RESEARCH ON EMISSIONS TRADING AMONG SEPARATE GENERATION SYSTEMS

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Abstract

In 1997, the United Nations Framework Convention on Climate Change required signatory countries to reduce their greenhouse gases emissions to a specific target by some time between 2008 and 2012. This agreement led to the development of trade in greenhouse gas (GHG) emission allocations among the industries of signatory countries, creating a new spot market for greenhouse gas emissions. Many companies sell unused GHG emission entitlements to other emitters which expect their emissions to exceed their assigned quota. Therefore, this study suggests a fair, equal and reasonable principle on which to base the spot market in emissions, namely the volume of emissions released by every generation unit in producing 1MW electricity regardless of fuel type used. Standardization of the burning efficiency of generators will facilitate the monitoring of emissions in the power industry and emissions trading, while also achieving the goal of emission control in separate generating systems. The emission trading mechanism presented herein will adapt the Sequential Unconstrained Minimization Technique (SUMT) to acquire the generation volume under the minimal generating cost to optimize emission trading price and volume.

1. Introduction

Deregulation of the power market has significantly influenced the way in which power is generated, transmitted, and distributed, thus overturning a system which had remained largely unchanged over a century. Deregulation has focused mainly on breaking up traditional monopolies, revitalizing the power market and establishing more regional power markets to improve power generation efficiency. However, this mechanism also potentially threatens the stability of the power market, including the cutting of funding on power generation emission reduction research and equipment maintenance costs, and reduced incentives to decrease emissions. Moreover, nuclear power plants might even reduce the budget on maintaining nuclear safety[1-4].

The following discusses the characteristics of the spot markets that developed during power market deregulation and how to reduce emissions through emissions trading. This study describes a novel method for trading in emissions allocations under minimum generation costs, thus allowing generator companies to effectively control their emission levels and sell unused emission allocations to other companies and in return for effective emission control. The second section then outlines how to establish an emissions trading model. Subsequently, the third section presents a simulated example of how the proposed system could work. Finally, some conclusions are presented.

2. Emissions Trading Model

In dealing with greenhouse gas emissions, the short-term emission control policy includes economic measures such as taxation or fines at source, based on the categorization that emissions costs are an externality. However, practical difficulties are encountered in evaluating exterior efficiency, making it impossible to evaluate the effectiveness of the environmental dispatch policy. This study categorizes emissions costs under the interior costs of the generating company, hoping that the sale of unused emissions to those who might exceed their quota will bring a reduction in overall emissions. However, emissions quota trading requires a fair and reasonable trading mechanism to assign emissions to each generating company. The mechanism examined herein treats every generating unit equally regarding the emissions it releases in producing 1MW electricity, regardless of the type of fuel used. Restated, the mechanism uses the electricity volume generated by the generating company and the burning efficiency of each generating unit to determine the emission allowance of each generating company. This approach forces low-generating cost and high-emission generating companies to cover their emission limits by purchasing emissions from high-generating cost and low-emission generating companies, and creates an incentive to reduce emissions.

As emissions trading proceeds, the problem of whether a market in emissions exists must be considered, "the spot market in emissions" means the "price of emissions trading" must be somewhere between the costs to the seller and buyer of producing 1 ton of emissions. Beyond this range, no market will exist, and emissions trade will be impossible. This study adopts the Sequential Unconstrained Minimization Technique (SUMT) [5-6], taking minimal cost as the objective function, to determine emission prices and the volume of trade in the spot market in trading emissions. The model is as follows:

Objective function: The purpose is to minimize the hourly generating cost of each generating companies.

$$\min \sum_{i=1}^{n} C_i(P_i) \qquad (1)$$

Subject to:

***Generating unit operation constraints**

$$P_{i,min} \le P_i \le P_{i,max} \quad \text{for } i = 1,2,3 \ldots n \qquad (2)$$

$$\sum_{i=1}^{n} P_i = P_{load} \qquad (3)$$

***Emissions restriction:** The mechanism for achieving fair emission allocations is to treat every generating unit equally regarding the level of emissions it releases in producing 1 MW of power per hour; that is $\frac{EM \times RES}{P_{load}}$.

Simultaneously, every generating companies is allocated equal hourly GHG (greenhouse gases) emissions (while hourly emissions allocations are identical, maximum generation allocations differ among generating companies), that is $\frac{EM \times RES}{P_{load}} \times P_{i,max}$. If a generating company a portion of their hourly emissions allocation, it can sell this portion to other generating companies whose emissions exceeds the standards. $EM \times RES$ refers to the total allowable restriction emission quotas per hour.

$$(SO_2(P_i) + NO_x(P_i) + CO_2(P_i) + \sum_{\substack{j=1 \\ i \ne j}}^{n})Q_{ij}) \le \frac{EM \times RES}{P_{load}} \times P_{i,max} \quad for\ i = 1,2,3 \ldots n \qquad (4)$$

$$\sum_{i=1}^{n} (SO_2(P_i) + NO_x(P_i) + CO_2(P_i)) = EM \times RES \qquad (5)$$

***Prevention of interference by emissions trading brokers:** To prevent interference from brokers trading emissions, a limited equation is established, to prevent generating companies from buying on margin or selling short. Emissions trades can only proceed when the amount a generating company is selling smaller than or equal to the amount assigned to it. For example, if Q_{12} is a positive value, then generating company 1 sells emission units to generating company 2, while it the value is negative, then the situation is reversed.

$$\begin{aligned} &-(\frac{EM \times RES}{P_{load}} \times P_{j,max} - SO_2(P_j) - NO_x(P_j) - CO_2(P_j)) \le \\ &Q_{ij} \le \frac{EM \times RES}{P_{load}} \times P_{i,max} - SO_2(P_i) - NO_x(P_i) - CO_2(P_i) \end{aligned} \qquad (6)$$

***Restriction of emission trading prices:** the trading prices of emission quotas must fall somewhere between the costs incurred by the seller and buyer in producing a ton of emissions. That is, the price must equal or exceed the buyer's generating costs, or be equal to or less than the seller's costs.

$$\begin{aligned} &\frac{C_i(P_i)}{SO_2(P_i) + NO_x(P_i) + CO_2(P_i)}\Big|_{i=buy} \le PRICE_{ij} \\ &PRICE_{ij} \le \frac{C_j(P_j)}{SO_2(P_j) + NO_x(P_j) + CO_2(P_j)}\Big|_{j=sell} \end{aligned} \qquad (7)$$

***Restriction on emission allocation volume:** This restriction aims to allow seller and buyer the same trading prices and amounts.

$$\sum_{i=1}^{n} \sum_{\substack{j=1 \\ i \ne j}}^{n} Q_{ij} = 0 \qquad (8)$$

$$\sum_{i=1}^{n} \sum_{\substack{i=1 \\ i \ne j}}^{n} (Q_{ij} \times PRICE_{ij}) = 0 \qquad (9)$$

Where

EM : overall hourly emissions with the lowest generating cost, without emissions trading and restrictions on emission volume.

RES : percentage of emissions per hour allowed by the system .

P_{load} : total hourly load demand.

$PRICE_{ij}$: emissions trading price per hour between generating companies i and j.

Q_{ij} : emission trading volume per hour between generating companies i and j.

The emission trading model established here is a traditional constrained optimized problem. The constrained optimized problems are transformed into a series of unconstrained optimized problems. The basic concepts and calculation methods used herein are presented in the following subsection.

3. Exterior Penalty-Function Method

This study uses the expansion of Lagrange to transfer a constrained problem to an unconstrained problem. By adjusting the penalty parameters the objective function can then gradually reach an optimal solution. This approach is called the "(Sequential Unconstrained Minimization Technique, SUMT) SUMT". Since this method does not require any reliable initial value, it can be applied to equality or inequality constraint nonlinear programming problems. This study will use exterior penalty-function methods to transfer the constrained optimization problems into unconstrained problems. The use of penalties can make the constrained optimized problem mentioned above resemble an unconstrained optimized problem. It is illustrated below:

$$minimize\ \phi(x, K) = min(f(x) + K \times B(x)), \qquad (10)$$

where $f(x)$ is the original objective function; penalty parameter K denotes a positive constant used to decide the size of penalty, and $B(x)$ represents a penalty function. A penalty function is a continuous nonnegative function, and can be represented as follows:

$$B(x)=\sum_{i=1}^{m}\{max[0,h_i(x)]\}^2+\sum_{j=1}^{p}\{g_j(x)\}^2 \qquad (11)$$

Therefore, as long as K is large enough and exceeds zero, then as value K becomes increasingly regular (in the essay, increased by the power product of 10), the function of the penalty will be increased. Consequently, the objective function of Eq. (1) and the constrained problems in Eqs. (2) to (9) can be transferred into unconstrained minimized problems, as represented below:

$$\begin{aligned}
& min\sum_{i=1}^{n}C_i(P_i) \\
& +K_1\times[\sum_{i=1}^{n}P_i-P_{load}]^2 \\
& +K_2\times[\sum_{i=1}^{n}(SO_2(P_i)+NO_x(P_i)+CO_2(P_i)+\sum_{\substack{j=1\\ i\neq j}}^{n}Q_{ij}-(\frac{EM\times RES}{P_{load}})\times P_{i,max})]^2 \\
& +K_3\times[\sum_{i=1}^{n}(SO_2(P_i)+NO_x(P_i)+CO_2(P_i))-EM\times RES]^2 \\
& +K_4\times[Q_{ij}-(\frac{EM\times RES}{P_{load}}\times P_{i,max}-SO_2(P_i)-NO_x(P_i)-CO_2(P_i))]^2 \\
& +K_5\times[-(\frac{EM\times RES}{P_{load}}\times P_{j,max}-SO_2(P_j)-NO_x(P_j)-CO_2(P_j))-Q_{ij}]^2 \\
& +K_6\times[\sum_{i=1}^{n}\sum_{\substack{j=1\\ i\neq j}}^{n}(\frac{C_j(P_j)}{SO_2(P_j)+NO_x(P_j)+CO_2(P_j)}\Big|_{i=buy,j=sell}-PRICE_{ij})]^2 \\
& +K_7\times[PRICE_{ij}-\sum_{i=1}^{n}\sum_{\substack{j=1\\ i\neq j}}^{n}(\frac{C_i(P_i)}{SO_2(P_i)+NO_x(P_i)+CO_2(P_i)}\Big|_{i=buy,j=sell})]^2 \\
& +K_8\times[\sum_{i=1}^{n}\sum_{\substack{j=1\\ i\neq j}}^{n}Q_{ij}]^2 \qquad (12) \\
& +K_9\times[\sum_{i=1}^{n}\sum_{\substack{j=1\\ i\neq j}}^{n}(Q_{ij}\times PRICE_{ij})]^2
\end{aligned}$$

This study adapts quasi-Newton methods and adjustment of penalty parameters $K_1 \sim K_9$, equation above can be convergent to the optimal solution, to optimize emission trading price and volume.

4. Simulation Results

To further explain the trading of the model, this study assumes three generating companies exist, each with only one generating unit and differing from one another in the type of fuel they use. The concept behind SUMT is to transfer the equality constraint or inequality constraint problems into unconstrained problems. Meanwhile, the adjustment of the values of the penalty parameters $K_1 \sim K_9$, allows the objective function to optimize the penalty solution (provided the value of $K_1 \sim K_9$ is large enough, the penalty to the objective function will be larger). Table 1(a)-(b) displays the reliability of the solutions acquired, the change in $K_1 \sim K_9$ and the differences in the solutions corresponding to this change. The 4th iterated value in the study proves that the adjustment of the $K_1 \sim K_9$ values will not disperse the optimal solution or make it fluctuate. Therefore, SUMT has a high convergence, and the adjustment of penalty parameters $K_1 \sim K_9$ is simple and effective, allowing a gradual convergence to the optimal solution within an affordable error. Figure 1 compares generating costs with and without an emission trading mechanism. The figure shows that an emission trading framework reduces generating costs. Therefore, the limitation of emissions allowances forces generating companies to ensure their emission conform to a legal standard. The existence of an emission trading mechanism allows generating companies who might exceed their permitted emission limits to purchase emission units unused by other companies.

From Figures 1-3, while limitations on emissions become stricter, generating units with high-emissions, like generating companies using coal-fired generators, will be assigned a smaller emissions quota. Therefore such companies will have to purchase emission from low-emission and high-allocation units, such as companies running gas generators. As limitations on emissions get stricter, generating companies of coal-fired generators need to purchase relatively more units. For example, when the emission allowance is 90%, company using coal generators needs to purchase 185.5894 tons of emission units from companies using gas generators at 10$/ton, and 138.3327 tons of emission units from companies using oil-burning generators companies at 4.7$/ton. However, when emission allowances are restricted to 80%, generating companies using coal generators will need to purchase 224.2764 tons of emission units from company using gas-fired units at 9.6048$/ton, and purchase 189.1122 tons of emissions from the companies using oil-burning generators at 5.2973$/ton. To prevent interference from brokers, a limitation equation is added, as in Eq. (4).

5. Conclusions

(1) Simulation results in this study demonstrated that high-generating costs and low-emission generating units can decrease emission generation volumes and lower generation costs; moreover, the profit from selling emission allocation can further reduce generation costs. Meanwhile, the low-generating cost and high-emission generating units will have to purchase emission quotas unused by other producers to bring themselves into line with emission constraint standards.

(2) Simulation results demonstrated the feasibility of the proposed emissions trading mechanism, and thus this mechanism is used herein as a reference policy for emission control following the future deregulation of the Taiwanese power market.

6. References

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Table 1 Parameter values

(a)

Iteration number i (i=1,2..)	Each item parameter value								
	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_9
1	1.00E+05	10	0.01	0.01	0.01	0.1	100	100	0.1
2	1.00E+06	100	0.1	0.1	0.1	1	1000	1000	1
3	1.00E+07	1000	1	1	1	10	10000	10000	10
4	1.00E+08	10000	10	10	10	100	100000	100000	100

(b)

Iteration number i (i=1,2..)	Bias value				Penalty function $B(x)$ (tons/h)
	ΔS (tons/h)	ΔN (tons/h)	ΔCO_2 (tons/h)	ΔS (tons/h)	
1	0.9231	1.2286	7.1912	0.9231	9.3428
2	0.9231	1.2286	7.1910	0.9231	9.3428
3	0.9195	1.2240	7.1910	0.9195	9.3345
4	0.9202	1.2249	7.1932	0.9202	9.3387

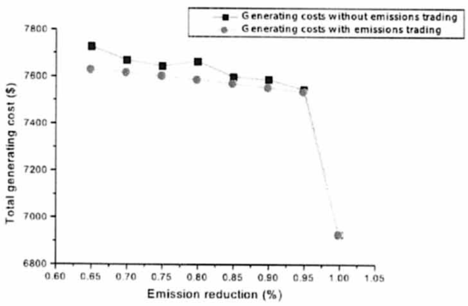

Figure 1. Comparison of generating costs with and without emission trading

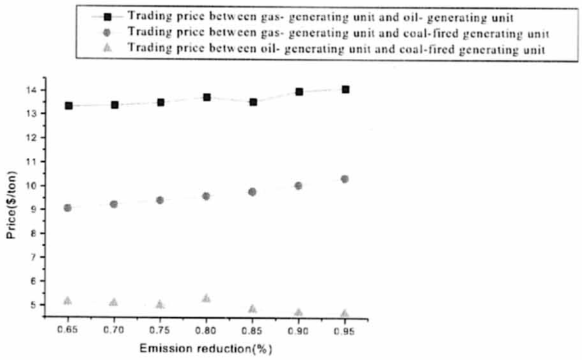

Figure 2. Emission trading price curve for generating companies

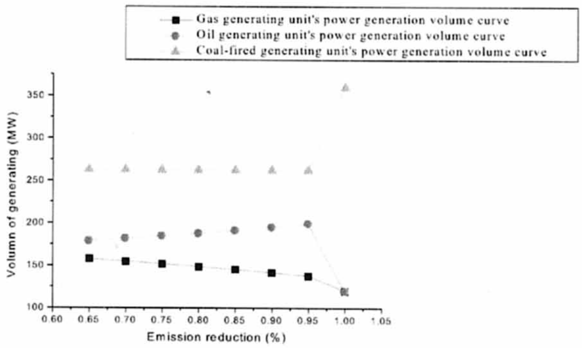

Figure 3. Emission trading volume curve for generating companies

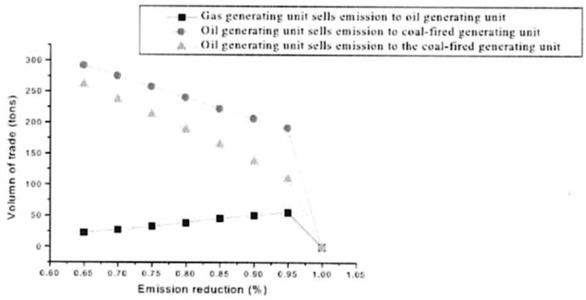

Figure 4. Comparison of power generation volume by generating companies