CHEMICAL ENGINEERING TRANSACTIONS

VOL. 67, 2018

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Valerio Cozzani, Bruno Fabiano, Davide Manca

ISBN 978-88-95608-64-8; **ISSN** 2283-9216

DOI: 10.3303/CET1867079

Grid-Air Environment Planning Considering Environmental Factors

Ke Gu, Cong Jiang*, Fengmin Wang, Wendong Cui

Jilin Electric Power Construction Supervision Co.,Ltd., Changchun 130000, China
jiangcong704@163.com

This paper aims to realize sustainable grid planning in the medium and long term. For this purpose, the author reviewed the objectives of the energy, environment and economic policies on air environmental protection, discussed the impact of these policies on power system planning and management, and created a grid-air environment planning model considering environmental factors like polluting gas emissions and the AERs. Specifically, the purchase of SO2, NOX and CO2 emission quotas in the power industry was deliberated, the impact of uncertain power demand on grid planning was taken into account, and the grid planning model was established by two-stage mixed integer random programming. Then, the proposed model was applied to prepare the AER supply plan, power generation plan and power expansion plan of the grid in Jilin Province, China, considering different development speeds of clean energy generator sets. The case study reveals that the proposed grid-air environment planning method can satisfy the emission targets of polluting gases under the relevant constraints, and significantly enhance the environmental and economic benefits considering the quota trading. The research results shed new light on optimizing industrial structure and improving energy efficiency.

1. Introduction

Recent years has seen China issuing a series of laws and regulations on energy-saving and emission reduction, such as the *Environmental Protection Law* (2015). These latest legislations form a well-organized system on polluter responsibility and victim compensation (Charles, 2018; Zamora et al., 2015; Dong et al., 2012). According to these laws and regulations, it is imminent to make structural adjustment to the power industry for the purpose of energy-saving and emission reduction (Wang et al., 2011; Zhang, 2014; Yu et al., 2017).

The main polluting gases of the power industry are SO_2, NO_x and CO_2 (Liu, 2016; Sun, 2016). To control the emissions of these gases, the power industry must realize stable and sustainable development in the medium and long term. The concrete measures include preparing a rational supply plan of air environmental resources (AERs), and optimizing the production and expansion plans for the generator set.

At present, much research has been done on the control of SO_2, NO_x and CO_2 at home and abroad. However, the studies on SO_2 and NO_x control concentrate on the microscale like developing control techniques, changing control quantity and evaluating control effect, while those on CO_2 control emphasise macroscopic analysis over microscale issues (Qiu et al., 2010).

As China evolves from a planned economy to a market economy, the uncertainties and risks associated with the economic institutions are being replaced by market changes and competition with other power producers. In this background, the goal of power investment has shifted from minimizing the total cost of the grid to maximizing the investment profit (Lyu et al., 2013; Wakiyama and Kuramochi, 2016; Zhou, 2012).

In light of the above, this paper reviews the objectives of the energy, environment and economic policies on air environmental protection, discusses the impact of these policies on power system planning and management, and creates a grid-air environment planning model considering environmental factors like polluting gas emissions and the AERs. Specifically, the purchase of SO_2, NO_X and CO_2 emission quotas in the power industry was deliberated, the impact of uncertain power demand on grid planning was taken into account, and the grid planning model was established by two-stage mixed integer random programming. Then, the

Please cite this article as: Gu K., Jiang C., Wang F., Cui W., 2018, Grid-air environment planning considering environmental factors, Chemical Engineering Transactions, 67, 469-474 DOI: 10.3303/CET1867079

proposed model was applied to prepare the AER supply plan, power generation plan and power expansion plan of the grid in Jilin Province, China, considering different development speeds of clean energy generator sets. The purpose is to realize sustainable grid development in the medium and long term.

2. Purchase of Emission Quotas

2.1 SO_2 and NO_X emission quotas

The power enterprises are allowed to purchase emission quotas from the market, so that they can expand production at a lower pressure of energy-saving and emission reduction. In general, there are two ways for power enterprises to purchase the emission quotas for polluting gases like SO_2 and NO_X. One is to pay the emission fee to the competent authority of environmental protection, and the other is to trade emission quotas with other power enterprises.

Among different power enterprises, thermal power plants often boast a great surplus in its emission quotas. However, these plants are prohibited from trading emission quotas with other power enterprises, according to the *Emission Standard of Air pollutants for Thermal Power Plants* (GB13223-2011). Considering the limited SO_2 and NO_X emissions of thermal power plants, the ban on the trade of emission quotas with these plants should be gradually relaxed to optimize the resource allocation in the power industry.

Through the above analysis, a power enterprise could fulfil its obligations on SO_2 and NO_X emission reduction by the following methods: First, buying emission quotas from the competent authority; Second, reducing their own SO_2 and NO_X emissions; Third, trading emission quotas with other power enterprises.

2.2 CO_2 emission quotas

Despite the popularity of carbon capture and storage (CCS), the power industry in China still releases a lot of CO_2. It is not yet mature to implement the emission quota trading in the power industry. Therefore, this paper only discusses the ways to meet CO_2 emission requirements in different planning periods.

For an expansion project, the SO_2 and NO_X emission targets can be realized easily through the said means, leaving a large space for CO_2 emission. In general, a power enterprise could fulfil its obligations on CO_2 emission reduction by the following methods: First, adopting CCS and other reduction measures; Second, trading emission quotas with other power enterprises.

2.3 Impact of uncertain power demand on grid-air environment planning

In actual operation, it is difficult for power enterprises to strike a balance between power supply and sales, because the homogenously generated power cannot be stored for a long time. Both short supply and over supply may cause great economic losses. During short supply, the production and living demands will not be satisfied; during over supply, a lot of power will be wasted. The supply chain of the power industry is driven by power demand, which is uncertain from area to area and from time to time.

Facing strict requirements on emission reduction, the power industry in China has to find a new alternative that generates power and expands generation capacity without sacrificing the air environment. Considering the uncertain power demand, the two-phase stochastic optimization method was introduced to reduce the uncertain arising from the random factors of power generation.

3. Construction of Grid-Air Environment Planning Model

3.1 Objective function

This section attempts to build the optimal AER supply plan, power generation plan and generator expansion plan that can minimize the cost of regional grid-air environment system. The cost of regional grid-air environment can be expressed as:

$$\min f = [C_1 + C_2 + C_3 + C_4 - C_5] \tag{1}$$

where f is the system cost (RMB 10^4 yuan); C_1 is the AER supply cost; C_2 is the emission fee of the main air pollutants; C_3 is the annual cost of the generator group; C_4 is the capacity expansion cost; C_5 is the income of new power output. The calculation formulas of each component of the system cost are as follows:

$$C_1 = \sum_{t=1}^{T}\sum_{i=1}^{2}(FEB_{ti} \cdot XEB_{ti} + FEP_{ti} \cdot XEP_{ti} + FET_{ti} \cdot XET_{ti}) + \sum_{t=l}^{T}(FCO_t \cdot XCP_t + FCT_t \cdot XCT_t) \tag{2}$$

where f is the number of planned years; i are the main air pollutants (i=1 for SO_2, i=2 for NO_X and i=3 for CO_2); FEB is the emission fee for main air pollutants specified by competent authority (RMB yuan/ton); XEB is the emission quota for main air pollutants purchased from competent authority (10^4 tons); FEP is the SO_2 and NO_X emission cost achievable through generating capacity reduction (RMB yuan/ton); XEP is the SO_2 and NO_X emission targets achievable through generating capacity reduction (RMB yuan/ton); FET is the price of the emission quota of SO_2 and NO_X on the market (RMB yuan/ton); XET is the amount of SO_2 and NO_X emitted through quota trading (10^4 tons); FCP is the CO_2 emission cost achievable through generating capacity reduction (RMB yuan/ton); XCP is the CO_2 emission targets achievable through generating capacity reduction (RMB yuan/ton); FCT is the price of the emission quota of CO_2 on the market (RMB yuan/ton); XCT is the amount of CO_2 emitted through quota trading (10^4 tons).

$$C_2 = E\left[\sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j=1}^{J}(PCC_i \cdot \frac{\lambda_{tij} \cdot (PPG_{tj} - XHP_{tj}) \cdot 10^4 \cdot (1-\beta_{ti})}{PEV_i})\right] \tag{3}$$

where j is the type of power generator; PCC is the emission fee of the i-th main air pollutant (RMB yuan/emission equivalent); λ is the average coefficient of the i-th main air pollutant emitted by type j generators in period t (kg/kWh); PPG is the planned annual generating capacity of type j generators in period t (108kWh); XHP is a decision variable representing the annual reduction of generating capacity of type j generators at period t in scenario h (108kWh); β is the average removal efficiency of the i-th main air pollutant of the generator in period t (%); PEV is the emission equivalent of the i-th main air pollutant (kg).

$$C_3 = E\left[\sum_{t=1}^{T}\sum_{j=1}^{J}(PUC_{tj} + \sum_{i=1}^{I} PEC_{tij}) \cdot (PPG_{ij} - XHP_{tj}) \cdot 10^4\right] \tag{4}$$

where PUC is the operation cost of type j generators (yuan/kWh); PEC is the reduction cost of the i-th main air pollutant for type j generators (RMB yuan/kWh).

$$C_4 = E\left[\sum_{t=1}^{T}\sum_{j=1}^{J}(CUB_{tj} + \sum_{i=1}^{I} CEB_{tij}) \cdot YEV_{tj} \cdot CIV_{tj}\right] \tag{5}$$

where CUB is the variable cost of capacity expansion (RMB yuan/kWh); CEB is the variable cost of environmental protection (RMB yuan/kWh);YEV is the new installed capacity of type j generators at period t; CIV is the base expansion of type j generators (10^8/kWh).

$$C_5 = E\left[\sum_{t=1}^{T} PPP_t \cdot ZOT_i \cdot 10^4\right] \tag{6}$$

where PPP_t is the market price of power purchase at period t (RMB yuan/kWh); ZOT is the external power supply in period t (10^8kWh).

3.2 Constraints

(1) SO_2 and NO_X emission quota

Table 1 shows the emission quota of polluting gases applicable to each period. In the 12-th Five-Year Plan period, the power industry could acquire emission quotas via the first and second methods (Section 2.1), and obtain the emission quota for capacity expansion through the second method, i.e. reducing their own emissions. Thus, the following constraint can be established:

$$\sum_{j=1}^{J}[\alpha_{ij} \cdot UEC_{tj}(PPG_{tj} - XHP_{tj}) \cdot (1-\beta_{ti}) \cdot 10^{-5}] \le XEB_{ti} + XEP_{ti} + XET_{ti}, t = 2; i = 1,2 \tag{7}$$

where α_{ij} is the amount of i-th polluting gas released by type j generators (kg/ton); UEC is the average energy consumption of type j generators (g/kWh); NEC is the average energy consumption of new type j generators (g/kWh); η is average removal efficiency of the i-th main air pollutant of the plant in period t (%); HOH is the maximum annual operating hours of type j generators (hour).

(2) CO_2 emission quota

The CO_2 emission should not exceed the total amount of CO_2 emission quota obtained through quota trading.

$$\sum_{j=1}^{J}[\alpha_{ij} \cdot NEC_{tj} \cdot YEV_{tj} \cdot CIV_{tj} \cdot HOH_{tj} \cdot 10^{-9}] \le XCP_t + XCT_t, \forall t; i = 3 \tag{8}$$

(3) Balance between power supply and demand

$$(1-\delta_t)\left[\sum_{j=1}^{J}(PPG_{tj}-XHP_{tj})\cdot(1-\gamma_{ti})-(POT_t+ZOT_t)\right]\geq TPD_t-SE,\forall t \tag{9}$$

$$PPG_{tj\max}\geq PPG_{tj}\geq XHP_{tj}\geq 0,\forall t,j \tag{10}$$

$$POT_t+ZOT_t\leq TOT_t,\forall t \tag{11}$$

where δ is the transmission line loss rate (%); γ is the power consumption of the plant (10^8kWh);TPD is the predicted power demand in period t (10^8kWh); SE is a random variable representing the power surplus in period t (10^8kWh); TOT is the generating capacity in period t (10^8kWh).

(4) Generating capacity

The installed capacity of each generator should meet the final plan on generating capacity.

$$\left(CIC_j+\sum_{t=1}^{T}YEV_{tj}\cdot CIV_{tj}\right)\cdot AGH_{tj}\cdot 10^4\geq PPG_{tj}-XHP_{tj},\forall j \tag{12}$$

where CIC is the initial installed capacity of type j generators (10^4kW); AGH is the average operation hours of type j generator in period t (hour).

(4) Power load

$$\sum_{j=1}^{J}\left(CIC_j+\sum_{t=1}^{T}YEV_{tj}\cdot CIV_{tj}\right)\geq MEL_t+SDP_t,\forall t \tag{13}$$

where MEL is the maximum power load of the system in period t (10^4kW); SDP is the system power reserve capacity in period t (10^4kW).

(5) Fossil energy supply

$$\sum_{j=1}^{J}UEC_{tj}(PPG_{tj}-XHP_{tj})\cdot 10^{-5}]\leq FSP_{tj},t=1;j=1,2 \tag{14}$$

where FSP is the fossil energy supply capacity at all times (10^4t).

(6) Installed capacity of clean energy

China is pushing for the development of clean energy. Almost all regions have formulated their goals of installed capacity of clean energy.

$$CIC_j+\sum_{t=1}^{T}YEV_{tj}\cdot CIV_{tj}\geq LEC_{tj},\forall t;\ j=3,4,5\cdots J \tag{15}$$

where LEC is the target of clean energy installed capacity in period t (10^4kW).

(7) Expansion capacity

The regional economy must be considered in the development of each generator. In view of resource supply and financial budget, the generator capacity should not exceed its annual maximum capacity expansion potential.

$$YEV_{tj}\cdot CIV_{tj}\leq HEC_{tj},\forall t,j \tag{16}$$

where HEC is the maximum expansion potential of type j generators in period t (10^4kW).

(8) Non-negativity

$$XEB_{ti}\geq 0;XEP_{ti}\geq 0;XET_{ti}\geq 0;XCP_{ti}\geq 0;XHP_{ti}\geq 0;YEV_{ti}\geq 0;ZOT_{ti}\geq 0,\forall t,i,j \tag{17}$$

4. Case study

4.1 Scenario design

The growth rate of clean energy installation is a key measure of the adjustment of grid structure. Hence, much importance should be attached to this measure during the planning for grid-air environment. Here, 3 scenarios are designed based on the growth rate of clean energy installation.

(1) Scenario 1

Under this scenario, there is no limit on the minimum installed capacity of clean energy generators.

(2) Scenario 2 (Uniform growth)

In the 13^{th} Five-Year Plan period, the installed capacity of clean energy generators increases at a constant rate from that in the 12^{th} Five-Year Plan period. Nuclear power units are the only exception, because they are highly policy-driven. The growth targets and installed targets of clean energy in the different plan periods are shown in Table 1.

Table 1: Capacity of the clean energy generation in scenario 2

	Hydro	Wind	Photovoltaic	Geothermal
GrowthTarget	45	180	15	0.5
CapacityTarget	140	396	15	0.5

(3) Scenario 3(Rapid growth)

In the 13^{th} Five-Year Plan period, the installed capacity of clean energy generators increases at a rapid rate from that in the 12^{th} Five-Year Plan period. Nuclear power units are no exception to the general trend. The growth targets and installed targets of clean energy in the different plan periods are shown in Table 2.

Table 2: Capacity of the clean energy generation in scenario 3

	Hydro	Wind	Photovoltaic	Geothermal
GrowthTarget	45	180	15	0.5
CapacityTarget	200	596	35	1

4.2 Results analysis

The proposed model was applied to simulate the grid in Dunhua, north-eastern China's Jilin Province. Table 3 lists the economic benefits of various power plants in different planning periods.

Table 3: Economic benefits of various power plants in the region during the planning period

Generator capacity	Genarator1 (600MW)	Genarator2 (700MW)	Genarator3 (700MW)	Genarator4 (800MW)
Generation income(108yuan)	1031.23	1883.71	1054.42	3783.9
Total Running cost(108yuan)	350.86	1548.02	785.87	2497.05
Net profit	680.37	335.69	268.55	1286.85

As shown in the table, the proposed grid-air environment planning method met the emission targets of polluting gases under the relevant constraints, and significantly enhanced the environmental and economic benefits considering the quota trading. Moreover, the results show that coal-fired generators have obvious cost advantages over clean energy generators in the long run. Therefore, more economic policies (e.g. rational pricing of clean energy-generated power) should be laid down to support the development of clean coal power generators, in addition to reducing the cost of clean energy and generators.

5. Conclusions

After reviewing the objectives of the energy, environment and economic policies on air environmental protection and discussing the impact of these policies on power system planning and management, the author set up a grid-air environment planning model considering environmental factors like polluting gas emissions and the AERs. Specifically, the purchase of SO_2, NO_X and CO_2 emission quotas in the power industry was deliberated, the impact of uncertain power demand on grid planning was taken into account, and the grid planning model was established by two-stage mixed integer random programming. Then, the proposed model was applied to prepare the AER supply plan, power generation plan and power expansion plan of the grid in

Jilin Province, China, considering different development speeds of clean energy generator sets. The case study reveals that the proposed grid-air environment planning method can satisfy the emission targets of polluting gases under the relevant constraints, and significantly enhance the environmental and economic benefits considering the quota trading. The research results shed new light on optimizing industrial structure and improving energy efficiency.

References

Charles C.I, 2018, Energy formulation for flexural – torsional buckling of thin-walled column with open cross-section, Mathematical Modelling of Engineering Problems, 5(2), 58-66, DOI: 10.18280/mmep.050202

Dong Q., Wang X.W., Zhang Z.Y., 2012, Research on the evaluation index system of energy saving in thermal power plant, China Electric Power Education,196(9), 56-57, DOI: 10.3969/j.issn.1007-0079.2011.09.028.

Liu Z.Y., 2016, Research of global clean energy resource and power grid interconnection, Proceedings of the CSEE, 36(19), 5103-5110, DOI: 10.13334/j.0258-8013.pcsee.160788.

Lyu T., Tang W., Cong P.W., Bo B., 2013, Multi-objective coordinated planning of distribution network incorporating distributed generators, Automation of Electric Power Systems, 37(21), 139-145, DOI: 10.7500/AEPS201301011.

Qiu X., Xia L.L., Li X.Y., 2010, Planning of distributed generation in construction of smart grid, Power System Technology, 34(4), 7-10.

Sun D.L., 2016, Theoretical studies on synergistic dispatch of power source and electric network in power system, Jinan: Shandong University.

Wakiyama T., Kuramochi T., 2016, Scenario analysis of energy saving and CO2 emissions reduction potentials to ratchet up Japanese mitigation target in 2030 in the residential sector, Energy Policy, 59(12), 96-102, DOI: 10.1016/j.enpol.2016.12.059.

Wang J., Li Y.H., Yan W.P., 2011, Integrated evaluation index of energy-saving and emission reduction of coal combustion power generation, Proceedings of the CSEE, 31(S1), 144-148.

Yu Z.Q., Ma W.H., Xie K.Q., Lv G., Chen Z., Wu J., Yu J., 2017, Life cycle assessment of grid-connected power generation from metallurgical route multi-crystalline silicon photovoltaic system in China, Applied Energy, 185(1), 68-81, DOI: 10.1016/j.apenergy.2016.10.051.

Zamora F.H.P., Kagan H., Pelegrini M.A., Zamboni L., Gardiman V.L.G., 2015, Evaluation of electric vehicles impacts on distribution networks under different penetration scenarios, Innovative Smart Grid Technologies Latin America, 1-7.

Zhang W., 2014, Weighing the Pros and Cons: Transformation of Angle of View for Three Gorges Dam, Natural Resources, 5(16), 1048-1056, DOI: 10.4236/nr.2014.516088.

Zhou C.L., 2012, Research on comprehensive assessment modeling method for thermal power unit operation condition, Beijing: North China Electric Power University.