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A Two-Layer Electric Energy Substitute Planning Model with the Rationality of Regional and Annual Target

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***Abstract*—There are some problems in the planning of electric energy substitution, such as the disconnection between headquarters planning and provincial planning, the disconnection between provincial planning and the unscientific measurement. To release them, a two-layer planning model is proposed, with which the headquarter has less restrictions on the time and the goal of promoting electric energy substitution in each province, and has given full play to the enthusiasm of promoting electric energy substitution in each province. Moreover, electric energy substitution planning in all provinces of the country is linked with each other. The planning has an overall perspective and forms an overall systematic strategic plan. Headquarter and provincial make plans for electric energy substitution scientifically by taking into account the cost of electrical energy, air pollution, as well as the relevant government planning in each region. Additionally, the model can also be used for the planning of other business of Grid Company after simple modification.**

Keywords—two-layer; planning model; electric energy substitute; provincial planning

I. Introduction

State Grid Corporation of China put forward the idea of electric energy substitution in 2013. After several years of development, electric energy substitution has faced a good situation and achieved good results, but some problems are gradually emerging, especially the research on planning of electric energy substitution is still weak [1]. At present, the main problems in the planning of electric energy substitution are as follows:

(a) The upper (State Grid corporation headquarter planning) and lower (Provincial power company planning) parts are not connected. At present, the planning of electric energy substitution still follows the pattern of the State Grid corporation headquarter making overall plans, assigning provincial task targets, and the provincial power companies making their own plans according to the tasks assigned by the headquarter. Under the current model, the headquarter has too many restrictions on the time and goal of promoting electric energy substitution in each province, and has not given full play to the enthusiasm of promoting electric energy substitution in each provincial power company. The provincial power companies aim to accomplish the tasks assigned by the headquarter plan and lack initiative.

(b) Planning in the provinces is not linked. Electric energy substitution planning in all provincial power companies of the country is not linked to each other, lacks a holistic vision, does not form an overall systematic strategic plan, and does not form a virtuous circle of mutual promotion and interconnection.

(c) The calculation is not scientific. At present, there are still some problems in electrical energy substitution planning, especially in the determination of investment scale and project planning and construction, such as the lack of mature quantitative operation means and optimization path. The existing provincial and sub-provincial electrical energy substitution planning is carried out by planners on the basis of personal experience and local calculations. Planning schemes vary from person to person, are less operational, less coherent and contrary to the concept of lean planning.

To sum up, due to the lack of extensive and sufficient consideration of internal and external factors, the over-reliance on personal experience in planning methods, the lack of regulatory basis, the lack of optimal approach, resulting in imprecise planning for energy substitution, unclear direction and path for the implementation of energy substitution, and no good connection with the market [2].

In the face of these problems and the increasing scale of substitution, the traditional electrical energy substitution planning methods need to be improved and adapted. This paper proposes a State Grid corporation headquarter and provincial power company two-layer electric energy substitute planning model considering the rationality of regional and annual target. The planning model can connect headquarter planning and provincial planning. Under the proposed model, headquarter has less restrictions on the time and goal of promoting electric energy substitution in each province, and has given full play to the enthusiasm of promoting electric energy substitution in each province. Electric energy substitution planning in all provinces of the country is linked with each other, and the planning has an overall perspective and forms an overall systematic strategic plan. Headquarter and provincial make plans for electric energy substitution scientifically by taking into account the cost of electrical energy, air pollution, as well as the relevant government planning in each region [3, 4].

II. TWO-LAYER ELECTRIC ENERGY SUBSTITUTE PLANNING

A. *Modelling of Two-layer Electric Energy Substitute Planning*

In the two-layer planning model of electric energy substitution, the amount of electric energy substitution planned to reach a province under the headquarter will only affect the amount of electric energy substitution in that province, and will not affect the amount of electrical energy substitution in other provinces. Similarly, the decisions of the provinces will not affect the decisions of other provinces. Therefore, the two-layer planning decision model of electric energy substitution is an uncorrelated decision model for lower decision makers grouping. The objective function of each province is a function of the amount of electric energy substitution planned to reach a province from headquarter, and its actual electric energy substitution amount.

The establishment of a two-layer planning model for electric energy substitution is as follows.

$F(x)$ and $f(y_i)$ represent upper and lower objective functions, respectively, and $[x_1, x_2,\dots, x_n,\dots, x_N]$ and $[y_{n1}, y_{n2},\dots, y_{nm},\dots, y_{nM}]$ are upper and lower decision variables, respectively. N indicates the number of regions covered by the headquarter plan, M indicates the number of electric energy substitution field covered by the plan.

Upper Model: x_n^0 is the initial electric energy substitution mission released by headquarter for *n-th* province. The upper layer makes a decision ($[x_1, x_2,\dots, x_n,\dots, x_N]$) according to the information ($[y_1, y_2,\dots, y_n,\dots, y_N]$) feedback from the lower layer, $y_n=\mathrm{sum}(y_{n1}, y_{n2},\dots, y_{nm},\dots, y_{nM})$. It is clear that in order to meet the headquarter's planned targets, the adjusted province planning totals must be greater than the initial headquarter planning totals, $\sum_{n=1}^{N} x_n \ge \sum_{n=1}^{N} x_n^0$. $\hat{y}_n$ is the accumulated deviation of electric energy substitution target in *n-th* province over the years. If the electric energy substitution amount actually achieved in *n-th* province is greater than the target issued by headquarter for *n-th* province, *n-th* province will exceed the target in the current year, and the accumulated deviation plus the excess electric energy substitution amount. If *n-th* province actually completes less electric energy substitution amount than the amount released by headquarter for *n-th* province, *n-th* province will not complete the target in the current year, the accumulated deviation minus the outstanding electric energy substitution amount. The objective function of the upper layer planning is the deviation between the final plan and the initial plan, including the deviation of the total amount and the deviation of the amount of each province [5].

Lower Model: y_{nm} is the electric energy substitution amount in the *m-th* field of the *n-th* province plan. There are m fields, such as residential heating, industrial (agricultural) production and manufacturing, transportation, power supply and consumption, etc. k_{nm} is the cost of one kilowatt-hour of electricity substituting other energy in the *m-th* field of the *n-th* province. LT_{nm} and LU_{nm} are the lower and upper limits of the electric energy substitution amount in the *m-th* field of the *n-th* province, respectively. The electric energy substitute projects can be divided into the enterprise independent type, the government leading type and the power grid pushing type. Enterprise independent and government-led electric energy substitution projects can be considered as the lower limits of electric energy substitution in this field, as they do not require grid push. Electric energy substitution projects of power grid push type will require the power grid to pay a corresponding cost to promote, the effectiveness depends on the cost of power grid input, can be regarded as the upper limits of electric energy substitution in this field. The objective function of the provincial power grid planning is to minimize the cost of the provincial power grid. d_n is the tolerance of the state to the deviation of *n-th* province, which is equivalent to the penalty coefficient. If the cumulative deviation is negative, it means that *n-th* province has not completed the assignment of the state, it has to be punished for *n-th* province, and the greater the deviation, the greater the penalty coefficient d_n. If the accumulated deviation is positive, it means that *n-th* province over completes the assignment of the state and does not punish *n-th* province, the penalty term is 0.

$$
\begin{aligned}
&\textit{Upper Model}:\\
&\min_{x_1,x_2,\dots,x_n,\dots,x_N} F(x_1,x_2,\dots,x_n,\dots,x_N)=\left(\sum_{n=1}^{N}x_n-\sum_{n=1}^{N}x_n^0\right)^2+\sum_{n=1}^{N}(x_n-y_n)^2\\
&s.t.\ \sum_{n=1}^{N}x_n\ge\sum_{n=1}^{N}x_n^0,\qquad b=\frac{\left|\sum_{n=1}^{N}x_n^0-\sum_{n=1}^{N}y_n\right|+\left(\sum_{n=1}^{N}x_n^0-\sum_{n=1}^{N}y_n\right)}{2\sum_{n=1}^{N}x_n^0}\\
&c_n=\frac{|x_n-y_n-\hat{y}_n|+(x_n-y_n-\hat{y}_n)}{2},\qquad d_n=\frac{c_n}{\sum_{n=1}^{N}c_n}\times10^b\\
&\textit{Lower Model}:\\
&\min_{y_{11},y_{12},\dots,y_{1m},\dots,y_{1M}} f(y_{11},y_{12},\dots,y_{1m},\dots,y_{1M})=\sum_{m=1}^{M}k_{1m}(y_{1m}-LT_{1m})+\frac{\left|x_1-\sum_{m=1}^{M}y_{1m}\right|+\left(x_1-\sum_{m=1}^{M}y_{1m}\right)}{2}d_1\\
&s.t.\ LT_{1m}\le y_{1m}\le UT_{1m},\ 1\le m\le M\\
&\vdots\\
&\min_{y_{n1},y_{n2},\dots,y_{nm},\dots,y_{nM}} f(y_{n1},y_{n2},\dots,y_{nm},\dots,y_{nM})=\sum_{m=1}^{M}k_{nm}(y_{nm}-LT_{nm})+\frac{\left|x_n-\sum_{m=1}^{M}y_{nm}\right|+\left(x_n-\sum_{m=1}^{M}y_{nm}\right)}{2}d_n\\
&s.t.\ LT_{nm}\le y_{nm}\le UT_{nm},\ 1\le m\le M\\
&\vdots\\
&\min_{y_{N1},y_{N2},\dots,y_{Nm},\dots,y_{NM}} f(y_{N1},y_{N2},\dots,y_{Nm},\dots,y_{NM})=\sum_{m=1}^{M}k_{Nm}(y_{Nm}-LT_{Nm})+\frac{\left|x_N-\sum_{m=1}^{M}y_{Nm}\right|+\left(x_N-\sum_{m=1}^{M}y_{Nm}\right)}{2}d_N\\
&s.t.\ LT_{Nm}\le y_{Nm}\le UT_{Nm},\ 1\le m\le M
\end{aligned}
\tag{1}
$$

If the cumulative deviation is negative, it means that *n-th* province has completed the assignment of headquarter, it has to be punished for *n-th* province, and the greater the deviation, the greater the penalty coefficient d_n. Adding a penalty term to the objective function can reflect whether the solution is located in the feasible domain, thus enabling the algorithm to find the optimal solution of the original problem under the action of the penalty term. Although it can be proved that when the penalty factor tends to be infinite, the solution of the objective function with penalty term will converge to the optimal solution of the original problem, but in practice, the method has the following limitations. If the penalty factor is too large, it will easily lead to numerical overflow and premature convergence to the local optimal solution. If the penalty factor is too small, the solution may not be the optimal solution to the original problem. Therefore, for the constrained optimization problem to be solved, it is usually necessary to determine the penalty factor through many experiments [6-8].

B. Solving Models

It is very difficult to solve the problem of two-layer programming because even the objective function and the constraint function are linear, but the two-layer programming is likely to be a non-convex problem. At present, there are some feasible algorithms for solving two-layer programming problems, such as KKT method, branch delimitation method, penalty function method and descent method, etc. However, these algorithms have high requirements on the performance of the objective function and the constrained function (such as convex, linearity, continuity, differentiability) in the model, and lack of research on the numerical performance of the algorithm. Compared with numerical algorithms, intelligent algorithms have the following advantages: 1. The performance requirements of objective function and constraint function are more relaxed; 2. Computational efficiency is high; 3. Optimization process is actually a process of population evolution. Because of the advantages of intelligent algorithms, which can cope well with the difficulties of numerical solution to two-layer programming problems, intelligent algorithms have become an important means to solve two-layer programming problems. Genetic algorithm, neural network method, tabu search algorithm, simulated annealing algorithm and ant colony algorithm are all used to solve two-layer programming problems.

Cooperative coevolutionary particle swarm optimization (CCPSO) algorithm is used to solve the model of National-provincial two-layer electric energy substitute planning in this paper. First, the initial planning value of each province (x_n^0) is derived from the electrical energy substitution planning model, that is, the national electrical energy substitution target first issued to each province. Secondly, taking x_n^0 as the upper decision variable, the CCPSO algorithm is used to perform the lower layer optimization problem and record its approximate optimal solution (y_{n1}, y_{n2},…, y_{nm},…, y_{nM}). Thirdly, the approximate optimal solution of the lower layer problem is combined with the upper layer decision variable to form a complete solution of the upper layer problem and to judge the termination condition. If the termination condition is satisfied, the result is output. Otherwise, the upper layer decision variable is updated and the lower layer subpopulation is reconstructed by using CCPSO algorithm to carry out the next iteration. Finally, the approximate optimal solution of the whole problem can be approximated to the exact solution with arbitrary precision by presetting the number of iterations.

The CCPSO algorithm is executed in the following steps.

Step1: Initialization. Initialize *K* populations within the feasible domain (i.e. initialize the positions and velocities of *K* populations respectively). Each population represents a variable of a complete solution, and each population size is *P*. Then, go to Step2(a).

Step2: Compose the complete solution.

(a) For the *k*-th population, an individual is randomly selected from the remaining *K*-1 population and is sequentially combined with the variables in the *k*-th population to form a complete population *k*. Then, go to Step3.

(b) For the *k*-th population, the current best individuals are selected from the remaining *K*-1 populations and are sequentially combined with the variables in the *k*-th population to form a complete population *k*. Then, go to Step3.

Step3: Evaluation contribution. For the *k*-th complete population, the fitness value is calculated according to the objective function, thus the individual contribution value of the *k*-th complete population is calibrated.

Step4: Population coevolution. For the *k*-th complete population, the individual optimal value of each particle and the global optimal particle are determined according to Step3, and then the population evolution of *K* populations is carried out sequentially using the particle swarm algorithm.

Step5: Detecting population stagnation. For the *k*-th population, if after Step4 evolution the population stagnation condition is not met, then go to Step7; otherwise, go to Step6.

Step6: Reinitializing Stagnation. The individuals with the best contribution value in the population were retained and the remaining *P*-1 individuals were randomly generated.

Step7: Detection algorithm termination conditions. If the termination condition is met, the result is output; otherwise, go to Step2(b).

In Step5 of the algorithm, the technique of detecting population stagnation is described as follows: If, within a certain evolutionary algebraic interval, a population contributes less to the fitness value in the process of coevolution than the expected value, that is, the evolution of the population stagnates, the population will die out and we will replace it with a new population, thus making the coevolution process more efficient. Stagnation in population evolution will be monitored using inequalities such as: $f(t)-f(t-\mathrm{L})<\mathrm{G}$, where $f(t)$ represents the optimal contribution value corresponding to the population at the time of generation t; L represents a fixed evolutionary generation interval; G represents the desired minimum contribution value improvement.

III. SIMULATION RESULTS

TABLE I. ANNUAL ELECTRIC ENERGY SUBSTITUTE PLANNING TARGET OF PROVINCES AND MUNICIPALITIES (10^9 KWH)

Provinces and municipalities	total	2018	2019	2020
Beijing	96.2	34.5	37.3	24.3
Tianjin	79.7	29.0	28.1	22.6
Hebei	218.8	60.4	73.3	85.1
Jibei	133.2	40.4	42.6	50.3
Shanxi	133.5	38.8	44.9	49.7
Shandong	302.5	85.5	106.1	111.0
Shanghai	53.9	17.2	17.4	19.3
Jiangsu	180.0	55.7	56.7	67.6
Zhejiang	123.4	36.0	39.7	47.7
Anhui	165.9	51.7	53.8	60.4
Fujian	165.5	49.6	53.0	63.0
Hubei	206.2	59.4	68.6	78.2
Hunan	244.7	77.4	79.9	87.4
Henan	253.6	81.0	81.8	90.9
Jiangxi	208.1	65.2	68.6	74.2
Sichuan	211.4	60.0	71.1	80.3
Chongqing	210.2	62.5	71.8	75.9
Liaoning	169.7	42.0	57.2	70.5
Jilin	166.5	48.0	54.8	63.7
Heilongjiang	78.5	20.3	24.1	34.1
Mengdong	113.1	29.2	37.9	46.1
Shaanxi	242.2	74.5	79.3	88.4
Gansu	125.3	33.9	44.3	47.1
Qinghai	86.3	34.8	23.8	27.6
Ningxia	42.3	12.2	14.2	15.9
Xinjiang	289.7	78.0	92.2	119.4

IV. SUMMARY

This paper proposes a State Grid corporation headquarter and provincial power company two-layer electric energy substitute planning model. The model provides a mechanism for power grid headquarters to negotiate and iteratively optimize with provincial power companies so that the final planning results can be agreed upon taking into account the interests of all parties concerned. The model also provides more flexibility to the provincial power companies, which can adjust their annual planning tasks according to their own circumstances, while the planning objectives of the headquarters can also be guaranteed. The model can also be used for the planning of other business of Grid Company after simple modification.

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REFERENCES

[1] Guiding Opinions on Promoting Electric Energy Substitution 2016.5.16.

[2] Implementing Electric Energy Substitute and Promoting Energy Consumption Revolution, 2016 *China Economic and Trade Guide.*

[3] Wei Tang, Scientific Implementation of Electric Power Substitute Planning *China Electric Power Enterprise Management*.

[4] Yi Sun, Peng Xu, Baoguo Shan and Bing Qi, Road map for “internet plus” energy substitution in electricity retail market reform in China, *Power System Technology 2016 40(12).*

[5] Yu Zhang, Fen Lin, Fengkui Luan and Ke Xiong, Analysis of Electric Energy Substitution Potential Based on Re-electrification Target, *2018 International Conference on Energy, Power and Materials Engineering (EPME2018).*

[6] Yu Zhang, Bao-Guo Shan, Peng Wu, Wei Tang, Fen Lin and Ke Xiong, A Three-Level Sustainability Evaluation Framework for Electric Energy Substitution Project, *2018 International Conference on Energy, Power and Materials Engineering (EPME2018).*

[7] Wei Tang, Yu Zhang, Baoguo Shan, Peng Wu, Fen Lin and Ke Xiong, On the Development Strategy of Electric Energy Substitution *2018 International Conference on Energy, Environment and Power Engineering (EEPE2018).*

[8] Yu Zhang, Bao-Guo Shan, Peng Wu, Peng Zheng, Fen Lin and Ke Xiong, A potential model of electric energy substitution for environmental protection based on emission reduction targets, *2018 International Conference on Computer, Electronic Information and Communications(CEIC2018).*