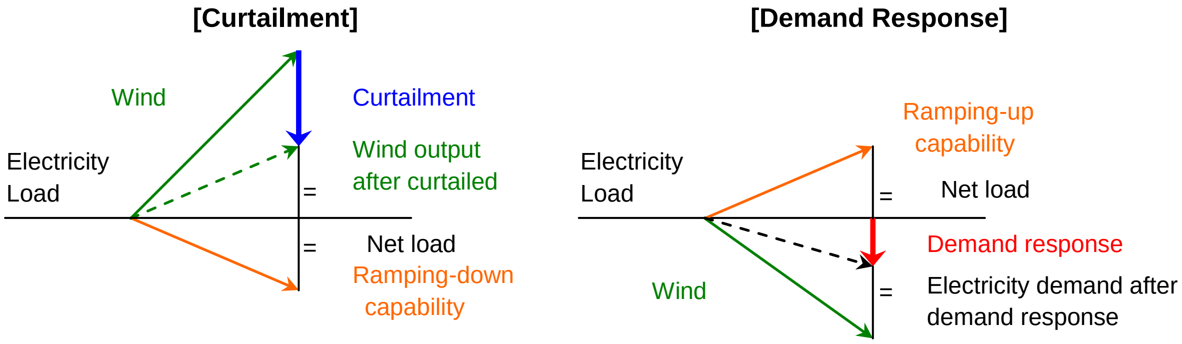
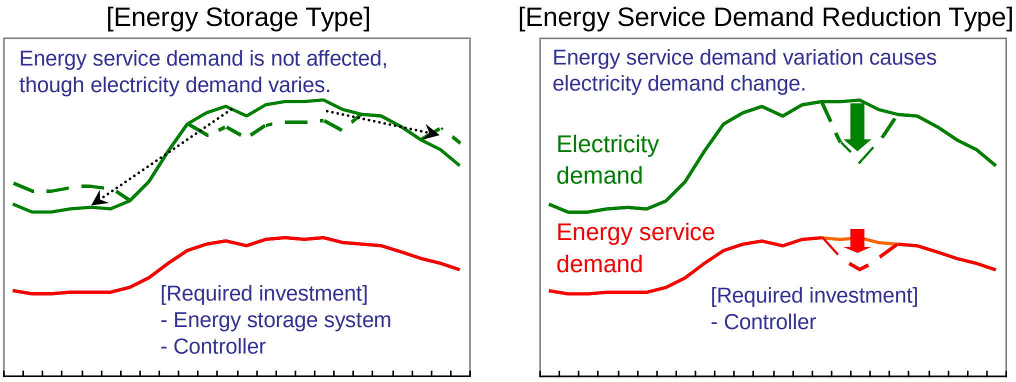


Fig. 1-2 Comparative Illustration of Two Types of Demand Response



Note : Energy service demand divided by equipment efficiency yields energy demand. As the energy storage type causes a time lag between input and output of energy, this relationship does not hold hourly.

1-2 Analysis Outline

First, the acceptable wind power output capacity is identified so that the largest increment/decrement of the hourly net load coincides with the ramping-up/ramping-down capability. The smaller wind power capacity identified based on the ramping-up capability and ramping-down capability is interpreted as the additional integration potential without measures (curtailment and demand response). Second, increasing the curtailment scale, the wind power capacity is identified so that the net benefit is maximized and also the required demand response scale is figured out.

The demand response identified here is no more than a necessary demand response, and its feasibility is disregarded.

By identifying the demand response capacity (or demand response rate), the number of events and time of events, the feasible demand response capacity and wind power introduction potential according to the demand response capacity are analyzed.

2. Wind Power Integration Limit by Curtailment and Required Demand Response

2-1 Economic Limit of Wind Power Integration

Fig. 2-1 presents analysis results of the capacity and electricity generation of the wind power integration potential governed by the ramping capability in the Tohoku area. This example shows that the ramping-down capability allows no more than 0.86GW of wind power, though 2.72GW can be integrated when the ramping-up capability would become a dominant constraint. Then, let us consider strongly implementing curtailment to remove the ramp-down constraint. The curtailment increases the acceptable wind power capacity, but, at the same time, more power generation is curtailed. Though curtailment is not yet implemented in Japan, it is assumed here that if curtailment is introduced, the feed-in–tariff would be paid for the electricity that would have otherwise been generated in favor of wind power generators.

Electricity from wind power flowing into the grid brings the benefit that utility companies can avoid power generation. Meanwhile, FIT is paid for the curtailed wind power in spite of the fact that it does not contribute to the avoided cost, incurring loss. Then, the below equations are defined;

Avoided cost (benefit) = Actual wind power generation [Wh] X Avoided price [JPY/Wh]

Opportunity loss (cost) = Curtailed wind power generation [Wh] X Feed-in-tariff [JPY/Wh]

From an economic (cost effectiveness) viewpoint, wind power capacity that maximizes the net benefit is the optimal (maximum) capacity. The avoided price, though varying depending on the power generation mix and fuel prices, is assumed to be JPY10/kWh based on the price applied in the FIT scheme 2012 and 2013 [5]. The feed-in-tariff for wind turbines is JPY23.1/kWh.

Fig. 2-1 shows that the maximum net benefit is brought by 7.04GW for the Tohoku area and wind power generation is curtailed from 14TWh to 12.9TWh. If wind power is integrated more than 7.04GW, the net benefit decreases. 7.04GW is the maximum wind power integration subject to cost effectiveness. However, 2.72GW subject to the ramping-up capability, which is smaller than 7.04GW, becomes the wind power integration potential.

2-2 Required Demand Response Capacity

Then, demand response that contributes to removing the ramping-up capability constraint is at the same time required in order to increase the wind power integration potential from 2.72GW to 7.04GW. Fig. 2-2 shows an example of the Kyushu region where the magnitude relationship between the capacity determined by the ramping-up constraint and the ramping-down constraint is opposite to the Tohoku region and the necessary demand response capacity is presumably greater than Tohoku.

Fig. 2-1 Wind Power Capacity and Power Generation (Tohoku region, wind condition in 2010)

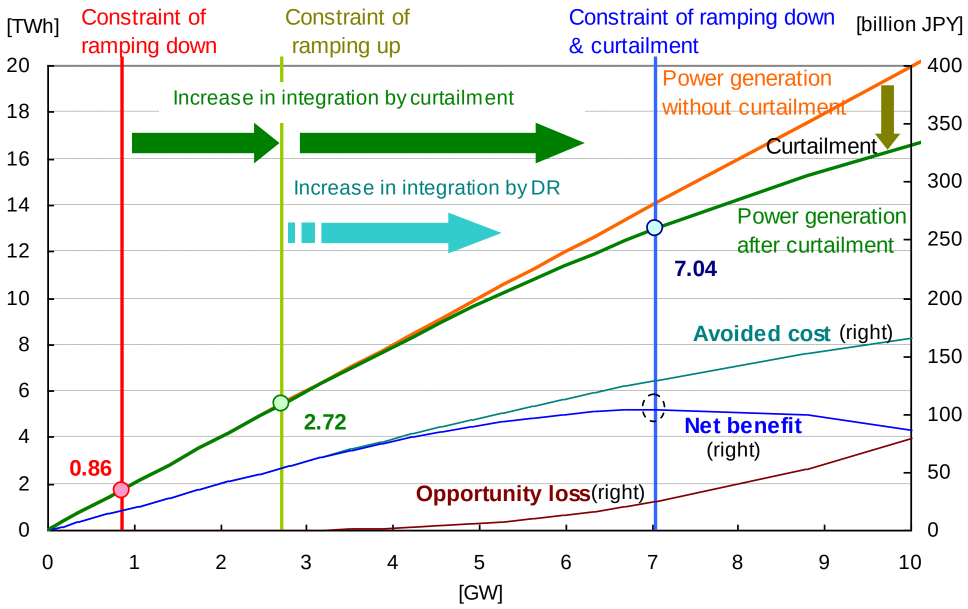
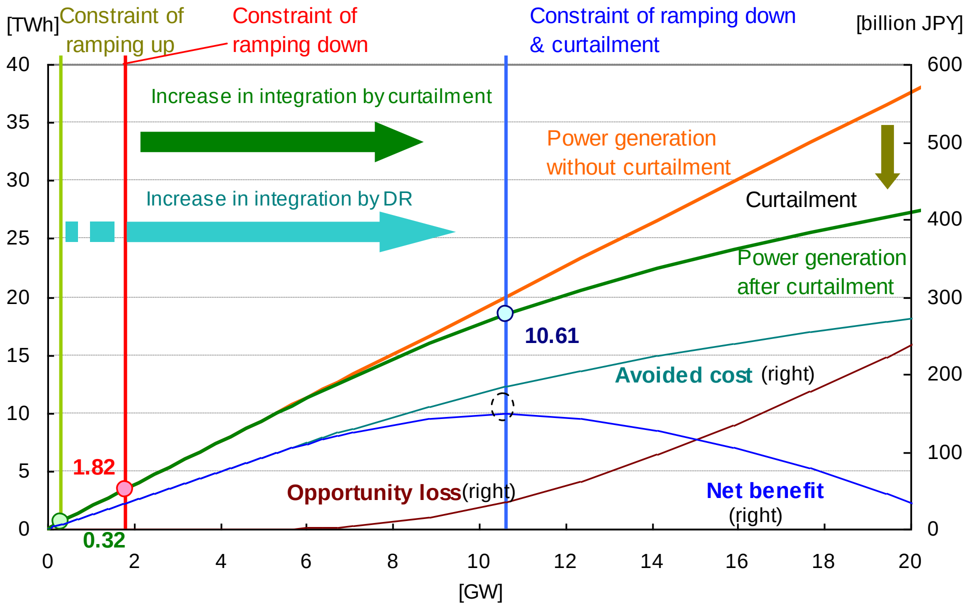


Fig. 2-2 Wind Power Capacity and Power Generation (Kyushu region, wind condition in 2010)



2-3 Analysis Results in the Individual Regions

Table 2-1 shows the analysis results. The wind power integration potential estimated here is the additional capacity to the existing capacity as of March 2012. Though the nationwide wind power integration potential without measures, depending on the wind condition, is estimated to be 7 to 8 GW, as much as 90 GW of wind power can be integrated by taking full advantage of demand response along with curtailment. The curtailment rate is about 10% and the actual power generation after curtailment is 140 TWh. It should be noted, however, that this potential is a limit of wind power integration that maximizes the net benefit and disregards the feasibility of demand response.

Table 2-1 Additional Wind Power Integration Potential based on Cost Effectiveness of Curtailment

Year of wind condition	Region	Wind capacity (GW)				Wind power generation (TWh)			
		Without measures			Upper limit by curtailment	Without measures	With curtailment		
		Subject to ramping(+)	Subject to ramping(-)	The smaller		The smaller	After curtailed	curtailment	Curtailed rate
2010	Hokkaido	0.8	0.1	0.1	3.2	0.3	6.6	0.7	9%
	Tohoku	2.7	0.9	0.9	7.0	1.7	12.9	1.1	8%
	Tokyo	8.8	4.4	4.4	30.1	6.8	41.9	4.7	10%
	Hokuriku	0.3	0.1	0.1	2.8	0.2	5.1	0.6	11%
	Chubu	7.4	1.5	1.5	13.4	3.3	25.8	2.5	9%
	Kansai	1.1	0.4	0.4	14.1	0.5	15.7	2.0	11%
	Chugoku	2.2	0.2	0.2	6.0	0.3	8.3	0.8	8%
	Shikoku	0.7	0.0	0.0	2.5	0.0	5.0	0.5	9%
	Kyushu	0.3	1.8	0.3	10.6	0.6	18.4	1.5	8%
	Japan	-	-	8.0	89.7	13.8	139.8	14	9%
2011	Hokkaido	0.5	0.2	0.2	3.2	0.5	6.7	0.6	9%
	Tohoku	5.2	0.5	0.5	7.0	1.0	13.7	0.9	6%
	Tokyo	10.1	4.2	4.2	31.8	6.0	41.0	4.2	9%
	Hokuriku	0.7	0.1	0.1	2.8	0.2	5.1	0.6	10%
	Chubu	6.8	1.6	1.6	15.1	3.5	29.2	2.9	9%
	Kansai	0.1	0.3	0.1	14.1	0.1	15.4	2.0	11%
	Chugoku	2.5	0.7	0.7	6.2	1.1	8.2	0.9	9%
	Shikoku	0.0	0.2	0.0	2.5	0.0	4.8	0.5	10%
	Kyushu	0.0	1.4	0.0	10.6	0.1	18.3	1.6	8%
	Japan	-	-	7.5	93.5	12.4	142.3	14	9%
2012	Hokkaido	0.5	0.1	0.1	3.2	0.3	6.4	0.7	9%
	Tohoku	4.2	0.4	0.4	8.8	0.8	15.8	1.9	11%
	Tokyo	7.5	4.7	4.7	31.8	7.0	42.6	4.8	10%
	Hokuriku	0.1	0.1	0.1	2.8	0.1	5.0	0.6	10%
	Chubu	10.5	0.1	0.1	15.9	0.1	28.4	3.5	11%
	Kansai	1.0	1.6	1.0	14.1	1.2	15.2	1.9	11%
	Chugoku	0.0	0.2	0.0	6.0	0.1	7.6	0.9	10%
	Shikoku	0.5	0.2	0.2	2.5	0.5	4.6	0.5	9%
	Kyushu	0.3	0.1	0.1	10.6	0.1	17.9	1.5	8%
	Japan	-	-	6.8	95.8	10.3	143.6	16	10%

Note : The wind power integration potential here is additional to the existing capacity as of March 2012.

The required demand response capacity to realize the wind power integration potential is presented in Table 2-2. The average demand response capacity in Hokkaido, Tohoku, Hokuriku, Chugoku and Shikoku ranges from about 0.2GW to 0.3GW, 0.5GW to 1GW in Chubu and Kyushu and 1GW to 2GW in Tokyo and Kansai. A demand response event is called from 10 to 30 times a year in the Tohoku, Tokyo and Chubu ranges, but more than 100 times in Hokkaido, Hokuriku and Kansai. A demand response is called as many as 300 times in Kyushu, whose frequency is once every one to two days. A maximum demand reduction rate at the time of event calling (maximum DR rate) below 10% is observed in some regions, but it is about 20% on average. In short, demand response that can reduce electricity demand in the whole region by as much as 20% should be prepared in order to integrate the wind power that is allowed based on the cost effectiveness of curtailment.

Table 2-2 Necessary Demand Response Capacity to Integrate Wind Power Potential based on Cost Effectiveness of Curtailment

Year of wind condition	Region	Max DR (GW)	Min DR (GW)	Avg. DR (GW)	Event number	Max DR rate
2010	Hokkaido	0.77	0.00	0.15	141	17%
	Tohoku	1.07	0.02	0.39	14	8%
	Tokyo	7.97	0.01	2.12	24	22%
	Hokuriku	0.72	0.00	0.19	107	15%
	Chubu	1.22	0.11	0.48	9	7%
	Kansai	4.50	0.02	0.96	101	21%
	Chugoku	1.04	0.00	0.33	40	13%
	Shikoku	0.78	0.00	0.21	80	23%
	Kyushu	3.03	0.00	0.55	258	25%
	Japan	21.10	-	-	-	17%
2011	Hokkaido	0.81	0.00	0.18	149	17%
	Tohoku	0.56	0.01	0.22	15	5%
	Tokyo	7.55	0.01	1.79	28	16%
	Hokuriku	1.07	0.01	0.21	119	24%
	Chubu	2.02	0.09	0.77	15	10%
	Kansai	4.37	0.03	0.88	77	22%
	Chugoku	1.20	0.00	0.27	55	17%
	Shikoku	0.68	0.00	0.20	65	17%
	Kyushu	2.34	0.00	0.51	277	21%
	Japan	20.59	-	-	-	16%
2012	Hokkaido	0.58	0.00	0.13	142	12%
	Tohoku	0.79	0.02	0.30	30	7%
	Tokyo	15.16	0.02	2.20	36	31%
	Hokuriku	0.75	0.01	0.21	122	17%
	Chubu	1.04	0.01	0.45	14	7%
	Kansai	6.16	0.02	1.01	104	30%
	Chugoku	1.13	0.00	0.33	34	18%
	Shikoku	0.87	0.01	0.23	72	20%
	Kyushu	2.92	0.00	0.54	294	24%
	Japan	29.39	-	-	-	23%

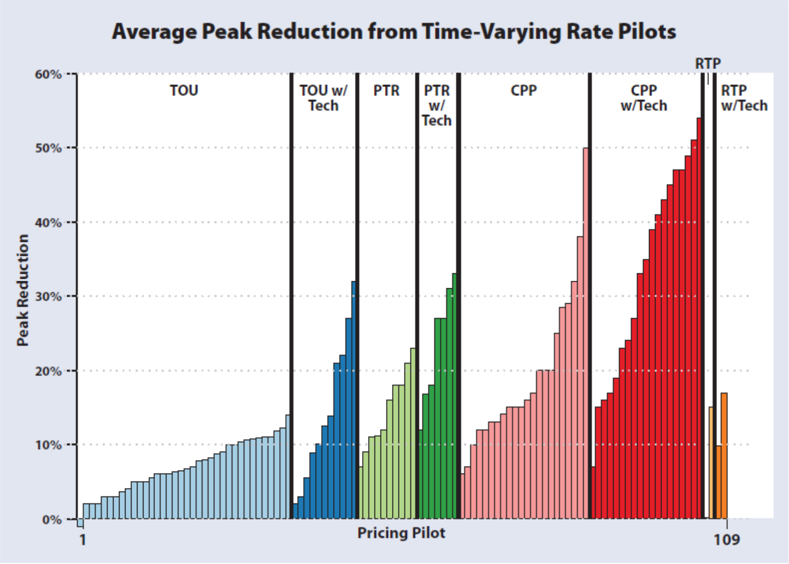
<Definition>
DR rate: DR capacity/electricity demand at the time the demand response event is called
Max DR rate: Maximum DR rate in a year, which does not necessarily coincide with maximum DR capacity.

2-4 Assessment of Electricity Reduction Rate by Demand Response in Case Studies

One of the examples of the active demand reduction is observed in the "Saving Electricity in a Hurry" campaign in the wake of the Great East Japan Earthquake in 2011. This electricity saving activity has a strong characteristic of national mobilization in an emergent situation and neither price signals nor economic incentives were offered. Though this is not a good reference for a general demand response program, the electricity demand in Tokyo in the summer of 2011 was reduced by 29% in the large business customer, by 19% in the small and medium business, and by 6% in the household sector. In 2012, the reduction rate was 2% to 7% in the winter and 5% to 12% in the summer, varying from region to region [6]. These saving rates prove that it is extremely difficult to secure a demand response with the 20% reduction rate required in 2.3.

In general, demand response is categorized into the tariff-based type that introduces a time-varying-rate and the incentive-based type that offers incentives as a function of reduced electricity demand and/or standby capacity [7]. Tariff-based demand response, which is expected to avoid excessive power generation investment in the long term, is constantly applied and not dispatchable. On the other hand, incentive-based demand responses are dispatchable when grid emergencies occur and the wholesale price hikes.

Fig. 2-3 Peak Reduction from Time-Varying Rate Demand Responses in the Households



Source : "Time-Varying and Dynamic Rate Design," The Brattle Group

Note : TOU is Time of Use, PTR is Peak Time Rebate, CPP is Critical Peak Pricing, RTP is Real Time Pricing. "w/Tech" means tariff-based demand responses equipped with automatic control system.

Note : These are pilot programs in North America, Australia and Europe.

According to a tariff-based demand response demonstration project in Japan [8], electricity demand was reduced by 10%[1]. Case studies in the world (Fig. 2-3) show a 10% to 20% reduction

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[1] This demonstration project observed 20% of electricity demand reduction by a combination of TOU and CPP, but reduction deriving from only CPP, which has an emergent measure, is 10%.

in the tariff-based demand response programs excluding Time-of-Use. However, these reductions were observed in the customers who participated in the programs and it must be extremely difficult to realize 20% reduction in a whole region that requires participation from all customers.

In principle, demand response designed to absorb wind power output variability requires certainty of response and should not be tariff-based but incentive-based, equipped with direct control. One of the cases of an incentive-based demand response program with direct control is the air conditioning control program of SDG&E in the United States [9], which shows that the electricity demand for air conditioning was reduced by 55% in households and by 21% in commercial buildings. Based on the summer electric load curve in Tokyo Electric Power Company [10], assuming the share of cooling in the peak demand to be 50% in either households or commercial buildings, applying the SDG&E results to Tokyo, the whole peak electricity demand is estimated to be reduced by 13%[2]. Assuming that the industrial sector also can reduce electricity demand by the same rate, a 13% reduction can be realized only if the all customers participate in the program. Though this rough calculation is carried out by only including air conditioning in the summer peak time, it can be concluded that demand response with a 20% reduction is unrealistically huge in scale.

To identify a feasible scale of demand response, detailed analyses on the potential in electricity demand reduction are required based on the electric load curve by type of use in the individual sectors. However, such detailed data is not available. Besides, it is not until the number and times of day of demand response events called are figured out that the feasibility of demand response can be evaluated.

In the following chapter, the maximum acceptable demand response rate in a whole region will be specified based on a study in the United States. Then, the feasible demand response is identified by analyzing the number and times of day of demand response events. Finally, how much contribution the demand response can make to increase wind power integration is revealed.

3. Evaluation of Feasibility of Necessary Demand Response Capacity

3-1 Maximum Required Demand Response and Wind Power Integration Capacity

Table 3-1 presents the peak demand reduction potential by incentive-based demand response in the United States. This potential comes from the reduction rate at the peak time where demand reduction is presumably easier and it is not evident that this reduction rate is also realizable in other

Table 3-1 Peak Demand Reduction Potential by Incentive-based Demand Response (USA)

	Summer	Winter
Wholesale market	4%	4%
Retail market	3%	4%
Overall market	7%	8%

Source : Estimated from the potential of demand response (“Demand Response & Advanced Metering Staff Report,” FERC, December 2012) and peak demand (“Electric Power Annual,” EIA, January 2013 EIA).

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[2] The peak time electricity demand is 18GW in the household sector and 25GW in the commercial sector. 18GW×50%×55%=4.95GW in the household sector, 25GW×50％×21％=2.63GW in the commercial sector and the total 7.85GW reduction is equivalent to 13% of 60GW peak demand.

times of day, and also a wholesale market does not exist in Japan. However, the threshold of the maximum DR (demand response) rate is assumed to be 5% here. And the relation between the maximum DR rate and the wind power integration potential is analyzed (Table 3-2).

The case of “Maximum DR rate = 0%” means that curtailment relaxes the constraint from ramping-down to ramping-up, which allows the wind power integration potential to increase. In this case, 24 GW to 26 GW of additional wind power to the existing capacity can be integrated nationwide. In addition, demand response with “maximum DR rate = 1%” and demand response with “maximum DR rate = 5%” allow 30 GW to 34G W and 44 GW to 48 GW, respectively. The wind power generation is about 45 TWh after curtailment by 0.5% to 2.6% in the case of “Maximum DR rate = 0%” and 80 TWh after curtailment by 3.3% to 4.9% in the case of “Maximum DR rate =5%.”

Table 3-2 Maximum DR Rate and Additional Wind Power Integration Potential

Year of wind condition	Region	Wind Power Capacity (GW)			Wind power generation (TWh) (after curtailment)			Curtailment rate		
		Max DR Rate			Max DR Rate			Max DR Rate		
		0%	1%	5%	0%	1%	5%	0%	1%	5%
2010	Hokkaido	0.79	0.86	1.33	1.8	2.0	3.0	0.1%	0.2%	0.7%
	Tohoku	2.72	3.27	6.16	5.4	6.5	11.6	0.2%	0.5%	5.4%
	Tokyo	8.78	9.44	12.10	13.6	14.6	18.6	0.1%	0.2%	0.5%
	Hokuriku	0.25	0.84	1.40	0.5	1.7	2.8	0.0%	0.6%	2.3%
	Chubu	7.36	8.20	11.92	15.3	17.0	23.6	1.3%	2.0%	6.4%
	Kansai	1.09	1.40	2.64	1.4	1.8	3.3	0.0%	0.1%	0.2%
	Chugoku	2.17	2.63	3.76	3.3	4.0	5.6	0.2%	0.5%	2.0%
	Shikoku	0.70	0.76	0.96	1.5	1.7	2.1	0.4%	0.5%	0.9%
	Kyushu	0.32	1.85	3.33	0.6	3.5	6.2	0.0%	0.0%	0.0%
	Japan	24.19	29.25	43.62	43.4	52.6	76.9	0.5%	0.8%	3.3%
2011	Hokkaido	0.50	0.69	1.39	1.1	1.6	3.2	0.0%	0.1%	0.7%
	Tohoku	5.18	5.56	7.04	10.5	11.2	13.7*	2.1%	2.7%	6.0%
	Tokyo	10.14	10.81	13.46	14.4	15.3	19.0	0.1%	0.2%	0.6%
	Hokuriku	0.72	0.87	1.34	1.4	1.7	2.6	0.2%	0.5%	1.7%
	Chubu	6.77	7.28	9.64	14.3	15.3	19.9	0.6%	0.9%	2.5%
	Kansai	0.08	4.40	7.00	0.1	5.3	8.3	0.0%	0.7%	2.5%
	Chugoku	2.54	3.03	4.11	3.7	4.3	5.8	0.6%	1.1%	3.1%
	Shikoku	0.02	0.24	0.82	0.0	0.5	1.7	0.0%	0.0%	0.6%
	Kyushu	0.04	1.25	3.66	0.1	2.4	6.9	0.0%	0.0%	0.1%
	Japan	25.99	34.13	48.45	45.6	57.7	81.2	0.8%	1.0%	2.4%
2012	Hokkaido	0.52	0.84	1.58	1.1	1.8	3.4	0.9%	1.1%	2.3%
	Tohoku	4.19	4.40	7.44	8.2	8.6	13.8	1.8%	2.0%	7.1%
	Tokyo	7.50	8.10	11.41	11.2	12.1	16.9	0.1%	0.1%	0.4%
	Hokuriku	0.08	0.73	1.08	0.1	1.4	2.1	0.7%	1.1%	1.7%
	Chubu	10.45	11.98	14.62	19.9	22.4	26.5	4.7%	6.3%	9.4%
	Kansai	1.01	3.33	4.25	1.2	4.0	5.1	0.0%	0.2%	0.6%
	Chugoku	0.04	1.00	2.79	0.1	1.4	3.9	1.0%	1.0%	2.0%
	Shikoku	0.48	0.67	0.90	1.0	1.4	1.8	0.7%	1.0%	1.4%
	Kyushu	0.28	1.90	3.43	0.5	3.5	6.3	0.4%	0.4%	0.4%
	Japan	24.55	32.96	47.49	43.4	56.7	79.9	2.6%	3.1%	4.9%

Note : Wind power generation is after curtailment.

Note : The necessary demand response rate to integrate the wind power potential allowed by curtailment while maximizing the net benefit in the Tohoku region in 2011 is 4.8%, less than 5%.

3-2 Annual Number of Demand Response Events

Table 3-3 shows the number of demand response events and the average demand response rate. If the wind power integration potential that is allowed by the curtailment cost effectiveness is introduced, about 100 events are to be called a year. The smaller the maximum demand response rate, the fewer the number of events: 10 times for demand response with “maximum DR rate = 5%” and two to three times for “maximum DR rate = 1%.” According to the cases in the United States (SD&G, PG&E, BG&E) [9][11][12] showing that the number of events in summer was 10 to 15 times, the number of events in the demand response with “maximum DR rate = 5%” is presumably the reasonable threshold.

Fig. 3-1 arranges all events by descending order in demand response rate, for the demand response with “maximum DR rate = 1%” and “maximum DR rate = 5%.” Even in the demand response with “maximum DR rate = 5%,” only a few events for demand response with a response rate close to the maximum rate are observed and the average demand response rate is no more than 2% (Table 3-3).

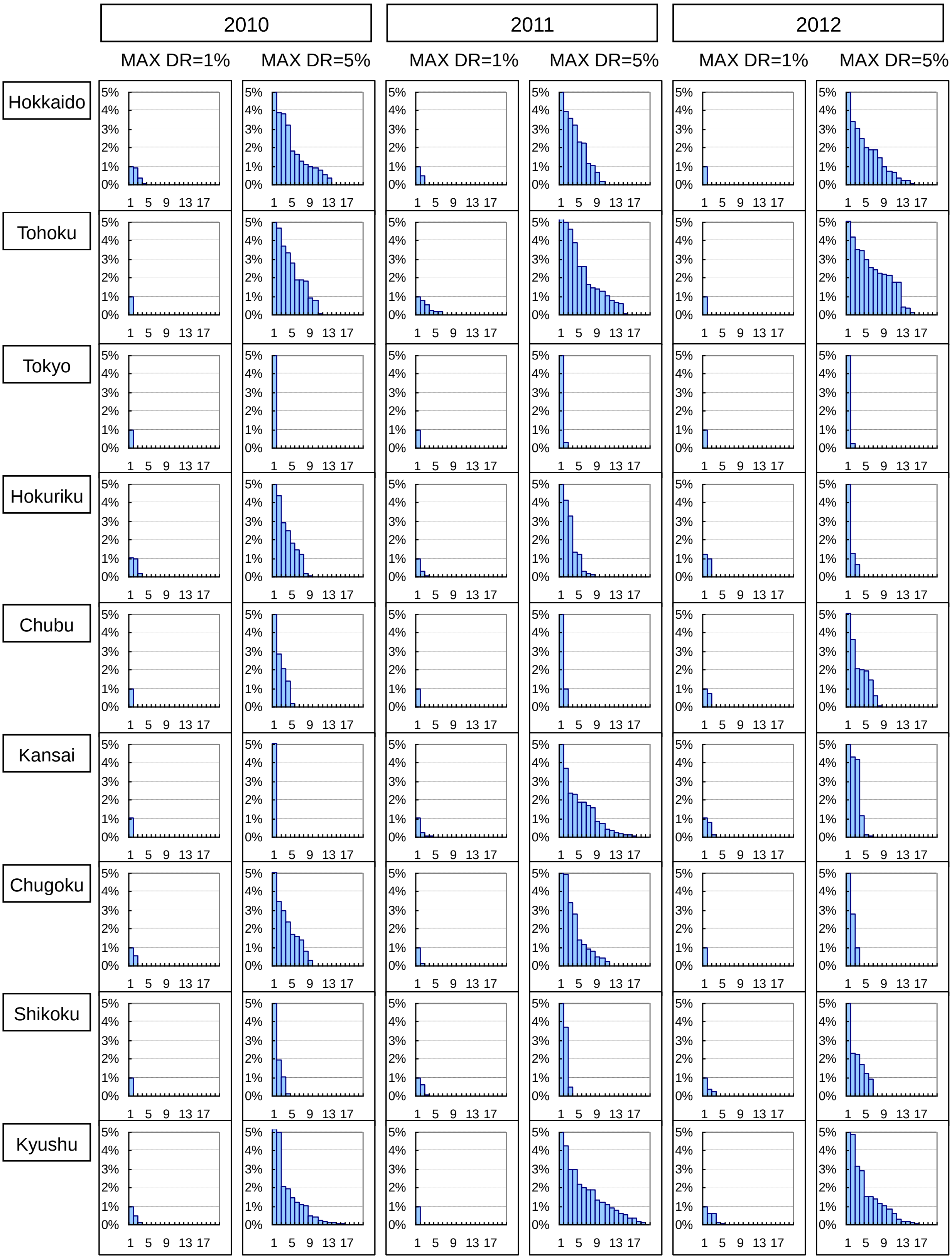
Table 3-3 Number of Demand Response Events and Average Demand Response Rate by Required Maximum DR Rate

Max DR rate→		Number of DR events				Average DR rate	
Year of wind condition	Region	1%	5%	10%	MAX*	1%	5%
2010	Hokkaido	4	14	43	141	0.6%	1.8%
	Tohoku	1	11	17	14	1.0%	2.6%
	Tokyo	1	1	3	24	1.0%	5.0%
	Hokuriku	3	9	37	107	0.7%	2.2%
	Chubu	1	5	16	9	1.0%	2.4%
	Kansai	1	1	4	101	1.0%	5.0%
	Chugoku	2	9	21	40	0.8%	2.2%
	Shikoku	1	5	16	80	1.0%	1.5%
	Kyushu	4	16	53	258	0.4%	1.3%
	Japan	2	8	23	86	0.8%	2.7%
2011	Hokkaido	2	10	74	149	0.8%	2.3%
	Tohoku	6	15	57	15	0.5%	2.2%
	Tokyo	1	2	16	28	1.0%	2.4%
	Hokuriku	3	8	31	119	0.4%	2.0%
	Chubu	1	2	11	15	1.0%	3.1%
	Kansai	4	17	27	77	0.4%	1.3%
	Chugoku	2	11	21	55	0.6%	1.9%
	Shikoku	3	3	22	65	0.6%	3.0%
	Kyushu	1	19	71	277	1.0%	1.6%
	Japan	3	10	37	89	0.7%	2.2%
2012	Hokkaido	1	15	119	142	1.0%	1.6%
	Tohoku	2	15	45	30	0.5%	2.4%
	Tokyo	1	2	3	36	1.0%	3.1%
	Hokuriku	2	3	9	122	1.1%	2.2%
	Chubu	2	8	16	14	0.9%	2.1%
	Kansai	3	6	13	104	0.6%	2.4%
	Chugoku	1	4	7	34	1.0%	2.1%
	Shikoku	3	6	9	72	0.5%	2.1%
	Kyushu	5	16	26	294	0.5%	1.5%
	Japan	2	8	27	94	0.8%	2.2%

Note : “MAX” means the maximum DR rate necessary to integrate the wind power potential allowed by curtailment while maximizing the net benefit (See Table 2-2) and varies depending on the region and year.

Note : There are some regions and years for which the maximum DR rate of “MAX” is smaller than 10%.

Fig. 3-1 Demand Response Rate of Individual Demand Response Events



Note : The vertical axis shows demand response rate.

3-3 Time of Day of Demand Response Event Called

Here, what time of the day in a year the demand response events are called is checked. Fig. 3-2 shows the case of Kyushu region based on the wind condition in 2012. The events are called 294 times a year in the demand response with “maximum DR rate = 24%,” and the events occur frequently at 16:00 to 19:00. In winter, more than 10 times as many are called in many time slots. As peak demand coincides with 18:00 to 19:00, it might be easier to reduce electricity demand. However, too many events are called. Decreasing the maximum DR rate to 10%, events are reduced to 26 times, but the busiest time slots stay at 16:00 to 19:00. Decreasing the maximum DR rate to 1%, the events become very sporadic.

Fig. 3-2 Number and Times of Demand Response Events by Required MAX DR Rate (Kyushu Region: 2012)

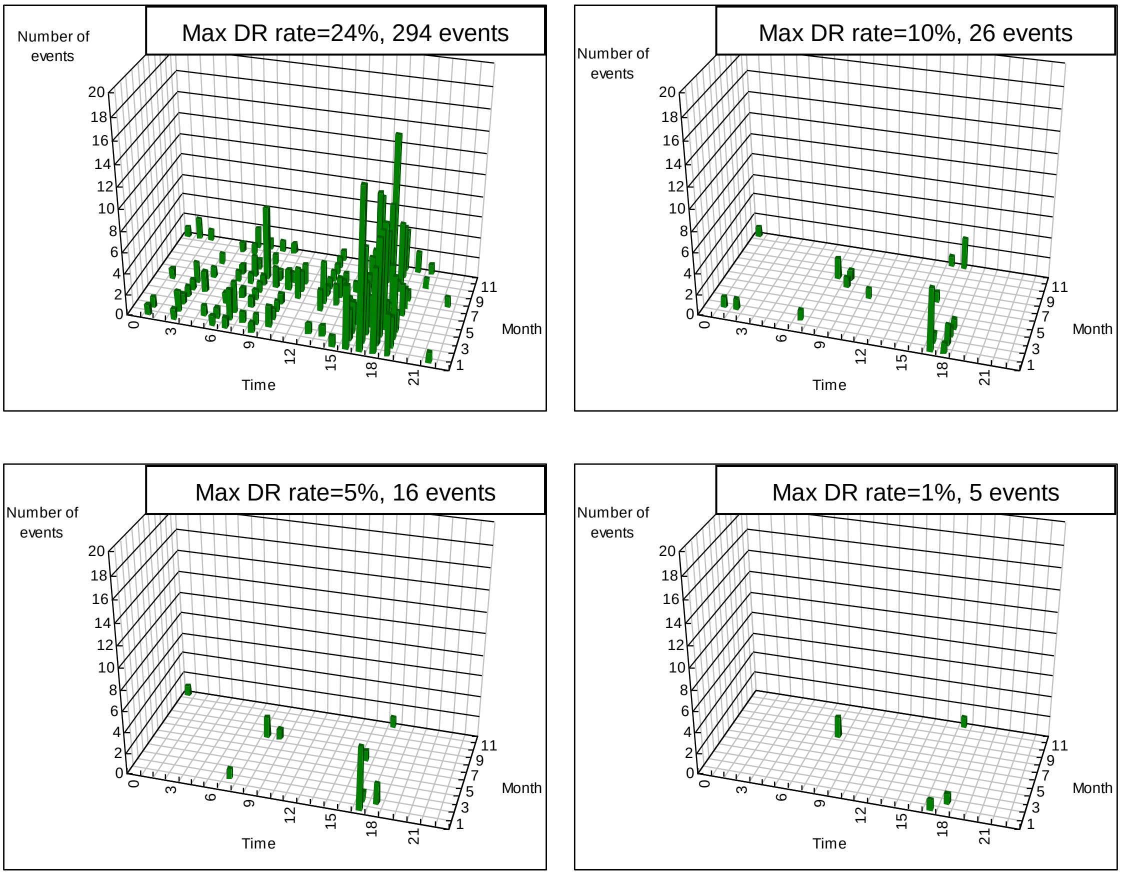
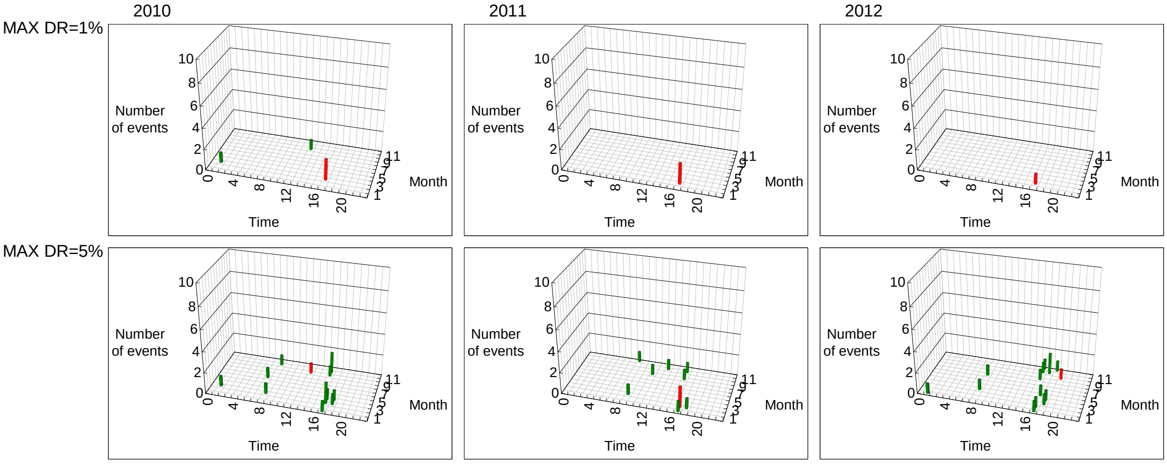


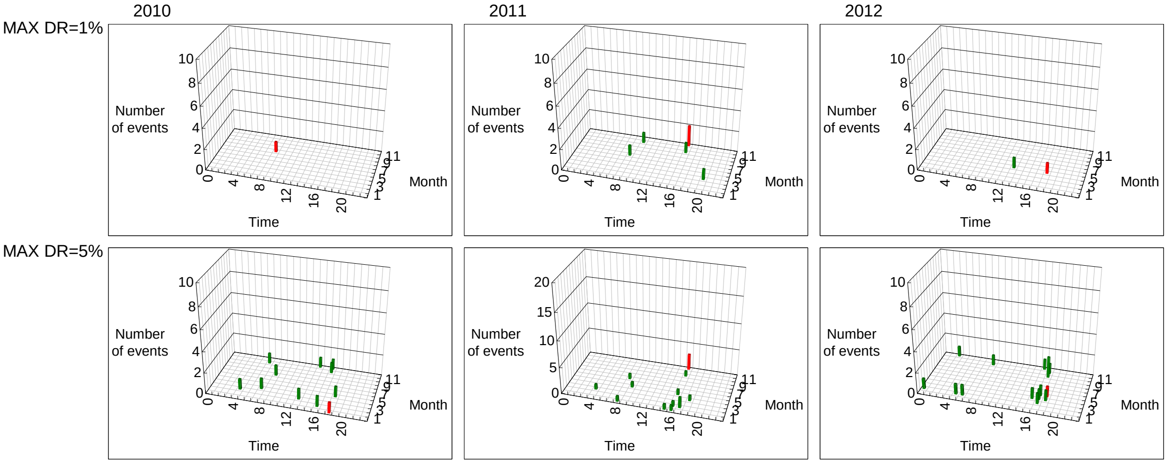
Fig. 3-3 - Fig. 3-5 show the number of events called in each time slot a year in the individual regions for the demand response with “maximum DR rate = 1%” and “maximum DR rate = 5%.” The red bar represents the time when the demand response with the maximum DR rate is called. Frequent event calls are observed in the morning and evening.

Fig. 3-3 Number and Times of Demand Response Event by Required MAX DR Rate (1)

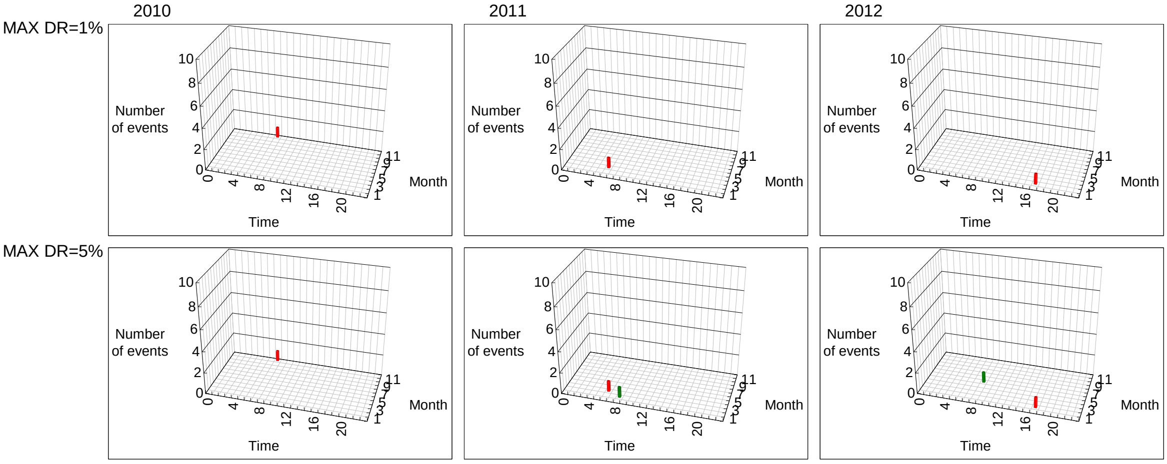
[Hokkaido]



[Tohoku]



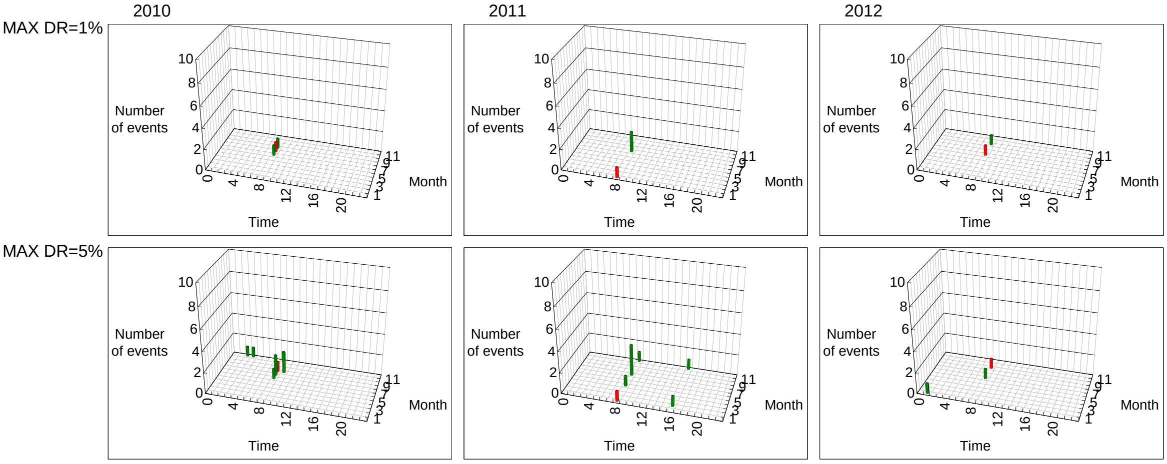
[Tokyo]



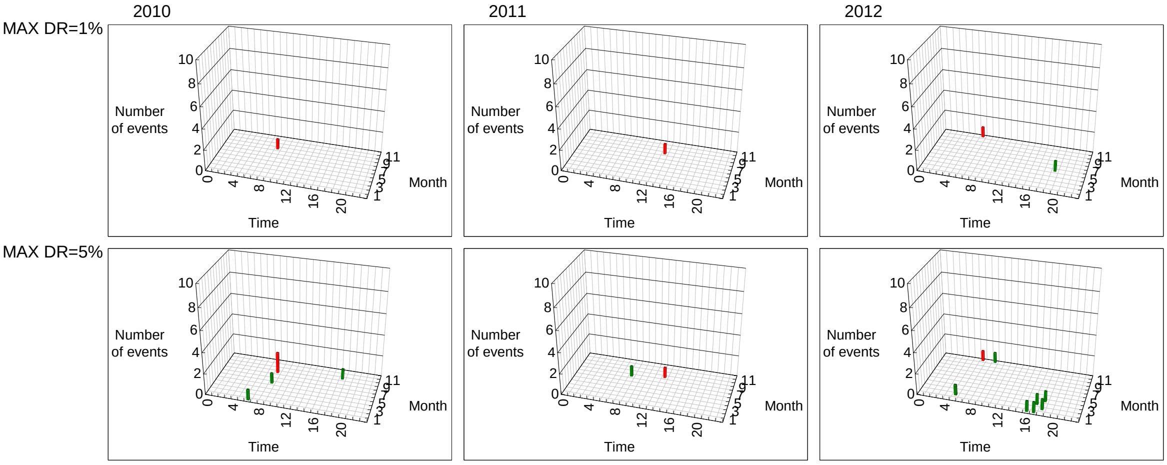
Note : Red bars represent the time when the demand response with the maximum DR rate is called. The demand response with the maximum DR rate is called only once a year.

Fig. 3-4　Number and Times of Demand Response Event by Required MAX DR Rate (2)

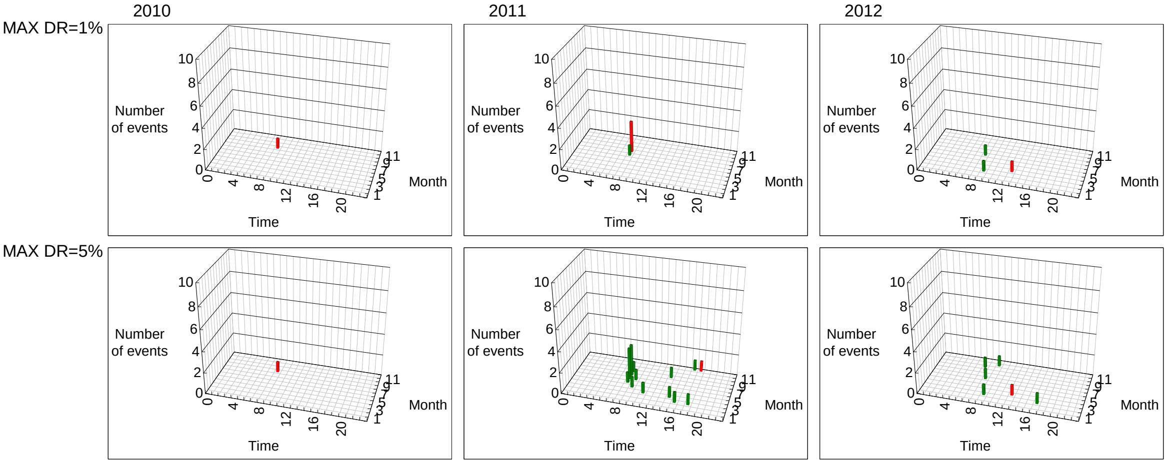
[Hokuriku]



[Chubu]



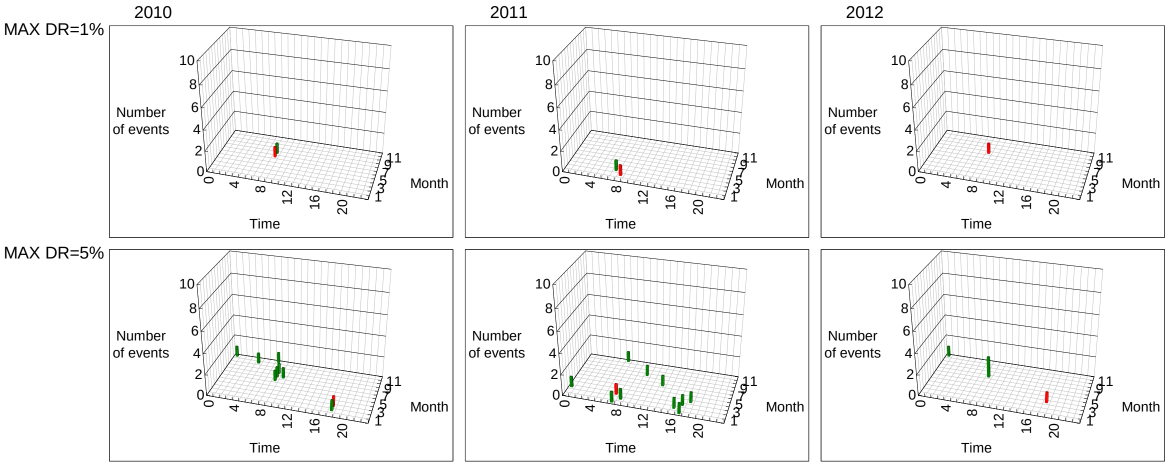
[Kansai]



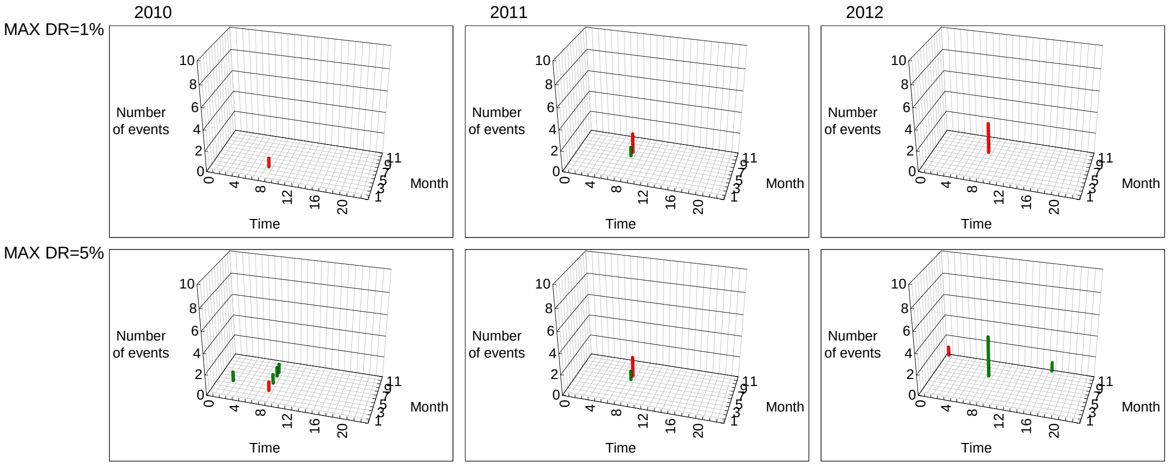
Note : Red bars represent the time when the demand response with the maximum DR rate is called. The demand response with the maximum DR rate is called only once a year.

Fig. 3-5 Number and Times of Demand Response Event by Required MAX DR Rate (3)

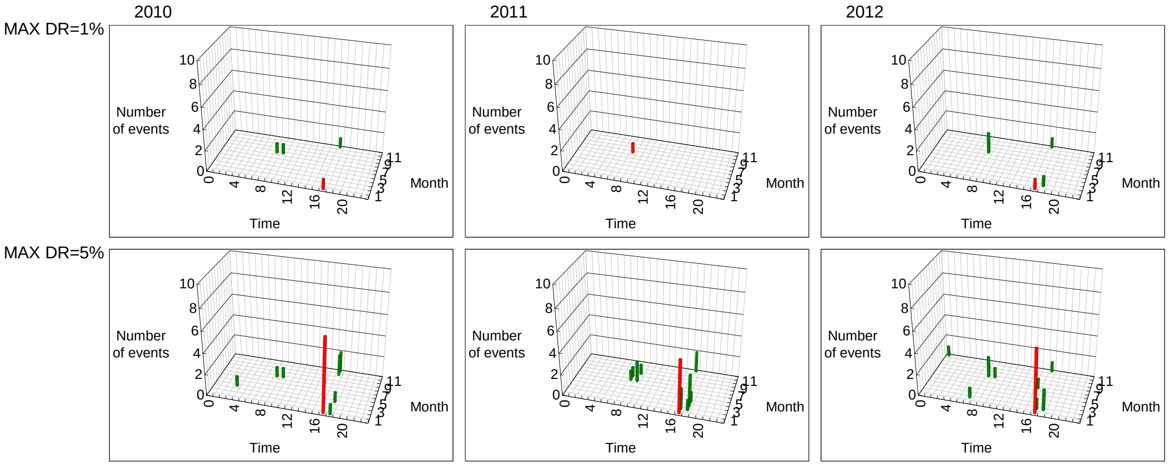
[Chugoku]



[Shikoku]



[Kyushu]



Note : Red bars represent the time when the demand response with the maximum DR rate is called. The demand response with the maximum DR rate is called only once a year.

3-4 Wind Power Integration Potential by Demand Response and Curtailment

In general, it can be easier to secure enough demand response at evening when the electricity demand is large. On the other hand, electricity demand analysis in detail by sector, by type of use and by equipment is necessary to evaluate whether demand response can be secured in the morning when the electricity demand starts rising. Although it would surely be rash to draw a conclusion based on the analyses above, demand response with “maximum DR rate = 1%” can be realized by 10% reduction in 10% of participants. On top of that, the number of demand response events is no more than twice a year. In the case of demand response with “maximum DR rate = 5%,” a higher participation rate and reduction rate are required and the number of events increases up to 10 times a year. Nevertheless, the demand response with a response rate close to the maximum DR rate is called less than a couple of times a year and the average DR rate is no more than 2%. As inconvenience on customers is limited, it is worthwhile to take up implementation of demand response designed to absorb the variability of wind power output. Incentive-based demand response with automatic control could make the response much more feasible.

Table 3-4 compares the demand response capacity by maximum DR rate with the capacity of the incentive-based demand response currently operated by the utilities with limited participation from large-scale customers in Japan, which is called “Demand & Supply Adjustment Contract.” The capacity lies between the necessary capacity for demand response with “maximum DR rate = 1%” and with “maximum DR rate = 5%.” Including the possibilities in the small- and medium-scale customers and households, it would presumably not be too difficult to secure the demand response capacity necessary for wind power integration.

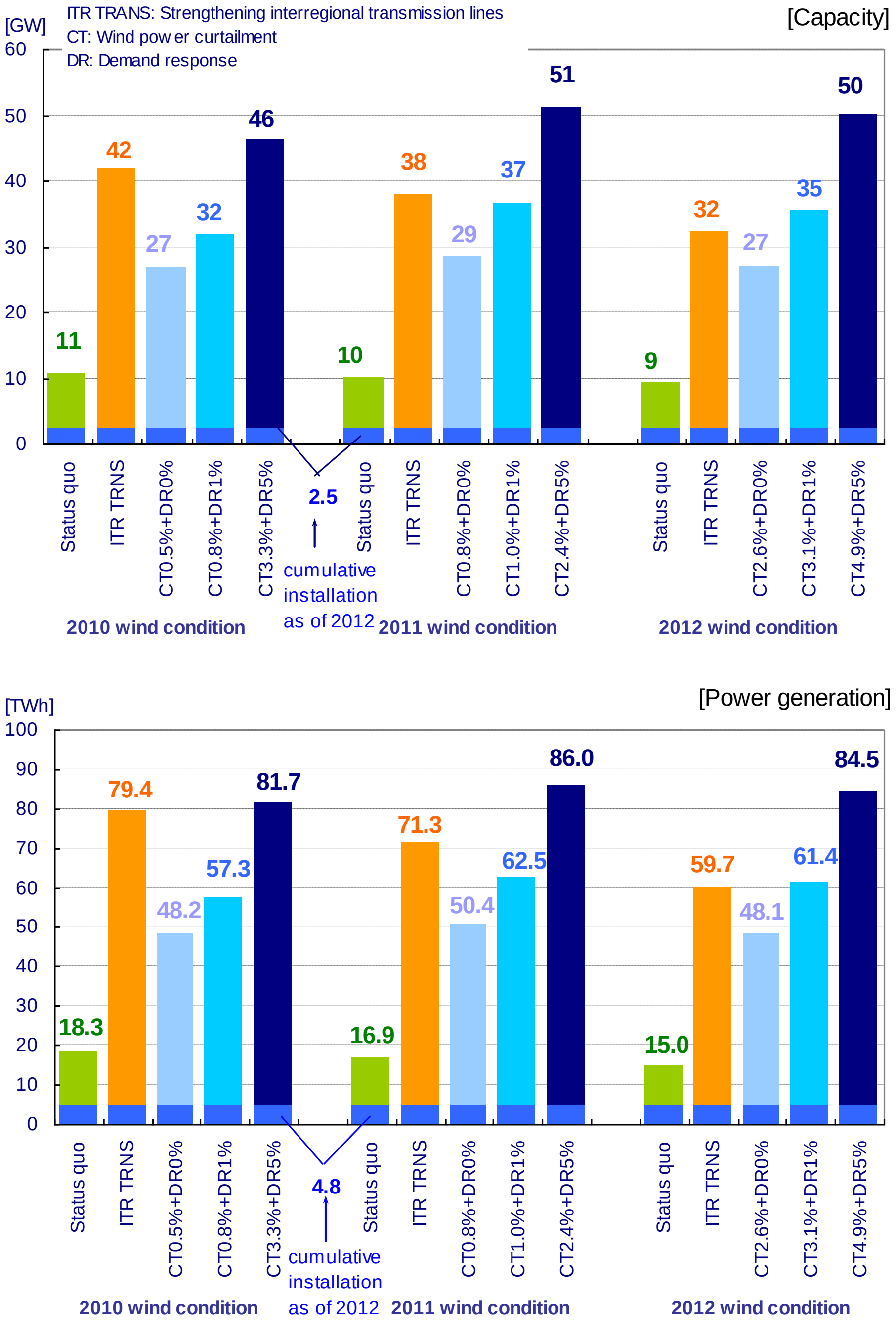
Table 3-4 Demand Response Capacity by Maximum Required DR Rate (GW)

Year of wind condition→	2010		2011		2012		D&S Adjustment contract[*2]
Max DR rate→	1%	5%	1%	5%	1%	5%	
Hokkaido	0.04	0.19	0.05	0.26	0.05	0.19	0.07
Tohoku	0.11	0.63	0.12	0.58	0.08	0.47	0.21
Tokyo	0.40	1.98	0.32	1.62	0.49	2.45	1.74
Hokuriku	0.04	0.19	0.04	0.23	0.04	0.17	0.20
Chubu	0.18	0.92	0.21	1.07	0.15	0.74	0.71
Kansai	0.20	0.99	0.22	0.98	0.21	1.01	0.36
Chugoku	0.09	0.39	0.09	0.40	0.09	0.30	1.14
Shikoku	0.03	0.16	0.04	0.20	0.04	0.15	0.21
Kyushu	0.12	0.61	0.12	0.55	0.12	0.62	0.33
Japan[*1]	1.23	6.07	1.22	5.88	1.27	6.09	4.96

*1 : As the event call time is different among regions, this does not mean the capacity required simultaneously.

*2 : Referred from “Electricity Outlook in Summer 2013,” The second committee of the Subcommittee for Evaluation of Electric Supply and Demand. D&S means demand and supply. Only “Occasional Adjustment Contract” that is designed to be called in an emergency is included; “Planning Adjustment Contract” is excluded.

Fig. 3-6 Wind Power Integration Potential by Curtailment and Demand Response



Note : The upper figure shows wind power capacity and the below shows power generation.

Note : The potential without measures and by strengthening interregional transmission lines are referred from [1].

Fig. 3-6 summarizes the wind power integration potential by curtailment and demand response in Japan. The wind power integration potential including the existing capacity as of March 2012 is 10GW without measures and power generation is 17TWh [1]. If the curtailment is implemented, the wind power capacity increases to 27GW and power generation is 49TWh after curtailment by

1% to 3%. Implementing the demand response with “maximum DR=1%” in addition to the curtailment, the potential increases to 32 to 37GW and power generation is 57 to 63TWh after curtailed by 1% to 3%. The demand response with “maximum DR=5%” can increase the potential to 46 to 51GW and power generation is 82 to 86TWh after curtailment by 2% to 5%. It is therefore revealed that 1% to 5% curtailment and demand response with 1% to 5% of the maximum DR rate can integrate wind power as much as 57 to 86TWh, equal to the impact brought by strengthening the interregional transmission lines [1].

3-5 Challenges toward Designing Demand Response

Although wind power curtailment should address institutional issues such as recompense for the curtailed power generation to the wind power generators, there are no major technological barriers, being widely implemented in the United States and Europe. Demand response employed majorly in the United States does not have technological barriers. Demand responses, though in most cases introduced aiming for peak cuts, are also playing a role in responding to grid emergencies, and could contribute to absorbing the output variability from renewable energy, if well-designed. Most of the cases of demand response for renewable integration use, at present, entail energy storage technologies that can reduce wind curtailment. However, the possibility of renewable integration by means of electricity demand reduction via demand response should also be addressed to avoid expensive energy storage technologies.

Among challenges in designing a demand response is that the demand response should be incentive-based and equipped with an automatic control system, since certainty in response is sine qua non for absorbing variable renewables. Involvement of aggregators who can provide the optimum demand responses by controlling a number of customers is highly recommended to assure response. Designing with regard to cost effectiveness, such as how much incentive should be offered for reduced electricity demand and/or standby capacity, is also one of the crucial issues.

METI Japan has started in 2013 the pilot projects for incentive-based demand response from which the results of economic analysis and feasibility evaluation are expected to come out soon.

Meanwhile, the most important challenge is to identify how much feasible demand response is available in each sector, type of use, equipment, season, day of the week and time of the day. It is not until the availability of demand response is identified in detail that the optimum combination of customers and type of use is proposed for designing the demand response with a 1% to 5% DR rate analyzed in this study. As a matter of course, energy usage with inertia such as air conditioning and refrigeration is able to surely provide demand response minimizing inconvenience on customers by automatic control, but we cannot heavily rely on lighting and miscellaneous usage. In addition, improvement in technology to forecast renewable energy power generation is also one of the crucial issues.

In order to tackle these challenges, collection of wide-ranging and detailed data and analysis of the data on both the demand and supply sides (renewable energy) are required, and BEMS (building and energy management system), HEMS (home energy management system) and AMI (advance metering infrastructure) are expected to play an important technological role. From an institutional point of view, the data collection and database architecture, contributing not only to renewable integration but also to energy management, energy supply planning and designing of smart energy network, should be addressed by every collaborating stakeholder.

4. Concluding Remarks

This study evaluated how much wind power can be integrated in Japan by adopting curtailment and demand response, subject to the ramping capability identified from the hourly electric demand variation, which can be interpreted as a “capability without additional effort” that the utilities are equipped with as aggregated dispatchable power plants. The required curtailment rate, demand response rate, number of demand response events and time of the year of the events were revealed.

The results show that the wind power integration, which is 10GW and 17TWh without any integration measures, increases as much as to 32GW to 51GW and 57 to 86TWh, equal to the potential yielded by strengthening interregional transmission lines, if 1% to 5% curtailment and demand response with 1% to 5% of the maximum DR rate are introduced. The average demand response rate is no more than 1% to 2% and the number of events called in a year is only two to ten. A very small fractional wind curtailment and demand response can yield a wind power potential equivalent to the potential by strengthening interregional transmission lines. Since strengthening the interregional transmission lines, which are important not only for renewable integration but for power exchange in Japan, requires huge investment cost and a long lead time, it is important that the demand response and curtailment measures should also be strongly promoted.

Research and development of energy storage technologies such as batteries and hydrogen as one of the renewable integration measures are of importance for their future exploitation. Nevertheless, these technologies remain within the concept that energy supply should follow energy service demand and this concept is the same as that of the stock-type centralized energy system. In order to integrate massive flow-type renewable energy, it is important to encourage consumers to be much more involved, not just relying on the supply side measures. Demand response, being effectively employed by existing and proven technology, can be expected to play an important role in involving consumers. Last but not least, for the demand response to be widely implemented, further evaluations on the feasibility of demand response based on the detailed data of hourly electricity demand by sector and by type of use as well as on renewable energy power generation are the challenges.

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