A COST OPTIMIZATION MODEL OF ELECTRICITY DISTRIBUTION CONSIDERING WHETHER SMART GIRD IS CONSTRUCED: A CASE STUDY OF THE EASTERN COAST INDUSTRIAL ESTATE OF KOREA

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Abstract

Today, global warming is one of the important issues all over the world. Global warming has accelerated by fossil fuel which has produced various energies. This study focuses on optimization of distribution of electric energy, among a wide variety of energies produced by fossil fuel, which is employed in a large scale industrial estate. In these days, many countries have some problems in the current electric energy network because of deterioration in electric energy distribution system, constant growth of the use of electric energy, incoming exhaustion of fossil fuel, carbon dioxide by fossil fuel, and so on. Then, smart grid, called the post-electric generation network, is deeply related with power management system because it can upgrade the current electricity distribution. Smart grid needs high technology and various energy sources. Examining the total cost of smart grid is not easy because it is the interactive electric energy network system. We illustrate how smart grid optimizes the total cost by applying the proposed model to a case study: the eastern coast industrial estate of Korea.

Keywords

Optimization, Smart grid, Electricity distribution.

Introduction.

Countermeasures for increase of electricity demand by continuous industry development and power management system backwater are still insufficient. Many countries which has diverse and huge industrial complex has been upgrading power management system.

As a method to solve those problems smart grid is given great attention. Smart grid is based on information-technology(Chen, Song et al. 2009). Smart grid basically pursues well-distributed electric energy system for improving current power management system which is central concentrated electricity system. Smart gird, which enables well-distributed electric energy system based on information technology, will improve safety and efficiency of power network. A lot of demonstration projects have already shown the promise of smart grid. This covers closed-loop systems using advanced protection(Fanning 2004), many using distributed storage and generation(Jiménez and Hatziargyriou 2006; Vollkommer, Fitchett et al. 2006). These studies tend to apply just safety and efficiency to smart grid. Smart gird also should be considered in terms of the cost. After several years, if smart grid is constructed with high technology, it will operate with alternative energy plants and self-generation as well as fossil fuel power plants.

Electric energy has been mainly produced by fossil fuel. This fossil fuel consumption is causing environmental

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problems, called global warming, worse day by day. Researchers have studied to minimize the use of fossil fuel and the amount of carbon dioxide which is generated by fossil fuel, the main culprit of global warming. Carbon dioxide generated by fossil fuel has given a rise to a new market by CO_2 emission trading scheme. Researchers are also spurred into far more practical action in order to develop and apply alternative energy and self-generation for using less fossil fuel.

Then, if the electricity demand of one consumer is constant, it is important how smart grid with carbon tax, alternative energy plants, and self-generation optimizes the cost compared with current electricity system. Figure 1 shows us the proposed model.

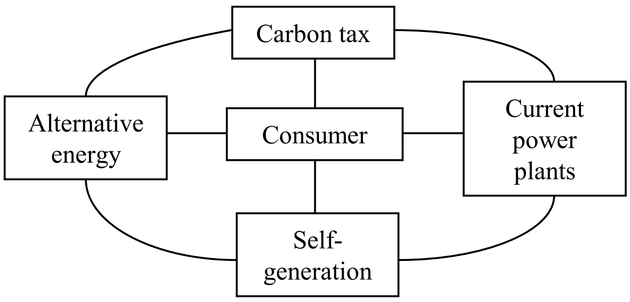

Figure 1. Illustration of the proposed model

The object of this work is to minimize the total cost in the proposed model by using a mathematical program.

Problem Statement.

A lot of trial and error happens for actual building of smart grid. But, there are no any visible evidences of success of smart grid from the point of the cost. Suppose that technical technology like information technology would keep developing on and on. Success of smart grid depends on how electricity distribution network works well and how the total cost is minimized.

We calculate how the total cost will be saved if we construct smart grid. We use mixed integer linear program algorithm(MILP)(Shi and Yao 2001) .

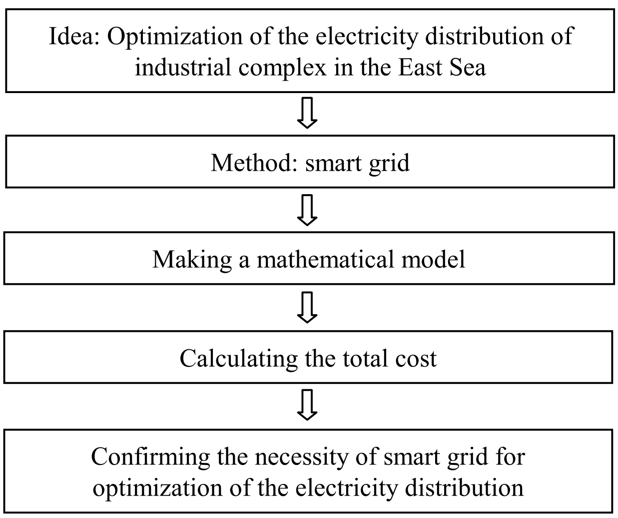

Figure 2.Steps about the proposed model

Figure 2 shows steps about the proposed model to construct well-distributed electricity network and minimized the total cost.

Mathematical Statement.

The objective function is to minimize the total cost of electric energy in every plant. This function consists of (a) the cost of electric energy with carbon tax, (b) the cost of electric energy without carbon tax, (c) the cost of electric energy from an alternative energy plant, (d) the cost of electric energy form Molten-Carbonate Fuel Cells (MCFC) at which is built in another plant, (e) the cost of electric energy from MCFC at which is built in its own plant, (f) set-up cost of MCFC, (g) the benefit as selling electricity of its own MCFC to another plant. The objective function of the proposed model reads as

$$\min \; f_{total} \tag{1}$$

$$f_{total} = c\_tax \times \sum_{i,f,t} (c\_co2_f \times y\_fossil\_tax_{i,f,t})$$

$$+\sum_{i,f,t} (c\_fossil\_cost_{i,f} \times y\_fossil_{i,f,t})$$

$$+\sum_{i,n,t} (c\_new_{i,n,t} \times y\_new_{i,n,t})$$

$$+\sum_{i,k,t} (c\_from\_other_{t,k,i} \times y\_from\_other_{k,i,t})$$

$$+\sum_{i,t} (c\_self_{t,i} \times y\_self_{i,t})$$

$$+CCR \times \sum_{i} (c\_set_i \times x\_set_i)$$

$$-\sum_{i,j,t} (c\_to\_other_{t,i,j} \times y\_to\_other_{i,j,t})$$

$$\forall f \in F, \; \forall n \in N, \; \forall i,k \in I, \; \forall t \in T$$

In eq 1, f means a fossil fuel plant. n means an alternative energy plant. i means a plant. t means time. c_tax (won/tCO_2) is carbon tax. c_co2_f (ton/kWh) is carbon emissions by a kind of generation fuel. $y\_fossil\_tax_{i,f,t}$ (kWh) is only electric energy with carbon tax from a fossil fuel power plant. $c\_fossil\_cost_{i,f}$ (won/kWh) is the cost of electricity by a kind of generation fuel. $y\_fossil_{i,f,t}$ (kWh) is electric energy come from fossil fuel power plants.

$c\_new_{i,n,t}$ (won/kWh) is the cost of electricity by a kind of generation fuel in alternative energy plants. $y\_new_{i,n,t}$ (kWh) is electric energy come from alternative energy plants. $c\_from\_other_{t,k,i}$ (won/kWh) is the cost of electricity in case of being given by self-generation in other plants. $y\_from\_other_{k,i,t}$ (kWh) is electric energy come from self-generation in other plants. $c\_self_{t,i}$ (won/kWh) is the cost of electricity in case of using self-generation. $y\_self_{i,t}$ (kWh) is electric energy come from self-generation. CCR is the capital charge rate. c_set_i (won/kW) the cost of constructing self-generation. x_set_i is a decisions binary variable of self-generation. $c\_to\_other_{t,i,j}$ (won/kWh) is the sales cost of electricity in case of selling electricity of self-generation to other plants. $y\_to\_other_{i,j,t}$ (kWh) is electric energy supplying to other plants.

There are some constraints related with the objective function. The main constraints are in the following.

Each plant is supplied with electricity from four regions, fossil fuel power plants, alternative power plants, MCFC in other plants, and its own MCFC.

$$y\_need_{t,i} = \sum_f y\_fossil_{i,f,t} + \sum_n y\_new_{i,n,t} + \sum_k y\_from\_other_{k,i,t} + y\_self_{i,t} \quad (2)$$
$$\forall f \in F,\ \forall i,k \in I\ ;i \neq k,\ \forall t \in T$$

In eq 2, $y\_need_{t,i}$ (kWh) is the electricity demand of each plant.

Each plant should be supplied with electricity from alternative power plants, MCFC in other plants, or its own MCFC over a fixed quantity by the national policies.

$$\sum_n y\_new_{i,n,t} + \sum_k y\_from\_other_{k,i,t} + y\_self_{i,t} \geq rate\_new \times y\_need_{t,i} \quad (3)$$
$$\forall n \in N,\ \forall f \in F,\ \forall i,k \in I\ ;i \neq k,\ \forall t \in T$$

In eq 3, $rate\_new$ is the ratio of alternative energy to the total amount of electric energy used in each plant.

In case of exceeding the reduction ratio of the use of electric energy from fossil fuel plants, carbon tax should be charged.

$$\sum_f y\_fossil_{i,f,t} \leq rate\_fossil \times y\_need_{t,i} + M \times x\_tax_{i,t} \quad (4)$$
$$\forall f \in F,\ \forall i \in I,\ \forall t \in T$$

$$\sum_f y\_fossil_{i,f,t} \geq rate\_fossil \times y\_need_{t,i} + M \times (1 - x\_tax_{i,t}) \quad (5)$$
$$\forall f \in F,\ \forall i \in I,\ \forall t \in T$$

In eq 4,5, M is big number.

Amount of electricity added to carbon tax is the value of subtracting the reduction ratio from the use of electric energy from fossil fuel plants.

$$\sum_f y\_fossil\_tax_{i,f,t} \geq \sum_f y\_fossil_{i,f,t} - rate\_fossil \times y\_need_{t,i} \quad (6)$$
$$\forall f \in F,\ \forall i \in I,\ \forall t \in T$$

In eq 6, $rate\_fossil$ is the reduction ratio of electricity come from fossil fuel power plants.

Each plant pays carbon tax.

$$c\_total\_tax_i = c\_tax \times \sum_{f,t} (c\_co2_f \times y\_fossil\_tax_{i,f,t}) \quad (7)$$
$$\forall f \in F,\ \forall i \in I,\ \forall t \in T$$

In eq 7, $c\_total\_tax_i$ (won) is carbon tax of each plant.

Case Study.

First, we choose an industrial region for a case study where is the eastern coast industrial estate of Korea. In the eastern coast industrial estate of Korea, there are a number of plants. Among those plants, we select big 5 plants, Daehan, SK energy, Hanhwa chemical, Tongsuh petrochemical, and Taekwang.

Second, we design 6 scenarios. First scenario is that carbon tax is 50 $/t$CO_2$, smart gird is not formed, and Korean government does not support the capital cost of MCFC. Second scenario is that carbon tax is 50 $/t$CO_2$, smart grid is formed, and Korean government supports the capital cost of MCFC. Third scenario is that carbon tax is 50$/t$CO_2$, smart grid is formed, and Korean government does not support the capital cost of MCFC. Fourth scenario is that carbon tax is 150 $/t$CO_2$, smart grid is not formed, and Korean government does not support the capital cost of MCFC. Fifth scenario is that carbon tax is 150 $/t$CO_2$, smart grid is formed, and Korean government supports the capital cost of MCFC. Last scenario is that carbon tax is

150 $/tCO$_2$, smart grid is formed, and Korean government does not support the capital cost of MCFC.

To practice a case study, initial conditions are built up. First is an assumption about emission trading scheme. Korean government announced climate policies for low carbon green growth including content that the emission of carbon dioxide would reduce 30 percent in Business As Usual (BAU) by 2020. Then, we suppose that Korea will take 70 percent of the allocation of the emission allowance in BAU. Second is expectation of demand of electric energy in 2020. We evaluate the expectation method of demand of electricity by using product-based emission factor method that is mentioned in Intergovernmental Panel on Climate Change (IPCC).

$$Y\_need_i = \sum_j PP_{i,j} \times CEF_{i,j} \times ECF \qquad (8)$$
$$\forall i \in I,\ \forall j \in J$$

In eq 8, j means a product. Y_need_i (kWh) is power demand of each plant. $PP_{i,j}$ (ton) is annual production of each prodcut in each plant. $CEF_{i,j}$ (tCO$_2$/ton) is CO_2 emission factor for each product in each plant. ECF (kWh/tCO$_2$) is electricity consumption factor.

Table 1. Parameters for scenarios in 2020

parameters	value
Economic growth (%)[a]	4.6
Average yearly growth rate in petrochemical (%)[b]	2.8
CO_2 emission factor (t CO_2/ton product produced)[c]	0.196(EDC) 0.294(VCM) 1.0(AN)
Electricity consumption factor (CO_2 MWh/t CO_2)[c]	0.424

a. KNSO, b. KIET, c. IPCC

Table 2. Maximum capacity of each generation system

generation system	capacity(kW)
Fossil fuel plant in Samchunpo(coal)[a]	3,723,270
New renewable power plant [b]	125,000(wind power)[b] 25,000(fuel cell)[c]
MCFC[d]	15,000(plant A) 25,000(plant B) 2,500(plant C) 5,000(plant D) 5,000(plant E)

a. KEPCO, b. Hankook Daily News, c. Newsis Daily News, d. assumption 5 percent of electricity demand in 2020

Average of electric energy unit cost in Samchunpo fossil fuel plant is 68.15 won. Averages of electric energy unit costs of wind power and fuel sell are 105.2 won and 207.5 won. Average of electric energy unit cost of MCFC is 190.25 won.

Table 3. Conditions for each scenario

scenario	carbon tax($/tCO$_2$)	smart grid	Supporting the capital cost of MCFC
1	50	X	X
2	50	O	O
3	50	O	X
4	150	X	X
5	150	O	O
6	150	O	X

It needs to calculate the amount of carbon dioxide emission in Samchunpo fossil fuel plant to practice each scenario with carbon tax. So, the emission coefficient of carbon dioxide per producing electric energy is 0.00095 tCO$_2$/kWh.

It also needs to know of the capital cost of each MCFC.

Table 4. Capital cost of each MCFC

plants	cost(won/kW)
A(Daehan)	5,400,000,000
B(SK energy)	9,000,000,000
C(Hanhwa chemical)	900,000,000
D(Tongsuh petrochemical)	1,800,000,000
E(Taekwang)	1,800,000,000

Results and Discussion.

The proposed model in this paper is MILP and the model is practiced by using CPLEX 9.0 solver in GAMS optimization software.

Table 5.Total cost of each scenario

	1	2	3	4	5	6
Total cost	14,985	14,034	14,858	20,510	16,057	16,995

(unit: 1 million won)

Table 6. Cost of each scenario with carbon tax

	1	2	3	4	5	6
A	758	489	474	2,273	1,078	294
B	1,384	594	580	4,161	819	1,816
C	107	23	22	320	106	97
D	279	122	127	837	314	190
E	233	99	91	700	240	196

(unit: 1 mililon won)

In table 5, each total cost of scenario 1, 2, and 3 is less than that of scenario 4, 5, and 6. In scenario 1, 2, and 3, the best scenario which has the minimum total cost is scenario 2. In scenario 4, 5, and 6, the best scenario which has also the minimum total cost is scenario 5. It means that on each carbon tax building smart grid and supporting the capital cost of MCFC would be the optimal solutions.

In table 5, we confirm that each company can save carbon tax as constructing smart grid because the cost in scenario 2 and 3 is much less than that in scenario 1 and also the cost in scenario 5 and 6 is much less than that in scenario 4. However the cost in scenario 3 is not always less than that in scenario 2 for all companies. The cost in scenario 6 is also not always less than that in scenario 5. It is the reason why we focused on optimizing the total cost not the cost of each company.

Conclusions

In this paper, we have suggested the proposed model and optimized the total cost about demand of each plant from 6 points of view. We have selected the specific region and the largest chemical plants, Daehan, SK energy, Hanhwa chemical, Tongsuh petrochemical, Taekwang in the eastern coast industrial estate of Korea and performed optimization process of electricity distribution in terms of smart grid. Objective function has been established to minimize the total cost. All equations consist of MILP.

In case of scenario 3 and 6, the total cost can be saved in 0.9 percent and 20.7 percent compared with scenario 1 and 4 relatively. In case of scenario 2 and 5, the total cost can be saved in 6.8 percent and 27.7 percent compared with scenario 1 and 4 relatively. In accordance with increase of carbon tax and vitalization of carbon trading scheme, the role of smart grid will be important.

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