CO_2 Emission Reduction for Power Industry Based on Total Emission Control of CO_2 (I): Modeling

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Abstract: Large amounts of carbon dioxide (CO_2) emissions caused more and more extreme weather. In this study, the maximum reduction of power CO_2 emissions is the management objective based on three significant ways in the planning period, which are energy conservation, reduction project and power structure adjustment. Therefore, in order to provide reference to the CO_2 emission reduction in power industry for administrative department, a mixed integer stochastic chance-constraint programming model based on power CO_2 emission reduction is developed, in consideration of energy-saving capacity, reduction project feasibility and structure adjustment space, besides constraints of CO_2 emissions control target, regional power demand, power load, expansion and so on.

Keywords: CO_2 emission reduction; energy conservation; generation expansion planning; integer programming ; stochastic chance-constraint programming

I. INTRODUCTION

Large amounts of CO_2 emission caused more and more extreme weather. China as one of the largest CO_2 emissions countries, has formally announced actions to control greenhouse gas emissions targets in 2009, planning to reduce 40%-45% CO_2 emissions per unit of GDP by 2020 from the 2005 level. It is facing severe challenge to meet the CO_2 emission reduction target during the periods of "12th Five-Year" and "13th Five -Year". Therefore, how to maximize the CO_2 emission reduction under the premise of regional economic development and energy requirements is the objective for regional administrative department.

According to the sources of China's CO_2 emissions, the current CO_2 released into the atmosphere are mainly attributed to the fossil fuel combustion, especially the power production, due to the coal is given priority to our country's energy structure. As a result, the power industry has inevitably become the main battlefield of energy conservation and emission reduction. Because the power industry is the guarantee of economy development and has responsibility for realizing environmentally-friendly society, a series of scientific and reasonable plans are need to be made for low-carbon power, that means to improve the efficiency of power production and transmission and also slow down the energy consumption. It is of great significance for the sustainable development of power industry. Simultaneously, low-carbon power also demands to optimize the power supply structure and raise the proportion of clean energy power generations [1].

At present, there are four kinds of ways to reduce CO_2 emissions from power industry in China, including energy conservation, CO_2 reduction project, power structure adjustment and market techniques.

1) Energy conservation is to promote power generation efficiency in order to reduce energy consumption and CO_2 emissions. This approach has many advantages such as low-cost, reasonable, effective and so on. In order to improve the power generation efficiency, the state council has issued the policy of *energy saving power generation dispatching* in 2007. Although the energy conservation and emission reduction are not completely consistent in terms of their targets, it is beneficial to reduce the power coefficient of CO_2 emissions and further reduce the overall through the implementation of energy-saving power generation dispatching, as thermal power is still the predominant power source in our country for a long time in the future.

Power production of energy conservation usually takes improving the efficiency as the goal, mainly reflecting in the optimal operation and technical transformation of the unit in active service, etc.

2) Reduction project, which is to reduce CO_2 emissions by CO_2 capture and storage technology (CCS). CCS is a process that separating CO_2 from industrial or related energy production chain, transporting to a certain spot to seal, and cut off from the atmosphere for a long time [2]. Using CCS technology can reduce 80% ~ 95% CO_2 emissions from power station, and the theory of reduction potential is tremendous. At present, CCS technology has been applied to a few small coal-fired power plants, which has already verified the feasibility of the CCS technology. However, it is still difficult to large-scale popularization and application due to the high energy consumption and cost.

3) Power structure adjustment has two aspects of meaning, according to the future development direction of

the power industry in our country. On one hand, from the perspective of energy consumption structure, power structure adjustment is to increase the installed capacity and power generation proportion of the clean energy such as renewable energy and nuclear energy. On the other hand, as it is difficult to change the predominant position of coal-fired power radically, which has obvious disadvantages of environmental protection compared with hydropower, wind energy, solar energy, biomass energy, nuclear energy and so on; power structure adjustment also means optimizing the coal-fired power structure and increasing application of clean coal generating technology. Obviously, under the influence of low-carbon economy and energy structure in our country, clean coal generating technology is the inevitable choice for power industry [3]. Hence, optimizing the structure of coal-fired power generating units is another important form of power structure adjustment to reduce power CO_2 emissions [4].

4) At present, the market techniques are mainly referring to carbon trading and the clean development mechanism (CDM). Of the two market techniques, CDM is the significant means to achieve the obligations of CO_2 emission reduction for developed countries. China is the largest CDM projects countries and the approved emission reductions (CERs) account for 50% of the world. Vigorously developing CDM projects is helpful to obtain large CO_2 emission reduction for developed countries, and introduce low carbon technology and capital to developing countries as well [5]. CDM projects of raising energy efficiency and developing new energy and renewable energy are key areas in China [6]. By the end of 2011, China has approved 3105 CDM projects, and the projects of new energy and renewable energy account most, reaching 71.63% [7].

Power industry is the main source of CO_2 emissions, having huge demand for CO_2 emission indicators itself, without the proper conditions of sale. Meanwhile, it can't achieve the purpose of reducing CO_2 emissions fundamentally from power industry by purchasing CO_2 emission indicators. Although carrying out CDM projects is the main market technique for power industry, it is only meaningful under the *Kyoto Protocol,* which will no more applicable with the developing countries assuming tasks of CO_2 emission reduction.

Therefore, ways of energy conservation, CO_2 reduction project and power structure adjustment are effective means to reduce CO_2 emissions from power industry. For regional administrative departments, it is should take into consideration of energy-saving capacity, reduction project feasibility and structure adjustment space.

II. METHODOLOGY

A. Mixed integer programming

Mixed integer programming, partial variables of which are restricted to integer in the model, has been widely used in programming management.

B. Stochastic chance-constraint programming

Stochastic chance-constraint programming method has the main feature that not all the constraints must be strictly

satisfied, but simply to satisfy parts under the given confidence level [8-15].

III. MODEL DEVELOPMENT

C. Construction of objective function:

In this section, the maximum of CO_2 emissions is composed of the objective function based on three ways to reduce CO_2 emissions in the planning phase of the regional power system, which is energy conservation, CO_2 reduction project and power structure adjustment, which are shown as follows:

$$Maxf = (1) + (2) + (3) \tag{1}$$

(1) CO_2 emission reduction of energy conservation

$$= \sum_{t=1}^{T} \sum_{j=1}^{1} 10^{-5} \cdot PER \cdot XCC_t \cdot CIC_j \cdot AGH_{tj} \tag{2}$$

(2) CO_2 emission reduction of reduction project

$$= \sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{i=1}^{I} 10^{-2} \cdot PPR_{tij} \cdot (1 - \varphi_{ti}) \cdot YIC_{tij} \cdot AGH_{tj} \tag{3}$$

(3) CO_2 emission reduction of structure adjustment

$$= \sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{k=1}^{K} 10^{-2} \cdot PSR_{tjk} \cdot ZPC_{tjk} \cdot CES_{jk} \cdot AGH_{tj} \tag{4}$$

As a result, the objective function can be expressed as:

$$Maxf = \sum_{t=1}^{T} \left\{ \begin{array}{l} \sum_{j=1}^{1} \left[\begin{array}{l} 10^{-5} \cdot PER \cdot XCC_t \cdot CIC_j \cdot AGH_{tj} \\ + 10^{-2} \cdot \sum_{i=1}^{I} PPR_{tij} \cdot (1 - \varphi_{ti}) \cdot YIC_{tij} \cdot AGH_{tj} \end{array} \right] \\ + \sum_{j=1}^{J} \sum_{k=1}^{K} 10^{-2} \cdot PSR_{tjk} \cdot ZPC_{tjk} \cdot CES_{jk} \cdot AGH_{tj} \end{array} \right\} \tag{5}$$

Where f represents the objective function, CO_2 emission reductions of planning periods, t; t represents the planning periods; i represents the engineering technology of CO_2 emissions reductions; j represents the type of power generation set; k represents the expansion plan of each type of power generation set; PER represents the CO_2 emission of a tons of standard coal combustion, $kgCO_2$/Mtec; XCC represents the reduced consumption capacity of power supply standard coal in planning periods by energy conservation and emissions reduction, which served as decision variable, g/kW·h; CIC is the initial capacity (except the units plan to shut down) of regional power generation sets in initial planning periods, 10^4kW; AGH is the average number of hours in power generation sets, h; PPR is the CO_2 emissions of unit capacity in the engineering emission reduction technology, gCO_2/kW·h; φ is the compared to emissions reductions, the CO_2 emissions of energy consumption per unit of electricity in the engineering emission reduction technology, %; YIC is the coal unit capacity by the engineering mitigation measures, which served as decision-making scalar, kW; PSR is the different expansion capacity of each type of generators, the CO_2 emission reductions of unit capacity, gCO_2/kW·h; ZPC is the capacity expansion ration of each type generator unit, which served as the decision variable, gCO_2/kW·h; and

CES is the expansion capacity options of each type generator unit, 10^4kW.

D. Construction of constraint conditions:

(1) Constraints of total emission control of power CO_2 emissions

The total CO_2 emissions in power industry should not be higher than the control objective of CO_2 emissions in the region, and the constraint condition is as follows:

$$\sum_{j=1}^{1} AGH_{tj} \cdot \left[\begin{array}{l} 10^{-5} \cdot PER \cdot \left(ICR - \sum_{t=1}^{T_t} XCC_t \right) \cdot CIC_j \\ - 10^{-2} \cdot \sum_{i=1}^{I} PPR_{tij} \cdot (1 - \varphi_{ti}) \cdot YIC_{tij} \\ + \sum_{t=1}^{T_t} \sum_{k=1}^{K} 10^{-2} \cdot SCC_{tjk} \cdot ZPC_{tjk} \cdot CES_{jk} \end{array} \right]$$
$$+ \sum_{j=2}^{3} 10^{-2} \cdot AGH_{tj} \cdot PCE_{tj} \cdot \left(CIC_j + \sum_{t=1}^{T_t} \sum_{k=1}^{K} ZPC_{tjk} \cdot CES_{jk} \right)$$
$$\leq CEI_t \cdot GDP_t, \quad T_t = 1,2,...,t$$

(6)

Where ICR represents the standard power supply coal consumption of regional coal unit in the end of the 11th five-year plan, g/kW·h; SCC is the CO_2 emission of unit capacity in the new power generation set, gCO_2/kW·h; PCE represents the CO_2 emission of unit capacity in the various types of power generation sets, gCO_2/kW·h; CEI is the target emissions intensity of CO_2 in regional unit of gross domestic product, $tCO_2/10^4$ yuan GDP; and GDP represents Gross national product in the region, 10^4 yuan.

(2) Constraints of clean energy capacity

$$\sum_{k=1}^{K} ZPC_{tjk} \cdot CES_{jk} \geq TIC_{tj}, \quad \forall t; j = 4,5,...,J \quad (7)$$

where TIC represents the installed new clean energy goals of region in the planning phase, GW.

(3) Constraints of energy conservation potential

$$XCC_t \leq ESP_t, \quad \forall t \qquad (8)$$

where ESP represents the standard power supply coal consumption potential in planning period, g/kW·h.

(4) Constraints of reduction project capacity

$$\sum_{t=1}^{T_t} \sum_{i=1}^{I} YIC_{tij} < CIC_j + \sum_{t=1}^{T_t} \sum_{k=1}^{K} ZPC_{tjk} \cdot CES_{jk},$$
(9)
$$j = 1; T_t = 1,2,...,t$$

(5) Constraints of structure scheme selection

$$ZPC_{tjk} \in \{0, N^+\}, \quad \forall t, j, k \qquad (10)$$

(6) Constraints of emission reduction cost

a) Cost constraints of energy conservation and CO_2 reduction project

Considering energy conservation and emissions reduction and project emissions to decrease the unit cost of CO_2 emissions, energy conservation and the constraints of project cost mainly from economic perspective in regional power generation company. It is not feasible to achieve good reduction effect and high power at the expense of economic cost.

$$\frac{CER_t \cdot PER \cdot XCC_t \cdot CIC_j \cdot 10^{-9} + \sum_{i=1}^{I} CPR_{ti} \cdot PPR_{tij} \cdot YIC_{tij} \cdot (1-\varphi_{ti})^{-1} \cdot 10^{-6}}{\left(CIC_j + \sum_{t=1}^{T_t} \sum_{k=1}^{K} ZPC_{tjk} \cdot CES_{jk} \right)}$$
$$\leq ACR_t, \quad \forall t; j = 1$$

(11)

b) Cost constraints of power structure adjustment

The cost constraints of the structure to reduce emissions, namely the expansion cost constraints in planning phase.

$$\sum_{j=1}^{J} \sum_{k=1}^{K} PPU_{tjk} \cdot ZPC_{tjk} \cdot CES_{jk} \leq TAF_t, \quad \forall t \qquad (12)$$

Where CER represents the energy conservation and emissions reduction cost of per unit of CO_2, yuan/ tCO_2; CPR represents the engineering reductions cost in carbon emissions of per unit of CO_2, yuan/ tCO_2; ACR is the increased cost of CO_2 emissions of per unit of electricity production in in the region, yuan/kW·h; PPU is the unit installed cost of the k kind of electricity power supply, yuan/ kW; and TAF is the fund to be used to dilatate the power supply in the planning phase regin, 10^4 yuan.

(7) Constraints of power supply and demand

$$\sum_{j=1}^{J} \left(CIC_j + \sum_{t=1}^{T_t} \sum_{k=1}^{K} ZPC_{tjk} \cdot CES_{jk} \right) \cdot AGH_{tj} \cdot \omega_{tj} \cdot (1 - \xi_{tj}) \cdot (1 - \delta_{tj}) (13)$$
$$\geq TPC_t, \quad \forall t; T_t = 1,2,...,T$$

Where ω represents the electricity access, %; ξ represents the power consumption rate, %; δ represents the line loss rate, %; and TPC represents the electricity demand in region, 104kW·h.

(8) Constraints of power load

$$\sum_{j=1}^{J} \left(CIC_j + \sum_{t=1}^{T_t} \sum_{k=1}^{K} ZPC_{tjk} \cdot CES_{jk} \right) \geq MEL_t + SDP_t, (14)$$
$$\forall T_t = 1,2,...,t$$

Where MEL represents the maximum electrical load, 10^4 kW; and SDP represents the reserve capacity, 10^4 kW.

(9) Constraints of resource supplying

c) Constraints of fossil energy supply:

$$\sum_{k=1}^{K} FEC_{tjk} \cdot \left(CIC_j + \sum_{t=1}^{T_t} ZPC_{tjk} \cdot CES_{jk} \right) \cdot AGH_{tj} \cdot 10^{-2} \quad (15)$$
$$\leq TES_{tj}, \quad \forall t; T_t = 1,2...t; j = 1,2,3$$

Where FEC represents the fossil energy consumption of unit capacity, g/kW·h (all calculate convert of standard coal); and TES represents the fossil energy supply, t.

d) Constraints of clean energy exploitation

$$\sum_{k=1}^{K} ZPC_{tjk} \cdot CES_{jk} \leq TPR_{tj}, \quad \forall t; j = 4,5,...,J \ (16)$$

where TPR represents the development capacity of clean energy in a year, 104kW.

(10) Nonnegative constrains

$$XCC_{tj} \geq 0; YIC_{tij} \geq 0; ZPC_{tjk} \geq 0 \tag{17}$$

$$\forall t,i,j,k$$

The balance constraints of power supply and demand are found to be main factors planning the electric power system. From the point view of environmental protection, a series of more stringent energy conservation and emissions reduction targets were formulated by country , which have an impact on the development of electric power thermal power unit. Therefore, the actual power supply level in region exists some uncertain. From the point view of the reduce emissions of power system, the uncertainty of supply will produce a direct impact on the result of the structure of CO_2 emission reduction plan and indirect impact on the result of the project to reduce emissions in the case of generators in operation time. Therefore, considering the uncertainty of the regional power supply capacity, constraints in the power supply must meet the regional demand at least $(1 - pr)$ probability level, which using the method of stochastic chance-constraint programming. The formula can be expressed as:

$$Pr \left\{ \begin{array}{c} \sum_{j=1}^{J} \left(CIC_j + \sum_{t=1}^{T_t} \sum_{k=1}^{K} ZPC_{tjk} \cdot CES_{jk} \right) \\ \cdot AGH_{tj} \cdot \omega_{tj} \cdot \left(1 - \xi_{tj}\right) \cdot \left(1 - \delta_{tj}\right) \\ \geq TPC_t \end{array} \right\} \geq 1 - p_r \tag{18}$$

$$\forall t; T_t = 1,2,...,T$$

IV. SUMMARY

In this study, a mixed integer stochastic chance-constraint programming model based on power CO_2 emission reduction is developed, with the maximum reduction of CO_2 emissions as the objective function, through three ways of energy conservation, CO_2 reduction project and power structure adjustment. In this model, energy-saving capacity, reduction project feasibility and structure adjustment space are taken into consideration, besides constraints of CO_2 emissions control target, regional power demand, power load, expansion funds and so on. The established programming model is planned to provide decision support of CO_2 emission reduction in power industry for administrative department under three ways in various periods.

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