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DESIGN THE LAYING SCHEME OF PHOTOVOLTAIC CELL ON SOLAR CABIN SURFACE BASED ON MULTIOBJECTIVE PROGRAMMING MODEL AND HEURISTIC ALGORITHM

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ABSTRACT

The main method to improve the invest benefit of photovoltaic electricity generation system on solar cabin surface is to increase the electricity generation capacity and decrease the building cost. To get the largest total electricity generation of cabin and the least unit electricity generation cost as the goal, the paper sets up a multi-objective programming model. Due to the limited conditions, complex constraint function, large solution space dimension, it is difficult to get the analytic solution. The time-consuming of traditional recursive algorithm is growing in exponential series with recursion depth, which is hard to find the optimal solution in the effective time. To solve this problem, the paper is inspired by "selection index", uses heuristic algorithm, fully considers the optimization target in the process of selection and arrangement, and finally get the optimization solution including the factors of total electricity generation, cost, and benefit and so on in a short time. A laying scheme of photovoltaic cell on solar cabin surface that meets the preconcerted target is obtained, and an experiment with true data shows that it is correct.

Keywords: *Multi-Objective Programming Model, Heuristic Algorithm, Solar Cabin, The Laying Of Photovoltaic Cell, Optimize*

1. INTRODUCTION

With the rapid development of economy, industry, traffic and the rising life demand for energy, the problem of global energy is very serious. Residential energy consumption takes a large proportion in total energy consumption. Solar energy, as one kind of conveniently obtaining, low cost and renewable clean energy, also has very big development potential in the construction field [1-3]. Combing the solar energy technology with building perfectly to design a solar house has extremely important realistic significance to protect the environment resource and alleviate the increasingly serious energy shortages of our country. Solar house is realized by laying photovoltaic cell on the building surface (roof and wall). The part of electricity is transformed into current (ac) by the inverter convert for household using; the rest is transformed to power grid. The main method to improve the invest benefit of photovoltaic electricity generation system on solar cabin surface is to increase the electricity generation capacity and decrease the building cost. In order to get the largest total electricity generation of cabin and the least unit electricity generation cost as the goal, the paper sets up a multi-objective programming model. Due to the limited conditions, complex constraint function, large solution space dimension, it is difficult to get the analytic solution. The time-consuming of traditional recursive algorithm is growing in exponential series with recursion depth, which is hard to find the optimal solution in the effective time. Heuristic algorithm can improve speed when seeking solution effectively[4].So, the paper is inspired by "selection index", uses heuristic algorithm, fully considers the optimization target in the process of selection and arrangement, and finally get the optimization solution including the factors of total electricity generation, cost, and benefit and so on in a short time. A laying scheme of photovoltaic cell on solar cabin surface that meets the preconcerted target is obtained at last.

2. ESTABLISH THE MODEL

There are two optimization objectives needing consider simultaneously in the design of the photovoltaic cells' laying scheme on solar cabin surface: one is the annual electricity generating amount of the annual solar photovoltaic should be large as far as possible, the other is the cost of electricity generating unit should be as small as

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possible. To achieve the multi-objective programming problem, we establish the corresponding objective function and constraint conditions [5-7].

2.1 The Design Objective

One is the electricity generating amount of the cabin's annual solar photovoltaic should be large as far as possible, the other is the cost of electricity generating unit should be as small as possible.

2.2 Constraints

① Each piece of photovoltaic cell components can't be overlapped with each other.

② Each piece of photovoltaic cell components must be laid on the wall.

③Each group cells' output voltage must not exceed the input voltage of the connected inverter.

④ Each group cells' output power must not exceed the input power of the connected inverter.

⑤ the difference between parallel photovoltaic cells' terminal voltage should not be more than 10 percent.

⑥different types of panels can not be in series.

2.3 The Objective Function

Suppose *l* represents each wall needed laid photovoltaic cell components. On each wall, the lower left corner is the origin of coordinates, and horizontal direction for *x* shaft, with vertical direction for *y* shaft to establish the rectangular coordinate system.

$P(l,m,i,j)$ represents the *l* surface, the m group (the photovoltaic cell components connected by the same inverter are called a group), *i* row (the *i* string in paralleled connection), the *j* column (in some string) model numbers of photovoltaic cell. There are three types in the subject, 24 kinds of types of photovoltaic cell components in total, therefore we can program them from1 to 24.

$X(P(l,m,i,j))$, the abscissa of the upper left corner of the photovoltaic cells.

$Y(P(l,m,i,j))$, the vertical coordinates of the upper left corner of the photovoltaic cell

$W(P(l,m,i,j))$, the width of the photovoltaic cell.

$H(P(l,m,i,j))$, the height of the photovoltaic cell.

$E(P(l,m,i,j))$, Total annual electricity generating of photovoltaic cell.

$P(P(l,m,i,j))$, the price of the photovoltaic cell.

$V(P(l,m,i,j))$, the output voltage of photovo-ltaic cell.

$C(P(l,m,i,j))$, the output power of photovoltaic cell.

$N(l,m)$ represents the model of inverter on *l* surface, the m group. Similar to photovoltaic cell components, 18 kinds of inverter type number can be compiled respectively from 1 to 18.

$\delta(N(l,m))$, the inverter efficiency of inverter.

$P(N(l,m))$, the price of the inverter.

$V_H(N(l,m))$, the allowed input voltage range limit of inverter.

$V_L(N(l,m))$, the allowed input voltage range limit of inverter.

$C(N(l,m))$, the input power of inverter.

J_{lmi} represents the number of photovoltaic cell on the *l* surface, in the *m* group and the *i* line series.

I_{lm} represents the parallel number of parallel photovoltaic cell connected by the same inverter on the *l* surface, in the first group.

M_l represents the number of inverter used on the l wall.

$\boldsymbol{S(l)}$: Represents the available area set of the l wall except the window, door and groove outside on the wall.

Then the model can be described as follows.

$$max \sum_{l=1}^{6}\sum_{m=1}^{M_l}\sum_{i=1}^{I_{lm}}\sum_{j=1}^{J_{lmi}} E(P(l,m,i,j)) \times \delta(N(l,m))$$

$$min \frac{\sum_{l=1}^{6}\sum_{m=1}^{M_l}(P(N(l,m)) + \sum_{i=1}^{I_{lm}}\sum_{j=1}^{J_{lmi}} P(P(l,m,i,j)))}{\sum_{l=1}^{6}\sum_{m=1}^{M_l}\sum_{i=1}^{I_{lm}}\sum_{j=1}^{J_{lmi}} E(P(l,m,i,j)) \times \delta(N(l,m))}$$

$$s.t.$$

$$(X(P(l,m,i,j)), Y(P(l,m,i,j))) \in \boldsymbol{S(l)}$$

$$(X(P(l,m,i,j)) + W(P(l,m,i,j)), Y(P(l,m,i,j))) \in \boldsymbol{S(l)}$$

$$(X(P(l,m,i,j)), Y(P(l,m,i,j)) - H(P(l,m,i,j))) \in \boldsymbol{S(l)}$$

$$(X(P(l,m,i,j)) + W(P(l,m,i,j)), Y(P(l,m,i,j)) - H(P(l,m,i,j))) \in \boldsymbol{S(l)}$$

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$$X(P(l,m,i,j)) - X(P(l,m,i,k)) \geq W(P(l,m,i,j)),\ j,k \in J_{lmi},$$

$$X(P(l,m,i,j)) > X(P(l,m,i,k))$$

$$Y(P(l,m,i,j)) - Y(P(l,m,i,k)) \geq H(P(l,m,i,j)),\quad j,k \in J_{lmi},$$

$$Y(P(l,m,i,j)) > Y(P(l,m,i,k))$$

$$\sum_{j=1}^{J_{lmi}} V(P(l,m,i,j)) \leq V(N(l,m))$$

$$\sum_{i=1}^{I_{lm}} \sum_{j=1}^{J_{lmi}} C(P(l,m,i,j)) \leq C(P(l,m,i,j))$$

$$\max\left(\sum_{j=1}^{J_{lmi}} V(P(l,m,i,j))\right) - \min\left(\sum_{j=1}^{J_{lmi}} V(P(l,m,i,j))\right) \leq 10\%\min\left(\sum_{j=1}^{J_{lmi}} V(P(l,m,i,j))\right)$$

$$P(l,m,i,j) = P(l,m,i,k)\quad j,k \in (1,2,\cdots J_{lmi})$$

3 SOLUTION OF THE MODEL

Because the problem is a multi-objective progr-amming problem, it is necessary for the above multi-objective the objective function to be treated in the process of solving model as follows.

$$max\quad \lambda_1\left(\sum_{l=1}^{6}\sum_{m=1}^{M_l}\sum_{i=1}^{I_{lm}}\sum_{j=1}^{J_{lmi}} E(P(l,m,i,j)) \times \delta(N(l,m))\right)' + \lambda_2\left(\frac{\sum_{l=1}^{6}\sum_{m=1}^{M_l}\sum_{i=1}^{I_{lm}}\sum_{j=1}^{J_{lmi}} E(P(l,m,i,j)) \times \delta(N(l,m))}{\sum_{l=1}^{6}\sum_{m=1}^{M_l}(P(N(l,m)) + \sum_{i=1}^{I_{lm}}\sum_{j=1}^{J_{lmi}} P(P(l,m,i,j)))}\right)'$$

$\lambda_1, \lambda_2 > 0$. The formula analysis indicates that if you want to satisfy the target that includes largest electricity generating amount and the minimum cost of unit electricity generating, you should make the objective function after processing as large as possible.

The quota of total electricity generating amount and the cost produced by the unit electricity generating are different in their units, so they can't be added directly. So we should normalized process the two indexes, eliminate dimensional, express the objective function with primed at the top right corner of the primitive function.

The value of λ_1, λ_2 in above formula depends on the degree of attention of the people to the two targets who are the investor, beneficiaries of building the solar photovoltaic facilities in Datong city. In practice, an investigation research can be organized to make the goal function fitter to the decision makers' goal. In the model solution, according to the description of the subject's importance, we can temporarily think the two indexes are equally important, take the two coefficients for one. In practice, we can organize investigation research to make configuration, adjustment to two coefficients according to the actual situation, so it can make the objective function more fit the decision makers' goal.

4 THE IMPLEMENT OF ALGORITHM

In order to solve the above programming problem, if traditional recursive algorithm is adopted, the time-consuming will grow in exponential series with recursion depth, which is hard to find the optimal solution in the effective time. To solve this problem, the paper is inspired by "selection index", and adopts heuristic algorithm to seek the way of photovoltaic cell components' installation and inverters' connection, simultaneously make sure the solution satisfies with optimization conditions.

During the process of solution, we found that because the solution space is very large, we can't directly seek solution or take long time to do it. So we will divide the solving process into two processes: the first is to design the scheme of decorating photovoltaic cell components on the wall, the second is to select inverter for the photovoltaic cell to lie well in the first process to connect.

4.1 The first step to seek solution: lay out photovoltaic cell components

In the heuristic algorithm about decorating the components, firstly we should establish "selection index" which is fit to the objective function target (considering the electricity generating amount and the cost of electricity generating unit) as the standards of choosing the components, then inspire. At last, we will gain a set of feasible solutions and optimize the electricity generating amount and cost index at the same time.

The concrete realization process is as follows.

Step 1: choose a wall to carry on the design.

Step 2: according to the selection index, select selection index score the highest components among the component models which meet the wall

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geometric size limit, then lay out photovoltaic cell components on the wall as much as possible (first horizontal then vertical, horizontal or vertical post), until there can't be laid by this kind of components so far because of the geometric size limit.

Step 3: divide the wall which is still not laid by the photovoltaic cells into two rectangles.

Step 4: repeat "step 2", "step 3"in the two rectangles split in "step 3".

Step 5: repeat "step 4" until all the walls which are not laid by photovoltaic cell components and received by division can't be laid by any type of photovoltaic cell components due to geometric limit .The wall's photovoltaic element arrangement can be regarded complete.

Step 6: select other walls, repeat "step 2" to "step 5" until complete all the walls' design scheme. After the completion of the execution, algorithm can be ended.

After the end of the process, we can obtain a more optimal photovoltaic cell components' laying scheme.

4.2 The second step to seek solution: select inverter for components wiring

Step 1: Choose a wall to design.

Step 2: Analyze the designed laying scheme of photovoltaic cell components in process one, count models and their numbers of photovoltaic cell components, and then divide them into groups by same model. For different subgroups, consider the problem of inverter wiring.

Step 3: Add up the maximum output power of the photovoltaic cell components by the same model (hereinafter showed model m), calculate the sum of maximum generated power.

Step 4: By the sum of maximum generated power defined in Step 3, select a certain number of inverters which meet the sum of power. Among these selected inverters, choose a model for the lowest price.

Step 5: Design series-parallel forms for the model m of all photovoltaic cell components, and then determine whether there is a series-parallel solution to meet the voltage requirement of the selected inverter. If so, choose this inverter and wiring.

Step 6: If there is no appropriate series-parallel scheme to meet the requirements of this inverter, repeat Step3, and choose the model of the second lowest price among these inverters which meet the power limit. Re-execute the design and judgment in Step 4. And so on, until the election to the appropriate inverter.

Step 7: For each model of photovoltaic cell pack, consider Step 3 to Step 6 repeatedly; finally, design the inverter wiring scheme for all photovoltaic cell components laid on the wall, and choose the inverter in demand.

Step 8: Select other wall, complete scheme design for all walls by Step 2 to Step 7 above. After the completion of execution, the algorithm ends.

After this progress is complete, it is available to get a better scheme about the laying mode of photovoltaic cell components and inverter wiring. This scheme meets the planning requirements.

The physical dimension of each cabin surface, the size of the position about windows, doors, groove, the annual electricity generation and the physical dimension of photovoltaic cell components of each model, the electronic properties of the inverter, the calculated selection indicators, all these above are input to the computer. By running the program, you can get a feasible scheme.

4.3 Calculate the total electricity generation of 35 years

The generating efficiency of all the photovoltaic components is disposed by the following program: efficiency is 100% in 1 to 10 years, discount at 90% in 11 to 25 years, and the efficiency discount at 80% after 25 years. Set the annual capacity E, then the total electricity generation of a photovoltaic component within 25 years is:

$$10 \times E + 15 \times E \times 0.9 + 10 \times E \times 0.8 = 31.5 \times E$$

5. ANALYSIS OF THE RESULT

Verify the feasibility of model and algorithm above via the experiment. Known conditions: (1) The design parameter and market price of photovoltaic cell component in three types (A monocrystalline silicon, B polycrystalline silicon, C amorphous silicon film). (2) The hourly parameter and radiation intensity from all sides of typical meteorological year in Datong city, Shanxi; (3) The parameter and price of inverter.

Use the known conditions (1) and (2) to calculate electricity generation; Use the known conditions (1) and (3) to calculate price; Use the known conditions (1) and (3) to calculate inverter wiring. Choose windows XP operating system and Matlab

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6.5 to program for simulation, experimental results are as follows.

The connect manners of Inverter wiring are described as follows.

The east wall: choose three types of inverter, each up to parallel 17 series, each series up to five photovoltaic components;

The west wall: choose two types of inverter, each up to parallel 14 series, each series up to four photovoltaic components;

The south wall: choose two types of inverter, each up to parallel 52 series, each series up to five photovoltaic components;

The north wall: choose three types of inverter, each up to parallel seven series, each series up to 20 photovoltaic components;

South of the top roof: choose two types of inverter, each up to parallel 17 series, each series up to 10 photovoltaic components;

North of the top roof: choose two types of inverter, each up to parallel three series, each series up to five photovoltaic components;

The annual electricity generation and laying costs of all walls according to this laying scheme is described in table 1.

Table 1 The Annual Electricity Generation And Laying Costs Of All Walls

	The east wall	The west wall	The south wall	The north wall	South of the top roof	North of the top roof
Electricity generation (kw/h)	2112.80	4236.40	194.59	334.05	17170	338.08
Costs(￥)	43569	58908	12235	26643	122620	12946

Add up each wall, the annual total electricity generation of this cabin is 24385.92 kilowatt-hours and the laying costs are 276921 yuan. Use the formula given above, the total electricity generation of this cabin is 768156.48 kilowatt-hours in the lifetime of 35 years; unit electricity generation cost is 0.3605 yuan per kilowatt-hour. Civil electricity price is 0.5 yuan per kilowatt-hour; the economic benefit is 384078.24 yuan in the lifetime of 35 years; the payback period of invest is 24.1 years.

6. CONCLUSION

Combing the solar energy technology with building perfectly to design a solar house has extremely important realistic significance to protect the environment resource and alleviate the increasingly serious energy shortages. To get the largest total electricity generation of cabin and the least unit electricity generation cost as the goal, the paper sets up a multi-objective programming model, and heuristic algorithm is adopted to seek solution. A laying scheme of photovoltaic cell on solar cabin surface that meets the preconcerted target is obtained at last. The corresponding experiment with true data shows that the method is correct. The furthur work includs realizing optimizing the house towards direction, and windows distribution etc.

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