Research on characteristics and benefits of multi-energy complementary integration optimization of Qinghai clean energy base under new electricity reform

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Abstract. By carrying out research work on Qinghai clean energy multi-energy complementary integration optimization, this paper demonstrates the multi-energy complementary optimal power supply ratio and operation scheme. It maximizes the ability of clean energy consumption and delivery, and contributes to the development of green energy in Qinghai. It plays a leading and innovation-driven role in the research and development of new energy research and development in the country.

1. Introduction
Faced with the challenges of world energy security, environmental pollution and climate change, it has become a global consensus to make full use of renewable energy and reduce carbon emissions. All countries in the world have developed and utilized sustainable clean energy as their future energy development strategy. As a major energy producer and consumer, China has promised to the world at the World Climate Change Conference: “By 2020, non-fossil energy will account for 15% of energy consumption; in 2020, carbon dioxide emissions per unit of GDP will be 40% to 45% lower than in 2005.” In 2016, General Secretary Xi Jinping pointed out during the inspection in Qinghai that Qinghai Province has abundant sunshine, abundant wind resources and a large area of Gobi desert, which is a unique condition for the development of clean energy power generation industry. Implementing clean alternatives is a systematic solution to the development of a low-carbon economy and the transformation of energy. In order to accelerate the transformation of China’s energy structure and realize the development and utilization of high-efficiency, low-carbon and clean renewable energy, it is necessary to promote the construction of a 10 million-kilowatt renewable energy industrial base in Qinghai, fully tap the potential of clean energy consumption and promote the optimal allocation of clean energy nationwide [1-3].

The global energy Internet is an important platform for the transformation of the world economy with low carbon. Horizontal multi-energy complementary integration optimization, vertical "source-network-load-storage" coordinated development is an important way to achieve energy Internet. In 2016, the National Development and Reform Commission and the National Energy Administration's "Implementation Opinions on Promoting the Construction of Multi-energy Complementary Integration..."
and Optimization Demonstration Projects” clearly stated that a number of national-level terminal integrated power supply demonstration projects and the national wind-light-water-fire-storage multi-energy complementary demonstration project will be completed during the “13th Five-Year Plan” period and regard the clean low-carbon energy as the main body of supply increment during the "13th Five-Year Plan" period[4]. It can be said that it is an inevitable choice for the sustainable development of China's energy system to cultivate and strengthen the energy reform represented by the integration and optimization of multi-energy complementary systems.

In order to implement the national strategic deployment, Qinghai province has established the wind-light-water-storage complementary energy resources and other advantages and given play to the role of hydropower regulation of the Yellow River to create a national green energy demonstration province as the lead, steadily and build ten million kilowatt level renewable energy base[5]. Through the research and development of Qinghai's clean energy multi-energy complementary integration optimization, we will demonstrate the optimal power ratio and operation plan of multi-energy complementary, maximize the clean energy consumption and delivery capacity, and help Qinghai's green energy development. It will play a leading and innovation-driven role in the development and research of new energy nationwide.

2. Operation principle of Qinghai’s clean energy multi-energy complementary optimization

2.1. Regulation characteristic analysis of adjustable power supply

2.1.1. Hydroelectric regulation characteristics. Hydropower stations with peak-shaving capacity generally need to have a reservoir capacity above the daily adjustment capacity, which can reallocate the amount of water coming from above the day and adjust the power generation output process of the hydropower station through the reservoir storage and discharge water to meet the needs of power system or new energy peak regulation. The hydropower regulation characteristics mainly analyze the inherent adjustment ability of hydropower itself from the perspective of the adjustment capacity and adjustable capacity of the power station.

2.1.2. Photothermal regulation characteristics. Compared with wind, light and other new energy sources, solar power stations are equipped with heat storage devices, which can adjust the power generation strategy to match the output of wind power, photovoltaic power and other new energy sources, which is conducive to the absorption of new energy. However, the heat storage system of the solar thermal power station has a heat storage time of the hour and it is not possible to adjust the power across the moon. The photothermal regulation characteristics mainly analyze the peak shaving characteristics of a single typical power station from the perspective of the adjustment capacity and adjustable capacity of the power station.

2.1.3. Pumped storage regulation characteristics. The pumped storage power station is the hydropower station which refers to the upper and lower reservoirs, which use the excess electric energy in the power system to pump the water from the lower reservoir into the upper reservoir, store energy in the form of potential energy, and then discharge water from the upper reservoir to the lower reservoir for power generation when needed. At present, China's pumped storage power stations are mainly responsible for peak regulation, valley filling and emergency standby tasks in the power grid. Otherwise, they also have functions of frequency modulation, phase adjustment and black start. However, no pumped-storage power stations have been built which are mainly complementary with multi-energy. According to the characteristics of the high proportion of new energy in Qinghai power grid permeability, besides the conventional load in valley and emergency task, it mainly undertakes the tasks of frequency modulation, phase adjustment, load tracking and energy storage for reducing new energy sources, so as to improve the quality of power supply and maintain the safety, stability, operation and economic operation of the power system.
2.2. Operation principle of multi-energy complementary during the year

During the year, the multi-complementary complement is mainly realized by hydropower stations with the ability to adjust above the season. Through the optimal dispatch of hydropower, the peaks are replenished and the problem of insufficient electricity in the month of power shortage is solved. Otherwise, the annual power generation of the cascade hydropower stations is basically unchanged and the planned load curve of the year is tracked. The monthly electricity consumption in the year before and after the complement-tracking Qinghai annual load curve is shown in figure 1. The monthly electricity-tracking DC delivery curve in the year before the complementation is shown in figure 2.

![Fig. 1](image1.png) The monthly electricity consumption in the year before and after the complement-tracking Qinghai annual load curve

![Fig. 2](image2.png) The monthly electricity-tracking DC delivery curve in the year before the complementation

2.3. Operation principle of multi-energy complementary during the day

The multi-energy complementary in the day is mainly through the daytime photovoltaic power in the form of reservoir water storage, photothermal heat storage and time redistribution. Finally, it can achieve the tracking load curve or fit into a smooth DC delivery curve.

Photovoltaic power station during the large-scale period (11:00 - 16:00): adjustable power supply, hydropower, light heat, pumping and storage combined with new energy output operation, hydropower, light and heat output reduced. At this time reservoir water storage, solar thermal storage power station heat storage and pumped storage power station pumping water mainly use photovoltaic and wind power output to balance the load.

Photovoltaic zero-period period: increase the output of hydropower, light and heat and the random output of wind power to meet the load power supply; the power with insufficient peak load is provided by the pumping station.

The multi-energy complementary during the day diagram and the tracking Qinghai load curve are shown in figure.3. The multi-energy complementary during the day diagram and the tracking DC external transmission curve are shown in figure.4.
3. Research on Multi-energy Complementary Integration Optimization of Qinghai Clean Energy

3.1. Wind-light complementary integration optimization

The output process of photovoltaics and wind power is unregulated. The regularity of photovoltaic output is stronger than that of wind power, with obvious day and night replacement and relatively stable characteristics. The daily output of the wind farm has a large random variation and there is no law to follow. The two power output processes are not controllable. Therefore, the wind power and photovoltaic complementarity are naturally complementary.

3.1.1. Electricity complementary benefit. After wind-light complementation, the electricity quantity complementation benefit is mainly studied and analyzed by the annual utilization hours, the output coefficient at 95% cumulative electricity quantity, the per unit value of monthly electricity output, the annual unbalance coefficient and the smoothing effect of daily electricity output [6]. The electricity
benefit of Qinghai Province after wind-photovoltaic complementation in 2020 is shown in table 1 and figure 5.

Table 1. The electricity benefit of Qinghai Province after wind-photovoltaic complementation in 2020

| Benefit indicator       | Unit     | Before wind-light complementary | After wind-light complementary |
|-------------------------|----------|---------------------------------|-------------------------------|
|                         | Wind power | Photovoltaic | Wind power | Photovoltaic |
| Installed capacity      | MW       | 7110           | 24000       | 31110         |
| Annual generation capacity | Ten thousand kWh | 1482043       | 3982711     | 5464753       |
| Annual utilization hours | h        | 2084           | 1659        | 1757          |
| Cumulative power 95% output coefficient | % | 55 | 64 | 52 |
| Annual imbalance coefficient |        | 0.18          | 0.1         | 0.1           |
| Monthly imbalance coefficient mean |        | 0.48          | 0.26        | 0.23          |

Fig. 5 Qinghai Province wind-light complementary monthly electricity standard value in 2020

It can be seen from Table 1 and Figure 5 that the annual utilization hours of wind-light complementary in Qinghai Province in 2020 is about 1757h. When the accumulated electricity is 95%, the output coefficient is about 52%, which is about 12% lower than that of photovoltaics. The annual unbalance coefficient is 0.1, which decreases by 0.08 compared with the wind power. The monthly power generation fluctuation decreases, and the smooth seasonal average monthly output is uneven. The monthly unbalance coefficient is 0.23, which decreases by 0.25 compared with the wind power. The fluctuation of daily power generation decreases. In addition, after wind-light complementary, the wind power is mainly large or flat when the small-scale photovoltaic is used; when the wind power is small, the photovoltaic is generally large or flat, and the wind-light complementary is less than one day. It shows that in 2020, Qinghai Province wind-light has certain complementarity in meteorology.

3.1.2. Power complementary benefit. The electricity benefit after wind-light complementarity is mainly reflected by the maximum output, photovoltaic large moment 11:00-16:00 hourly guarantee rate 95% output, the maximum daily peak demand and the output variability. The power benefit of Qinghai Province after wind-light complementary in 2020 is shown in table 2 and figure 6 and figure 7.

Table 2. The power benefit of Qinghai Province after wind-light complementary in 2020

| Benefit indicator                         | Unit     | Before wind-light complementary | After wind-light complementary |
|-------------------------------------------|----------|---------------------------------|-------------------------------|
|                                           | Wind power | Photovoltaic | Wind power | Photovoltaic |
| Installed capacity                        | MW       | 7110           | 24000       | 31110         |
| Maximum output                            | MW       | 6761           | 22995       | 27378         |
| 11:00-16:00 hourly guarantee rate 95% output | MW     | 156-219       | 4989-6795   | 6736-8578     |
| Maximum daily peaking demand              |          | 0.89           | 0.96        | 0.82          |
| Output variation within ±20% of installed capacity | %   | 94.62          | 90.04       | 98.42         |
Fig. 6 The output of the wind-light time-guaranteed rate of 95% in Qinghai Province in 2020

Fig. 7 Wind-light complementary hourly output amplitude frequency distribution in Qinghai Province in 2020

It can be seen from table 2, figure 6 and figure 7 that the maximum output of wind-light complementary in Qinghai Province in 2020 is about 8% lower than that of the complementary front wind-photoelectric output. When the hourly guarantee rate from 11:00 to 16:00 is 95%, the output is 6736MW-8578MW [7,8]. Compared with Photovoltaic, it increases 1747MW-1783MW, increasing the guaranteed output size. Due to the complementary effect of wind and light in Hainan and the west of Hainan, the maximum daily peak regulation demand is 0.82, which decreases by 0.14 compared with the maximum daily peak regulation demand of photovoltaic, reducing the peak regulation demand. The output variability is 98.42% within ±20% of the installed capacity, which is about 8.4% higher than that of photovoltaics. The output is more concentrated and the volatility is reduced. In 2020, the wind-light complementarity in Qinghai Province has certain complementarity.

3.2. Wind-light-water-photothermal complementary integration optimization complementary
Under the conditions of power generation equipment and power system restrictions, according to the changes of solar energy resources and wind energy resources, photovoltaic power plants, solar thermal power stations and wind farms can be output according to their power generation capacity; the cascade hydropower output of the upper reaches of the Yellow River is a process after the regulation of each reservoir of the hydropower station group. Therefore, after analyzing the natural complementarity between photovoltaic, solar thermal and wind power in the planning level of Qinghai Province, it will complement the unoptimized operation of hydropower to cope with the monthly electricity imbalance in the power system. The planned annual level of photovoltaic, solar thermal, wind power and Qinghai's
cascade hydropower monthly power generation and monthly power generation in Qinghai Province are shown in table 3 and figure 8 respectively.

Table 3. Hydropower, photovoltaic, wind power and photothermal monthly power generation standard value in Qinghai Province in 2020

| Month  | Hydropower | Photovoltaic | Wind power | photothermal | Month  | Hydropower | Photovoltaic | Wind power | photothermal |
|--------|------------|--------------|------------|--------------|--------|------------|--------------|------------|--------------|
| January| 312406     | 297246       | 100514     | 68760        | July   | 606360     | 361346       | 113906     | 58483        |
| February| 297640    | 294677       | 146508     | 57540        | August| 642965     | 355584       | 93149      | 52518        |
| March  | 338446     | 370244       | 156612     | 77810        | September| 397656     | 338545       | 96408      | 68918        |
| April  | 311904     | 374435       | 147168     | 70401        | October| 364039     | 329148       | 116138     | 68004        |
| May    | 337181     | 362801       | 142178     | 66224        | November| 284400     | 291122       | 101088     | 60653        |
| June   | 389160     | 343792       | 137232     | 50306        | December| 306230     | 273792       | 130944     | 60791        |
| Annual imbalance coefficient | 0.30 | 0.10 | 0.18 | 0.12 | - | - | - | - | - |

Fig. 8 Hydropower, photovoltaic, wind power and photothermal monthly power generation standard value in Qinghai Province in 2020

It can be seen from table 3 and figure 8 that in 2020, the annual imbalance coefficient of cascade hydropower in the upper reaches of the Yellow River in Qinghai Province is 0.30, and the monthly electricity fluctuations are large during the year. The imbalance coefficients of wind power, photovoltaic and photothermal are 0.18, 0.10 and 0.12, respectively. The monthly electricity fluctuations are relatively small during the year. In 2020, the annual power generation of hydropower in Qinghai Province accounts for about 42% of the total annual power generation of hydropower, photovoltaic, photothermal and wind power. After the integration of the four types of power sources, the imbalance coefficient decreases to 0.14, slightly higher than photovoltaic, photothermal sources and far lower than hydropower power sources. The monthly fluctuation of electricity consumption in Qinghai has been significantly reduced, effectively alleviating the imbalance of monthly electricity caused by the imbalance of hydropower and seasonal electricity in Qinghai Power System.

4. Conclusion

4.1. Wind-light complementary benefit
(1) Electricity benefit

The output coefficient of Qinghai Province is about 52% when the accumulated wind power is 95% after the annual wind-light complementation, which is about 12% lower than that of photovoltaic. The annual imbalance coefficient is about 0.06 lower than that of wind power, and the monthly power generation fluctuation is reduced. The daily electricity output is highly complementary, and the extreme
output decreases, showing the characteristics of "the wind rises and the clouds surge" and "the wind is mild and the sun is beautiful".

2) Power benefit
The maximum output of Qinghai Province's planned level of annual wind-light complementation is reduced by more than 8% compared with the maximum output of complementary wind-light. During the peak load period of the receiving end, the output of the wind-light complementary is greatly improved compared with the photovoltaic power generation alone. Within ±20% of installed capacity, the hourly output variation rate is more than 98%. Compared with the 7% increase of photovoltaic, the output is more concentrated and the volatility is reduced.

4.2. Wind-light-water-photothermal complementary characteristics
In the case of unoptimized operation of hydropower, after the wind-light-photothermal complementation, the overall power imbalance factor is 60% lower than that of hydropower, and the monthly electricity fluctuations are reduced, alleviating the monthly electricity imbalance problem caused by the seasonal electricity imbalance of hydropower in Qinghai power system.

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