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Research on Multi-objective Optimization of Economic Performance of Solar Thermal Power System

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Abstract: Aiming at the problems of high cost and low efficiency of solar thermal power generation system, CMOPSO classical optimization algorithm is used to analyze the multi-objective optimization of its economic performance. Firstly, a multi-objective optimization model of total generating capacity, normalized KWH cost and total investment of the power station is established under the constraint condition of load deficit rate. Secondly, two optimization algorithms CMOPSO are used to optimize and analyze the non-inferior solution sets of the solar thermal power station with the capacity of 10MW and 50MW respectively. Finally, taking some parameters of the solar thermal power demonstration project under construction in western China, the results can be seen to be consistent with the actual and have a certain engineering reference value.

Key words: Solar energy, Thermal power generation system, CMOPSO algorithm

I. INTRODUCTION

The development of new energy resources, energy saving and emission reduction have become the strategic concerns of the world, and the solar thermal power generation is an important upgrading technology of the traditional thermal power generation. In 2015, Arora R et al. conducted a multi-objective optimization study on the dish concentrated solar thermal power generation, and applied multi-objective genetic algorithm to optimize the output power and thermal efficiency, but did not consider the economic indicators[1] . Spelling J et al. chose to reduce investment costs and CO_2 emissions as targets, and the analysis results showed that the investment cost of the combined power generation system was reduced by nearly 60% compared with that of the single solar trough power generation system [2-3], but the reliability of the system was not considered. In literature [4] and [5], multiple objectives such as output power and thermal efficiency were selected to optimize and analyze the disk solar thermal power generation system. Boukelia et al. optimized the trough solar thermal power plant, but it lacked comparison with different heat storage media, and a single power generation system could not guarantee the reliability of power supply[6] . In literature [7], it is assumed that the annual generation is known, and the heat storage and heat abandonment rate are not considered, leading to a high LCOE. Yuqiang Li et al chose single objective, two objective and three objective for optimization research, and the optimization results show that it is more reasonable and feasible to consider the three objective optimization results at the same time [8]. In 2015, Li Xin et al. analyzed the cost and price of tower solar power generation system[9]. In 2013, Geng Lishan studied the heat collection performance and power generation cost of trough solar power generation system [10].

Based on the above analysis, this paper carries out multi-objective optimization analysis on the economic performance of solar thermal power generation system, considers the load factor, chooses the load defect rate less than or equal to 10% as the constraint condition, establishes the total investment, installed capacity and the calibrated KWH cost as the three-objective optimization model, applies the optimization algorithm to carry out the multi-objective optimization analysis, and the optimization results are basically consistent with the actual research results. It can explain the correctness of the results of this study.

II. MULTI-OBJECTIVE ECONOMIC PLANNING MODEL

The economic planning objectives of solar thermal power generation generally include four indicators, namely, system reliability, plant capacity, total investment cost and the cost of quasi - normalized KWH.

A. Load power failure rate

The load deficit rate, usually described as the quotient of the missing supply demand of the system to the total supply demand during the system evaluation period, is expressed by the following formula.

$$LPSP=\frac{\sum_{t=1}^{T}P_{\text{load}}(t)-[\eta_{\text{e}}(Q_u+\eta_{\text{v}}Q_V)]}{\sum_{t=1}^{T}P_{\text{load}}(t)} \tag{1}$$

Where, $P_{\text{load}}(t)$ is the demand of electricity load, and T is the assessment period.

B. Cost model

The cost function consists of the construction cost and the operation and maintenance cost of the system. C_{tol} is the investment cost function, which can be expressed by the following formula:

$$C_{\text{tol}}=C_{\text{jian}}+C_{\text{yun}} \tag{2}$$

$$C_{\text{jian}}=C_{\text{col}}+C_{\text{pow}}+C_{\text{stor}} \tag{3}$$

Where, C_{col} , C_{pow} , C_{stor} are the cost of heat collection system,

The expression of C_{yun} is:

$$C_{\text{yun}} = \sum_{i=1}^{n} \frac{C_i}{(1+r)^n} \qquad (4)$$

Where, n represents the operation cycle of the power station, year; C_i is the operating cost in year ith (unit yuan), and r is the capital discount rate.

C. Calibrate the electricity cost model

Generally, it can be simplified as equation (5) :

$$LCOE = \frac{C_{\text{tol}}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad (5)$$

Where: E_t is power generation of the system in year t.

D. Heat abandonment rate model

Heat Rejection Rate (HRTA) refers to a power system containing solar power generation, and the proportion of the remaining amount of solar heat collection except power generation and heat storage.

Δ_i' defines the energy unbalance:

$$\Delta_i' = Q_{u(i)} - Q_{v(i)} - Q_{\text{L}(i)} \qquad (6)$$

Where, $Q_{u(i)}$ is the available energy of solar energy on day i , and $Q_{\text{L}(i)}$ is the electricity demand of load on day i .

E. Multi-objective economic planning model and constraint conditions

(1) Multi-objective economic planning model

The multi-objective optimization of solar thermal power generation takes $\min\{E_G, C_{\text{total}}, LCOE\}$ as three optimization indexes, which are expressed by Equation (7).

$$\begin{cases} \mathbf{max}\, E_G = \max\left[\eta_{\text{e}}(Q_u \pm \eta_v Q_v)\right] \\ \min C_{\text{tol}} = \min(C_{\text{jian}} + C_{\text{yun}}) \\ \min LCOE = \min \frac{C_{\text{tol}}}{E_{\text{tol}}} \end{cases} \qquad (7)$$

Among them, $C_{\text{jian}} = C_{\text{col}} + C_{\text{pow}} + C_{\text{stor}}$.

Considering the reliability of the system, the load power shortage rate is selected as the constraint condition to ensure the normal operation of the system. The two objectives of total investment cost and the quasi-KWH cost are taken as the main objectives, and the capacity of the power station is taken as the secondary objectives for analysis.

(2) Constraint conditions

① Constraint condition of load power shortage rate: $LPSP \le 0.1$. Load power failure rate can ensure the reliability of the system,

According to the total capacity of the power station and load capacity.

(3) Upper and lower limit constraints of mirror field area: $s_{\min} \le s \le s_{\max}$. According to the reliability of the system, the power station

The upper and lower limits of the heat collecting area of the mirror field were determined by the capacity, total investment cost and the quasi - metric electricity cost.

③ Upper and lower limit constraints of heat storage duration: $h_{\min} \le h \le h_{\max}$. According to the local direct solar radiation intensity,

Total heat storage and reliability determine the heat storage duration.

(4) Constraints on the cost of calibration electricity: $LCOE \le 1.15$. Set an upper limit on the cost of calibration KWH according to China's state subsidy policy.

Multi-objective optimization simulation analysis of solar thermal power generation

The CMOPSO optimization algorithm is used to optimize the solar thermal power system. The simulation process parameters can be: $\eta_{\text{m}} = 0.38$, $\eta_{\text{e}} = 0.37$, $\eta_t = 0.95$. The solar radiation intensity is $I = 900\text{W} / \text{m}^2$. $\Delta T = 30^0 C$, $C_{\rho} = 1.45\text{kJ} \cdot \text{kg/k}$, The operating cost of solar thermal power generation is 0.05 yuan /kWh compared with that of coal-fired power generation. Unit equivalent peak utilization hours 4313 hours, $2.1 \times 10^5 \le s \le 12.5 \times 10^5$.

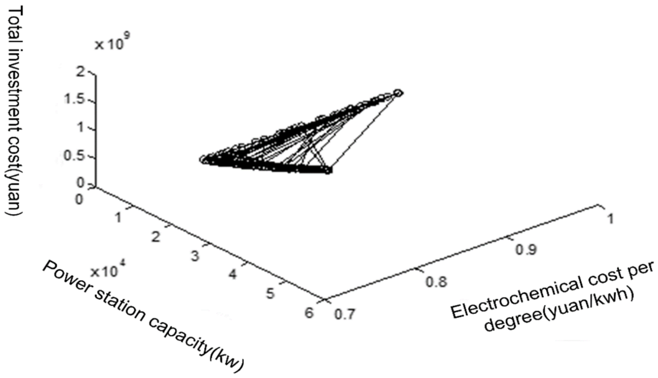

Fig. 1Three-objective optimization results of different installed capacity

Table 1 Optimization results of heat storage duration of 18 and 10 hours

Index \ capacity	10MW	30MW	50MW
LPSP	0.1	0.1	0.1
Heat storage duration/h	18/10	18/10	18/10
Total investment /per million	344.901/ 330.855	1034.702/ 992.564	1752.096/ 1680.742
LCOE/yuan/kWh	0.792/ 0.937	0.770/ 0.912	0.759/ 0.883

It can be seen from the above analysis that the optimization results of the two algorithms are basically similar.

(1) When the installed capacity is less than 50MW, the larger the installed capacity is, the lower the calibrated KWH cost of the power generation system will be, but the total investment will increase, which reflects the scale effect of solar thermal power system.

(2) At the same time of heat storage, the larger the capacity of the power station, the lower the cost of normalization degree electricity.

(3) When the power station capacity is the same, the longer the heat storage time, the lower the cost of normalized kilowatt electricity, but the total investment increases. The above conclusions can confirm the analysis results in Chapter 2.

Fig. 2 shows the optimization results of the two algorithms when the installed capacity of solar thermal power generation is 50MW. Table 2 shows the data analysis.

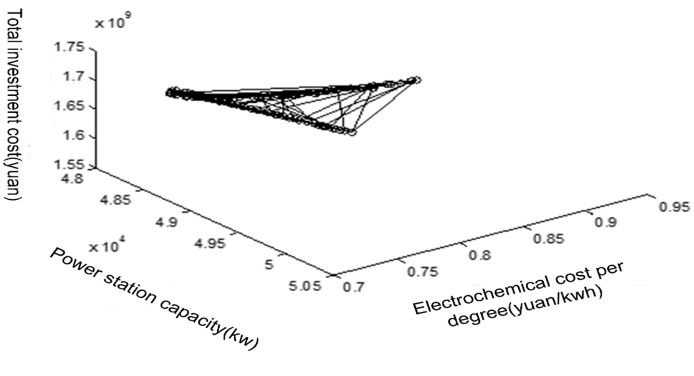

Fig 2 CMOPSO optimization results

Table 2 CMOPSO optimization results when the plant capacity is 50MW

LPSP	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Heat storage duration /h	8	10	12	14	16	18	20
Total investment /per million	1660.675	1680.742	1700.166	1718.698	1736.091	1752.096	1766.466
LCOE/yuan/kWh	0.946	0.882	0.832	0.797	0.768	0.751	0.746

The optimization results all reflect the relationship between the construction cost and the capacity of the power station is proportional to the growth. When the power station capacity of 50MW is selected and the power supply meets 90% of the load, the longer the heat storage time, the construction cost will increase correspondingly, but the normalization kilowatt electricity cost will decrease.

III. CONCLUSION

In this paper, two different algorithms are selected to optimize the solar thermal power system, and the results are basically similar. When the load deficit rate is less than or equal to 0.1 and the calibration kWh cost is less than 1.15 yuan /kWh, the multi-objective optimization results can reflect the scale effect of the solar thermal power system. The larger the capacity, the smaller the calibration KWH cost and the larger the total investment. When the heat storage duration is 10 hours, the LCOE of 10MW and 50MW is reduced, but the total investment cost is increased. When the heat storage time is 18 hours, the LCOE is 0.759 yuan /kWh and 0.751 yuan /kWh. When the heat storage time is 18 hours, the LCOE is 0.759 yuan /kWh and 0.751 yuan /kWh. This method provides some reference for the planning of solar thermal power system. It is of certain significance to both improve the efficiency of heat collection and heat utilization and reduce the cost of solar thermal power generation.

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