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The Optimal Operation for Community Energy System Using a Low-Carbon Paradigm with Phase-Type Particle Swarm Optimization

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Abstract - By development of renewable energy and more efficient facilities in an increasingly deregulated electricity market, the operation cost of distributed generation (DG) is becoming more competitive. International environmental regulations of the leaking carbon become effective to reinforce global efforts for a low-carbon paradigm. Through increased DG, operators of DG are able to supply electric power to customers who are connected directly to DG as well as loads that are connected to entire network. In this situation, a community energy system (CES) with DGs is a new participant in the energy market.

DG's purchase price from the market is different from the DG's sales price to the market due to transmission service charges and other costs. Therefore, CES who owns DGs has to control the produced electric power per hourly period in order to maximize profit. Considering the international environment regulations, CE will be an important element to decide the marginal cost of generators as well as the classified fuel unit cost and unit's efficiency.

This paper introduces the optimal operation of CES's DG connected to the distribution network considering CE. The purpose of optimization is to maximize the profit of CES. A Particle Swarm Optimization (PSO) will be used to solve this complicated problem. The optimal operation of DG represented in this paper would guide CES and system operators in determining the decision making criteria.

Keywords: Optimal operation, Community energy system, Carbon emission, Particle swarm optimization

1. Nomenclature

$G_{CES,DG}$	DG owned and operated by CES
$P_{CES,DG}(t)$	Active power provided for customers in CES's control area at time t
$Q_{CES,DG}(t)$	Reactive power provided for customers in CES's control area at time t
$H_{CES,DG}(t)$	Thermal energy provided for customers in CES's control area at time t
$G_{ind,DG}$	DG located in CES's control area and owned by an individual
$P_{ind,DG}(t)$	Active power supplied for customers by an individually owned DG
$Q_{ind,DG}(t)$	Reactive power supplied for customers by an individually owned DG
$P_i(t)$	Active power load of customer i
$Q_i(t)$	Reactive power load of customer i
$H_i(t)$	Thermal load of customer i
$P_n(t)$	Active power flowing in and out of network interconnected with CES's control area
$Q_n(t)$	Reactive power flowing in and out of network interconnected with CES's control area
$P_{PV}(t)$	The power production of photovoltaic generator at time t
$\eta_p(t)$	Energy conversion efficiency of PV at time t
A_p	Area of the PV array
K_p	Correct coefficient for PV's generation
$G(t)$	Radiation intensity at time t
$\alpha_g, \beta_g, \gamma_g$	Coefficients of gas turbine cost function
$\alpha_b, \beta_b, \gamma_b$	Coefficients of boiler cost function
$\alpha_{c,p}, \beta_{c,p}, \gamma_{c,p}$	Coefficients of CHP cost function based on active power
$\alpha_{c,h}, \beta_{c,h}, \gamma_{c,h}$	Coefficients of CHP cost function based on heat
κ	Active/thermal rate
$\Xi_{CE,n}(t)$	The amount of CE at t [ton-CO_2]
$\xi_{CE,n}$	The average amount of CE according to 1[MW] power supply of entire network
$\Xi_{CE,CES}(t)$	The amount of CE according to generation of DGs in CES's control area at t [ton-CO_2]
$\Xi_{CE,CES,n}(t)$	The amount of CE for supplying energy demand in CES's control area at t [ton-CO_2]
CE_{CES,DG_i}	CE coefficient of CES's DG i by fuel type

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	[ton-CO_2/MWh_f]
CE_{ind,DG_i}	CE coefficient of individual DG *i* by fuel type [ton-CO_2/MWh_f]
η_{CES,DG_i}	Generation efficiency[GJ_e/GJ_f] of CES's DG *i*
η_{ind,DG_i}	Generation efficiency[GJ_e/GJ_f] of individual DG *i*
EUA_p	CE cost based on European Union Allowance [$/ton-$CO_2$]
$f(t)$	Total profit of CES at time *t*
$P(t)$	Difference between total active power and total active load in CES's area
$Q(t)$	Difference between total reactive power and total reactive load in CES's area
$C_{P,customer}$	Sales price of active power for CES's customer
$C_{H,customer}$	Sales price of thermal energy for CES's customer
$C_{P,market}$	Market price of active power to buy or sell
$C_{Q,market}$	Market price of reactive power to buy or sell
C_{CES,DG_i}	Generation cost of CES's DG *i*
$C_{P,ind,DG}(t)$	Price of active power from individual DGs to CES at time *t*
$C_{Q,ind,DG}(t)$	Price of reactive power from individual DGs to CES at time *t*
$C_{CE}(t)$	CE cost at time *t*
k	The dimension of the optimization problem
$iter$	Iteration number for optimization problem
$iter^{max}$	Total iteration number for optimization problem
w_{iter}	The inertia weight at iteration *iter*
w^{max}	The maximum inertia weight
w^{min}	The minimum inertia weight
c_1, c_2	Acceleration coefficients
r_1, r_2	Uniformly distributed random numbers [0,1]
$V^j_{iter,k}$	The *k*th element of the particle *j*'s velocity vector at iteration *iter*
$X^j_{iter,k}$	The *k*th element of the particle *j*'s position vector at iteration *iter*
$Xbest^j_{iter,k}$	The *k*th element of the particle *j*'s best position vector until iteration *iter*
$Xbest^g_{iter,k}$	The *k*th element of the swarm's best position until iteration *iter*
m	A coefficient for calibrating the particle's velocity

2. Introduction

Distributed Generation (DG) such as hydro, photovoltaic arrays, fuel cells, microturbines and battery storage, generally stands for small scale generators connected to distribution networks. DG is useful for maintaining system stability, offering a spinning reserve, reducing transmission costs and distribution cost [1]. It gives comfortability of energy supply and improvement in quality to electricity energy consumers [2], [3]. Renewable energy also helps to reduce greenhouse gases that is mainly caused by large power stations. Also, electricity price is expected to drop due to the competition in generation, transmission and distribution through greater deregulation. However, the price will be floating in the new competitive structure. In this circumstance, DG is a good alternative for reducing transmission costs and electricity price.

Recently, DGs connected in distribution network are being increasingly installed and spreading around the world because generally DG has the characteristics of low-carbon emission as the paradigm in line with environmental agenda internationally. In this situation, the operator of DG is able to supply electric power to customers who are connected directly to DG as well as loads that are connected to entire network. Recently, Community Energy System (CES) with DGs is a new participant in the energy market. CES can be regarded as an improved type of DGs like Virtual Power Plant (VPP) or microgrid [4]. CES supplies both electrical and thermal energy to customer who is in its control area. Because of the international environmental regulation, diffusion of high-efficiency generators as well as renewable energy sources contributes to increasing the business of CES. The studies for optimal operation of DGs possessed by CES are required. This paper reflects dynamic market price of active and reactive power and proposes optimal operation of CES considering carbon emission (CE). Photovoltaic generator, which is one of the renewable energy, gas turbine, combined heat and power (CHP) are applied to the case study as DGs. To optimize the amount of generation, Particle Swarm Optimization (PSO) algorithm is used because it is required to have fast and robust solutions for the operation of DGs.

3. Community Energy System Description

CESs are recently new participants in power market supply active and reactive power and thermal energy to a control area with renewable energy and high-efficiency plants according to the demand of the control area.

3.1 Structure of Community Energy System

CES can participate in a power market when it has generally more than 50% (each nation has a different standard) of load demand in a control area. It can trade overs and shorts of energy through an interconnected network. Therefore, CES can join in a power market as both power generation operator and customer. This is represented in Fig.1.

CES firstly supplies thermal energy to the CES's control area and then generates active and reactive power for the

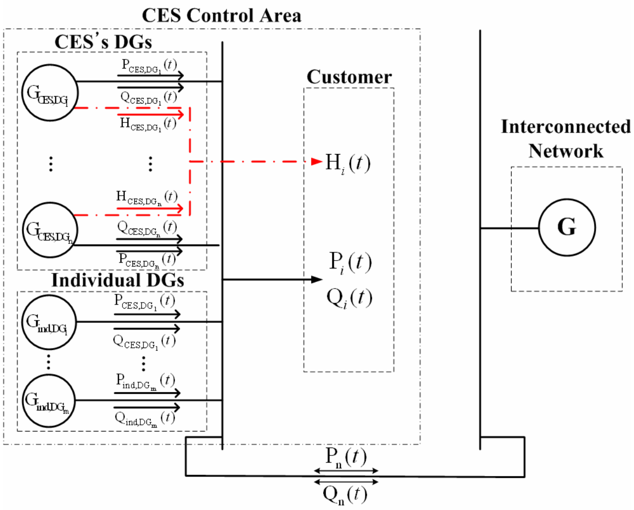

Fig. 1. Configuration of Community Energy System

customer's demand. Generally, thermal energy is provided by boiler and CHP. If active and reactive power generated by CES's DGs and, at the same time, bought from individual DGs, is not sufficient for its own customer's demand, it should be supplied from the neighbor network connected to CES's control area.

3.2 Operation Cost by Distributed Generator Types

There are various forms of DGs, such as hydro, photovoltaic arrays, fuel cells, microturbines and so on. This paper discusses the optimal generation of each generator type for the maximum operation profits when CES provides a customer with active and reactive power and thermal energy through photovoltaic, gas turbine, boiler, CHP and SVC.

3.2.1 Photovoltaic Generator

The production power and operation cost of photovoltaic generator (PV) are represented by insolation around solar battery and the efficiency of energy conversion as follows:

$$\mathrm{P}_{\mathrm{PV}}(t) = \eta_{\mathrm{p}}(t) \cdot \mathrm{A}_{\mathrm{p}} \cdot \mathrm{K}_{\mathrm{p}} \cdot \mathrm{G}(t) \tag{1}$$

$$\mathrm{C}_{\mathrm{PV}}\left(\mathrm{P}_{\mathrm{PV}}(t)\right) = 0 \tag{2}$$

where the operation cost in order to produce power of PV can be ignored because PV uses rays of the sun as the origin of energy.

3.2.2 Gas Turbine

If a gas turbine produces regular power for an hour, the cost function per hour is commonly given in the form of a quadratic equation as follows.

$$\mathrm{C}_{\mathrm{GT}}(t) = \alpha_{\mathrm{g}} + \beta_{\mathrm{g}} \cdot \mathrm{P}(t) + \gamma_{\mathrm{g}} \cdot \mathrm{P}(t)^2 \tag{3}$$

3.2.3 Boiler

Boiler produces heat energy instead of electric energy, and other features are similar to gas turbine.

$$\mathrm{C}_{\mathrm{Boiler}}(t) = \alpha_{\mathrm{b}} + \beta_{\mathrm{b}} \cdot \mathrm{H}(t) + \gamma_{\mathrm{b}} \cdot \mathrm{H}(t)^2 \tag{4}$$

3.2.4 Combined Heat and Power

CHP produces heat and electric energy at the same time. This paper uses thermal ratio due to the amount of active power generated.

$$\begin{aligned}\mathrm{C}_{\mathrm{CHP}}(t) &= \alpha_{\mathrm{c,p}} + \beta_{\mathrm{c,p}} \cdot \mathrm{P}(t) + \gamma_{\mathrm{c,p}} \cdot \mathrm{P}(t)^2 \\ &= \alpha_{\mathrm{c,h}} + \beta_{\mathrm{c,h}} \cdot \mathrm{H}(t) + \gamma_{\mathrm{c,h}} \cdot \mathrm{H}(t)^2\end{aligned} \tag{5}$$

$$\mathrm{P}(t) = \kappa \cdot \mathrm{H}(t) \tag{6}$$

4. Carbon Emission

Conventionally, the generators with competitive price will hold a prominent position in the market without regulation for CE, however, if considering the international environment regulation, CE newly will be important elements to decide marginal costs of generators as well as the fuel cost and generators efficiency [6,7].

Only fossil fuels give off carbon and the amount of carbon differs based on the source so that CE coefficient for each fuel needs to be determined separately [5]. This paper refers to IPCC's (Intergovernmental Panel on Climate Change) CE coefficient for each fuel [kg-CO_2/GJ_f].

In cases where active power and thermal energy are supplied in CES's control area through entire network, CE is calculated as follows:

$$\Xi_{\mathrm{CE,n}}(t) = \left[\sum_{i \in \mathrm{CES,Load}} \mathrm{P}_i(t) + \sum_{i \in \mathrm{CES,Load}} \mathrm{H}_i(t)\right] \cdot \xi_{\mathrm{CE,n}} \tag{7}$$

The amount of CE at time t is analyzed by the average amount of CE according to 1 [MW] power supply of entire network for supplying electricity energy from entire network without CES to customers in CES's control area.

In cases where CES operates DGs with various characteristics of fuel types, the expected amount of CE as generation of CES' DGs and individual DGs and as supplier electric energy according to power and thermal load in CES's control area are represented, respectively, as follows:

$$\Xi_{\mathrm{CE,CES}}(t) = \sum_{i \in \mathrm{CES,DG}} \mathrm{P}_{\mathrm{CES,DG}_i}(t) \cdot \frac{\mathrm{CE}_{\mathrm{CES,DG}_i}}{\eta_{\mathrm{CES,DG}_i}} + \sum_{i \in \mathrm{ind,DG}} \mathrm{P}_{\mathrm{ind,DG}_i}(t) \cdot \frac{\mathrm{CE}_{\mathrm{ind,DG}_i}}{\eta_{\mathrm{ind,DG}_i}} \tag{8}$$

$$\Xi_{\mathrm{CE,CES,n}}(t)=\begin{bmatrix}\sum_{i\in\mathrm{CES,Load}}\mathrm{P}_i(t)-\sum_{i\in\mathrm{CES,DG}}\mathrm{P}_{\mathrm{CES,DG}_i}(t)-\sum_{i\in\mathrm{ind,DG}}\mathrm{P}_{\mathrm{ind,DG}_i}(t)+\\ \sum_{i\in\mathrm{CES,Load}}\mathrm{H}_i(t)-\sum_{i\in\mathrm{CES,DG}}\mathrm{H}_{\mathrm{CES,DG}_i}(t)\end{bmatrix}\cdot\xi_{\mathrm{CE,n}} + \left[\sum_{i\in\mathrm{CES,DG}}\mathrm{P}_{\mathrm{CES,DG}_i}(t)\cdot\frac{\mathrm{CE}_{\mathrm{CES,DG}_i}}{\eta_{\mathrm{CES,DG}_i}}+\sum_{i\in\mathrm{ind,DG}}\mathrm{P}_{\mathrm{ind,DG}_i}(t)\cdot\frac{\mathrm{CE}_{\mathrm{ind,DG}_i}}{\eta_{\mathrm{ind,DG}_i}}\right] \tag{9}$$

CES should supply thermal energy preferentially to meet the needs of customers in CES's control area. This paper assumes that individual DGs cannot produce thermal energy. The amount of CE can be calculated by equations (8) and (9) suggested in this paper according to CE coefficient by fuel type and generation efficiency by DG.

In practice, considering European Union Allowance (EUA), the additional generation cost by CE can be obtained according to CO_2 emission based on 1 ton as follows:

$$\mathrm{C}_{\mathrm{CE}}(t)=\mathrm{EUA}_{\mathrm{p}}\cdot\Xi_{\mathrm{CE}}(t) \tag{10}$$

This paper compares CES's operation cost with/without CE cost in the case studies.

5. Objective Function of Community Energy System

The objective function in this paper is to maximize the total benefit of CES, benefit from transaction, cost of active/reactive power, generation cost of CES' s DG and extra cost for CE. As an additional expenses, CE cost is estimated by using equations (8) and (10). The objective function can be formulated as follows:

$$\begin{aligned} f(t)=&\ \mathrm{C}_{\mathrm{P,cutomer}}\cdot\sum_{i\in\mathrm{CES,Load}}\mathrm{P}_i(t)+\mathrm{C}_{\mathrm{H,customer}}\cdot\sum_{i\in\mathrm{CES,Load}}\mathrm{H}_i(t)\\ &+\ \mathrm{C}_{\mathrm{P,market}}(\mathrm{P}(t))+\mathrm{C}_{\mathrm{Q,market}}(\mathrm{Q}(t))\\ &-\sum_{i\in\mathrm{CES,DG}}\mathrm{C}_{\mathrm{CES,DG}_i}(\mathrm{P}_{\mathrm{CES,DG}_i}(t))-\sum_{i\in\mathrm{CES,DG}}\mathrm{C}_{\mathrm{CES,DG}_i}(\mathrm{H}_{\mathrm{CES,DG}_i}(t))\\ &-\sum_{i\in\mathrm{ind,DG}}\mathrm{C}_{\mathrm{P,ind,DG}}(t)\cdot\mathrm{P}_{\mathrm{ind,DG}_i}(t)-\sum_{i\in\mathrm{ind,DG}}\mathrm{C}_{\mathrm{Q,ind,DG}}(t)\cdot\mathrm{Q}_{\mathrm{ind,DG}_i}(t)\\ &-\ \mathrm{C}_{\mathrm{CE}}(t)\end{aligned} \tag{11}$$

CES makes hourly generation plans of active and reactive power and thermal energy. However, CES should supply thermal energy preferentially. Overs and shorts of active and reactive power will be traded through individual DGs and interconnected network. It is assumed that the supplying price of active power and thermal energy is constant because this paper focuses on the operation technique of DGs according to the low-carbon paradigm. On the contrary, it is assumed that the hourly prices of active/reactive power transacted through interconnected network and individual DGs are flexible.

Each DG's capacity is limited:

$$\begin{cases}\mathrm{P}_{\mathrm{CES,DG}_i,\min}\le\mathrm{P}_{\mathrm{CES,DG}_i}(t)\le\mathrm{P}_{\mathrm{CES,DG}_i,\max}\\ \mathrm{Q}_{\mathrm{CES,DG}_i,\min}\le\mathrm{Q}_{\mathrm{CES,DG}_i}(t)\le\mathrm{Q}_{\mathrm{CES,DG}_i,\max}\\ \mathrm{H}_{\mathrm{CES,DG}_i,\min}\le\mathrm{H}_{\mathrm{CES,DG}_i}(t)\le\mathrm{H}_{\mathrm{CES,DG}_i,\max}\end{cases} \tag{12}$$

The constraints between load and generation are given by:

$$\begin{cases}\sum_{i\in\mathrm{CES,Load}}\mathrm{P}_i(t)\le\sum_{i\in\mathrm{CES,DG}}\mathrm{P}_{\mathrm{CES,DG}_i}(t)+\sum_{i\in\mathrm{ind,DG}}\mathrm{P}_{\mathrm{ind,DG}_i}(t)+\mathrm{P}(t)\\ \sum_{i\in\mathrm{CES,Load}}\mathrm{Q}_i(t)\le\sum_{i\in\mathrm{CES,DG}}\mathrm{Q}_{\mathrm{CES,DG}_i}(t)+\sum_{i\in\mathrm{ind,DG}}\mathrm{Q}_{\mathrm{ind,DG}_i}(t)+\mathrm{Q}(t)\\ \sum_{i\in\mathrm{CES,Load}}\mathrm{H}_i(t)\le\sum_{i\in\mathrm{CES,DG}}\mathrm{H}_{\mathrm{CES,DG}_i}(t)\end{cases} \tag{13}$$

When CES purchases or sells the electricity in interconnected networks, power factor (PF) should be kept up considering system stability. The following shows the constraint of PF.

$$|\tan\theta|\ge\left|\frac{\mathrm{Q}(t)}{\mathrm{P}(t)}\right| \tag{14}$$

6. Optimization Method

6.1 Particle Swarm Optimization

The PSO algorithm is a population-based stochastic optimization technique [8, 9, 10]. The potential solutions, called the particles, fly through the search space by following the current optimal particle. Objective function values are used as the fitness values of particles to guide the search process. Each particle records its best individual fitness and position (*pbest*) for iteration. Moreover, each particle knows the best fitness and position for iteration in the group (*gbest*) among all individuals. The velocity of a particle is influenced by three components inertial, cognitive, and social. The mathematical model for PSO is as follows:

$$\begin{aligned}\mathrm{V}^j_{iter,k}=&\ w_{iter}\times\mathrm{V}^j_{iter-1,k}+c_1\times r_1\times(\mathrm{Xbest}^j_{iter-1,k}-\mathrm{X}^j_{iter-1,k})\\ &+c_2\times r_2\times(\mathrm{Xbest}^g_{iter-1,k}-\mathrm{X}^j_{iter-1,k})\end{aligned} \tag{15}$$

$$w_{iter}=w^{\max}-(w^{\max}-w^{\min})\times\left(\frac{iter}{iter^{\max}}\right) \tag{16}$$

6.2 Phase-Type Particle Swarm Optimization

Here, DGs of renewable energy type which are intermittent and uncontrollable to produce the electric energy are not considered. Therefore, this paper focuses on issues to find the optimal generation of controllable DGs. The generating capacity of controllable DGs is limited by its output characteristics.

This paper newly proposes a phase-type PSO algorithm. In our proposed PSO algorithm, the position and velocity of particles have an identical dimension with the total number of DGs which are non-renewable energy type that is controllable. And its elements have the phase values from 0° to 360°.

$$0^{o} \le X_{iter,k}^{j} \le 360^{o}$$
$$P_{CES,DG_i}(t) = \frac{(P_{CES,DG_i,max} - P_{CES,DG_i,min})}{360^{o}} \cdot X_{iter,k}^{j} + P_{CES,DG_i,min} \quad (17)$$
$$(k = \{DG_i \mid DG_i \text{ is possessed and controllable by CES}\})$$

The limit of velocity should be adjusted according to the phase portion of a generating capacity boundary as follows:

$$-\frac{m \cdot 360^{o}}{P_{CES,DG_i,boundary}} \le V_{iter,k}^{j} \le \frac{m \cdot 360^{o}}{P_{CES,DG_i,boundary}} \quad (18)$$
$$(P_{CES,DG_i,boundary} = P_{CES,DG_i,max} - P_{CES,DG_i,min})$$

6.3 Flow Chart for Optimization Problem

Finally, the process to obtain the optimal operation of CES using newly proposed phase-type PSO is expressed by the following flow chart.

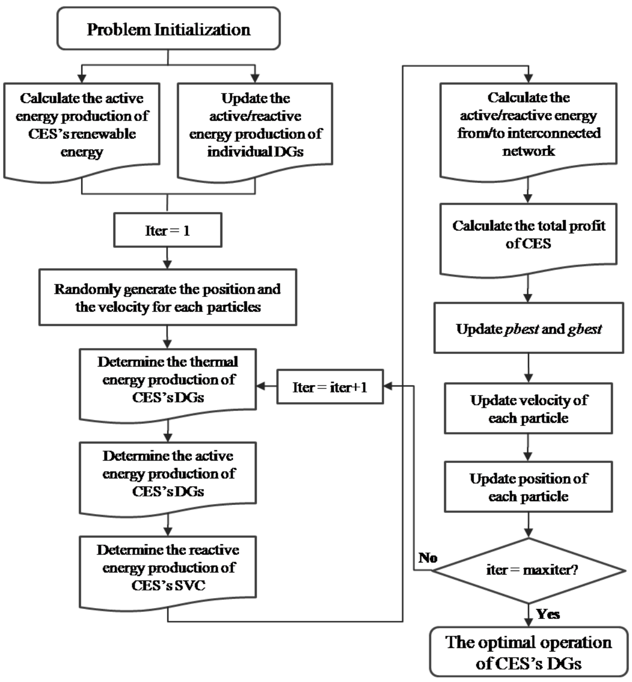

Fig. 2. Flow chart for the optimal operation of CES's DGs.

7. Case Study and Discussion

It is assumed that CES operates generators composed of photovoltaic generators (2), gas turbine (2), boiler (1) and CHP (1) in this case study to supply customers in CES's control area with electric power and thermal energy. SVC (Static Var Compensator) compensates for the lack of reactive power.

CES buys active and reactive power from individual DGs, and re-sales active power to customers in CES's control area. The parameters of DGs operated by CES are given in Tables I, II and III.

Table 1. Parameters of DGs

	α	β	γ	CE_{CES,DG_i}	η_{CES,DG_i}	Active/ Thermal Rate	Limit [MW]	
							Min	Max
GT 1	21	1.258	2.978	0.05508	0.38	1/0	2.0	25.8
GT 2	23	2.271	5.264	0.05508	0.30	1/0	1.6	15.0
Boiler	19	2.025	2.698	0.09648	0.41	0/1	0	17.2
CHP	31	1.354	2.787	0.07200	0.86	1/0.8	2.3	21.5

Table 2. Parameters of PVs

	A_p	η_p	K_p
PV 1	65	0.12	0.8
PV 2	107	0.12	0.8

Table 3. Energy Price

	customer		Individual DGs		Market	
	Active [$/MW]	Thermal [$/MW]	Active [$/MW]	Reactive [$/MVAr]	Active [$/MW]	Reactive [$/MVAr]
Buy	0	0	85	2.8	95	3
Sell	100	85	0	0	90	2.8

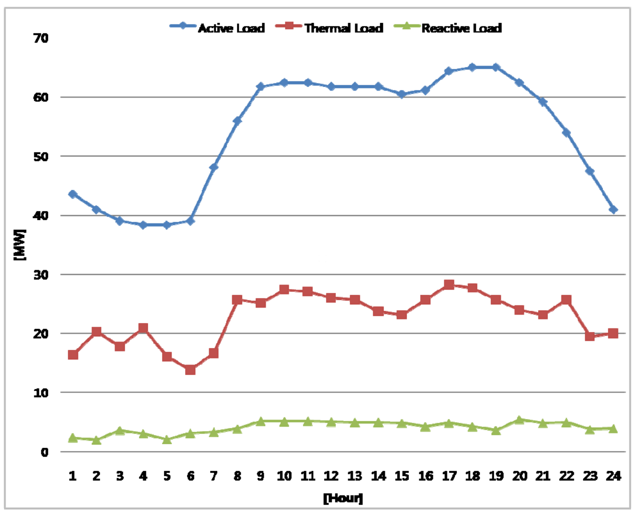

Fig. 3. hourly active, reactive and thermal load in CES's control area.

Generally the supplying prices of active power and thermal energy to the end user are flat. Here, it is assumed that the hourly prices of active/reactive power transacted through interconnected network and individual DGs are variable. Active/reactive power price to buy or sell in Table III are the maximum values.

SVC compensates for lack of reactive power from -2 to 2 [MVar]. Also, it is assumed that PF sets over 0.9.

Thermal load of customer is a matter of the highest priority to CES. Load data of RBTS summer weekday is modified and it is used as shown in Fig. 3.

In phase-type PSO, the size of population is 1000 for the case study. Maximum number of iteration is set to 100 for case 1 and case 2 as well. The inertia max weight, min weight and acceleration coefficients of c_1 and c_2 for case study are set to 0.9, 0.4, 2 and 3 respectively.

7.1 Case 1: without CE

If CES provides customers with generation power of DGs without considering CE, Fig. 4 and Fig. 5 shows th e amount of hourly active generation and amount of hourly reactive generation and PF.

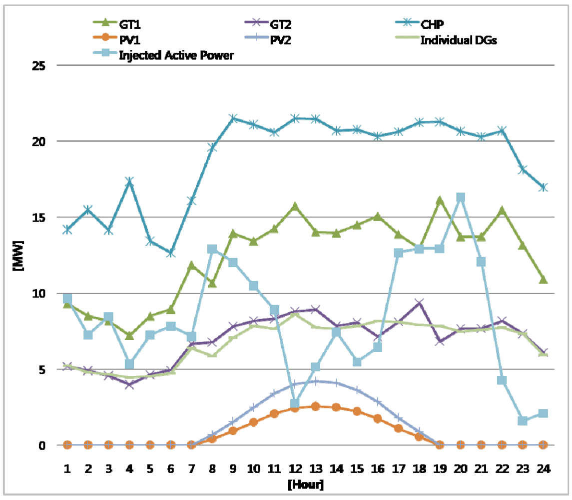

Fig. 4. The amount of hourly active generation.

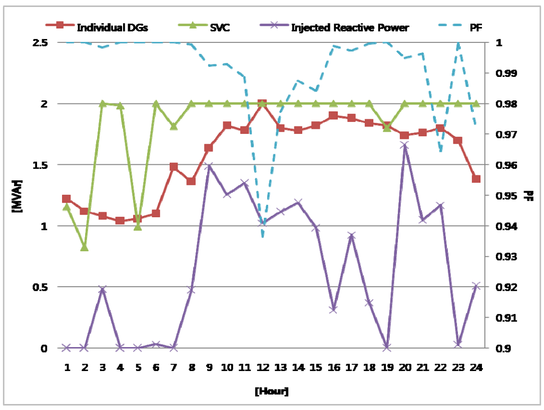

Fig. 5. The amount of hourly reactive generation and power factor.

Thermal demand of customer is provided by CES's boiler and CHP. Then, hourly thermal generation can be depicted in Fig. 6.

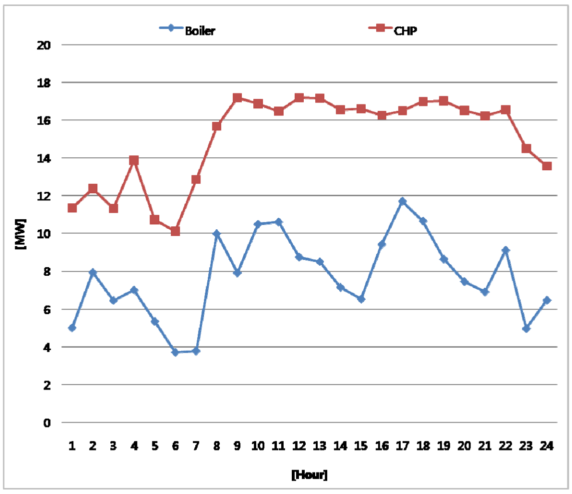

Fig. 6. The amount of hourly thermal generation.

7.2 Case 2: with CE

Considering CE depending on the amount of generation by DG types, the operation cost of respective generators will change. Then, the amount of hourly active generation and the amount of hourly reactive generation and PF are shown in Fig. 7.

EUA_p is assumed with 31 [\$/ton-CO_2] (EUA in Aug. 2008), daily total generation cost and CE cost by DG types are presented in Fig. 8.

A CHP has higher generation efficiency than the other generators. As a result, CHP has lower CE cost relatively than the others. Hourly total generation cost and total CE cost of CES are as follows.

Hourly operation profit in case 2 decreases compared to case 1. This change is represented in Fig. 10.

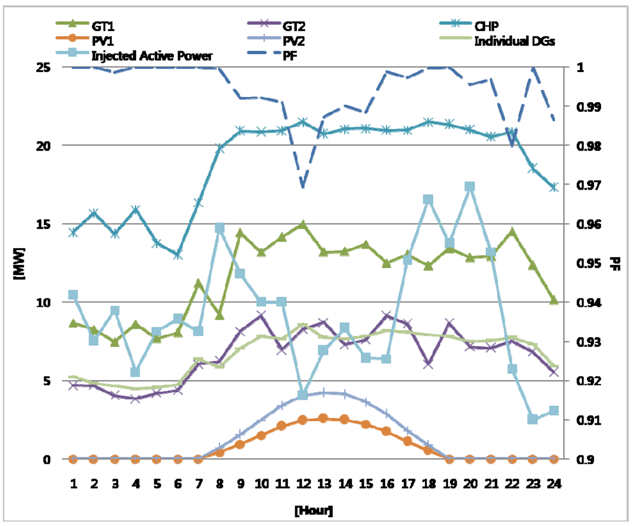

Fig. 7. The amount of hourly active generation and power factor.

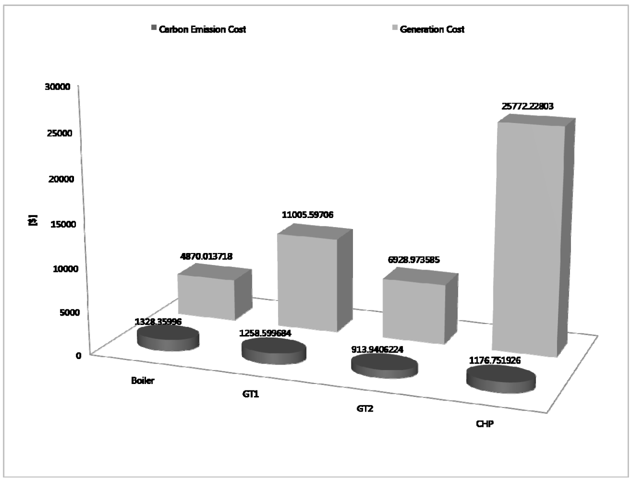

Fig. 8. Total generation cost & CE cost by DG types.

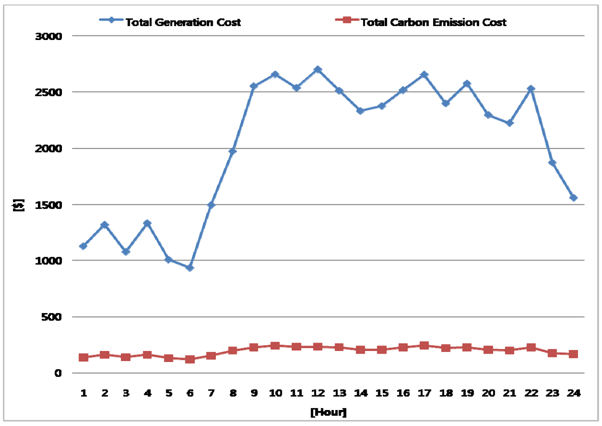

Fig. 9. Total generation cost & total CE cost of CES.

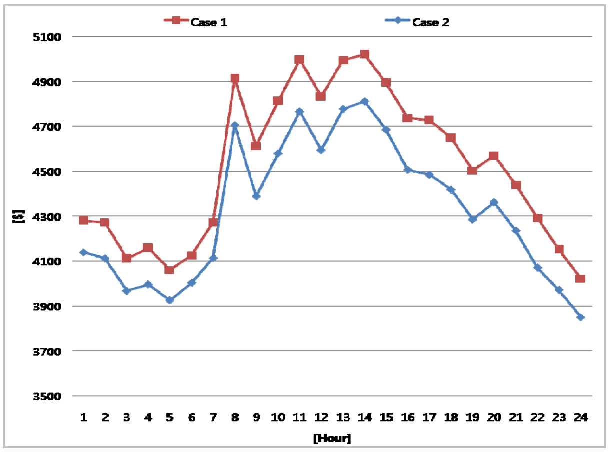

Fig. 10. Total operation profit of CES case by case.

The amount of CE and the profit by CE changed with CES or without CES in which all energy is supplied directly through a network. The profit by CE is reduced. The amount of CE with CES and without CES is depicted in Fig. 11.

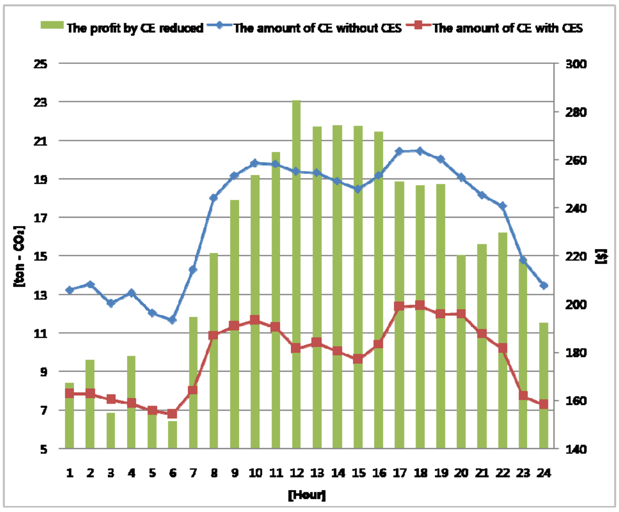

Fig. 11. Hourly profit by CE reduced and the amount of CE without CES and with CES.

The amount of boiler's thermal generation decreases while that of CHP increases in case 2 which takes CE into consideration compared with case 1. Table IV shows hourly thermal generation of boiler and CHP case by case.

Table 4. Hourly Thermal Generation of Boiler and CHP case by case

	Case 1		Case 2	
	boiler	CHP	boiler	CHP
1	5.0064	11.35	4.7974	11.559
2	7.9342	12.37	7.7592	12.545
3	6.4506	11.315	6.2793	11.487
4	7.0016	13.866	8.1431	12.725
5	5.3413	10.733	5.0525	11.022
6	3.7098	10.108	3.4084	10.41
7	3.7815	12.856	3.5488	13.089
8	9.9811	15.681	9.825	15.837
9	7.9117	17.186	8.3596	16.738
10	10.484	16.87	10.671	16.683
11	10.599	16.473	10.329	16.743
12	8.744	17.2	8.744	17.2
13	8.5003	17.162	9.078	16.584
14	7.1426	16.545	6.8436	16.844
15	6.5252	16.599	6.2502	16.874
16	9.4133	16.249	8.9018	16.76
17	11.697	16.503	11.424	16.776
18	10.652	16.984	10.439	17.197
19	8.6395	17.022	8.5929	17.069
20	7.4499	16.52	7.1754	16.795
21	6.9054	16.219	6.6884	16.436
22	9.1074	16.555	8.9724	16.69
23	4.9603	14.498	4.6407	14.817
24	6.4606	13.561	6.1724	13.85
total	184.3987	360.425	182.0961	362.73

In case 2 which considers CE when thermal energy is supplied by boiler and CHP of CES, the output of boiler is on the decrease and the output of CHP is on the increase compared with case 1.

8. Conclusion

Due to deregulation, environmental reasons and technical improvement, recently DGs connected to networks are increasingly being used. The more DGs installed, the more CES will participate in power market.

A CES tries to make the maximum profit by controlling generation of DGs according to the hourly price of active, reactive power. However, considering CE costs result from the recent international environmental regulation, CES's existing operational strategy of generators is not suitable for the purpose of maximizing profit. By analyzing the result of case studies, this paper proposes an operational technique matched to the characteristics of DG types and depending on the dynamic market price. It suggests a new generation scheduling technique for CES within a low-carbon paradigm. In the case study, PSO algorithm proved to perform well in various fields is used to find the optimal generation of generator type.

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