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Case Study of Demand Response Operation using Management Program in South Korea

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ABSTRACT

In this study, integrated demand response management solution experience is described in South Korea. To show an experience, real contracted capacity and payment between consumer and load aggregator are shown. To calculate CBL (Customer Baseline Load), RRMSE (Relative Root Mean Squared Error) and payments, power consumption profiles of the selected customers are investigated. In the case of 10MW contracted customer, it shows 110.88 % delivery rate and the benefit of 432,992,650 KRW. The result illustrates that integrated demand response management solution contributes to reduce contracted power and it gives a benefit and satisfaction to the consumer.

Keywords: Demand Response, Demand Response Management Program, Electricity Market, DR Aggregator, Integrated Demand Response Management Solution

I. INTRODUCTION

There is a problem that it is difficult or expensive to store electrical power in a central operating system, supply and demand must always be balanced to ensure the stability and safety of the power system. Traditionally, to coordinate supply and demand has been the supplier's responsibility and the demand side has been considered secondary. The power system operator predicts the demand then secures the supply capacity to meet the demand after that market price changed to supply capacity serves as criteria for deciding the facility capacity. The capacity that cannot be adjusted on the supply side is supplemented by DRM (Demand Response Management) such as temporarily reducing or moving the load on the demand side. [1, 2]

Recently, however, there has been a growing interest in considering the demand as the same as the supply side. Technological changes are occurring both on the supply side and on the demand side. On the supply side, power generation is becoming harder to control due to the growth of renewable energy with irregular power generation characteristics. The biggest technological change on the demand side is the spread of smart meter and advanced metering infrastructure. According to this environment, traditional DSM programs should redesign to an automated market-based mechanism. Also, the responses from the demand-side resources should be reliable, fast, flexible and large enough to compete with the supply-side resources. DSM programs can be classified into Load Management (LM) type and Energy Efficiency (EE) type. [3,4,6,7]

In this paper, a case study of DRM program implementation in South Korea is introduced. Demand Resources have played an important role in Korea more than 20 years. For reducing peak demand during summer and winter, DR programs and the operation system have been researched and implemented as a demonstration since 2010. In 2014, commercial and industrial customers were able to sell their reduced demand in the electricity market like supply resources. [7,8]

This paper is composed as follows. Section 2 introduces the status of demand resource market in South Korea. Section 3 shows the case study of the DRM result from DR Aggregator Company. Section 4 presents the result and analysis. Finally, the conclusion is given in section 5.

II. STATUS OF DEMAND RESOURCES MARKET, SOUTH KOREA

The role of Korea Power eXchange (KPX) is a control of the operation of South Korea’s electricity market and the power system, as well as the execution of the real time dispatch and the establishment of the basic plan for supply-demand. Every year, KPX has issued an annual report for electricity market trend and analysis. In this section, the status of demand resource market from 2016 annual report is summarized. “Demand response refers to a suite of policies and institutions to provide efficient and stable electric power service at the lowest cost by helping consumers change their consumption pattern. Under the current contract-based utility rate schemes in South Korea, consumers have a very weak incentive to participate in the demand response voluntarily. [8]

The introduction of the demand response program may be effective in stabilizing the electricity market and operation of its system. The demand-response can decrease investment in the power system including generation, transmission and transformation networks; enhancing reliability in electric-power supply. Consumers can take part in the demand response programs by reducing their electricity usage at critical times through monitoring demand or securing a load that can be shut down by KPX and then makes a bid on a load.

In early 2008, when the demand response market opened, it was bidding-based sponsored by the Electricity Industry Fund and now, is making a transition into an advanced demand response market where market price and real-time system operation are linked with each other for resource transaction. In 2012, a smart demand response market opened where demand resources in small and medium quantity are traded in an effort to tap into the highly-reliable and easily-accessible demand resources using smart grid technology. The smart demand response market makes payment at a fixed rate on the condition of keeping the capacity to be curtailed unchanged. A payment is also made to those who cut down demand at the system operator's request for load curtailment. As the Electricity Business Act was revised to allow demand resources trading in the electricity market in 2014, the demand response market and smart demand response market sponsored by the Electricity Industry Fund were abolished in late 2014, and the elimination of the two-month-ahead and week-ahead programs was followed in late 2015. [7,8,9]

Turning 2015, a new demand response market replaced these previous programs and was integrated into the electricity market. Fig. 1. shows the process of the trading mechanism of demand response market. The demand response market trades demand resources arranged by retailers, and each demand resource is required to come from more than ten end users and be valued at above 10 MW. DR Aggregator collects consumers to organize demand resources. After registration to KPX, these resources are certified for trading under the same rule governing the centrally dispatched generators. Demand resources are put on a bid against power generation resources on a daily basis and when sold, demand curtailment began. In the system operation process, consumers are required to cut down on demand within an hour of dispatch order. [7]

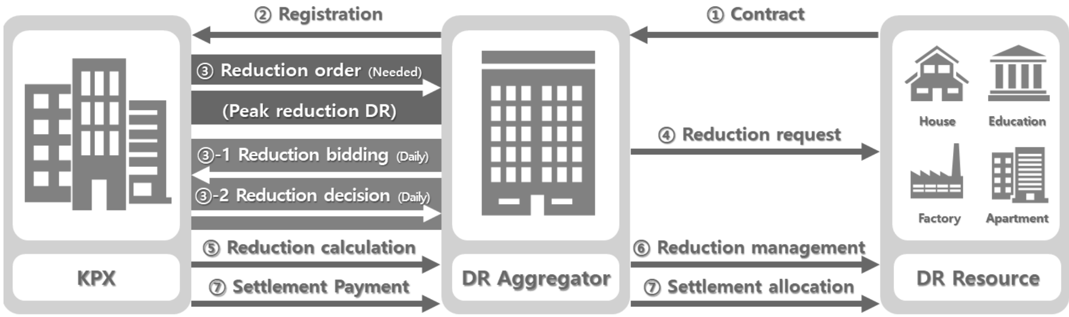


Figure 1. Trading Mechanism of a demand response market

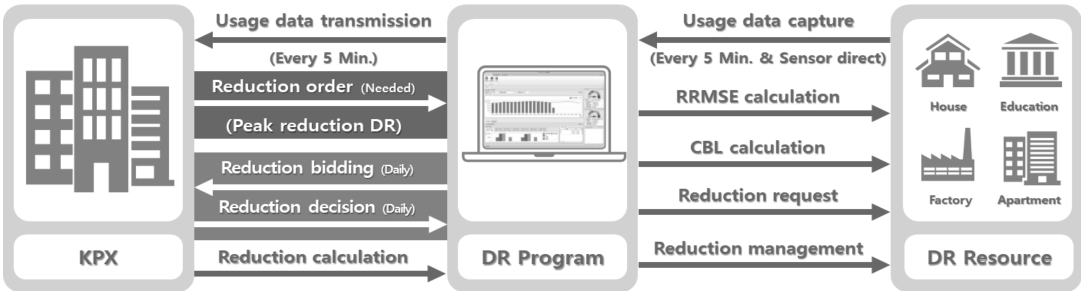


Figure 2. The mechanism of an Integrated Demand Response Management Solution

Fig. 2. shows the process of the mechanism of an integrated demand management solution. The DR program captures usage data every 5 minute from demand resources such as house, factory, apartment and factory. Then these usage data send to the KPX to consider a reduction order to DR program. After reduction order request to DR program, DR program call to request DR resources and demand curtailment began. In the system operation process, consumers are required to cut down on demand within an hour of dispatch order. DR program also calculates RRMSE(Relative Root Mean Square Error), CBL(Customer Baseline Load) of DR resources as regularly to keep as a DR resources in Korea electricity market.

KPX calculates curtailed energy and make payment to retailers who allocate the profits to consumers. As indicated in the Table 1 and 2, the demand response market has seen a significant progress from both quantity and quality perspectives. The number of consumers grew from 90 to 3,592 and curtailed energy amounts to 175,771 MWh, up by 342.6 times from 513MW, becoming a world-renowned global demand response market. The transition to an advanced demand response market is also politically compelling. As the program matures along with demand resources integrated into the electricity market, market participants will feel easy to understand the system and the market will flourish. Furthermore, lower resistance towards generators and greenhouse gases are expected along with eased market exploitation and more efficient market. [7,8,9]

Table 1. Consumers and curtailed power before market opening [7,8]

Year	2010	2011	2012	2013	2014
No. of consumers	90	119	158	159	159
Capacity available for Curtailment (MW)	2,219	3,049	3,612	3,615	3,615
Curtailed Power (MWh)	513	690	785	556	682

Table 2. Consumers and curtailed power after market opening

Year	2014.12~ 2015.05	2015.06~ 2015.11	2015.12~ 2016.05	2016.06~ 2016.11	2016.12~ 2017.05	2017.06~ 2017.11	2017.12~ 2018.05	2018.06~ 2018.11
No. of DR Aggregators	11	15	14	15	14	17	20	22
No. of consumers	861	1,323	1,519	1,970	2,223	3,195	3,580	3,592
Capacity available for Curtailment (MW)	1,520	2,444	2,889	3,272	3,885	4,352	4,271	4,222
Curtailed Power (MWh)	117,075	91,034	98,898	293,955	113,661	62,110	121,206	-

III. CASE STUDY OF DRM (DEMAND RESPONSE MANAGEMENT)

III.I Methodology Integrated Demand Response Management Solution

Fig. 3 shows the power consumption and CBL of the desired date and time. The bar graph illustrates power usage at 5 min, 10 min, 30 min respectively and the line means the CBL of every hour. At the bottom dialog box shows contracted curtail power, CBL, Load, result of curtailed power and remained contracted curtail power in an order.

Figure 3. Dashboard of power usage

Fig. 4 illustrates Customer baseline load (CBL) calculation. CBL is an average hourly energy consumption calculated as follows. The CBL calculation method are either MAX 4/5 or Mid 6/10. The Max 4/5 method is calculated by the electricity usage in normal working as a consecutive 5 days. To calculate CBL, firstly the smallest electricity usage day of the 5 days is excluded then the average usage for 4 days is used as Max 4/5 CBL. The Mid 6/10 method is calculated based on the power electricity usage in normal working as a consecutive 10 days. Two days are excluded from top and bottom usage of the 10 days respectively. The average usage of the remained six days is used as Mid 6/10 CBL. Table 3 explains how calculate CBL as MAX 4/5. Firstly, D-2 is a smallest electricity usage day so this day is excluded. Then average usages of the remained 4 days are added then divide by 4. [7,8,9]

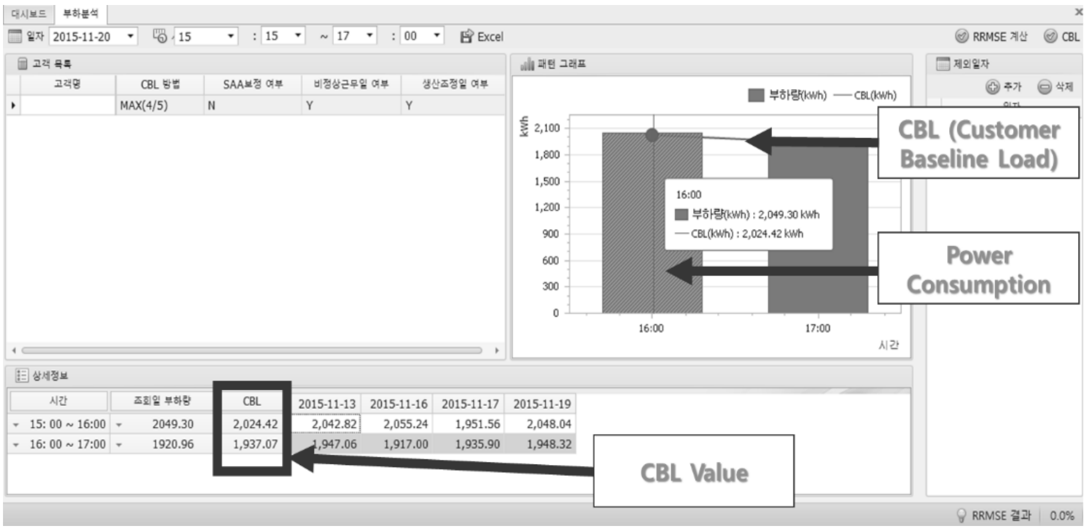


Figure 4. Customer baseline load calculation

Table 3. CALCULATION EXAMPLE OF CBL (MAX4/5 METHOD)

	Load (kWh)	Selection
D-1	2,048.04	O
D-2	1,889.74	X
D-3	1,951.56	O
D-4	2,055.24	O
D-5	2,042.82	O
CBL	2,024.42	

Fig. 5 Shows RRMSE for the customer who wants to participate in demand response market and equation (1) shows that RRMSE calculation. To calculate RRMSE for the customer, equation (1) is used. In this equation, D is an investigation day, D(n) are number of investigation days, T is a time duration of investigation day, T(n) are number of time durations of investigation day, CBLd,t is a customer baseline load at t hour on d day and Loadd,t is an Electricity usage at t hour on d day. The RRMSE is calculated by dividing RMSE(Root Mean Square Error) with average value of electricity usage data. The fluctuation between CBL and actual electricity usage is a critical judgment criterion as a reliable DR resource. To register as a DR resource in a Korea electricity market, RRMSE value must be less than 0.3, if the value exceeds 0.3, it is not allowed to join the DR market. This calculation is based on data of 45 days of weekdays from the date of verification. For example, the flat line of the electricity usage graph in fig 4. indicates 0.1, 10% , that means fig. 4 is a reliable DR resource then this customer can participate in DR market. [8,9]

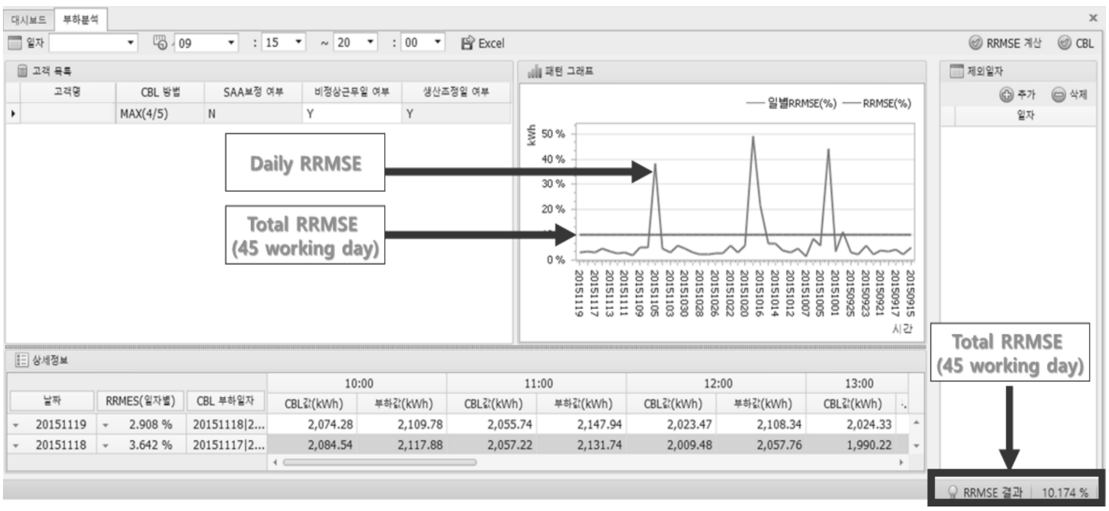


Figure 5. RRMSE for customer

$$\sqrt{\frac{\sum_{d\in D,\, t\in T}(CBL_{d,t} - Load_{d,t})^2}{D(n)\times T(n)}} \div \frac{\sum_{d\in D,\, t\in T} Load_{d,t}}{D(n)\times T(n)} \quad (1)$$

D : Investigation day

D(n) : Number of investigation days

T : Time duration of investigation day

T(n) : Number of Time durations of investigation day

$CBL_{d,t}$: Customer baseline load at *t* hour on *d* day

$Load_{d,t}$: Electricity usage at *t* hour on *d* day

III.II Experience of DRM from DR aggregator

Table 4 shows the result of demand response management from DR aggregator in South Korea. According to the contract between customer and load aggregator, the customer identification cannot open to the public so that they have been classified based on their contracted capacity. From the contracted customers of DR aggregator, they are classified three sizes, large amount 10,000[kW], medium 1,000[kW], and small amount 40 [kW]. Base load line, peak, average power consumption, CBL are calculated based on the customer's power usage which are monitored and recorded from electricity smart meter. Fig.5, fig.6 and fig.7. show the data on Jun. 26, 2017. Each of customers' sampled data, delivery rate on and payment of 1st quarter 2017 are indicated in Table 4.

Table 4. Demand Response Management Implementation Result

Amount	Large	Medium	Small
Name	N Company	Provincial Government	G store
Type	Factory	Building	Retail
Baseline Load (kW)	19,140	1,005	37
Peak (kW)	24,561	2,002	57
Average Power Consumption (kW)	22,306	1,534	52
CBL (kW)	22,218	1,652	53
Contracted Capacity (kW)	10,000	1,000	40

The large amount, N company is a chemical company located in southwestern area, South Korea. Power consumption pattern of N company is a typical factory type. Fig 6 illustrates the power consumption pattern base load line, and peak. The medium amount, provincial government building is located in central area, South Korea. CBL of this customer is 1,938.56 at 13:00~14:00 on Jun. 26, 2017 in fig. 7. Lastly, the small amount, G store is a retail store located in southeastern area, South Korea. Fig. 8 shows RRMSE value as 9.815 %, less than 30%.

Figure 6. N company power consumption and base load line

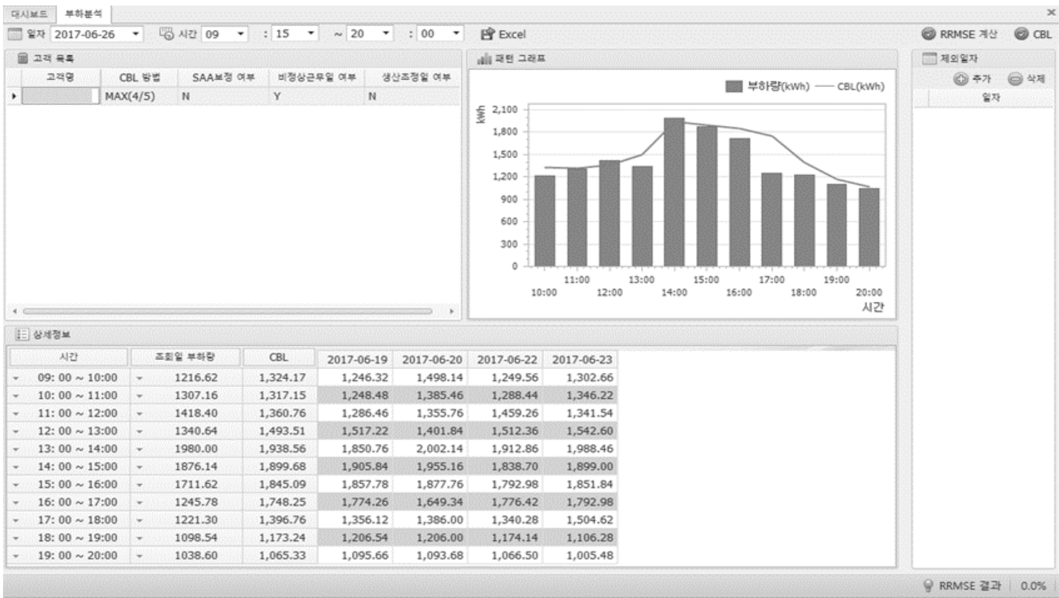


Figure 7. Provincial government building CBL calculation

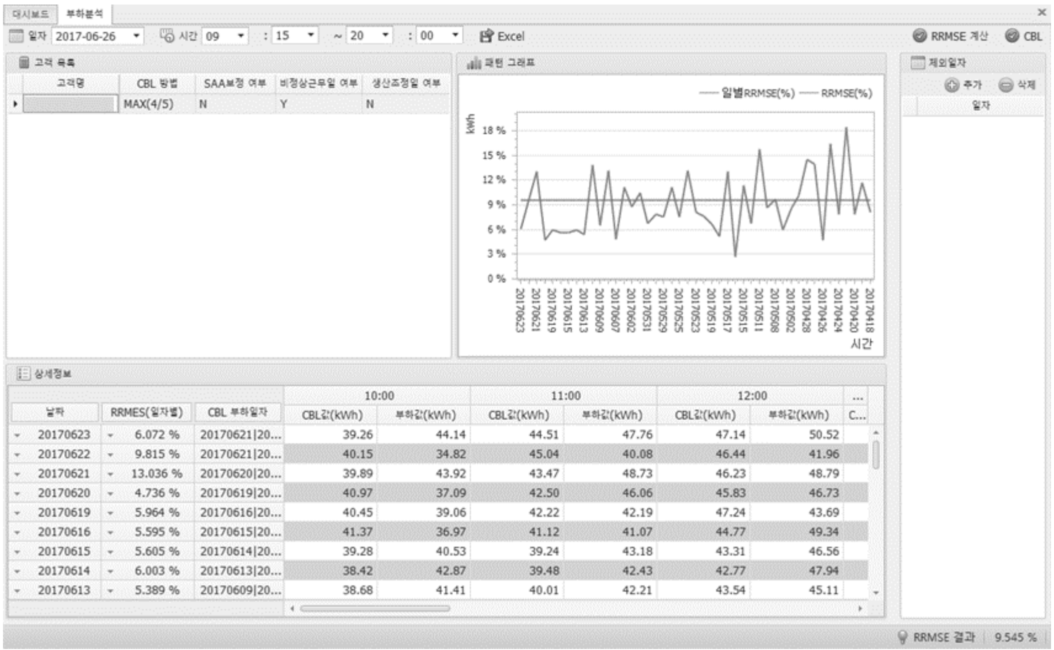


Figure 8. G store power RRMSE

IV. RESULT AND ANALYSIS

The incentive by participating in the DR market can be classified into basic settlement and performance-settlement, and the monthly basic settlement payment is as shown in the table 5. According to the reduction duration time, the actual performance-settlement payment is different.

Table 5. Monthly Basic Settlement Payment 2016-2017

Month	Basic-settlement Payment [KRW/kW]	Weekday
2016.12	5,186.22	22
2017.01	4994.68	20
2017.02	4475.45	20
2017.03	3767.84	22
2017.04	1462.24	20
2017.05	1335.86	20
2017.06	3858.63	21
2017.07	5395.95	21
2017.08	4930.56	22
2017.09	3694.44	21
2017.10	1213.57	17
2017.11	2919.16	22
Total	43,234.60	248

To calculate the basic settlement money and the performance settlement money, equation (2) is applied to Integrated Demand Response Management Solution.

$$
\begin{aligned}
&\mathrm{DRBP}_{i.m} = \mathrm{ORC}_{i.m} \times \mathrm{BP}_{m} \times 1{,}000 \\
&\mathrm{IBPC}_{i.m} = \frac{\mathrm{TDRBP}_{i}}{\mathrm{ORC}_{i.m}\times\mathrm{MRT}} \times \sum_{t}^{m} DRD_{i.t} \times 2 \times DF_{i,t} \\
&DRD_{i.t} = \ Max(RSO_{i,t} \times 0.97 - DR_{i,t}\,, 0) \qquad (2) \\
&\mathrm{BPC}_{i.m} = Min(\mathrm{DRBP}_{i.m}, \mathrm{IBPC}_{i.m}) \\
&\mathrm{FDRBP}_{i.m} = \mathrm{DRBP}_{i.m} - \mathrm{BPC}_{i.m}
\end{aligned}
$$

$DRBP_{i.m}$: Demand Response Basic Payment by monthly[KRW]

$ORC_{i.m}$: Obligation Reduction Capacity [MW]

BP_{m} : Basic Price by monthly[KRW/kW]

$IBPC_{i.m}$: Initial Basic Penalty Charge[KRW]

$TDRBP_{i}$: Total Basic settlement money during the contract period [KRW]

MRT : Maximum Reduction Time (Max 60 hrs.)

$DRD_{i.t}$: Dispatch Reduction Deficiency [kWh]

$RSO_{i,t}$: Reduction Ordered by System Operator [MWh]

$DR_{i,t}$: Dispatched Reduction [kWh]

$DF_{i,t}$: Dispatch Flag [1 for active, 0 for non-active]

$BPC_{i.m}$: Basic Penalty Charge by monthly [KRW]

$FDRBP_{i.m}$: Final Demand Response Basic Payment by monthly[KRW]

Table 6. shows the electricity payment reduction result of three contracted customers after participating DR program. N company case is selected to demonstrate the result. In the case of N Company, the contracted capacity is 10 MW, participating in the 7-hour DR dispatch during the year. As a result, DR delivery rate is an average 110.88% and the benefit from DR participation is 432,236,870 KRW (basic settlement benefit is 425,586,87 KRW and actual settlement money is 6,661,776 KRW) are occurring, and the annual electricity cost reduction money is about 755,780 KRW.

Table 6. Electricity Payment Reduction Result

Name			N Company		
Month	Reduction order	Reduction duration time	Basic-settlement [KRW]	Performance-settlement [KRW]	DR Delivery Rate [%]
2016.12	O	2 hour	51,862,200	2,224,080	121.65%
2017.01	X	-	49,946,800	-	-
2017.02	X	-	44,754,500	-	-
2017.03	O	1 hour	37,678,400	1,129,080	121.44%
2017.04	X	-	14,622,400	-	-
2017.05	X	-	13,358,600	-	-
2017.06	X	-	38,586,300	-	-
2017.07	O	3 hour	53,221,870	2,429,646	95.30%
2017.08	X	-	49,305,600	-	-
2017.09	X	-	36,944,400	-	-
2017.10	X	-	11,421,800	-	-
2017.11	O	1 hour	23,884,000	878,970	105.14%
Total			425,586,870	6,661,776	-

Name			Provincial Government		
2016.12	O	2 hour	5,186,220	211,700	114.32%
2017.01	X	-	4,994,680	-	-
2017.02	X	-	4,475,450	-	-
2017.03	O	1 hour	3,767,840	99,475	105.72%
2017.04	X	-	1,462,240	-	-
2017.05	X	-	1,335,860	-	-
2017.06	X	-	3,858,630	-	-
2017.07	O	3 hour	5,395,950	336,334	127.28%
2017.08	X	-	4,930,560	-	-
2017.09	X	-	3,694,440	-	-
2017.10	X	-	1,142,180	-	-
2017.11	O	1 hour	2,305,028	76,229	91.24%
Total			42,549,078	723,738	-

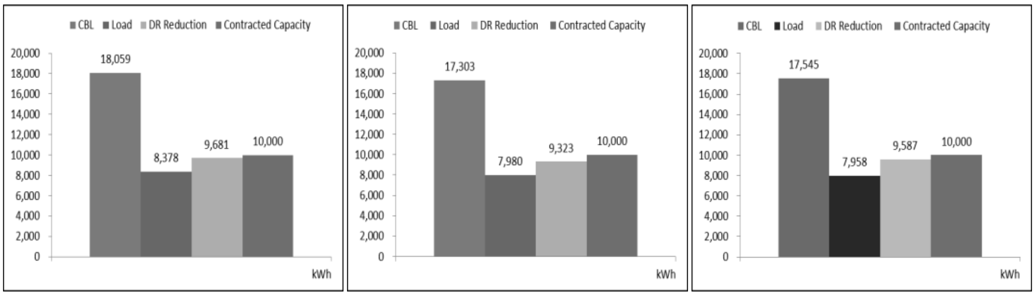
Name			G store		
2016.12	O	2 hour	610,614	21,309	95.73%
2017.01	X	-	599,362	-	-
2017.02	X	-	537,054	-	-
2017.03	O	1 hour	446,284	10,547	93.41%
2017.04	X	-	175,469	-	-
2017.05	X	-	160,303	-	-
2017.06	X	-	463,036	-	-
2017.07	O	3 hour	647,514	36,711	170.65%
2017.08	X	-	591,667	-	-
2017.09	X	-	443,333	-	-
2017.10	X	-	137,062	-	-
2017.11	O	1 hour	262,012	8,323	82.96%
Total			5,073,710	76,890	-

To verify the capacity of demand response from customer, the request form KPX on Jul. 20. 2017, 14:00 ~ 17:00 , is displayed in table 7.

Table 7. Demand Response Management Implementation Analysis

Amount		Large	Medium	Small
Name		N Company	Provincial Government	G store
Type		Factory	Building	Retail
Contracted Capacity (kW)		10,000	1,000	120
CBL(kW)	14:00~15:00	18,059	1,944	356
	15:00~16:00	17,303	1,904	349
	16:00~17:00	17,545	1,882	302
Real Load(kW)	14:00~15:00	8,378	669	158
	15:00~16:00	7,980	634	121
	16:00~17:00	7,958	470	113
DR Reduction Result(kW)	14:00~15:00	9,681	1,275	198
	15:00~16:00	9,323	1,270	227
	16:00~17:00	9,587	1,412	189
DR Delivery Rate(%)	14:00~15:00	97%	128%	165%
	15:00~16:00	93%	127%	189%
	16:00~17:00	96%	141%	158%

The large customer N company, big factory which has a contracted capacity 10,000 kW delivered 97%, 93%, 96% for each period and the average delivery rate is 95%. Fig 9. Illustrates CBL Load, DR reduction result and delivery rate of each period. For example, fig 9 (a) shows CBL is 18,059 kW, real load is 8,378 kW, DR reduction is 9,681kW and contracted capacity is 10,000 kW at 14:00~15:00.



(a) **(b)** **(c)**

Fig.9. N company Demand Response Analysis

V. CONCLUSION

In this paper, the Demand Response Management experience in South Korea is introduced and explained. The experience from the consumer and DR aggregator shows that the Integrated Demand Response solution technologies is a fast responding approach in a cost-effective way. The curtailed power from contracted customer contributed to reduce peak power in national power grid and can effectively provide a reliability of the power system. The demand resource can be an alternative to the redundant generation in short term such as 5 minutes.

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