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A Method for Design Production System with Multi Energy Resources

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This research proposes a strategy for reducing both electricity charge and environmental load by considering multi energy sources. The reduction of the contract electric demand is considered, and its differential cost is used for purchasing substitute power sources. Some variables, such as the amount of reduced contract demand, and amount of electricity are generated by each substitute power source. By using those variables, we formulate a simulation model that enables to minimize the energy cost and environmental cost.

1. INTRODUCTION

Japan has been divided into 10 regions in which there is one electric company. The electric power generation sources are mainly thermal power, and hydraulic power, nuclear energy power. Each region has a different ratio of generated electricity of each power sources. In the national average, the ratio of thermal power generation is about 60%, hydraulic power generation 20%, nuclear power generation 20%. [1]

Recently, private enterprises have been allowed to sell electricity by the revision of Electric Utility Law, in other words the Independent Power Producer business has been started. Many companies have declared to break into the electric power supply business, such as oil companies, gas companies, steel industry and so on. [2]

Additionally, research and development of new power sources have been progressed. Technologies of solar cell, wind power generation and fuel cell have been rapidly improved. Especially, the use of solar cell has been increasing as a home electric power source. [3]

Therefore, in this paper we propose a method for planning the combination of the electric power sources to contribute to environmental problem and enterprise profit.

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2. RELATION BETWEEN ELECTRIC POWER SUPPLY SYSTEM AND ENVIRONMRNTAL PROBLEM

Thermal power, hydraulic power, and nuclear power are mainly used for the large-scale plant. Almost their electricity are supplied by the electric power companies. Recently, the wind power generation is used in some regions.

Many steel and oil companies have used the private thermal power generation, and other private companies have also used the co-generation, i.e. diesel electric power generation to cover the surplus electricity exceeding their contract demand.

Solar cells and the wind power generation have been used for small-scaled home use. (Table1)

Table 1 Electric power sources

The electric power generation source	Electric power company	Company	Individual
Hydraulic power	○		
Thermal power	○	○	
Nuclear power	○		
Solar cell		○	○
Wind power	○	○	○
Fuel cell	○	○	

As each power source has different amount of environmental loads, they should be evaluated from the viewpoint of Life Cycle Assessment in **Table2.** Environmental load is classified into two types, i.e. abolished material and exhausted material to the atmosphere. Some environmental load are shown below.

(1) CO_2, NOx, SOx

(2) power generation loss, power transmission loss

(3) waste

Relations between environmental load and the electric power source are reviewed and shown in **Table2.**

Table2 The environment load of the electric power generation source

	The electric power generation source	Direct	Indirect	Current	Type
ES1	Hydraulic power	0	Cement	Interchange	Plant
ES2	Thermal power	CO_2 NO_X	Steel	Interchange	Plant
ES3	Nuclear power	Radioactive waste	Fuel	Interchange	Plant
ES4	Solar cell	0	Cell	Direct current	Distributed
ES5	Wind power	0	Steel	Direct current	Distributed
ES6	Fuel cell	0	Steel	Direct current	Distributed

3. PLANNING OF COMBINATION OF ELECTRIC POWER SOURCE

Two points of view are considered to plan the combination of electric power source. One is the electric power charge that affects directly to the profit of each company. The other is the environmental accounting. In environmental accounting, relation among cost and environmental pollutants should be evaluated previously.

3.1 Symbols

Following symbols are used in this method.

- i :The electric power source. $(i=1,2,..,n)$
- t :month $(t=1,..,m)$
- x_{it} :The amount of electricity usage in t-th month supplied by electric power source i.
- Q_t :Total amount of electricity usage in t-th month.
- v_i :The fixed cost of the i-th electric power source.
- u_{it} :The variable cost of the i-th electric power source in t-th month.

3.2 Planning of the combination of electric power source considering only electric power charge

(1) Fixed cost

Each electric power source has different fixed cost, that is composed of depreciation, operation cost of the facility, labor cost and so on. The fixed cost increases nonlinearly with the increase of the peak electric energy.

In this method, we assume that fixed cost of i-th electric power source could be simulated by **eq. (1)**.

$$v_i=a_i \cdot \left(\max_{1\leqq t\leqq m}\{x_{it}\}\right)^2+b_i \cdot \left(\max_{1\leqq t\leqq m}\{x_{it}\}\right) \qquad (1)$$

Where, we assume that two coefficients ai and bi have been given by a preliminary survey.

(2) Variable cost

The variable cost increases nonlinearly with the increase of the electric power consumption. For example, in a electric power company, electricity rate is ¥ 17/kwh as the total consumption is below 120kwh.[4] However, it increases to ¥ 24/kwh as the consumption is in range from 120kwh to 340kwh. So, we assume that the relationship between electric power consumption and variable cost is represented by **eq. (2)**.

$$u_{it}=c_i x_{it}^2+d_i x_{it} \qquad \begin{matrix}(t=1,2,..,m)\\(i=1,2,..,n)\end{matrix} \qquad (2)$$

Where, confficient c_i and d_i are given by preliminary survey.

(3) Energy cost

Energy cost Z is the sum of variable cost and fixed cost. It is obtained by **eq. (3)**.

$$Z=\sum_{i=1}^{n} v_i+\sum_{i=1}^{n}\sum_{t=1}^{m} u_{it} \qquad (3)$$

(4) Model for planning a combination of electric power sources

The combination of power sources is required to minimize the energy cost.

(a) Objective function

As the objective function aims to minimize the energy cost, it is formulated by **eq. (4)**.

$$min\ Z=\sum_{i=1}^{n} v_i+\sum_{i=1}^{n}\sum_{t=1}^{m} u_{it} \qquad (4)$$

(b) Constraints

The total amount of electric power of all power sources should exceed the demand of t-th period. This constraint is showed in **eq. (5)**.

$$\sum_{i=1}^{n} x_{it} \geqq Q_t \qquad (t=1,..,m) \qquad (5)$$

Additionally, amount of planned electricity of each power source must be positive.

$$x_{it} \geqq 0 \qquad (i=1,..,n),(t=1,..,m) \qquad (6)$$

The combination of electric power sources is formulated as a nonlinear planning problem. This problem could be solved by the Newton method. In this paper, procedure by Newton method is not showed by the limitation of paper's space.

3.3 Planning of power source's combination considering the environmental accounting

(1) Environmental cost

The amount of environmental cost of company has been increasing since environmental problems have attracted a great deal of attention.

Environmental cost classified into two groups as follows.

(a) Basic program cost

The environment activity cost of a company. (w1)

The cost for inspector and lawyer. (w2)

The cost for development of technology which relates to the environmental problems.

(company level and factory level) (w3)

The cost for specific program for environmental problems in the company and community surrounding the company. (w4)

Operation and maintenance works for the pollution management. (w5)

The depreciation of the environmental management equipments. (w6)

(b) Cost for environmental reconstruction, disposal of waste materials and other factors

Cost of lawyer for corresponding purification demand from community. (w7)

The disposal of waste materials. (w8)

The environmental tax. (w9)

The environmental reconstruction. (in the company) (w10)

The environmental reconstruction. (out of the company) (w11)

(2) Estimation of environmental cost

Environment cost of each company has been reviewed every year, and it is reported to the stockholders as an annual environmental report.[5] Thus, the multiple regression analysis is executed to analyze the relation between electric power sources and environmental cost. It's multiple regression model is shown by **eq. (7)**.

$$W_{it}=\sum_{i=1}^{11} w_{it}=e_i \cdot x_{it}^2+f_i+x_{it} \qquad (7)$$

However, symbols e_i and f_i mean the regression coefficients of i-th electric power sources.

The relationship between electric power source and environmental cost are estimated by using the above mentioned multiple regression analysis.

(3) Combination of electric power sources

The combination of electric power sources is planned with an aim to minimize the environmental cost. Environment cost W_{it} of i-th power source is evaluated by **eq. (7)**. The environment cost W_{it} could be used instead of u_{it} in **eq. (3)** and **(4)**. Therefore, the problem considering the environmental accounting is formulated by substituting W_{it} for u_{it}.

4. APPLICATION EXAMPLE

The application example of the proposed method is shown below.

4.1 Precondition

Amount of electric usage in each period is given in **Fig.1**. The usable power sources are 4 types. (electric power company x_{0t}, solar cell x_{1t}, fuel cell x_{2t} and diesel electric power generation x_{3t}) [6]

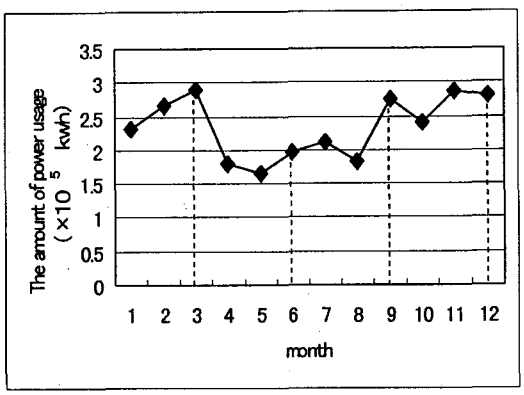

Fig.1 The amount of power usage in each month

Under the above mentioned preconditions, a combination of energy sources was determined so that the total energy cost was minimized.

4.2 Formulation of problem

(1) Objective function

The problem for minimizing energy cost was formulated as follows.

Variable cost is given by **eq. (8)**.

$$V=0.2(max\{x_{0t}\})^2+0.1max\{x_{0t}\}+1.8(max\{x_{1t}\})^2+1.6max\{x_{1t}\} +2.9(max\{x_{2t}\})^2+2.1max\{x_{2t}\}+2.5(max\{x_{3t}\})^2+1.1max\{x_{3t}\} \quad (t=1,2,3,4) \qquad (8)$$

Where, the period t is three month. One year is divided into 4 periods in order to make the problem small, and the peak amount of electricity consumption in each period is used as the demand of the period t.

Fixed cost given by **eq. (9)**.

$$F=\sum_{t=1}^{4}(1.8x_{0t}^2+2.5x_{0t})+\sum_{t=1}^{4}(2.0x_{1t}^2+2.8x_{1t})+\sum_{t=1}^{4}(2.5x_{2t}^2+3.2x_{2t})+\sum_{t=1}^{4}(2.5x_{3t}^2+1.0x_{3t}) \qquad (9)$$

Therefore, the objective function is given by **eq. (10)**.

$$\min \quad Z = F + V \qquad (10)$$

(2) Constraints

Total energy consumption of t-th period should be satisfied. This constraints are given by **eq. (11)**.

$$x_{01}+x_{02}+x_{03}+x_{04}\geqq 287{,}976\ (kwh) \qquad x_{11}+x_{12}+x_{13}+x_{14}\geqq 197{,}520\ (kwh)$$
$$x_{21}+x_{22}+x_{23}+x_{24}\geqq 274{,}032\ (kwh) \qquad x_{31}+x_{32}+x_{33}+x_{34}\geqq 285{,}456\ (kwh) \qquad (11)$$

4.3 Combination of electric power sources

As the combinatorial problem is solved by using Newton method **Fig.2** shows result, that is the amount of each energy source.

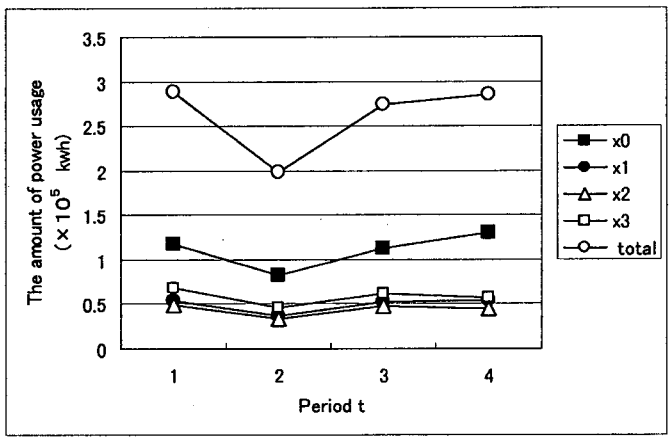

Fig.2 The amount of power usage in period t

The following facts are gotten from the **Fig.2**. Power supply by an electric power company (x_1) greatly fluctuates in every period. However, the amount of other electric power sources are sustained constant. And the energy cost could be minimized as the electric power of each source is controlled as shown in **Fig.2.**

5. CONCLUSION

This research proposed a method for determining the combination of various power sources to minimize the energy cost.

First, only electric power charge is considered and the method is formulated in order to determine a combination of electric power sources.

Secondly, the method that is related to the combination of electric power sources considering environmental cost and electric power charge.

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