Discussion on the Over-frequency Generator Tripping Scheme of the Power Grid

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Abstract. The over-frequency generator-tripping and under-frequency load shedding devices play an important role as the third defensive line for frequency emergency control measures, which have a great significance for maintaining the power grid to operate safely and stably. At present, the abnormal operation frequency of hydropower generating units is mainly set based on the standard of the thermal power unit. Thus when the proportion of hydropower is too large, it can easily cause over-frequency generator tripping and under-frequency load shedding devices act one after the other, which may causes the frequency collapse. In this paper, an over-frequency cutting scheme for power grid with hydropower unit is formulated. The paper analyses and summarizes the over-frequency protection of the hydropower unit, by studying the 10 machine 39 node model with PSD-BPA software. The paper also gives a reasonable frequency action value of the high frequency cutting machine. The results show that the first-round operation value of the high-frequency cutting device of the hydropower unit should be higher than the operation value of the thermal power unit. With the first-round operation value of the high-frequency cutting device set near 52.0Hz, it can effectively avoid both of the over-frequency generator tripping and the under-frequency load shedding device, and also ensure the safety and stability of the power grid. In the hydro-thermal power grid, because of the frequency of hydropower unit cuts increasing, the power grid should remove the thermal power unit firstly, which is more beneficial for the power system frequency to stabilize rapidly.

1. Introduction

China is rich in hydropower resources and hydropower has become an important part of China's power grid. In some regions, hydropower units account for a large part of the power grid, such as the power grid in Xishuangbanna, Guizhou, Sichuan Jiushiya regional power grid [1~2]. The power grids in hydropower-rich regions mostly are a kind of sending system and far away from the load centre. Because of the large capacity of hydropower units, when the fault of the power supply network in the area which hydropower accounts for a large part of the power supply, it may lead to large frequency fluctuations[3]. If the over-frequency generator tripping and under-frequency load shedding (UFLS) devices in the power grid are not reasonable, the large unit will trip and be over-cut when the frequency of the sending system exceeds the allowable operating range. Also, it may result in an insufficient regional output which can make the system frequency to drop sharply and trigger the UFLS device. Then the frequency of system may rise significantly that triggers the operation of the over-frequency generator...
tripping device. This cycle process will lead to the collapse and blackout for the power grid, which brings great economic losses [4-7]. Therefore, the operation value of over-frequency generator tripping should be set reasonably to avoid the occurrence of large-scale power outages caused by repeated operation of over-frequency generator tripping and UFLS devices, so as to ensure the safe and stable operation of the power grid.

At present, there are no relevant technical regulations for over-frequency generator tripping in China. Moreover, the over-frequency generator tripping program does not have its own fixed algorithm, which can only be set by multiple simulation analysis or engineering experience.

In fact, most of the literatures only focus on the optimization of the cut amount in the scheme, but not the frequency operation value. Wu Chen [8] considers that the hydropower unit has a wide adaptability to the frequency, and the speed protection value can be set to 75 Hz. However, the maximum allowable range of the turbine unit is only 51.5 Hz. It can be seen that the allowable frequency range of the hydropower unit is much wider than that the turbine unit. Wu Guoyang [9] believed that in practical operations, the manufactures and power plants often set the protection values of generator conservatively from the responsibility of protecting equipment. Yang Fan [10] considered that due to the weak link between the regional grid and main grid, the frequency fluctuation is large when the grid is disconnected. The high-frequency machine operation should not be premature. Zhou Lei [11] agrees that the hydropower units account for a large part of the Yunnan power grid, and the frequency range is relatively wide. The maximum operate frequency of the high frequency cutting in regional power network is even up to 55Hz. Therefore, the scheme of high frequency cutting machine with hydropower unit according to the frequency abnormal operating range of thermal power unit is unreasonable. Zhou Chuanmei, Sun Huadong, et al.’s [12-16] reach consensus that due to the flexibility of start and stop of hydropower units, the emergency measures are given priority of removing the hydropower generating units. When the capacity of hydropower units is insufficient, some thermal power units are removed. Chen Shuyong [10] proposals that the frequency limit of the hydropower plant can be increased appropriately or the cutting delay can be prolonged. This method can be used to avoid the over-cutting phenomenon. However, the paper does not explain why the frequency limits of hydropower units can be increased, nor suggest how much the frequency limit of hydropower generating units can be increased.

Focus on above problems, this paper first analyses the range of the abnormal operate values frequency and the reason why the turbine frequency limit can be increased. The research is based on the model of 10 machines and 39 nodes, and the first round of frequency operation value of the high-frequency cutting device of the hydropower unit is determined by simulation. By comparing with the conventional over-frequency generator tripping device, the over-frequency machine frequency operation value of the hydropower unit is determined. Finally, according to the conclusions above, the over frequency generator tripping scheme in the hydro-thermal power mixed power network is simulated and analysed, and the results are obtained.

2. Discussion on setting principle of over-frequency generator tripping for hydropower unit

At present, the national standard [17] clearly rules the scope of the abnormal frequency operation of turbine generators. As shown in table 1, the operating values of the over-frequency generator tripping and the UFLS device are usually based on this range.

| Frequency range (Hz) | Cumulative allowable run time (min) | Allow run time each time (s) |
|---------------------|-----------------------------------|------------------------------|
| 51.0≤f≤51.5         | >30                               | >30                          |
| 50.5≤f≤51.0         | >180                              | >180                         |
| 48.5≤f≤50.5         | Continuous duty                   | Continuous duty              |
| 48.0≤f≤48.5         | >300                              | >300                         |
| 47.5≤f≤48.0         | >60                               | >60                          |
| 47.0≤f≤47.5         | >10                               | >20                          |
| 46.5≤f≤47.0         | >2                                | >5                           |
However, previous studies have shown [6] [18-19] that abnormal operating capacity of the hydro-generator is superior to the turbo-generator. The highest frequency can reach 75Hz, and the lowest value can reach 43.75Hz. Therefore, it’s relatively conservative for the frequency value of the hydropower generator unit to be set according to the abnormal frequency allowable range of operation of the turbine unit.

3. Over-frequency protection of hydropower units
In china, there are clear national standards for the installation of over frequency protection devices: High frequency protection should be installed for 100MW or more turbo-generator or hydro-generator with load above rated frequency, protection operation and demagnetization or program tripping [20-21]. At the same time, Chinese standard [22] also stipulates that the high frequency protection device should cooperate with the over-frequency generator tripping device, and the protection value of the over-frequency protection should be higher than the last round of the over-frequency generator tripping device. In these regulations, the hydropower unit only needs to install the high frequency protection. Nowadays, the set value of over frequency protection of hydropower plants in our country is usually determined based on operational experience. Once an accident occurs in the system, the load changes sharply and the unit frequency exceeds the range of 47~53Hz [23]. Therefore, in order to avoid the influence on the scheme of over frequency generator shedding for the main network, the power frequency protection is usually setting at 52~56Hz, and the time delay is 2~5s [24]; some hydropower plants also have optimized the over-frequency protection and the optimization results are shown in the following table [23][25-27].

| Hydropower plant          | Over frequency protection original frequency (Hz) | Over frequency protection optimization frequency (Hz) |
|--------------------------|--------------------------------------------------|-----------------------------------------------------|
| Majitang Hydroelectric power plant | 53.00                                             | 55.00                                               |
| Nanjindu Hydropower Station | 52.70                                             | 54.00                                               |
| 52.48                                                          | 54.00                                             |
| Gaoliangjian Hydropower Station | 50.50                                             | 55.00                                               |

All in all, the low-frequency tolerance of hydraulic turbine unit is strong. In the power system and the low-frequency operation range where the load is allowed, the operation of the hydropower unit is not limited, so the minimum threshold of the hydropower unit may not be considered. Because of the maximum frequency value of over-frequency protection for the hydropower unit is 55Hz, the frequency value of over-frequency generator tripping can be improved properly.

4. Optimization frequency operation value of over-frequency generator tripping for hydropower units

4.1. System overview and selection of the first round of frequency operation value
This paper uses the IEEE-recommended 10-machine 39-node model to study and analyze the action values of over-frequency generator tripping scheme, as shown in Fig 1. In the model, 10 hydropower units are installed and equipped with corresponding governors and excitation system devices. Assuming that two lines of BUS16-BUS15 and BUS16-BUS17, if one of these is overhauled and the other has a three phase permanent short-circuit fault, or a three phase permanent short-circuit fault happens on both of the lines, it will result in the area near the BUS16 being disconnected from the main network and a power outgoing isolated network being formed. There are four hydraulic turbine
units in this power outgoing isolated grid, with a total active power output of 2350MW. Under different operating modes, the system will have an unbalanced power from 70MW to 920MW. If without a stable control measures, the system frequency deviation is shown in Fig. 2.

It can be seen from Fig.2 that in various operating modes of the power system, the system frequency can reach 61.5Hz when no frequency emergency control measures are taken. The highest frequency obtained with the system not destabilized is set as the threshold operation value for the first round of over-frequency generator tripping. The first round operation value of over-frequency generator tripping measures for hydropower units is 52.0 HZ.

![Fig. 1. 10-machine 39-node power flow diagram](image1)

![Fig. 2. System frequency deviation under different operation modes](image2)
4.2. **Comparison and simulation of frequency operation values for Hydro-generator Units’ over-frequency generator tripping**

In addition to the over-frequency generator tripping, the system frequency emergency control measures should be provided with UFLS. According to the national standard and the system scale, there are five rounds of UFLS in this paper, with 0.2Hz difference and 0.2s delay per round. The first round of UFLS is 49Hz. Three rounds of over frequency generator tripping are set in the same way. In general, the frequency operation value of the first round of over-frequency generator tripping in China is 50.8Hz, and the last round of frequency operation does not exceed 51.4Hz. From the 3.1 conclusion, it can be obtained that the first round value of over-frequency generator tripping operation is set as 52.0Hz. In this paper, the correctness of this conclusion is verified by the three modes of the operation mode 2, the operation mode 3 and the operation mode 6, with the first round of operation frequency being set to 50.8Hz, 52.0Hz and 52.5Hz respectively. The frequency deviation curves under different operating modes are shown in the following figures:

![Fig 3 frequency deviation of operation mode 2](image)

![Fig 4 frequency deviation of operation mode 3](image)

In Fig. 3, the frequency can’t be controlled with all the three round of the over-frequency generator tripping device operating at 50.8Hz under operation mode 2. As the frequency fluctuation is too high, Triggering the action of the over-frequency protection device of the last unit, causing the frequency drops rapidly and removing all the loads, the system eventually loses the stability. When the frequency value of the first round is 52.0Hz, the figure shows that the frequency quickly returns to stability after two round of over-frequency generator tripping and UFLS. When the first round of frequency optional value is 52.5Hz, the frequency fluctuation curve is similar to the one of 52.0Hz, while the fluctuation range is larger. Based on the above analysis, the first frequency operation value of the over-frequency generator tripping device should be selected as 52.0 Hz under this mode.

From Fig. 4, all three schemes go through only one round of over-frequency generator tripping and remove equal-capacity units. Comparing with the results in which the unit is removed at 50.8Hz and 52.0Hz, the values of stable frequency are almost same and the under frequency load shedding device is not triggered in both of the processes. Although the amplitude of the first frequency action is more obvious at the frequency of 52.0Hz than that at 50.8Hz during the frequency recovery process, it’s still within the allowable range. If the unit is removed at 52.5Hz, it will trigger the first round of UFLS and take a longer time to make the frequency stable.

From Fig.5, the simulation system is operated in operation mode 6, with the first round of over frequency generator tripping device at 50.8Hz. According to the frequency curve, once the over frequency generator tripping device acts, the frequency drops sharply and causes in the action of UFLS. Because of the cyclic process, the system finally loses its stability. Besides, even if this system without any protective measures, the grid fault will not make the maximum frequency exceed 52.0 Hz. So, in the schemes with the over-frequency generator tripping devices set at 52.0Hz or 52.5Hz, the
devices will not be triggered for the reason above. Only with the hydraulic turbine governing system and excitation system, the stability of the frequency can be maintained.

According to the simulation results, when the first round of the over-frequency generator tripping for the hydropower unit is set as 52.0Hz, the unnecessary load shedding or generator tripping can be avoided. It also ensures the safety and stability of the power grid and solves the problem that the mismatch between the over-frequency generator tripping and the UFLS which may lead to a blackout.

4.3. Over-frequency generator tripping scheme for priority removal of the thermal power units.
Considering that the tolerance of hydropower unit of frequency is stronger than thermal power units, the tripping frequency of hydropower units could be higher. The over-frequency generator tripping device should adopt the method of “removing the thermal power unit in priority” and reserve the function of frequency regulation by hydropower unit, which is more beneficial to the stability of the power system.

Based on the statistical data of the power system almanac in 2016, the thermal and hydropower units in the 10-machine 39-node model are set according to the current capacity of water and thermal power generators installed in China (about 76% :24%). In order to verify the correctness and feasibility of this method, it is still assumed the same faults above. But the BUS-36 unit in the power outgoing orphaned grid system was set as a hydropower unit, the other three units were set as thermal power units.

According to the traditional over-frequency generator tripping strategy, when the frequency reaches 50.8Hz, the first round of over-frequency generator tripping acts with a priority of removing the hydropower unit firstly. As the BUS-36 being removed, the frequency of the power system collapses. The frequency curve is shown in Fig.6.

If the thermal power unit in the system is set according to the traditional over-frequency generator tripping strategy, the first round of frequency operate value is 50.8Hz, while the operate value of
hydropower is 52.0Hz. When the system frequency reaches 50.8Hz, the first round of over frequency generator tripping acts with a priority of removing the thermal power units firstly. The frequency curves are shown as follow.

When the system is operated in mode 3, its delivery power is 562.9MW, so the BUS-33 or BUS-34 thermal power unit can be considered when choosing to remove the thermal power unit. If the BUS-33 unit is cut off at the first round of the over frequency generator tripping at 50.8Hz, a round of UFLS will be triggered and the frequency will eventually return to be stable. If the BUS-34 unit is cut off at the first round of the over frequency generator tripping at 50.8Hz, it will not trigger the operation of the UFLS device and the frequency will also return to be stable.

From the comparison of the above figures, it can be concluded that the frequency regulation ability and tolerance ability of hydropower unit is superior to the thermal power unit. It’s more beneficial to maintain the stability of frequency to remove the thermal power unit firstly.

![Fig 7 removing BUS-34 unit in priority](image1)

![Fig 8 removing BUS-33 unit in priority](image2)

5. Conclusion

(1) The abnormal frequency is allowed to be set in a larger range, when the hydropower generating unit operates. If the frequency operate value of the over-frequency generator tripping is properly raised, the phenomenon of overcutting can be avoided as well as the repeated motion of over-frequency generator tripping and under frequency load reducer. It can prevent the power grid away from the collapse caused by power outages and make sure safety and stability of the grid operation.

(2) It’s important to choose a suitable first round operation frequency of the over-frequency generator tripping. This frequency is set according to the maximum frequency value that ensures the system stability without any emergency frequency control measures.

(3) In the hydro-thermal power grid, when the frequency of the system is increased because of the excess power, the scheme of cutting a part of thermal power unit firstly is beneficial to stabilize the system frequency.

6. References

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