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An Analysis on Power Demand Reduction Effects of Demand Response Systems in the Smart Grid Environment in Korea

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Abstract – This study performed an analysis on power demand reduction effects exhibited by demand response programs, which are advanced from traditional demand-side management programs, in the smart grid environment. The target demand response systems for the analysis included incentive-based load control systems (2 month-ahead demand control system, 1~5 days ahead demand control system, and demand bidding system), which are currently implemented in Korea, and price-based demand response systems (mainly critical peak pricing system or real-time pricing system, currently not implemented, but representative demand response systems). Firstly, the status of the above systems at home and abroad was briefly examined. Next, energy saving effects and peak demand reduction effects of implementing the critical peak or real-time pricing systems, which are price-based demand response systems, and the existing incentive-based load control systems were estimated.

Keywords: Smart Grid, Demand Response, Incentive-based, Price-based, Demand Reduction

1. Introduction

Smart grids can be defined as the next-generation grids that optimize energy efficiency through interactive exchanges of real-time power information between the supplier and the consumer by integrating information & communication technology (ICT) into existing grids. When smart grids are built up, interactive power information exchanges, which are differentiated from the existing one-way information exchange system, are enabled. This, in turn, encourages the reasonable energy consumption of consumers and realizes the supply of high-quality energies and various supplementary services. In addition, smart grids are an open system that can facilitate the incorporation and expansion of clean green technologies such as renewable energies and electric vehicles, thereby enabling the creation of new businesses through the convergence and integration of industries.

In particular, among the above smart grid concepts, this study focused on the concept of demand response based on the advanced metering infrastructure (AMI), which is a key infrastructure in the 'smart consumer' field. When smart grids are redefined based on this technology, these can be defined as the 'infrastructure that provides customers with sufficient information to rationally use electricity by comparing and analyzing tariffs under various tariff systems. If such smart grids are distributed, the rationalization of energy consumption will become possible by establishing an interactive total energy management system based on the AMI, evolved from the current one-way and closed energy supply system. Moreover, by installing smart meters or building an AMI, the supply of household appliances which can save energy consumption in response to electricity prices, and load management will be realized. This, in turn, will give rise to energy saving and peak demand reduction effects.

However, to more effectively induce changes in the power consumption of customers, most countries not only equip themselves with an AMI system, but also implement supplementary systems such as demand response systems. Demand response systems are designed to help consumers make rational use of power consumption patterns by responding in a way to prevent price variations or the decline of supply reliability that can take place in such cases as rapid fluctuations of power generation prices, power facility accidents, and abrupt fluctuations of power demand. These systems are largely divided into price-based and incentive-based systems. The price-based systems include real-time pricing (RTP) and critical peak pricing (CPP) systems. The incentive-based systems include various systems related to permanent or emergency demand reduction. In a review of Korean cases, currently implemented systems include the demand control system for designated periods, weekly-notice demand control system, and demand bidding system (demand resources market). Basically, smart girds have the function to provide sufficient information to help customers save their electricity by spontaneously comparing and analyzing electricity prices.

In other words, smart grids should provide information in a manner that clearly conveys customers the idea that electricity rates increase if they increase electricity consumption during specific hours by delivering time-

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based rate variations. Along with this, if the RTP system that implements real-time changes in electricity rates or the CPP system that increases electricity rates only during peak hours are implemented, consumers are encouraged to make further efforts to reduce electricity consumption in response to such systems.

In general, if a customer's electricity bills vary across time, he/she is likely to compare the current bills or energy consumption with those of the same month in the past, or with those of another consumer who has the same consumption scale and characteristics with his/hers. Based on this activity, if the customer's electricity consumption or bills are found to be well above an average level, he/she will attempt to reduce the consumption of electric energy by gaining the tendency to analyze its causes, thereby returning to a standard level. In response to such an information delivery system, customers are likely to respond to the following concepts. Firstly, they will try to reduce the hours of using electric devices for a simple reduction in energy consumption or curb the use of unnecessary electric devices. Secondly, if electricity rates vary with time as the result of their analysis, the customers are likely to move a part of their electricity consumption to other time slots that offer relatively lower rates. Besides such measures, customers may consider more fundamental solutions. For example, they may replace electric appliances with the largest electricity consumption levels among their electric devices with high-efficiency devices that lower electricity consumption. Moreover, they might switch to other energy sources that present price advantages (e.g. gas, oil). However, in terms of the response to electricity prices, customers with large levels of electricity consumption are inclined to be much more sensitive. This can be easily explained by a large difference in actual payments caused by the same 10% raise of electricity prices, for example, a monthly average increase from 10,000 won to 11,000 won, and a monthly average increase from 1 billion won to 1.1 billion. In other words, smart grids are also a means of saving energy through customers' spontaneous response of comparison and analysis on their electricity prices.

The most important thing in analyzing the effects of establishing a smart grid infrastructure is to estimate the energy saving potential that can be attained by such demand responses. Essentially, smart grids are perceived as an important instrument to save energy rather than reduce peak loads. However, besides energy saving, smart grids also have an important meaning in basic plans for demand supply. In particular, facing the recent events of power shortage, the analysis of peak load reduction effects when demand responses are implemented after a smart grid infrastructure has been established presents an important meaning. Therefore, this study intended to analyze the above two aspects simultaneously.

Demand response systems are divided into incentive-based and price-based systems. For the analysis of overall energy saving effects stemming from demand responses, firstly, energy saving effects and peak load reduction effects of domestically implemented incentive-based systems were analyzed. Domestically implemented incentive-based systems include the demand control system for designated periods, weekly-notice demand control system, and demand bidding system. According to the internal data of Korea Electric Power Corporation (KEPCO), 97% of the customers participating in these systems were for industrial purposes. Their loads exhibited a minimal proportion of immediately controllable lighting or cooling and heating loads. Thus, they were mostly participating in the systems in the form of adjusting operations or repair times.

Secondly, while not currently implemented in Korea, the CPP system and the RTP systems, which are representative price-based systems, were analyzed in terms of their effects. Most industrial loads exhibit consistent patterns across time intervals, thereby lowering the effects of price-based systems even if they are applied. In this respect, the price-based systems were analyzed with a focus on residential and commercial (including educational) loads.

2. Demand Response Systems

To analyze energy saving effects exhibited by the implementation of demand response systems via smart grids, firstly, the data of the US, the country that has operated various demand response programs by creating a more advanced power market than Korea, were firstly examined. The following demand response programs have been implemented in the US to date [1].

- Incentive-based demand response
  - Direct load control
  - Interruptible/curtailable rates
  - Demand bidding/buyback programs
  - Emergency demand response programs
  - Capacity market programs
  - Ancillary-services market programs

In the country, most states are operating market-based demand response programs in lieu of the past programs based on the concept of load management. The participation of consumers is based on their response to compensation levels. In this case, 'demand response' indicates the consumer response of reducing power consumption or changing consumption hours if electricity rates increase during peak demand hours in power systems, or the consumer response when power system operators or utilities offer incentives. In other words, demand response refers to the response of power users to time-based differential pricing systems or incentive systems to reduce power usage in times of price hikes in the power market or lowered system reliability, thereby changing their power consumption patterns. In the US, soaring electricity prices once became social problems, mainly surrounding the regions that had introduced competitive wholesale power markets, such as California and New York. One of the causes for this was that customer power consumption patterns did not change even when the price signals did not properly work and prices soared. As this shows, demand response programs have been introduced to resolve the problem of price elasticity.

In traditional demand management programs, loads have been controlled at the discretion of utilities. On the other hand, in demand response programs, consumers who are awakened to the economic values of power participate in the power market and practice load control according to their own judgment. In other words, demand response systems enable consumers to change their power consumption patterns in a near real-time pattern in response to electricity price variations. The demand response systems can be divided into price-based and incentive-based systems depending on the ways to create demand response, in other words, how to induce consumer responses. Other categories include permanent programs that pursue the economic benefits of utilities and emergency programs aimed at maintaining reliability in case of backup power drops or accidents.

Among them, the incentive-based demand response programs are introduced and operated by utilities or load service entities (LSE). These programs offer their consumer participants demand curtailment incentives. These incentives can be programmed to vary according to time or have fixed values based on averages. Requesting customers to reduce their power demand is necessary when a system's reliability is seriously lowered or market prices sharply rise. Such requests are directly made by the program operator to customers. Most incentive-based demand response programs specify the methods to set power consumption standards for consumers, by which consumer demand reduction levels are measured and checked.

In comparing the above programs with the load control systems and demand response in Korea, both similarities and differences are revealed. The above programs are similar to the spontaneous systems and emergency demand response systems out of the incentive-based demand response systems among the country's demand response systems. However, while such programs are introduced in case of rapid back power declines or accidents in overseas markets, the Korean load management pricing systems have been introduced to suppress peak demands that take place during the summer season.

On the other hand, in the state of New York (NY) in the eastern U.S. and the states of Pennsylvania, New Jersey, and Maryland (PJM), demand response systems are employed for emergency resources. In the NY state, incentives are provided based on \$0.45/kWh. As for emergency resources, incentives are set at higher levels. The NY program is an emergency demand response program. In this program, while customers who reduce loads during peak hours are provided with incentives, their practice of load reduction is not compulsory, but voluntary. In other words, upon the utility's notification, customers can still give up incentives and reject load reduction. Even if some customers do not reduce loads, the utility does not impose fines. The incentive levels are mostly determined in advance, and on average, range from \$350/MWh to \$500/MWh for reduced loads. The emergency programs offered by utilities are mainly utilized by independent system operators (ISO) and regional transmission organizations (RTO). Particularly, the emergency demand response program (EDRP) of the New York Independent System Operator (NYISO) succeeded in drawing a high level of customer participation. The EDRP's operation played the role of supplying a majority of resources on the demand side during the periods of backup power shortage in NY over the past couple of years.

Meanwhile, a FERC report [2] noted that the U.S. exhibited an average 7% of energy saving potential based on the national maximum peak within annual 100 hours via the demand response systems. Certainly, this is a ratio to the national peak power. In case of single loads, the ESP varies from 0% to 30%.

Next, an analysis was performed on the reduction rates based on standard loads during peak hours according to customer types while the CPP system (20kW or higher commercial and industrial customers, between 11:00am and 6:00pm, 18 times per year, advanced notice at 3:00 pm the day before) and the RTP system (residential, commercial, and industrial customers) were actually applied in California (PG&E, SCE, SDG&E). In a review of the analysis data [3-5], firstly, the CPP system was implemented between 2:00pm and 6:00pm, whereas the electricity rates during the 'event days' were raised more than five to ten times. According to the analysis results, based on individual loads during the respective hours, the average reduction rates ranged from 5% to 20% kW of standard loads. However, given that total loads cannot be reduced at such radical levels, reduction effects against the total loads certainly become much lower.

The representative demand response programs in the U.S. were summarized as follows. Detailed explanations were omitted for lack of space.

- ○ The NYISO Programs in the U.S.
  - Emergency Demand Response Program (EDRP)
  - ICAP/Special Case Resources (ICAP/SCR): Auction
  - Day-Ahead Demand Response Program (DADRP): Market-based
  - Demand-Side Ancillary Service Program (DSASP): Market-based
- ○ The PJM(Pennsylvania, New Jersey, etc) programs in the USAx

Table 1. Outline of domestic load management systems

Category	Means of implementation	System name	Load management type	Implementation period	Method	Characteristic
Load control systems	Load reduction (No installation of devices) - Permanent	2 month-ahead demand control system	Peak demand reduction, Peak shifting	In summer	Provision of incentives	Voluntary
		1~5 days ahead demand control system	Peak demand reduction, Peak shifting	In summer/winter, In backup power shortage	Provision of incentives	Voluntary
		Demand bidding system	Peak demand reduction, Peak shifting	In summer/winter, In backup power shortage	Provision of incentives	
	Load reduction (No installation of devices) - Emergency	Direct load control support system	Peak demand reduction	In summer/winter, In backup power shortage	Provision of incentives	
		Emergency voluntary energy-saving system	Peak demand reduction	Emergency (In absolute backup power shortage)	Provision of incentives	Voluntary

- Emergency-Energy only, Emergency-Capacity only, Emergency-Full : Market-base
- Economic Program: Day Ahead Market, Real-Time Market : Market-based

○ The California Utilities (SCE, PG&E, SDG&E, etc) Programs (* partial implementation) in the U.S.
- Base Interruptible Program
- Large Interruptible Program
- Agricultural and Pumping Interruptible Program
- Scheduled Load Reduction Program
- Demand Bidding Program: Market-based
- Critical Peak Pricing (critical peak pricing system)
- Optional Binding Mandatory Curtailment Plan (Self-reduction in rolling blackouts)
- Summer Discount Plan (Installation of central cooler control devices)
- Smart Thermostat Program* (Installation of residential cooling temperature control devices)
- Schedule 20/20* (for small and medium commercial customers)
- Peak Generation Program*(operation of self-powered devices)

○ The TEXAS-region (within the operation of the ERCOT) Utilities Programs in the U.S.
- Voluntary Load Response (VLR)
- Load Resources
- Emergency Interruptible Load Service (EILS)

As a next step, domestically implemented incentive-based systems were examined [6]. Among the various systems implemented in Korea, the incentive-based systems that account for the largest share in curbing peak demands are the load control systems. The purpose of these systems is to reduce peak power when necessary based on the voluntary contract of customers, not through variations in electricity rates or the installation of devices. The leading systems include the 2 month-ahead demand control system for designated periods, 1~5 days ahead demand control system, and demand bidding system, which are preferred permanent systems, as well as the direct load system and emergency voluntary energy-saving system, which are emergency systems. Their contents are briefly listed in the below table.

3. An Analysis on Domestic Energy Saving Effects of Demand Response Systems

As mentioned earlier, demand response systems are divided into incentive-based and price-based systems. To analyze the overall energy saving effects created by demand response, firstly, domestic incentive-based systems were analyzed. Domestically implemented incentive-based systems include 2 month-ahead demand control system, 1~5 days ahead demand control system, and demand bidding system. According to the internal data of KEPCO, 97% of the customers participating in such systems are industrial customers. The company was reported to carry out energy saving activities equivalent to daily about two hours for about 40 days per year [9]. As a result, the company generated energy saving effects of around 2% to 3% of the peak demand (around 1,460 to 2,200MW, when assuming a peak demand of 73,000MW). Essentially, these systems are not aimed at saving energy, but saving peak energy. Despite the fact, the analysis on energy saving effects of these systems revealed the energy saving amount of about 176[GWh], which was equivalent to an energy saving rate of 0.04% based on the total energy of 471,966[GWh] in 2013. This suggests that the actual effects were minimal.

$$\frac{2{,}200\text{MW} \times 1{,}000 \times 40\text{days} \times 2\text{hours}}{1{,}000{,}000} = 176[\text{GWh}] \qquad (1)$$

Following this, the effects of the price-based demand response systems were examined. The representative demand response systems which are implemented through smart grids are the CPP system and RTP system. However, these systems have not yet been implemented in Korea. Therefore, their analysis was only enabled based on certain assumptions.

Firstly, reviewing the CPP system, this system encourages the reduction in power demand by greatly raising electricity prices during the hours when demands are concentrated in summer or winter seasons. Based on the analysis of weekly power consumption over the past 10 years [7], in general, the power consumption during peak periods increased about 10% higher compared to the annual averages. Korea's annual peak hours can be defined as annual about 80 hours during the key periods of summer and winter seasons (four weeks from June to September, four weeks from December to February, and daily two hours for five weekdays over the combined eight weeks = 8*5*2=80 hours). If customers can reduce their power consumption by 10% via the CPP system, the annual energy saving rate can be estimated as follows. In this equation, 1.1 represents 10% higher compared to the averages. And 0.1 means 10% reduction in power consumption.

$$\mathrm{SAV}(\%) = \left(\frac{80\times1.1\times0.1}{8{,}760}\right)\times 100 = 0.1(\%) \tag{2}$$

In the same manner, if customers can reduce their power consumption by 20% via the CPP system, the annual energy saving rate becomes 0.2%. Given this, the energy saving effects of the CPP system are relatively minimal. If the annual sales of KEPCO are assumed at 40 trillion won, its 0.1% or 40 billion won can be saved. If the company's annual sales are 80 billion won, its 0.2% or 80 billion won can be saved.

Next, this study attempted to analyze the energy saving effects when real-time information is delivered and the RTP system is implemented. If the RTP system is implemented, customers will try to reduce their power consumption during high-price hours and raise their power consumption during low-price hours, which is likely to eventually result in the smoothing of power consumption. Therefore, to analyze the effects of the RTP system, firstly, the energy saving rate when customers smoothen price fluctuations by smoothening their power consumption was examined.

However, unlike overseas markets, the domestic electricity market exhibits low fluctuations in seasonal marginal prices (SMP), which, in turn, reduces the system effects. An analysis of the actual 365-day data for the year 2011 [7] yielded the following results. The calculation method was to obtain the difference between A and B.

$$A = \frac{\sum_1^{24}(\text{Hourly SMP}\times\ \text{Hourly Capacity})}{24}$$
$$B = (\text{Average hourly SMP}\times\text{Average Hourly capacity}) \tag{3}$$

$$\text{Reduction rate }(\%) = \left(\frac{\text{A}-\text{B}}{\text{A}}\right)\times 100 \tag{4}$$

Based on the above calculation, the smoothened value of B became slightly smaller. The maximum reduction rate was 5.75% and the average reduction rate was 1.01% (days with above average values were about one third of the year). The months with the largest differences were July, August, and September. A relatively large difference exhibited in February is presumably because of the New Year's holidays in lunar calendar. January, the month with the largest peak, rather exhibited wrong low signals. This is considered closely related to the company's power generator repair schedule.

However, the above assumption is highly extreme. In reality, even if real-time information is delivered and the RTP system is implemented, such straight smoothing lines will not materialize. Therefore, in this study, the assumption of around 30% to 50% of the estimates (around 0.3% to 0.5% of energy saving effects of the national total) was considered reasonable.

At such rates, if KECO's annual sales are assumed at 40 trillion won, the energy saving worth about 120 to 200 billion won is realized.

Based on the above analysis, 24-hour graphs about the cases of large differences (mostly summer) and the cases of

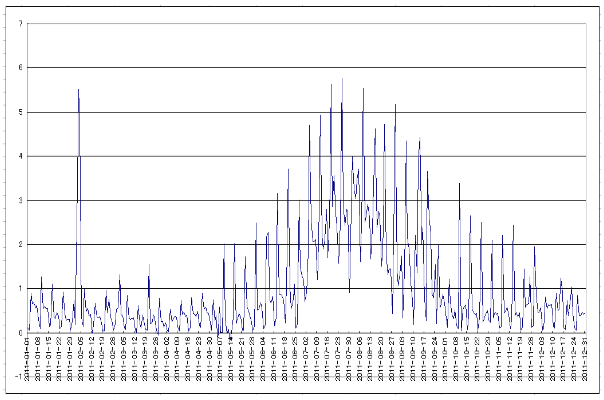

Fig. 1.SMP and energy saving rates in demand smoothing

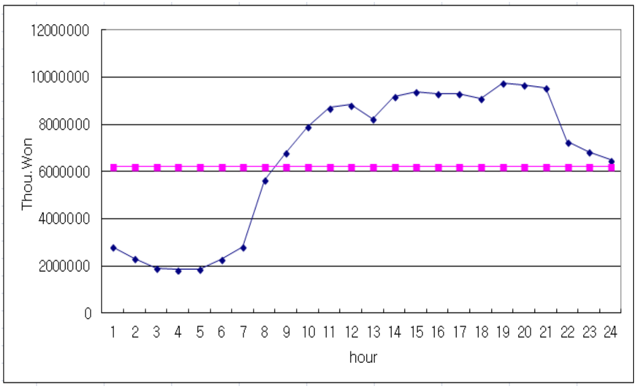

Fig. 2. 24-hour graph of a case of large differences (August 8, 5.5%)

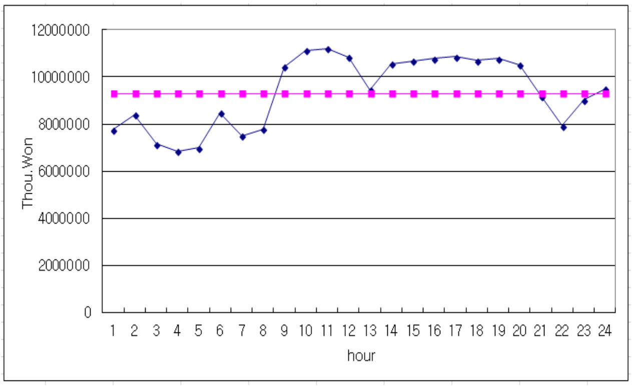

Fig. 3. 24-hour graph of a case of small differences (January 11, 0.5%)

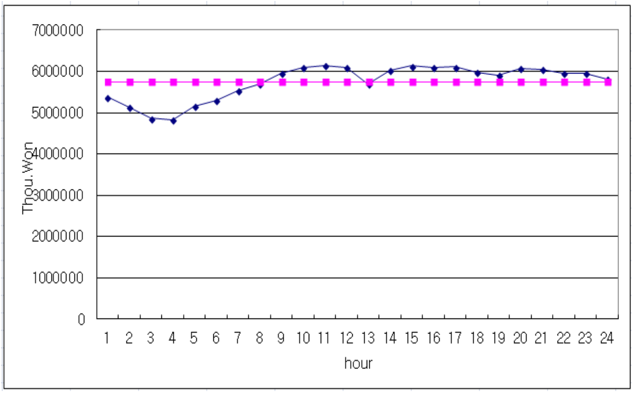

Fig. 4. 24-hour graph of a case of small differences (May 12, 0.07%)

small differences (winter, spring, and fall) are shown as follows. The red line(flat) means B in eq. (3), and blue line means ‘hourly SMP× hourly capacity’ in eq. (3).

When incorporating the energy saving effects exhibited bythe demand response systems (price-based and incentive-based) by combining the above findings, the total annual energy saving rate resulted in about 0.54% of the total annual energy demand (incentive-based 0.04% + CPP system 0.1% + RTP system 0.4%).

4. An Analysis on Domestic Peak Energy Saving Effects of Demand Response Systems

In this chapter, an analysis was performed on the peak energy saving effects when demand response systems are implemented in Korea. The systems applied in this chapter were limited to the representative peak energy saving systems: the critical peak pricing system and the incentive-based system.

In general, commercial loads mostly exhibit flat usage curves across time intervals. Thus, even if the CPP system is applied, its effects become negligible. Therefore, it is reasonable to target the cooling and heating loads of residential and commercial (including educational) loads that are most time-sensitive and exhibit largest usage fluctuations. One problem is that no such systems targeted at cooling and heating loads have been implemented in the country. In this regard, to some extent, assumptions were necessary to perform the analysis.

On the other hand, peak energy savings of the incentive-based systems can be identified by analyzing the results of actual performances in the country. KEPCO’s internal data reported that 97% of the customers who participate in the load control systems (for designate periods, based on weekly-notice, and demand bidding) implemented in the country were industrial customers. In a review of the performances by industry, based on the amount of load curtailment, the steel and ceramic (cement) industries were revealed to take up over 60% of the total load management amount. Typically, the domestic industries that use the largest amounts of electricity out of industrials loads are the steel, semiconductor, petrochemical, oil refining, LCD, cement, and paper manufacturing industries. Among them, the steel, semiconductor, petrochemical, oil refining, and LCD industries are characterized by continuous manufacturing processes, which makes it highly problematic to perform temporary load reduction or shifting. On other hand, the steel, nonferrous metal refining, cement, and paper manufacturing industries can relatively easily reduce temporary loads. In particular, most of such industrial customers have a minimal share of heating or lighting loads (around 5%). Thus, to reduce power demand in preparation for peak periods, they were investigated to employ the methods of reducing the use of their own industrial loads (This means operational downscaling, making it difficult to implement in good economic times), moving to other time slots, repairing facilities during the due hours, or operating self-powered devices.

In Korea’s load control systems, most participants are industrial customers. The present shares of industrial loads are unlikely to undergo great changes in the future, given that most of the industries that are capable of participating in the systems are currently participating. Therefore, a review of the past statistical data is considered highly meaningful.

Firstly, to estimate the target amounts to be reflected in power supply plans in implementing the load control systems, previous annual maximum power and maximum load reduction levels via the load control systems were analyzed based on the KEPCO data. According to the results, the maximum amounts of power reduction ranged from about 1,800 to 2,000MW. When the latest maximum power is estimated at 73,000MW, this range accounted for less than 3% of the maximum power.

As a following step, the effects of the CPP system were examined. For this task, as noted earlier, it was considered most reasonable to focus on the cooling and heating loads of residential and commercial (including educational) loads which are most time-sensitive, and the analysis was performed accordingly. While not participating in the domestic load control systems in earnest, cooling and heating or thermal loads are the type of loads that offer large amounts of load reduction other than industrial loads, the easiest load curtailments, and the highest level of contribution during peak periods.

In fact, the actual influence of cooling and heating loads is marginal in industrial loads. Cooling and heating load curtailments are mostly employed when industries participate in load management programs. Given this, the present analysis was conducted only on the residential and general (including educational) loads [8] excluding industrial loads.

In effect, cooling and heating systems are installed and used under the influence of each building's area and number of people to be accommodated, which creates the need for individual researches. However, the recently researched data inform that heaters are used for average 10 hours per day and coolers are used for average eight hours per day[10]. The average power consumption capacity per household was 40 to 60 W for fans, 3 to 4 kW for air conditioners, 2 to 3 kW for electric heaters, and 10 kW for heat pumps.

In addition, the share of most cooling and heating loads is estimated to reach up to 50% to 60% levels based on peak kW demand. Certainly, the share becomes lower when based on energy (kWh). As the cooling and heating load reduction measures include temperature control, the installation of a remote controller (cycling on/off controller, frequently implemented in the U.S.), or partial shutdown, the effects of such measures can also be exhibited in various patterns.

As noted above, the share of cooling and heating loads is estimated to generally reach up to 50% to 60% of the peak consumption of individual customers based on peak kW demand (assuming 50% in usual summer and winter seasons, and 60% in abnormal temperature conditions). In addition, the full implementation of individual coolers and heaters in replacement of a central control system is considered difficult unless remoter controllers are installed. Therefore, the below Table 2 briefly analyzed the load reduction effects when a possible load control capacity of 50% and load reduction rates of 10% to 30% were assumed.

The composition ratios by usage were based on the Statistics News Bulletins of KEPCO [8]. The reason for dividing general and educational loads into low and high voltages was because high-voltage customers mostly have an automatic meter reading (AMR) system installed, thereby being allowed to immediately apply demand response programs by calculating meters according to time intervals. Here, the reduction rate indicates the reduction rate to the present year's peak.

Looking at the results of Table 2, on average, the energy saving potential of the cooling and heating loads accounted for about 2.1% of the peak demand. When the total peak demand is assumed at 73,000 MW, the possible reduction capacity is estimated at a maximum of 1,500MW. Based on this assumption, the total residential and commercial cooling and heating loads are estimated at about 15,000MW at present. As this omits industrial cooling and heating loads (73,000*0.54*0.03=1,183MW), the total cooling and heating loads may be greater than the above figure (about 16,183MW).

At abnormal temperatures from dramatic temperature rises or falls, the share of cooling and heating loads exceeds 60% at times. Considering this, a higher load reduction rate than the above level is probable. When reviewing the cases in which the share of cooling and heating loads was 60%, the load reduction rates in Scenarios 1, 2, and 3 were estimated at around 1.2%, 2.4%, and 3.6% respectively.

Therefore, when assuming that the average reduction rate is about 2.4% of the peak demand and the peak demand is 73,000MW, the possible reduction is estimated at about 1,750MW. Based on this assumption, the total residential and commercial cooling and heating loads are currently assumed at about 17,500MW. As industrial cooling and heating loads (73,000*0.54*0.03=1,183MW) were omitted from this, the total cooling and heating loads are considered greater than this (about 18,683MW).

In conclusion, if smart grids are distributed, the domestic peak load reduction potential is a maximum of around 5%. Based on the latest peak demand of 73,000MW, it results in about 3,700MW. This is certainly based on the assumption that the CPP system or the demand response systems with the participation of cooling and heating loads are

Table 2. Estimation of the reduction rates of cooling and heating loads excluding industrial loads (load share of 50%)

Category	(%) Percentage of total	(Ratio of cooling and heating loads (%)	(Possible control50%) Reduction rate scenario 1 - 10% reduction (%)	(Possible control50%) Reduction rate scenario 2 - 20 reduction (%)	(Possible control50%) Reduction rate scenario 3 - 30% reduction (%)
Residential	15	50	0.38 (=0.15*0.5*0.5*0.1)	0.75 (=0.15*0.5*0.5*0.2)	1.13 (=0.15*0.5*0.5*0.3)
Commercial/Educational low voltage	12	50	0.30 (=0.12*0.5*0.5*0.1)	0.60 (=0.12*0.5*0.5*0.2)	0.90 (=0.12*0.5*0.5*0.3)
Commercial /Educational high voltage	15	50	0.38 (=0.15*0.5*0.5*0.1)	0.75 (=0.15*0.5*0.5*0.2)	1.13 (=0.15*0.5*0.5*0.3)
Total	-	-	1.05	2.10	3.15

implemented. The mere distribution of smart grids does not lead to immediate load curtailments.

5. Conclusion

The present study performed an analysis on power demand reduction effects exhibited by the demand response programs, which are advanced from traditional demand management programs, in the smart grid environment. The target demand response systems for the analysis included the existing incentive-based load control systems (demand control system for designated periods, weekly-notice demand control system, and demand bidding system) and the price-based demand response systems (mainly the CPP system and the RTP system, currently unimplemented in Korea.

Firstly, the status of the relevant individual systems at home and abroad was briefly examined. Secondly, their energy saving effects and peak load reduction effects were estimated when the CPP and RTP systems, which are price-based demand response systems, and the existing incentive-based load control systems are implemented.

According to the research, 97% of the customers who participated in the domestically implemented incentive-based load control systems (load control for designated periods, weekly-notice load control, and demand bidding) were industrial customers. In addition, these systems were reported to carry out daily about two-hour and annual forty-day load curtailments and generate load saving effects of around 2% to 3% of the peak demand (assuming the peak demand of 73,000 MW, about 1,460 to 2,200MW). Based on such statistical data, load reduction effects of the systems were estimated.

On the other hand, incentive-based demand response systems such as the CPP or RTP systems have not yet been implemented in the country. Accordingly, their effects were estimated by setting assumptions. In most countries, the CPP system induces demand reduction by raising electricity prices during the hours of demand concentration in the summer (or winter) season. Given this, the systems' domestic energy saving effects were estimated based on the assumption that customers reduce power consumption by 10% to 20% for 80 hours a year during the representative peak periods of summer and winter seasons (four weeks from July to September, four weeks from December to February, and daily two hours over five weekdays of the eight total weeks = 8*5*2=80 hours). On the other hand, for the RTP system, as the system reduces power consumption during the hours of high electricity rates and increase power consumption during the hours of low electricityrates, an assumption was set that this will eventually realize the smoothing of consumption. Under this assumption, the study examined the reduction rates when the variability of the results of multiplying time-based SMP prices by energy consumption amounts was smoothened.

The peak load reduction effects when the CPP or RTP systems were implemented were analyzed based on the following assumption. Most industrial customers exhibit a significantly low share of cooling and heating loads (around 5%) and flat usage curves across time intervals. Therefore, their load reduction effects will be negligible even if the CPP or RTP systems are implemented. Thus, it was considered reasonable to limit the analysis on effects of the CPP or RTP systems to residential and commercial (including educational) loads which are most time-sensitive and show the highest levels of variability. Meanwhile, one problem was that no such systems have been implemented within the country to date, thereby yielding no relevant statistical data. Accordingly, this study estimated that based on peak-kW demand, most cooling and heating loads reach up to 50% to 60% of the peak consumption of individual customers (assuming 50% in usual summer and winter seasons, and 60% in abnormal temperature conditions). Given that the full implementation of individual coolers and heaters in replacement of a central control system is unlikely without the installation of remote controllers, this study analyzed the load reduction effects when assuming a possible load control rate of 50% and load reduction rates of 10% to 30%.

In a review of the final results, energy saving effects exhibited by the demand response systems (price-based and incentive-based) were estimated at about 0.54% (incentive-based 0.04% + CPP system 0.1% + RTP system 0.4%) of the annual total energy demand in terms of total reduction rate. In addition, provided that smart grids are distributed in the future, the country's future peak load reduction potential was projected to be a maximum around 5% of the peak demand. Based on the latest peak demand of 73,000MW, this is equivalent to about 3,700MW. Certainly, this is based on the assumption that the currently unimplemented CPP system or the demand response systems with the participation of cooling and heating loads participate are implemented in the future. The mere distribution of smart grids does not lead to such estimates. When considering only the currently implemented systems, the peak load reduction potential is lowered to a maximum about 3% of the peak demand.

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