Study on control strategy of output stability of wind-solar reservoir thermal system

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Abstract—In view of the landscape reservoir heat output coordinated control demand, based on the topology of the hybrid energy storage system of the three ports heating model, using the sunlight with the electricity output of the complementary and heat accumulation can be regulatory, intends to research a kind of based on photo-thermal storage heat and scenery electricity heating output port control method, in order to achieve the goal of fast and smooth regulating heat output fluctuations, The coordinated output control of integrated wind-landscape storage and heat collection is realized.

1. INTRODUCTION
At present, scholars at home and abroad have put forward an idea: Various forms of three-port DC-DC converter topologies can achieve the optimal drive of the converter through the reasonable distribution of the energy of the hybrid energy storage, and also achieve the goal of coordinated control of the wind-solar DC microgrid. Based on this idea, this article starts with the operating principles and characteristics of the solar collector system. Finally, through simulation examples and energy flow analysis, based on the complete acceptance of the thermal energy output by the solar thermal collector, under the premise that the system's multi-energy combined output minimizes thermal energy fluctuations, and combined with wind power output, a daily output strategy for the combined operation of wind and solar heat storage is worked out.
2. OUTPUT PRINCIPLE OF WIND AND SOLAR HEAT STORAGE AND COLLECTION SYSTEM

Solar heat collection is affected by solar radiation, resulting in discontinuous heat supply. Therefore, a large amount of supplementary heat is required from a spare heat source. The wind energy is huge, renewable, and pollution-free. The output of wind power also fluctuates due to changes in wind speed. Therefore, the application of these two clean energy technologies alone is not effective. This article proposes a solar and wind energy complementary heating system. The principle is shown in Figure 1. The solar thermal energy output by the solar collector is used as the basic output heat, and the wind-solar complementary power generation electric energy is converted into thermal energy supplement through the electric furnace, and the proportion of wind-solar complementary energy in the heating system is increased. Another part of the electricity generated by wind-solar hybrid power generation is allocated to energy storage batteries to improve wind-solar absorbing capacity. When the electric energy of the energy storage battery is insufficient, the electric energy is output to the electric heating furnace.

Figure 1 Output principle of wind-solar storage thermal
3. ANALYSIS AND STRATEGY OF OUTPUT STABILITY OF WIND AND SOLAR THERMAL STORAGE SYSTEM

In order to alleviate the environmental fluctuation of the solar heat collection system, the heat collected by the solar heat collector is first collected into the hot water storage tank, and then the heat storage tank supplies heat to the user; According to the volatility of solar and wind energy, the output electric energy is transmitted and distributed to energy storage batteries and electric boilers; Use electric boilers to generate heat to supply heat to users. The energy storage battery can provide secondary power to the electric boiler according to the heating situation. According to the thermal load prediction curve determined by the thermal load variation range in the control period, and based on factors such as wind power and solar thermal forecast output and heat storage capacity, optimize the operating position of the solar thermal-wind power-storage combined system within the thermal load curve within the dispatch period. In order to ensure the sufficiency of the heat output of light and heat, when there is light in the daytime, the light and heat should be in a heat storage or heat release mode while outputting heat according to the light conditions. During this period, wind and wind power generation can be used for

Figure 2 output joint scheduling strategy of wind-solar storage heat system
adjustment or fine adjustment. When the light is weak or the heat load is the most at night, the heat storage device is used to adjust the wind power according to the heat load and wind power output.

The joint scheduling strategy is shown in Figure 2

1) Predict the light irradiance and wind speed data in the next day. According to the limiting factors such as wind speed, sunlight, ambient temperature and heat load in a day, estimate the upper and lower ranges of the planned output and heat output of the solar thermal, wind and solar combined storage system.

2) Smoothly fill the solar thermal energy storage through the output of wind and solar complementary power generation, collect the relevant light, wind speed, and temperature data of the thermal system to obtain the real-time output of the solar thermal-wind photovoltaic energy storage system. Then compare the combined system's output with the user's calories. If the output heat energy of the combined system is greater than the upper limit, that is, when wind and light are sufficient, the heat storage device stores heat and energy, and the electric energy storage device stores energy. On the contrary, the heat storage device releases heat, and the insufficient part is output by the electric energy storage device through the electric furnace [1].

![Figure 3 Start and stop control strategy of heat storage electric boiler](image-url)
3) The start and stop of the thermal storage electric boiler is shown in Figure 3. The start and stop of the heat storage electric boiler is mainly used during the low heat supply period. In special weather conditions, wind-solar and electric energy storage or grid supplementary output plans can be arranged according to the power output needs of the solar thermal-wind power combined system. This article takes 24 hours as a scheduling period, and the operation control strategy is to judge the trough period. If during the trough period, the electric boiler will mainly supply heat by wind-solar complementary power generation. When wind-solar hybrid power generation does not meet the heating demand of the thermal load, conventional power is used; During non-trough periods, the electric energy storage device stores energy.

4. HEAT DISPATCH MODEL OF WIND AND SOLAR HEAT STORAGE SYSTEM

When the output of the solar thermal collection system is basically stable, the capacity adjustment is limited and the cost is high, wind photovoltaic energy storage is used to supplement it. This requires consideration of the wind and photovoltaic power storage depth peak shaving when the power of the solar thermal collection system is fully adopted, and the start-up and shutdown of the power thermal boiler. The adjustability of light and heat as the basic heat energy, and wind and photoelectricity as a complementary output of thermal energy storage should be fully utilized. Through the adjustment and scheduling of solar thermal and wind photovoltaic, the output of the combined system has the smallest fluctuation in the range. Based on the above analysis, a model is established.

4.1 Solar collector model

Using solar collectors, flat-plate collectors and evacuated tube collectors are usually selected. Choose a flat plate collector here.

Useful heat of flat plate collector

\[ Q_u = A_s \eta_Lc = Gc_f \Delta T = Gc_f(T_{t,o} - T_{t,i}) \]  

Among them, \( Q_u \) is the useful energy output of the collector per unit time. \( \eta_Lc \) is the heat collection efficiency of the flat plate collector. Take 0.855; \( G \) is the flow rate of the heat collecting medium flowing through the heat collector; \( c_f \) is the specific volume of the heat transfer working fluid; \( T_{t,o} \) The outlet temperature of the heat collecting working medium in the heat collector; \( T_{t,i} \) The inlet temperature of the collector working medium in the collector; \( A_s \) is the lighting area of the collector; \( I \) is the solar irradiance.

The heat output of the photothermal collection system at time \( t \) is \( Q_{c,t} \). In the case of flat plate collectors, the heat output is \( Q_u \) [2-3].

4.2 Model of hot water storage tank

The heat supply of the hot water storage tank per unit time is:

\[ Q_r = \Delta m_c c_s T_{qs} \]  

Among them, \( \Delta m_c = m_j - m_c \), is the difference between the hot-end water supply flow \( m_j \) and the return water flow \( m_c \), kg/s; \( C_s \) is the specific heat capacity of water at constant pressure; \( T_{qs} \) is the initial temperature of water storage in the hot water storage tank in \( \Delta t \), °C; \( Q_r \) is the heat supply per unit time of the hot water storage tank, W [4-5].

4.3 Wind photoelectric model

(1) The basic power equation of wind turbines is based on the wind power equation:

\[ P_w = \frac{1}{2} \rho A V^3 \]  

The output power of the wind turbine is

\[ P_o = P_w C_p \eta_t \eta_m \]
Among them, \( \rho \) is the mass density of the air; V is the wind speed; A is the area swept by the wind turbine blades; \( \eta_t \) is the power conversion efficiency of the generator, taking 0.98; \( \eta_m \) is the mechanical transmission efficiency, taking 0.98; \( C_p \) is the wind energy utilization coefficient.

(2) Since the photoelectric output is greatly affected by factors such as temperature, light intensity, etc., the solar radiation intensity and the power under the ambient temperature are calculated here. Let \( U_m \) and \( I_m \) be the photovoltaic module parameters under the conditions of solar irradiance and ambient temperature at a certain time, and the relationship is:

\[
I_m = I_m\left(\frac{S}{S_{ref}}\right)[1 + a(t - t_{ref})]\]

(5)

\[
U_m = U_m[1 - c(t - t_{ref})][1 + b\left(\frac{S}{S_{ref}} - 1\right)]
\]

(6)

Among them, \( S \) is the real-time light intensity; \( S_{ref} \) is the standard sunshine intensity, taking 1kW/m\(^2\); \( t \) is the real-time temperature of the photovoltaic module; \( t_{ref} \) is the standard temperature for photovoltaic module testing, which is 25°C. The coefficients a, b, and c take typical values: \( a=0.0025/^\circ C, b=0.5/^\circ C, c=0.00288/^\circ C \). The optimal output power of the photovoltaic array at any solar radiation intensity and ambient temperature is:

\[
P = I_mU_m
\]

The conversion efficiency of solar cells is generally about 15% [6].

4.4 Objective function

It is required to control the output heat fluctuation of the combined solar-thermal-wind-photoelectric storage system to minimize, that is, the variance of the output heat of the combined solar-wind and solar storage system is the smallest.

\[
\min f = \frac{1}{T} \sum_{t=1}^{T} \left[ Q_{wc,t} - Q_{wc,av} \right]^2
\]

(7)

\[
Q_{wc,t} = (P_{f,t} + P_{g,t})\eta_{fg} + Q_{c,t}
\]

(8)

\[
Q_{wc,av} = \frac{1}{T} \sum_{t=1}^{T} Q_{wc,t}
\]

(9)

In the formula: \( Q_{wc,t} \) is the actual output of the photothermal-wind photoelectric joint at time \( t \); \( Q_{wc,av} \) is the average value of the combined output of light, heat and wind in the calculation period \( T \); \( P_{f,t} \) is the actual wind power output at time \( t \); \( P_{g,t} \) is the actual photovoltaic output at time \( t \); \( \eta_{fg} \) is the conversion efficiency of the electric boiler.

4.5 Constraints

1) Constraints on the output heat balance of the combined solar thermal-wind photovoltaic energy storage system

\[
Q_{c,t} + Q_{b,t} + Q_{r,t} = Q_{L,t}
\]

(10)

\[
Q_{b,t} = (P_{f,t} + P_{g,t})\eta_{fg} = (P_{f,t} + P_{g,t})c_{dh}
\]

(11)

Where: \( Q_{c,t} \) is the output of the solar thermal collection system at time \( t \); \( Q_{c,t} \) is the output of the hot water storage tank at time \( t \); \( Q_{L,t} \) is the heat output at time \( t \); \( Q_{b,t} \) is the output of the electric energy storage device at time \( t \); \( c_{dh} \) is the electric heating conversion coefficient of the electric boiler, taking 0.98.

2) Output constraints of the CSP system

\[
Q_{c,min} + Q_{c,t}^{down} \leq Q_{c,t} \leq Q_{c,max} - Q_{c,t}^{up}
\]

(12)
In the formula: $Q_{c,max}$ and $Q_{c,min}$ are the maximum and minimum output of the heat collection system respectively; $Q^\text{down}_{c,t}$ and $Q^\text{up}_{c,t}$ are the lower limit output standby and upper limit output standby of the CSP system at time t, respectively.

3) The capacity of the hot water storage tank is restricted as

$$Q_{r,t}^\text{min} \ll Q_{r,t} \ll Q_{r,t}^\text{max}$$ (13)

Where: $Q_{r,t}$ is the thermal energy capacity stored in the hot water storage tank at time t; $Q_{r,t}^\text{max}$, $Q_{r,t}^\text{min}$ are the maximum and minimum heat storage capacity of the hot water storage tank.

4) Wind farm output constraints

$$0 \leq P_{f,t} \leq P_{f,max}$$ (14)

Where $P_{f,max}$ is the maximum output power of wind power generation.

5) Constraints on the output of photovoltaic power plants

$$0 \leq P_{g,t} \leq P_{g,max}$$ (15)

Where $P_{g,max}$ is the maximum output power of photovoltaic power generation.

6) The constraints of the electric boiler are the constraints of the electric-heat conversion coefficient and the constraints of the power consumption [7].

$$Q_{b,t} = c_{dh}P_{b,t}$$ (16)

$$0 \leq P_{b,t} \leq P_{b,max}$$ (17)

Where: $Q_{b,t}$ is the heat output of the electric boiler at time t; $P_{b,t}$ is the power consumption of the electric boiler at time t.

5. EXAMPLE ANALYSIS AND RESULTS

In order to verify the feasibility of the scheduling model, two flat-plate collectors are selected. A 100L hot water storage tank, an electric boiler, an electric energy storage battery, an inverter controller for wind and photovoltaic power generation, and a user thermal load. According to the actual situation of Xining, the load is divided into 2 categories according to the season: Heating season, transition season. Here, select the heating season on January 3, 2021, and analyze the heat transmission situation of the system. The heating chamber has an area of 15m$^2$. Here we analyze the integrated system of solar thermal storage and wind photoelectric thermal output. The analysis period is set to 24h.

5.1 Wind speed, solar radiation, and outdoor temperature on a certain day in the winter heating season

The environmental data measured on January 3, 2021 are shown in Figure 4, Figure 5, and Figure 6.
5.2. Independent operation of the collector system

Figure 7 According to heating regulations, building heating generally takes the range of 45 ~ 70W/m². Here, $Q_Y$ is taken as 45W/m², and the actual heat load index is expressed as $Q_{FZ} = \frac{Q_Y(T_{IN} - T_{W})}{(T_{IN} - T_{CP})}$. Among them, the calculated indoor temperature of $T_{IN}$ is 18°C. $T_{W}$ is the outdoor ambient temperature. $T_{CP}$ is the monthly average temperature, here is -7.3°C [8]. The surface temperature of the collector plate enters a stable state after being powered on for 10 minutes. Under different air volume, the surface temperature of the collector plate decreases with the increase of the system air volume [9]. Under different solar radiation, the surface temperature of the collector increases with the increase in irradiance. The lower the outdoor ambient temperature, the more heat is actually used.

5.3. Independent operation of wind power

Figure 8 selects a wind turbine with a power of 1KW. The diameter of the wind wheel is 2.6m. The atmospheric pressure in Xining in winter is 77.406Kp. The air density is calculated with $\rho = 1.29 \times \frac{(77.406 \times 273.15)}{(101.325 \times (273.15 + t))}$, where $t$ is the outdoor air temperature. The power of wind turbines increases with the increase of wind speed, and the temperature and humidity increase during the day. The actual power generation output has been reduced.

\[ \text{Figure 7 Independent operation of collector} \]
5.4. Independent operation of photovoltaic power generation

Figure 9 selects two monocrystalline silicon solar photovoltaic modules with a power of 90W. The maximum current is 5.45A, the maximum voltage is 16.6V, the short-circuit current is 6.11A, and the open circuit voltage is 21V. During the day, the output power increases and decreases with the change of irradiance.

The Qinghai-Tibet Plateau has a relatively long heat output due to the winter weather, and the heat load is generally output within 24 hours a day. There is a high-load floating standard (including heating) in each of the three time periods of 06:00-8:30, 14:00-15:00, and 19:30-22:00. Prescribe a thermal float standard. There is a load trough in each of the three time periods of 9:00-13:30, 16:00-19:00, and 22:30-05:30. Provide a low-heat floating standard (not including heating). The solar and thermal energy storage system in the joint operation of the wind and solar energy storage system regulates the wind and solar energy through the heat storage box. When the output of wind and photovoltaic increases, the output of light and heat is reduced. On the contrary, increase the output of light and heat through the heat storage box to ensure that the heat energy output by the wind and solar energy storage combined system is stable within the range of system adjustment. Two issues need to be paid attention to during the adjustment process of the light and heat output by the collector: First, the heat output of the wind and solar storage system cannot exceed the upper and lower limits of output; Second, the capacity of the hot water storage tank when outputting heat cannot be lower than the limited capacity.

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