EMISSION CONCERNED ECONOMIC DISPATCH CONSIDERING CARBON DIOXIDE QUOTA POLICY

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***Abstract*— This paper presents the mathematical formulation of economic dispatch problem in electricity market under emission concerned policy, which is carbon dioxide quota policy. The formulation using Lagrangian relaxation methods is presented in this paper. An algorithm, which is developed using MATLAB, is proposed to solve economic dispatch problem considering the carbon dioxide quota policy. Data from four generators in IEEE 14-bus system are used in this formulation. By using the proposed algorithm, the results for the economic dispatch problem can be obtained and fulfil the quota policy. In this manner, the problem of emission of carbon dioxide can be reduced and controlled.**

Keywords – Economic dispatch, Lagrangian relaxation, greenhouse gasses, carbon dioxide quota policy, low carbon economy, MATLAB.

I. INTRODUCTION

This study is proposed as the concern toward world's problem involving the emission of carbon dioxide called greenhouse effect. Greenhouse effect occurred when sunlight reaches the earth, some of it is converted to heat. Greenhouse gasses absorb some of the heat and trap it near the earth's surface, so that the earth is warmed up. Greenhouse gases are within the troposphere (the lower part of atmosphere)[1] .Electricity sectors are the largest inventors in this problem due to the uses of fuels such as coal, oil and gas that can result emission of carbon dioxide[2]. A more sustainable, low-carbon economy has been under consideration by many industrialized and developing countries[3].

Several policies can be used to control the carbon dioxide emission in electricity sectors such as Carbon Dioxide Tax Policy, Carbon Dioxide Quota Policy and Carbon Dioxide Cap and Trade Policy. But, in this study, only Carbon Dioxide Quota Policy is considered. Carbon dioxide quota allows the generators in power sector to emit only certain upper limit of carbon dioxide during a given period of time. Countries with high cost of emission reduction will find it worthwhile to purchase quotas from countries where the costs of reducing emission were lower[4]. As to ensure total quantity of permitted emission allocated is consistent with the realistic reduction target for the industry, it is important to this electricity generation industry to solve economic dispatch problem by considering emission control [5].

Economic dispatch minimizes the production cost of electricity. Emission can also be included in the economic dispatch by converting them into their equivalent cost. In addition, other than fuel and emission costs, production costs also include maintenance costs and overhead. And, in this study, only the fuel and emission cost are considered.

The power and energy research community has attempted engineering solutions to incorporating carbon dioxide emission constraints into the power system operations for almost 40 years. The earliest work dates back to 1971, which described a so-called "minimum-emission dispatch" scenario[6]. However, the trade-off between economics and emissions was not the main concern in that paper. In 1995, a Lagrangian relaxation-based emission-constrained economic dispatch algorithm, which is similar to the carbon dioxide quota policy, was proposed [7]. In 1998 a quadratic programming method was proposed to solve the similar problem[8]. However, Lagrangian and quadratic programming posed the problem in the context of vertically integrated utility structure rather than for the electricity market structure. In 1997, a fuzzy logic controlled genetic algorithm was investigated to solve the environmental/economic dispatch problem under the carbon dioxide tax policy. However, no analytical solution method is discussed.

In this paper, methods an algorithm that formulated from Lagrangian relaxation method in order to reduce or control the carbon dioxide emission is proposed. It is important for the electricity generation industry to ensure that the total quantity of emission permits allocated is consistent with the realistic reduction target for the industry. An algorithm proposed in this paper formulated from Lagrangian relaxation method in order to reduce or control the emission of carbon dioxide.

II. PROBLEM FORMULATION FOR EMISSION CONCERNED ECONOMIC DISPATCH

A. For simplification, the following symbols are usedin this paper:

$P_{Gi}(k)$	: Power output of unit i at time step k, (MW)
K	:Total number of time steps in the optimization horizon.
$C_i (P_{Gi}(k))$	:Operating cost of unit i when generating at $P_{Gi}(k)$
$\hat{\lambda}_i (k)$	:expected electricity price at the location of unit i at time step k
$E_i(P_{Gi}(k))$	:Carbon dioxide emission of unit i when generating at $P_{Gi}(k)$, (in tons)
E_i^{max}	: CO_2 emission quota for unit i in the entire period of K time steps
G	: Set of all the generator unit
G_r	: Set of all intermittent generator unit

Several general assumptions are made throughout this study:

- All units in *G* are considered to be committed throughout the entire period *K*. In other words, the unit commitment problem is not of the concern in this paper.
- The operational cost functions Ci(PGi (k)) are convex.

With these assumptions, a problem formulation of emission concerned economic dispatch under carbon dioxide quota policy is presented.

Under the carbon dioxide quota policy, Independent Power Producers (IPP) is given the certain amount or upper limit for carbon dioxide to emit in a given period of time and usually for entire year. The IPP maximize their own profit over this period of time, while observing the generation capacity and total emission. Under the price projection, $\hat{\lambda}_i$, unit i maximize its own profit as follows:

$$\sum_{k=1}^{K}[\hat{\lambda}_i(k)P_{Gi}(k) - C_i(P_{Gi}(k))] \tag{1}$$

Subjected to:

- The generation limit

$$\hat{P}_{Gi}{}^{min} \leq P_{Gi}(k) \leq \hat{P}_{Gi}{}^{max} \tag{2}$$

- The system demand (system losses are not considered)

$$\sum_{k=1}^{K} P_{Gi} = P_{demand} \tag{3}$$

- Emission quota limit

$$\sum_{k=1}^{K} E_i(P_{Gi}(k)) \leq E_i^{max} \tag{4}$$

By disturbing the projected price vector $\hat{\lambda}_i$ up and down by a certain percentage, the optimization of (1) – (4) generate another optimum generation vector.

III. METHODOLOGY

The implementation of the algorithm related to the previous formulation that introduced in Section II is presented in this section by introducing basic of Lagrangian relaxation method in this algorithm. This is followed by the simulation algorithm for the IPP's decision process under the carbon dioxide quota policy.

A. EconomicDispatch Algorithm Under Carbon Dioxide Quota Policy

In order to manage the interdependencies between the emission-concerned policy and power system economic dispatch, an algorithm is formulated based on the basic of Lagrangian Relaxation problem [3]. The formulation is shown below:

$$Z_{LR} = \max_{P_{Gi}} \left[\sum_{k=1}^{K}(\hat{\lambda}_i(k)P_{Gi}(k) - C_i(P_{Gi}(k))\right] + \mu\left[E_i^{max} - \sum_{k=1}^{K} E_i(P_{Gi}(k))\right] \tag{5}$$

Subjected to:

- The generation limit

$$\hat{P}_{Gi}^{min} \leq P_{Gi}(k) \leq \hat{P}_{Gi}^{max} \tag{6}$$

- The system demand $\mu \geq 0$

$$\sum_{k=1}^{K} P_{Gi} = P_{demand} \tag{7}$$

- Where

$$\mu \geq 0 \tag{8}$$

The flow chart for solving the emission dispatch considering carbon dioxide quota policy is illustrated in Figure1.

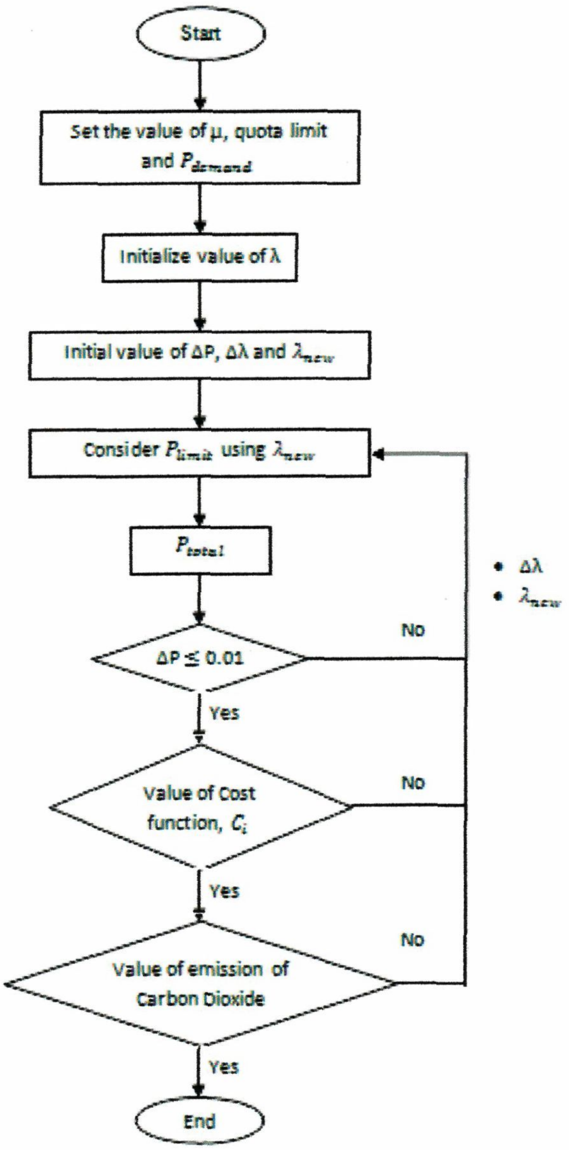

Figure1: Flow chart for the proposed algorithm.

IV. RESULT AND DISCUSSION

In this section, numerical as shown in Figure 2 are illustrated on a modified IEEE 14-bus system, which consists of four generators. The operating cost function of generators are assume to be a quadratic.function $C_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi}$ .The carbon dioxide emission from unit i $E_i(P_{Gi}(k))$ is assume to be a linear function of the amount of power produced. The generators parameters in this system are listed in Table 1.

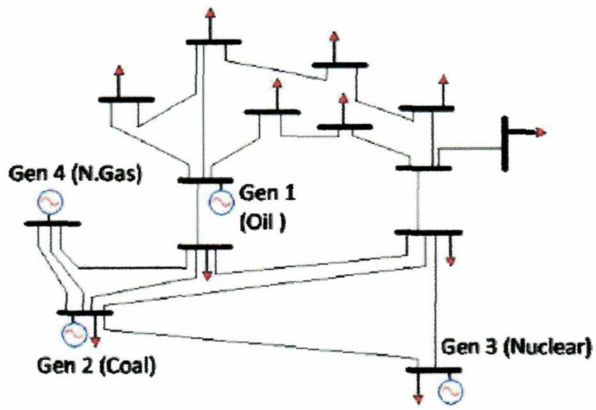

Figure2: IEEE 14-Bus System (modified from [15])

Table1: Generators Parameters of The 14 Bus System

Unit	Type	P_{Gi}^{max}(MW)	P_{Gi}^{min}(MW)	a_i(k$/MW^2)	b_i(k$/MW)	E_i(ton/year)
1	Oil	100	25	0.006	0.6	21360
2	Coal	400	100	0.00153	0.16	25632
3	Nuclear	350	140	0.00175	0.18	2136
4	Natural gas	155	25	0.00463	0.5	20506

The proposed algorithm is developed using MATLAB R2008b on a laptop with "Windows 7", Intel (R) Core (TM) 2 Duo CPU 1.67GHz, 2.0 GB Memory and operate in 32-bit operating system.

In this study, a quota parameters value of 4000k ton/year is used and the demand is set at 975MW. It is targeted the value of $Z_{LR} \leq$ 4000k ton/year with the value of $\mu = 1$.

That means only 4000 k ton/year and below of carbon dioxide can be emitted to the atmosphere and can simultaneously control or reduce the percentage emission of carbon dioxide and reduce the greenhouse effect.

The proposed algorithm gives the results as shown in Table 2.

Table 2: Results for λ initial = 0.7

Iteration	λ ($)	P_1(MW)	P_2(MW)	P_3(MW)	P_4(MW)	P_{total}(MW)	Z_{LR}(ton/year)
Initial	0.7	8.3333	176.4706	148.5714	21.5983	354.9736	-
1	-	72.6112	400	350	104.8957	-	-
2	1.7196	93.2973	400	350	131.7027	975	3931.2k

Table 3: Results for λ initial = 0.9

Iteration	λ ($)	P_1(MW)	P_2(MW)	P_3(MW)	P_4(MW)	P_{total}(MW)	Z_{LR}(ton/year)
Initial	0.9	25	241.8301	205.7143	43.1965	515.7409	-
1	-	72.6112	400	350	104.8957	-	-
2	1.7196	93.2973	400	350	131.7027	975	3931.2k

Table 4: Results for λ initial = 0.5

Iteration	λ ($)	P_1(MW)	P_2(MW)	P_3(MW)	P_4(MW)	P_{total}(MW)	Z_{LR}(ton/year)
Initial	0.5	-8.3333	111.1111	91.4286	0	194.2063	-
1	-	72.6112	400	350	104.8957	-	-
2	1.7196	93.2973	400	350	131.7027	975	3931.2k

Table 5: Results for λ initial = 1.8

Iteration	λ ($)	P_1(MW)	P_2(MW)	P_3(MW)	P_4(MW)	P_{total}(MW)	Z_{LR}(ton/year)
Initial	1.8	100	535.9477	462.8571	140.3888	1239.2	-
1	-	72.6112	400	350	104.8957	-	-
2	1.7196	93.2973	400	350	131.7027	975	3931.2k

The results obtained. Table 2, Table 3, Table 4 and Table 5 also shows that a total generator is 975MW which met the demand of 975MW. It shows the relationship between the electricity prices, λ $(Lnew)$ with the amount of the carbon dioxide emitted into the atmosphere. As long as the demand is not met, the electricity price will vary until it reaches the demand. That means, with the proposed method, the value of electricity price, λ $(Lnew)$ can be obtained and achieve the power demand. As a result, the emission of carbon dioxide is reduced and controlled.

V. CONCLUSION

In this study, the solution to the economic dispatch problem considering the emission quota policy has been proposed using Lagrangian Relaxation method. The emission of carbon dioxide value obtained is below than the specified quota and fulfill the demand it can be concluded that the objective of proposed method met is to solve this problem.

For future development, this method can be proposed to solve economic dispatch problem by considering emission and system losses.

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