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PRIMARY RESEARCH

Relation between air pollutants emissions and BESS capacity operated for maximizing customer's profit

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Index Terms
Relation
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Abstract—At COP 21, participants of the UNFCC reached an agreement for mitigation of greenhouse gas emissions. It is not mandatory, but new policies and technologies are needed for each country to accomplish Intended Nationally Determined Contributions (INDC). Especially in the power section, Smart Grid, Renewable energy, Battery Energy Storage System (BESS), Distributed Generation and Microgrid are emerged as solutions to reduce GHGs. These technologies are known as the GHGs mitigation Technologies. However, researches are needed to reveal that is true or not. BESS can be operated for diverse purpose. This paper presents the GHGs emissions changes resulting from the unit commitment with BESS that is applied to Korea power system for minimizing end-user's costs. This study is based on IEEE 39-bus system to reveal the influence of BESS on GHGs. As a result, in a certain condition, the increasing of BESS capacity could result the increasing of GHGs emissions.

I. INTRODUCTION

The Kyoto Protocol which put obligation to reduce greenhouse gas emissions on developed countries was limited to curb climate change. So, new framework that can reduce risks and impacts of climate change was needed. As a result, 'Paris agreement' was adopted by consensus at 21st Conference of the Parties of the UNFCCC on Dec 2015.

Each country should accomplish their Intended Nationally Determined Contributions, but they are not bound by the international laws. The only duty of member nations is that contributions should be reported to UNFCCC secretariat every five years. Despite the circumstances, new policies and technologies like energy savings, improving energy efficiency, renewable generation are needed to accomplish INDC. Especially in the power section, Smart Grid, Renewable energy, BESS, Distributed Generation and Micro-grid are emerged as solutions to reduce GHGs.

These technologies are also known as the GHGs mitigation Technologies. If they are commercialized and restructuring of power market is done, customers who will live in smart cities will be able to participate in power trading, and they try to set a schedule for minimizing their electricity usage cost by using advanced technology. [1] This paper focuses on relationship between GHGs emission and these activities of customers who have BESS and operating it.

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II. ENERGY STORAGE SYSTEM

A. Definition and Classification

ESS can overcome electricity's essential characteristic that production and consumption happen at the same time and they must be balanced. It can make using power more efficient. Generally grid-scale(for transmission, distribution) ESS can be used in a variety of ways - load leveling, peak cutting, frequency regulation, solution to renewable energy's intermittency, and emergency reserve. When customers use small-scale (up to 10 MW) ESS, they would get benefit from difference in energy price. Or they could make profit by operating ESS with renewable generation. Customers who live in several countries that have already reached grid parity combine renewable generation and ESS, and then consume power themselves or sell surplus power to make their profits. The others who are not living in where grid parity isn't reached are operating ESS to save their power rates, or get margin by charging during off-peak and discharging on peak.

B. Current State of BESS in Korea

Korea government chose Frequency Regulation BESS as the one of 'new energy industry project'. They have installed 236 MW till 2015, and make plans to expand capacity up to 500 MW and improve performance. The Laws and regulations were revised to allow ESS to use it as emergency power source. If ESS capacity is larger than 1 MW, its owner can participate in power market. Also, large capacity ESS which is more than 10MW is considered as scheduled generator that means generator dispatched by system operator-Korea Power eXchange(KPX). Government adopted Renewable standard portfolio which is a regulatory mandate to increase production of energy from renewable sources since 2012. If renewable providers interconnect their existing solar with ESS, they could get more renewable energy certificates (REC) than their real generation quantity. Also, government made a new electricity pricing rate which will save base rate as much as customer's reduced maximum peak to promote investment for ESS by shortening investment payback period [2].

TABLE 1
F/R ESS CONSTRUCTION SITUATION AND PLAN [2]

Year	2014	2015	2016	2017	Total
Capacity(MW)	52	184	140	124	500
Budget(100 million KRW)	570	1,900	1,890	1,890	6,250

TABLE 2
CURRENT SITUATION OF BESS CONSTRUCTION IN KOREA OF 2015 [2]

S/S location	New Gyeryong	New Gimje	New Hwasun	Ulju	Uiryeong	Gyeongsan	New Chungju	Total
capacity(MW)	24	24	24	24	24	48	16	184

C. Power system of Korea

Base load is the minimum level of electricity demand required over a period of 24 hours. It is needed to provide enough power to components that keep running at all times. Peak load is the time of high demand. Nuclear and coal-fired plants are base load plants, and the others like LNG, diesel plants which use more expensive fuels than base load plants are used for peak load in Korea. When customers use ESS for minimizing their power cost, they would charge ESS in base time when electricity price is low and discharge power to grid in peak time when the price is expensive, if ESS is commercialized, and result of power market restructuring makes power price as Real time price. Customer's activities as above would reduce daily maximum peak load and increase load factor, so these also reduce total energy production cost of power system. It is widely known that coal-fired plants emit GHGs more than LNG plants. The fact that the spread of ESS can reduce GHGs emission is seen as a true, but it may well be wrong because ESS operation for cost minimization will shift energy at peak time to off-peak when base load plants operate. Nuclear plants are already operated at maximum power output, so coal-fired must be used to handle shifted energy

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III. METHODOLOGY

Study on entire power system in Korea has lots of difficulties because of scale and complexity of problem. So IEEE 39-bus system data is used for case study in this paper. We set 4 cases. The first is case without ESS, and the others are applying different ESS capacity.

TABLE 3
ESS CAPACITY PER EACH SCENARIO

Scenario	ESS capacity (MW)
1	None
2	100
3	200
4	300

And we determine Unit Commitment in each case, and calculate total generation cost, CO_2, NOx and SOx emissions, health cost and treatment cost. Table 4 shows us air pollutants emission factors in electric power plants. Processing cost is shown in table 5. In this paper, ESS is modeled as load shifting resource and affects result of unit commitment by changing daily load. This paper formulates unit commitment algorithm based on dynamic programing and compares results from previous papers to verify accuracy.

TABLE 4
AIR POLLUTANTS EMISSION FACTORS (TON/MWH) [3]

Pollutant	Anthracite	Bituminous	LNG
CO_2	0.9143	0.823	0.3625
SOx	0.00061	0.00039	0.00000
NOx	0.00098	0.00032	0.00003

TABLE 5
PROCESSING COST [4], [5]

Pollutant	Cost (KRW/ton)
CO2	21,000
SOx	16,050,000
NOx	11,400,000

A. Modeling of load-shifting operation of ESS [6]

The objective function for load-shifting is formulated as below.

Minmize $\sum_{t=1}^{T}(L_t + P_t^{ESS})^2$ (1)

$P_t^{ESS} = ep_t^c - ep_t^d$ (2)

There are some technical constraints for operating ESS. EP_t^c, EP_t^d are charging power and discharging power (MW) inside view on ESS at time t. These are formulated by using efficiency constants and charging power and discharging power in view of power system at time t. This paper assumes that there are no losses, so efficiency constants are 1, because we just need to check effect of shifted power and changing in pollutants from fluctuation of each generator's output.

$\mathrm{EP}_t^c = \eta^c \times ep_t^c$ (3)

$\mathrm{EP}_t^d = ep_t^d / \eta^d$ (4)

(Constraint (5) imposes a limit on the charging and discharging power of the ESS.

$0 \le \mathrm{EP}_t^c \le \mathrm{EP}^{rated}, 0 \le \mathrm{EP}_t^d \le \mathrm{EP}^{rated}$ (5)

Eq. (6) describes the SOC of ESS. Constraint (6) limits SOC of the battery to be less than ESS capacity and prevents the deep discharging from ESS by imposing minimum limit of SOC.

$\mathrm{SOC}^{min} \le SOC^{initial} + \sum_{i=1}^{t} EP_i^c - \sum_{i=1}^{t} EP_i^d \le SOC^{max}$, *each* $\forall\, t$ (6)

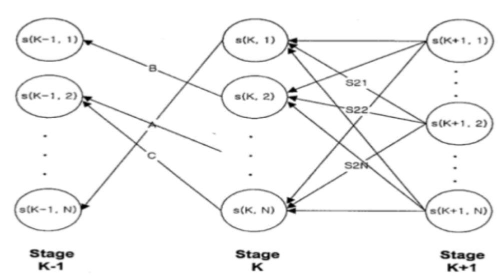

Fig. 1. states of dynamic programming

Eq. (7) is final condition limit of SOC at end time T. SOC at time T must be between SOC^{final1} and SOC^{final2}.

$\mathrm{SOC}^{final1} \le SOC^{initial} + \sum_{i=1}^{T} EP_i^c - \sum_{i=1}^{T} EP_i^d \le SOC^{final2}$ (7)

EP^{rated}: rated power of ESS (MW)

η^c, η^d : charging efficiency and discharging efficiency of ESS.

SOC_t: SOC of ESS at time t. (MWh)

$SOC^{initial}$: Initial SOC of ESS (MWh)

SOC^{final}: Final SOC of ESS (MWh)

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SOC^{min}: Minimum allowed SOC of ESS (MWh)
SOC^{max}: Maximum allowed SOC of ESS (MWh)

This paper uses forward dynamic programming methods for Unit Commitment. Figure 1 shows the concept of DP. Table 6 is basic load data of case1. Table 7 shows specs of each generator–fuel, power out range, constants of cost function(a, b, c), minimum down time, minimum up time and etc.

TABLE 7
GENERATING UNIT DATA

Unit	Unit1	Unit2	Unit3	Unit4	Unit5	Unit6	Unit7	Unit8	Unit9	Unit10
fuel	nuclear	nuclear	anthracite	anthracite	anthracite	bituminous	bituminous	LNG	LNG	LNG
Min (MW)	150	150	20	20	25	20	25	10	10	10
Max (MW)	455	455	130	130	162	80	85	55	55	55
a_i	0.00048	0.00031	0.002	0.00211	0.00398	0.00712	0.00079	0.00413	0.00222	0.00173
b_i	16.19	17.26	16.60	16.50	19.70	22.26	27.74	25.92	27.72	27.79
c_i	1000	970	700	680	450	370	480	660	665	670
MUT (H)	8	8	5	5	6	3	3	1	1	1
MDT (H)	8	8	5	5	6	3	3	1	1	1
Cold Start Time	5	5	4	4	4	2	2	0	0	0
Hot Start Cost ($)	4500	5000	550	560	900	170	260	30	30	30
Cold Start Cost ($)	9000	10000	1100	1120	1800	340	520	60	60	60
Initial Status(H)	8	8	-5	-5	-6	-3	-3	-1	-1	-1

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RESULTS

TABLE 8
LOAD CHANGING RESULT OF EACH CAPACITY

	1	2	3	4	5	6	7	8
ESS 0	700	750	850	950	1000	1100	1150	1200
ESS 100	724.998	775	950	950	999.993	1100	1150	1200
ESS 200	750	800	850	950	1000	1100	1150	1200
ESS 300	775	825	850	950	1000	1100	1150	1200
	9	10	11	12	13	14	15	16
ESS 0	1300	1400	1450	1500	1400	1300	1200	1050
ESS 100	1300	1400	1449.833	1450.169	1400	1300	1200	1050.37
ESS 200	1300	1400	1425	1425	1400	1300	1200	1075
ESS 300	1300	1400	1400	1400	1400	1300	1200	1100
	17	18	19	20	21	22	23	24
ESS 0	1000	1100	1200	1400	1300	1100	900	800
ESS 100	1049.628	1100	1200	1350	1299.996	1100	900	799.999
ESS 200	1075	1100	1200	1300	1299.995	1100	900	800
ESS 300	1100	1100	1200	1275	1275	1100	900	800

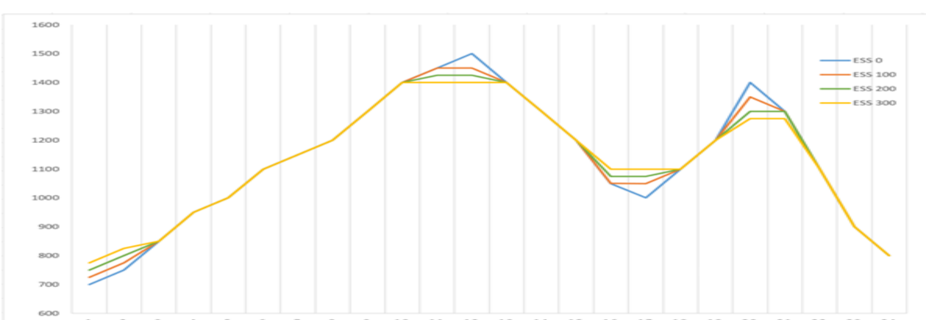

Fig. 2. Load changing result of each capacity

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TABLE 9
UNIT COMMITMENT RESULT OF SCENARIO 1

hr	Power output (MW)										Total power (MW)	Cost ($)
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10		
1	455	245	0	0	0	0	0	0	0	0	700	13683.13
2	455	295	0	0	0	0	0	0	0	0	750	14554.50
3	455	395	0	0	0	0	0	0	0	0	850	16301.89
4	455	455	0	0	40	0	0	0	0	0	950	18597.67
5	455	455	0	0	90	0	0	0	0	0	1000	19608.54
6	455	455	130	0	60	0	0	0	0	0	1100	21891.43
7	455	455	130	0	110	0	0	0	0	0	1150	22910.26
8	455	455	130	0	160	0	0	0	0	0	1200	23948.99
9	455	455	130	130	130	0	0	0	0	0	1300	26184.02
10	455	455	130	130	162	68	0	0	0	0	1400	28768.21
11	455	455	130	130	162	63	0	0	55	0	1450	30848.56
12	455	455	130	130	162	78	25	10	55	0	1500	33291.13
13	455	455	130	130	162	68	0	0	0	0	1400	28768.21
14	455	455	130	130	130	0	0	0	0	0	1300	26184.02
15	455	455	130	0	160	0	0	0	0	0	1200	23948.99
16	455	440	130	0	25	0	0	0	0	0	1050	20927.03
17	455	390	130	0	25	0	0	0	0	0	1000	20051.16
18	455	455	130	0	25	0	0	10	25	0	1100	23469.09
19	455	455	130	0	50	20	25	10	55	0	1200	26798.02
20	455	455	130	0	162	70	63	10	55	0	1400	31300.72
21	455	455	130	130	130	0	0	0	0	0	1300	26184.02
22	455	455	0	130	60	0	0	0	0	0	1100	21860.29
23	455	315	0	130	0	0	0	0	0	0	900	17764.14
24	455	215	0	130	0	0	0	0	0	0	800	16021.71

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TABLE10
UNIT COMMITMENT RESULT OF SCENARIO 2

hr	Power output (MW)										Total power (MW)	Cost ($)
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10		
1	455	270	0	0	0	0	0	0	0	0	724.998	14118.59
2	455	320.01	0	0	0	0	0	0	0	0	775.006	14990.87
3	455	395	0	0	0	0	0	0	0	0	850	16301.89
4	455	455	0	0	40	0	0	0	0	0	950	18597.67
5	455	455	0	0	89.993	0	0	0	0	0	999.9931	19608.40
6	455	455	130	0	60.007	0	0	0	0	0	1100.007	21891.57
7	455	455	130	0	110	0	0	0	0	0	1150	22910.26
8	455	455	130	0	160	0	0	0	0	0	1200	23948.99
9	455	455	130	130	130	0	0	0	0	0	1300	26184.02
10	455	455	130	130	162	68	0	0	0	0	1400	28768.21
11	455	455	130	130	162	62.833	0	0	55	0	1449.833	30844.70
12	455	455	130	130	162	38.169	25	0	55	0	1450.169	31451.93
13	455	455	130	130	162	0	25	0	43	0	1400	29886.67
14	455	455	130	130	105	0	25	0	0	0	1300	26842.13
15	455	455	130	0	160	0	0	0	0	0	1200	23948.99
16	455	440.37	130	0	25	0	0	0	0	0	1050.37	20933.51
17	455	439.63	130	0	25	0	0	0	0	0	1049.628	20920.50
18	455	420	130	0	40	20	25	10	0	0	1100	23787.53
19	455	455	130	0	115	20	25	0	0	0	1200	25005.28
20	455	455	130	0	162	80	58.006	10	0	0	1350.006	29198.68
21	455	435	130	130	105	20	25	0	0	0	1299.996	27309.38
22	455	435	0	130	60	20	0	0	0	0	1100	22327.62
23	455	315	0	130	0	0	0	0	0	0	900	17764.14
24	455	215	0	130	0	0	0	0	0	0	799.9994	16021.70

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TABLE 11
UNIT COMMITMENT RESULT OF SCENARIO 3

hr	Power output (MW)										Total power (MW)	Cost ($)
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10		
1	455	295	0	0	0	0	0	0	0	0	750	14554.50
2	455	345	0	0	0	0	0	0	0	0	800	15427.42
3	455	395	0	0	0	0	0	0	0	0	850	16301.89
4	455	365	0	130	0	0	0	0	0	0	950	18637.68
5	455	415	0	130	0	0	0	0	0	0	1000	19512.77
6	455	455	0	130	60	0	0	0	0	0	1100	21860.29
7	455	455	0	130	110	0	0	0	0	0	1150	22879.12
8	455	455	0	130	160	0	0	0	0	0	1200	23917.85
9	455	455	130	130	130	0	0	0	0	0	1300	26184.02
10	455	455	130	130	162	68	0	0	0	0	1400	28768.21
11	455	455	130	130	162	80	0	13	0	0	1425	30045.64
12	455	455	130	130	162	68	25	0	0	0	1425	29942.21
13	455	455	130	130	162	0	68	0	0	0	1400	29221.58
14	455	423	130	130	162	0	0	0	0	0	1300	26290.58
15	455	455	130	0	160	0	0	0	0	0	1200	23948.99
16	455	455	130	0	35	0	0	0	0	0	1075	21389.48
17	455	455	130	0	25	0	0	0	0	10	1075	22138.16
18	455	455	130	0	60	0	0	0	0	0	1100	21891.43
19	455	455	130	0	135	25	0	0	0	0	1200	24358.09
20	455	455	130	0	162	73.005	25	0	0	0	1300.005	27197.98
21	455	455	130	0	162	80	0	0	17.995	0	1299.995	27351.86
22	455	455	0	0	162	28	0	0	0	0	1100	22098.01
23	455	315	0	130	0	0	0	0	0	0	900	17764.14
24	455	215	0	130	0	0	0	0	0	0	800	16021.71

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TABLE 12
UNIT COMMITMENT RESULT OF SCENARIO 4

hr	Power output (MW)										Total power (MW)	Cost ($)
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10		
1	455	320	0	0	0	0	0	0	0	0	775	14990.77
2	455	370	0	0	0	0	0	0	0	0	825	15864.46
3	455	395	0	0	0	0	0	0	0	0	850	16301.89
4	455	365	0	130	0	0	0	0	0	0	950	18637.68
5	455	415	0	130	0	0	0	0	0	0	1000	19512.77
6	455	385	130	130	0	0	0	0	0	0	1100	21879.33
7	455	435	130	130	0	0	0	0	0	0	1150	22755.04
8	455	455	130	130	0	30	0	0	0	0	1200	24149.97
9	455	455	130	130	130	0	0	0	0	0	1300	26184.02
10	455	455	130	130	162	68	0	0	0	0	1400	28768.21
11	455	455	130	130	162	58	0	10	0	0	1400	29456.25
12	455	455	130	130	162	58	0	10	0	0	1400	29456.25
13	455	455	130	130	162	0	68	0	0	0	1400	29221.58
14	455	455	130	130	105	0	25	0	0	0	1300	26842.13
15	455	455	130	0	135	0	25	0	0	0	1200	24601.13
16	455	455	130	0	60	0	0	0	0	0	1100	21891.43
17	455	455	130	0	60	0	0	0	0	0	1100	21891.43
18	455	455	130	0	60.001	0	0	0	0	0	1100.001	21891.45
19	455	455	130	0	160	0	0	0	0	0	1200	23948.99
20	455	455	0	130	162	73	0	0	0	0	1275	25992.73
21	455	455	0	130	162	73.995	0	0	0	0	1275.995	26015.92
22	455	455	0	130	0	60	0	0	0	0	1100	21945.19
23	455	315	0	130	0	0	0	0	0	0	900	17764.14
24	455	215	0	130	0	0	0	0	0	0	800	16021.71

Fig. 3. Total cost of each scenario

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TABLE 13
POLLUTANTS EMISSIONS OF EACH SCENARIO (TON/DAY)

	CO2	SOx	NOx
case 1	5421.86	3.47	5.44
case 2	5455.60	3.51	5.48
case 3	5534.56	3.60	5.61
case 4	5554.47	3.62	5.64

TABLE 14
POLLUTANTS TREATMENT COST OF EACH SCENARIO (TEN MILLION KRW)

	CO2	SOx	NOx	Total
case 1	11.39	5.57	6.20	23.16
case 2	11.46	5.64	6.25	23.35
case 3	11.62	5.77	6.40	23.80
case 4	11.66	5.80	6.43	23.90

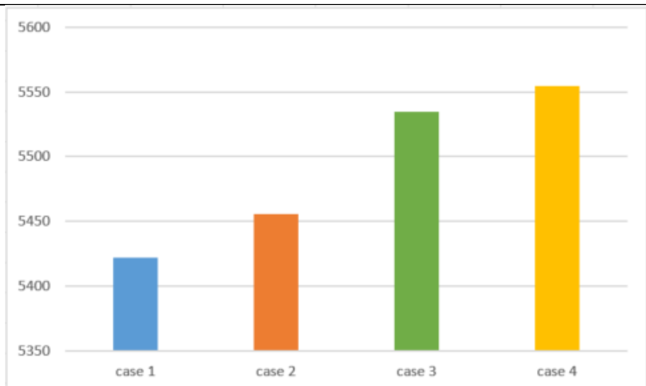

Fig. 4. CO2 emissions (ton/day)

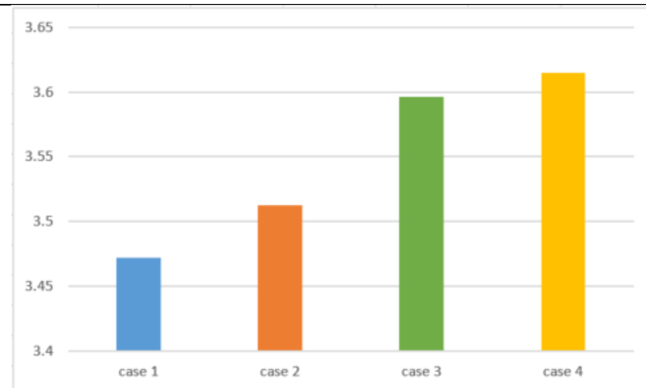

Fig. 5. Sox emissions (ton/day)

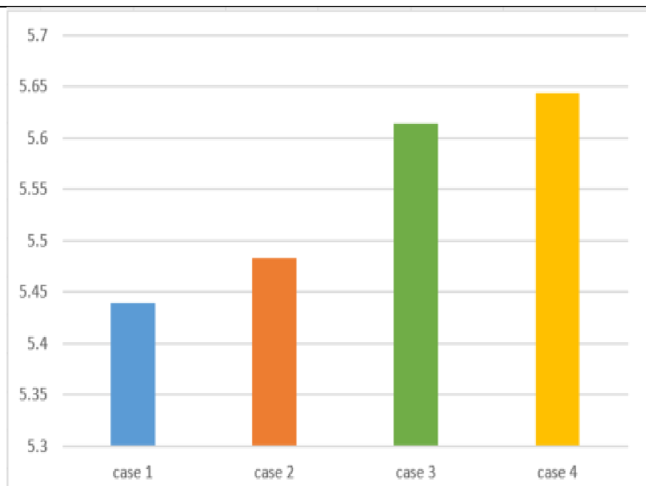

Fig. 6. NOx emissions (ton/day)

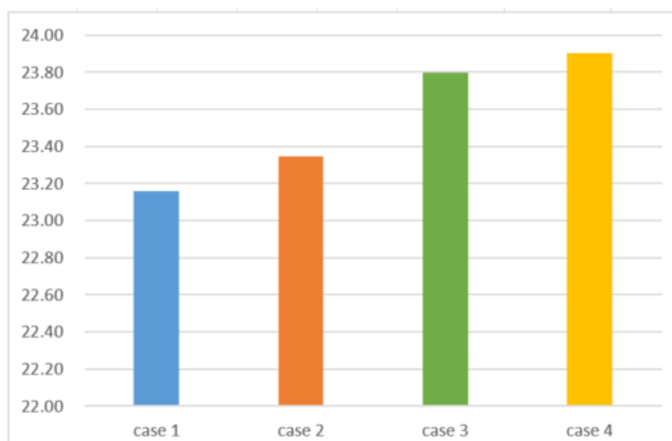

Fig. 7. pollutants treatment cost

IV. CONCLUSION

The object of this study is to research relationship between air pollutants emissions in power sector of Korea and capacity of BESS which is operated for maximizing customer's profits in the near future. It is observed from results that a gradual increasing total capacity of customer's ESS can reduce total cost in power system, but it increases pollutants emissions–NOx, SOx, CO2 and treatment cost. It was revealed that Spread of ESS for customer in the near future could have a negative effect in

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some way. The study was basic research using IEEE 39-bus data which was roughly adjusted to be similar but simplified for real power system of Korea. It requires a necessity for a further study in which many things are considered to be carried out.

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— This article does not have any appendix. —

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