Research on Reverse Power Mechanism of Grid-connected Hydropower Units in Asynchronous Network

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Abstract. Under normal conditions, the hydropower unit is less equipped with reverse power protection. In order to solve the problem of large frequency oscillation caused by the reverse power of the hydropower unit when the hydroelectric unit is connected to the grid due to the large amplitude of the frequency oscillation, the paper passes the simulation. Through analysis and on-site comparison test, the frequency deviation range of different power plants connected to the grid is given, and the impact curve of power under different frequency differences is fitted. After the asynchronous networking of regional power grids, the theory of safe and reliable grid connection of hydropower units is provided.

1. Introduction
In 2016, Yunnan Power Grid was disconnected from the main network of the South Network through DC lines. This has increased the ability of Yunnan Power Grid to deliver electricity. At the same time, the moment of inertia of the Yunnan power grid is declining, and the frequency fluctuations are relatively large, which may lead to reverse power impact when the hydropower units of Yunnan Power Grid are connected to the grid. The existing research on reverse power mainly focuses on steam turbine units and pumped storage units [1]. Literature [3] discussed the problem of setting values for reverse power and loss of field protection, and proposed a reasonable action logic for loss of field protection. Literature [4] analyzed the protection settings of conventional thermal power plants and nuclear power plants, and proposed the power setting between forward low power protection and reverse power protection. In [5], the principle deviation of the existing inverse power protection algorithm mainly comes from the characteristics of power factor angle. The paper gives the optimization method of power factor angle. The literature [6-7] proposes to determine whether the active power absorbed by the generator from the system reaches the set value as the basis for starting the reverse power protection. The literature [8, 9] proposed a new inverse power protection method for the problem that the distributed power supply had reverse power reversal resulting in its access capacity.

2. Analysis of grid-connected reverse power mechanism
2.1. Conventional Reverse Power Protection
The existing research on reverse power mainly focuses on the protection of hydropower units themselves. The basic principle is as follows [10]:

\[ P = U_a \times I_a \times \cos \delta + U_b \times I_b \times \cos \delta + U_c \times I_c \times \cos \delta \] (1)
Where: $\hat{\theta}$ is the angle of the voltage lead current; the action criterion is $P > P_{\text{set}}$, $P_{\text{set}}$ is the inverse power protection action setting value.

It can be seen from formula (1) that the existing reverse power protection mainly uses active power as the relevant criterion, and does not consider the influence caused by frequency fluctuation. On the other hand, with the rapid development of UHV DC, the Yunnan and Sichuan-Chongqing power grids have been asynchronously connected to the main network. The system frequency fluctuations increase significantly, causing the generator to reverse power oscillation.

2.2. Reverse power grid connection caused by frequency fluctuations

In order to avoid current, power and the resulting mechanical stress shock inside the generator, the grid connection should meet:

1) The frequency of generator is the same as the grid frequency, ie $f_g = f_c$;

2) The generator excitation potential and the grid voltage should have the same amplitude, polarity and phase, ie $E_0 = U_0$;

If the unit frequency and grid frequency are not equal, there will be relative motion between the unit and the grid's voltage phasor. Let $f_g > f_c$, and treat the grid voltage as relatively static, then the potential phasor of the unit will rotate forward at the relative speed of $\omega_g - \omega_c$. At this time, there will be a constant change in size and phase between the unit and the grid. When the grid is connected, the potential difference will generate a circulating current with varying magnitude and phase in the unit and the grid. In some moments, the power factor is less than 90°. The unit will send power to the grid. At another instant, the power factor is greater than 90° and the unit draws power from the grid. The power grid will cause a certain power oscillation. Due to the existence of huge transient current and torque, the internal mechanical stress of the generator will damage the performance of the generator.

3. Reverse power grid connection test and analysis

Several grid-connected tests were carried out in a hydropower plant to test the unit frequency, vane opening, active power, etc. The test results are as follows:

![Figure 1. The grid-connected process waveform of frequency difference 0.027Hz](image)

| After grid connection | Before grid connection |
|-----------------------|------------------------|
| **Frequency (Hz) / kW** | 50.02 | 50.047 |
| **Guide vane opening (%)** | 14.4 | 13.2 |
| **Active power after the first fluctuation (MW)** | 18.10 | |
| **Active power after the second fluctuation (MW)** | -10.1 | |

Table 1. The grid-connected result of frequency difference 0.027Hz
As can be seen from the above table, the first and second power change rates are 5.2% and -2.85%, respectively.

Table 2. The grid-connected result of frequency difference 0.027Hz

|                          | After grid connection | Before grid connection |
|--------------------------|-----------------------|------------------------|
| Frequency (Hz) / kW      | 50.018                | 49.987                 |
| Guide vane opening (%)   | 14.7                  | 133                    |
| Active power after the first fluctuation (MW) | -29.2                | 11.2                   |

Table 3. The grid-connected result of frequency difference 0.067Hz

|                          | After grid connection | Before grid connection |
|--------------------------|-----------------------|------------------------|
| Guide vane opening (%)   | 15.8                  | 13.9                   |
| Active power after the first fluctuation (MW) | 46.4                  |                        |
| Active power after the second fluctuation (MW) | -24.8                |                        |

Figure 2. The grid-connected process waveform of frequency difference 0.031Hz

Figure 3. The grid-connected process waveform of frequency difference 0.067Hz
Figure 4. The grid-connected process waveform of frequency difference 0.101Hz

Table 4. The grid-connected result of frequency difference 0.101Hz

| Frequency (Hz) / kW | After grid connection | Before grid connection |
|--------------------|------------------------|------------------------|
| 50.01              | 50.201                 |
| Guide vane opening (%) | 14.8                 | 13.8                  |
| Active power after the first fluctuation (MW) | 80.5                  |
| Active power after the second fluctuation (MW) | -23.4                |

As can be seen from the above table, the first and second power change rates are 23% and -6.7%, respectively.

Table 5. The analysis of grid connection process

| Frequency difference (Hz) | Power change rate after the first fluctuation (%) | Power change rate after the second fluctuation (%) |
|--------------------------|---------------------------------------------------|---------------------------------------------------|
| -0.031                   | -8.3                                             | 3.2                                               |
| 0.027                    | 5.2                                              | -2.85                                             |
| 0.067                    | 13.2                                             | -7                                                |
| 0.101                    | 23                                               | -6.7                                              |

Figure 5. The power change - frequency difference change

When the unit is connected to the grid, the difference between the unit frequency and the grid frequency is linear with the first fluctuation of the active power. According to the test results, it can provide reference for the set value of the grid connection time of the unit.

After asynchronous networking, the Yunnan power grid is in a small network with large scale power generation mode, and the system frequency fluctuates greatly. When large scale units are connected to
the grid, large power impact may occur due to large deviation between unit frequency and system frequency.

When the Yunnan power grid is not operating asynchronously, the grid frequency rarely exceeds ±0.05 Hz, and the probability that the limit frequency difference exceeds 0.1 Hz when the unit is connected to the grid is small. After asynchronous operation, the frequency fluctuation of Yunnan power grid increased significantly. Analysis of the measured data shows that the grid frequency difference is close to ±0.1 Hz for most of the time, and the limit frequency difference may exceed 0.15 Hz when the unit is connected to the grid. It can be seen from the measured grid connection curve of a power plant that the maximum power fluctuation is 80.5 MW when the frequency difference is 0.101 Hz. The reverse power switching value of the power plant power transmitter is 90MW. This explains why the power plant has a high probability of reverse power switching power transmitters after asynchronous operation. At the same time, it also confirmed the reverse power problem of other hydropower plants in Yunnan.

4. Conclusion
When the unit is connected to the grid, the unit frequency has a certain deviation from the grid frequency. After the grid connection, these deviations will be immediately synchronized by the grid. According to the reverse power analysis mechanism and the logic defects of large hydropower plants in Yunnan, the following suggestions are proposed:

1) The active power transmitter used in the governor of the hydropower plant shall have the function of measuring the reverse power;
2) Optimize power sampling device design logic;
3) When connecting to the grid, the capacity of the generator unit and the structure of the grid should be considered at the same time.

REFERENCES:
[1] LUO Yin,ZHANG Xu,XU Peng,et al. Analysis on reverse power protection action of pumped-storage units[J].Water Power,2013,39(9):59-63.
[2] WANG Youming,The operation of rever power protection and its countermeasures[J].Electric Safety Technology,2006,8(1):30-31.
[3] LIU Wei-liang,CHEN Hong,LIU Yu,et al. Discussion about loss-of-field and reverse-power protection configuration from the generator loss-of-field fault [J].Power System Protection and Control,2010,37(23):164-166,169.
[4] GUAN Xin-juan,ZHU Zhong-ting LI,Dong-ling. The configuration and value calculation for the generator's positive low power protections and adverse power protections[J].Power System Protection and Control,2011,39(4):110-112,131.
[5] XIAO Xiaolong,YU Yanwei,CAO Haorun. Analysis and improved technology research of process-control reverse power power protection refusing tripping[J].Power System Protection and Control,2017,45(21):152-156.
[6] JIN Jianbo,DONG Xiaoying,LI Zhichao. The Three Gorges hydropower plant water wheel generator reverse power protection application analysis[J].Huadian Technology,2010,32(3):17-18.
[7] FENG Yaguang.6kV auxiliary power switch failure analysis[J].Electric safety technology,2006,8(1):18.
[8] ZHANG Zhihua,FENG Xingtian,YIN Mingze,et al. Improved Reverse Power Protective Relaying for Spot Network With DER Based on Sequence Current Components[J].Power System Technology,2016,40(11):3566-3573.
[9] GAO Jinyan,LI Donghui. An elliptical fitting algorithm based detection method for reverse power[J].Power System Technology,2014,38(7):1842-1847.
[10] ZHANG Maoqiang,LI Yuhai. Improvement of generator & transformer protection action reliability[J].SHAANXI ELECTRIC POWER,2006,34(5):38-41.