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Estimation on possibility and capacity of residential peak electricity demand reduction by demand response scenario in rural areas of Japan

Abdur Rohman and Hisashi Kobayashi*

Department of Regional and Environmental Science, Graduate School of Agriculture, Ibaraki University 3-21-1 Chuuo, Ami, Inashiki, Ibaraki,Japan 300-0393

Abstract

This study analyzes the potential peak demand reduction based on actual measurement result and outage scenarios acceptable to rural residential customers in Japan. To obtain the actual demand, load measurement was carried out on 18 households in Tsuru and 8 households in Izu during a week in winter, spring, and summer. The measurement result shows that the maximum demand in both areas occurred in winter. Daily aggregate peak demands extracted from the measurement were then modelled using Lognormal and Weibull distribution to obtain the probability of outage in any system's peak capacity value. On the other hand, to gauge the outage scenario that is acceptable to electricity consumers, an outage scenario representing an extremely rare case was selected from a nationwide survey. The survey result shows that six 2-hour outages per year with annual bill reduction of JPY30,000 is a feasible scenario. The modelling demonstrates that this scenario can result in 10.2% peak demand reduction in Tsuru and 5.2% peak demand reduction in Izu. The result of this study may be beneficial for distributed power system designers to determine optimum power system capacity as well as demand response programs acceptable to rural residential customers.

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Keywords: *peak demand reduction; power system capacity; demand response*

1. Introduction

In the wake of the 2011 Fukushima nuclear accident, the Government of Japan is preparing to reform the electricity system, including the expansion of renewable energy introduction and full liberalization of the electricity retail market and power generation[1]. Under this reform, decentralized generation of electricity from renewable energy resources is expected to grow in the near future especially in rural areas.

To design a decentralized power system, determining the system's optimum capacity to supply peak demand is crucial. A decrease in peak demand is always preferable because it will result in reduction in the operating cost of the expensive units needed to supply peak demand capacity and the cost of transmission line reinforcement [2].

* Corresponding author. Tel.: +81-29-888-8590; fax: +81-29-888-8525.
E-mail address: qkoba@mx.ibaraki.ac.jp

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The Demand Response (DR) approach has been implemented in several countries to reduce peak demand. The basic idea of this approach is that if the customers accept power reliability deterioration for monetary incentives, optimum trade-off between peak demand capacity and monetary incentives can be reached. A survey by FERC in 2012 found that the reported potential peak reduction generated by DR programs in the US has reached 66,351 MW, of which 30.5% was achieved during 2011[3]. A previous DR-related study[4] demonstrates the awareness of Japanese consumers to voluntarily reduce consumption of their main electrical appliances during peak period soon after the 2011 earthquake, and the resulted peak demand reduction. However, the study was not supported by the households' actual demand data.

The objective of this research is to estimate the possibility and capacity of peak reduction of residential demand in rural areas of Japan as a result of a DR approach. A novel method to estimate the possibility and capacity of peak reduction, based on actual demand measurement and a survey, is presented.

2. Method

Two areas with different characteristics were selected. These were Tsuru in Yamanashi Prefecture (Area 1) and Izu in Shizuoka Prefecture (Area 2). To obtain seasonal electricity demand profiles, the actual electricity current of 18 households in Area 1 and 8 households in Area 2 was recorded using clamp sensors and loggers with 2-minute intervals for at least one week in, respectively, winter, spring, and summer. The measurement was carried out in January and February 2013 for winter (14 days in each area), May 2013 for spring (7 days in each area), and July and August 2013 for summer (8 days in Area 1 and 13 days in Area 2).

Meanwhile, a nationwide survey was conducted to gauge the range of deterioration in a power system that costumers are willing to accept. The survey was conducted with 1,668 subjects during the period between November 2012 and January 2013. The survey presented three sets of hypothetical outage scenarios, namely: various outages with no bill reduction, ones with various amounts of bill reduction, and 2-hour outages occurring six times per year. The respondents were asked if they could accept each outage option. As for the six-times-2-hour-outages scenario, respondents who would accept it were then asked to suggest the amount of electricity bill reduction that would enable them to accept it. This scenario was presented to represent an extreme deterioration.

3. Result and Discussion

3.1 Measurement Results

The maximum daily peak demand in both areas occurred in winter. Fig. 1 shows an example of aggregate demand of 18 households of Area 1 calculated from measurement data in winter. The daily peak demand values of the whole measurement in both areas are summarized in Table 1.

3.2 Survey Results

The number responses of the survey amounted to 1,629 responses for no-bill-reduction outage scenarios, 1,626 for various-bill-reduction outage scenarios, and 1,655 for six-times-2-hour-outages scenario. As for the no-bill-reduction outage scenarios, five scenarios gained acceptance rates higher than 50%, namely one to four 30-minute outage(s) per year (76%, 69%, 60%, and 57%, respectively) and one 1-hour outage per year (51%). As for various-bill-reduction outage scenarios, the survey result shows that the acceptance rate correlated strongly with the amount of bill reduction. As for six 2-hour outage scenario, 666 (40.2%) respondents could accept it provided they would receive a specified amount of annual bill reduction, whereas others refused the scenario. The summary of bill reduction data suggested by the respondents is shown in Table 2. The annual bill reduction of JPY30,000 was accepted by 84.8% of the 666 respondents, including 11 of 12 respondents of Area 1, and 8 of 9 respondents of Area 2. The acceptance rate of 40.2% for six 2-hour outages per year with JPY30,000 annual bill reduction, despite the extreme inconvenience of this scenario compared to other scenarios, demonstrated that it is a feasible scenario for both areas.

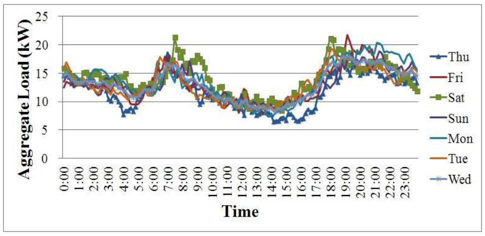

Fig 1. Aggregate winter demand of 18 households in Area 1

Table 1. Summary of Peak Demand Measurement Data

	Area 1	Area 2
Number of Days	29	34
Maximum(kW)	23.10	13.00
Minimum(kW)	12.92	6.95
Mean	17.13	10.30
Standard Deviation	2.78	1.80
Skewness	0.32	-0.48

Table 2. Summary of Bill Reduction Data (n=666)

Minimum	1st Qu	Median	3rd Qu	maximum	Mean	sd
JPY0	JPY10,000	JPY20,000	JPY30,000	JPY360,000	JPY22,870	JPY26,920

3.3 Modeling the Results

We modeled the daily peak demands for both areas using a probability distribution based on the Empirical Cumulative Distribution Function (ECDF) of the daily peak demand data. Five probability distributions, namely, Exponential, Normal, Lognormal, Gamma, and Weibull, were fitted to the daily peak load data. The Kolmogorov-Smirnov test (K-S test) using Monte Carlo procedures proposed in[5] with 10000 synthetic datasets was used to select the distributions that best fitted the data. The K-S test result shows that Lognormal best fitted peak demand data of Area 1, while Weibull best fitted the data of Area 2, as shown in Table 3 and Fig 2.

Table 3 K-S test error of six probability distributions and their p-values
(Note : A model will be ruled out if its p-value ≤0.05)

Distribution Name	Peak Demand of Area 1		Peak Demand of Area 2	
	KS Test Error	p-value	KS Test Error	p-value
Exponential	0.530	0	0.491	0
Normal	0.172	0.029	0.098	0.560
Lognormal	**0.152**	**0.081**	0.131	0.143
Gamma	0.159	0.059	0.118	0.266
Weibull	0.175	0.021	**0.093**	**0.629**

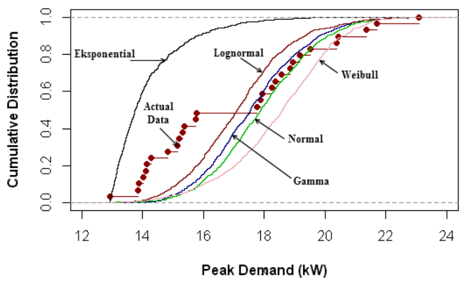

Fig 2 Visualization of goodness of fit among five CDFs and ECDF of actual peak demand of Area 1

The probability of exceedance of a daily peak load Xp is defined as

$$P(X>Xp) = 1 - P(X \le Xp) \quad \ldots\ldots(1)$$

where $P(X \le Xp)$ is the probability that random daily peak demand X has the value less or equal to Xp. The value of $P(X \le Xp)$ is found in the CDF of corresponding distribution of X.

Assuming that the daily peak demand occurs independently, the return period of Xp, which is the expected days between two successive Xp, can be derived as[6]:

$$R(Xp) = 1/P(X>Xp) \quad \ldots\ldots(2)$$

A peak demand value with a 10-day return period, for instance, can be expected to occur once in 10 days. It also means the value has the probability of occurring of 1/10 in any day. Table 4 shows peak demand values of households in both areas and the corresponding return periods based on calculation using Lognormal distribution for Area 1 and Weibull distribution for Area 2. The peak demand value of 23.69 kW is expected to be exceeded once in 60 days in Area 1. Thus, if a power system supplying the 18 households in Area 1 is designed with 23.69 kW capacity, six outages can be expected in a year. This system design will be acceptable if the scenario of six outages per year, as the one presented in our survey, is acceptable to the system's customers.

Table 4 Peak demand values with their corresponding return period

Return Period (days)	Peak Demand (kW) Area 1	Area 2
60	23.69	13.41
120	24.71	13.71
180	25.28	13.86
360	26.24	14.11
400	26.38	14.14

Table 5 Peak demand reduction with various scenarios of outage frequencies

Annual Outage Frequency	Area 1		Area 2	
	Aggregate (kW)	Average (W/household)	Aggregate (kW)	Average (W/household)
1	0.14	7.78	0.03	3.75
2	1.10	61.11	0.28	35.00
3	1.67	92.78	0.43	53.75
6	2.69	149.44	0.73	91.25

To calculate the peak capacity reduction resulted from the scenario, the value of 26.38 kW and 14.14 kW are set as the system's base capacity for Area 1 and Area 2, respectively. These values, each of which have 400-day return period, are selected because they represent zero-annual-outage scenarios. As seen in Table 4 and Table 5, comparison of the six-2-hour-annual-outage capacity with the base capacity shows that 26.38-23.69 =2.69 kW (10.2%) peak capacity reduction can be expected for Area 1. In the same way of reasoning using 13.41 kW as the six-2-hour-annual-outage capacity, peak capacity reduction of 5.2% can be expected for Area 2. If the scenario of three outages per year, instead of six, is implemented, the expected peak demand reduction will be 1.67 kW (6.3%) for Area 1 and 0.43 kW (3.0%) for Area 2.

4. Conclusion

This study demonstrated the strong possibility that a Demand Response scenario in the form of annual outages with specified amount of bill reduction is an approach acceptable to residential customers in Japan. The scenario could reduce peak demand and thus facilitate optimization of the design of the renewable electricity supply system in rural areas. In the future, research with larger samples of daily peak demand data will be necessary to improve the current model.

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Biography

Abdur Rohman is a Master student at Department of Regional and Environmental Science, Graduate School of Agriculture, Ibaraki University.

Hisashi Kobayashi is a Professor at Department of Regional and Environmental Science, Graduate School of Agriculture, Ibaraki University. He received Dr.Agr from Tokyo University of Agriculture and Technology (1996).